GTI ENERGY

solutions that transform

FINAL PUBLIC REPORT
PHMSA #693JK32110001POTA
OTD PROJECT NUMBER 5.22.j
GTI ENERGY PROJECT NUMBER 23059

Design and Placement of Compact Service Regulators

Project Start Date:
September 30, 2021

Project Completion Date:
December 31, 2023

Date Submitted:
December 31, 2023 (Draft)
December 26, 2024 (Final)

Project Sponsors
PHMSA & OTD

Project Manager
Joe Carlstrom
Senior Program Manager
708-829-7291
jcarlstrom@gti.energy

Technical Contact
Joe Irwin
Tom Bates
Jake Witecha

1700 S. Mount Prospect Rd.
Des Plaines, Illinois 60018
www.gti.energy

GTI ENERGY

Legal Notice

This information was prepared by GTI Energy for Operations Technology Development (OTD) and Department of Transportation Pipeline and Hazardous Materials Safety Administration.

Neither GTI Energy, the members of GTI Energy, the Sponsor(s), nor any person acting on behalf of any of them:

a. Makes any warranty or representation, express or implied with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately-owned rights. Inasmuch as this project is experimental in nature, the technical information, results, or conclusions cannot be predicted. Conclusions and analysis of results by GTI Energy represent GTI Energy's opinion based on inferences from measurements and empirical relationships, which inferences and assumptions are not infallible, and with respect to which competent specialists may differ.

b. Assumes any liability with respect to the use of, or for any and all damages resulting from the use of, any information, apparatus, method, or process disclosed in this report; any other use of, or reliance on, this report by any third party is at the third party's sole risk.

c. The results within this report relate only to the items tested.

Table of Contents

Legal Notice i
Table of Contents ii
Table of Figures iv
List of Tables vi
Executive Summary 1
Introduction 2
Project Objective 2
Background, Industry Need & Business Value 2
Project Approach 4
Gas Service Regulator Function 6
Venting Process 6
Two-stage Gas Service Regulators 8
Clearance Procedures 10
Component Definitions 10
Regulatory and Procedure Requirements 14
Testing Plan 19
Background 19
Testing Design 20
Regulator Models Included in Testing 31
Summary of Results (Part 1: Emission Volume Measurement) 32
Lockup Test Results 34
Relief Test Results 38
Summary of Results (Part 2: Methane Concentration Measurement) 43
Best Practice Guidelines and Recommendations 51
Part 2 Clearance Results – Max LEL at 12 in, 24 in, & 36 in 51
Conclusions 54
References 56
List of Acronyms 57
Appendix A – Test Plan 58
Appendix B – VL1 & VL2 Manufacturer Test Data 86
Appendix C – VL3 & IRV3 Manufacturer Test Data 441

Appendix D – VL4 & VL5 Manufacturer Test Data 597
Appendix E – IRV1 Manufacturer Test Data 1012
Appendix F – IRV2 Manufacturer Test Data 1192
Appendix G – IRV4 Manufacturer Test Data 1362

Table of Figures

Figure 1. Single Stage Traditional IRV Gas Service Regulator Design....6
Figure 2. (left) No Gas Usage by Customer....7
Figure 3. (right) IRV is Closed....7
Figure 4. (left) Customer Using Gas....7
Figure 5. (right) Gas Usage Stops Raising Pressure Above IRV Set Point....7
Figure 6. Two-stage Service Regulator....9
Figure 7. MSA Installed Outside....11
Figure 8. Regulator Installed Indoors with Vent Outdoors....12
Figure 9. Regulators Installed Outdoors and Gas Meters Installed Indoors....12
Figure 10. Example of a Gas Utility Clearance Procedure....13
Figure 11. Part 2 Outlet Pressure Repeated for Each Single Lockup Test....26
Figure 12. Part 2 Outlet Pressure Repeated for Each Mult-Lockup Test....27
Figure 13. Inside Regulator (Lever and Diaphragm)....28
Figure 14. Linkage Cutoff the Diaphragm....28
Figure 15. Diaphragm and Cutting Guide....29
Figure 16. Primary and Secondary Diaphragm (Cutting Guide)....30
Figure 17. Diaphragm and Cutting Guide....30
Figure 18. Consistent Cut and Location for Each Diaphragm....31
Figure 19. Lockup Test - Output Flow vs Time....35
Figure 20. Lockup Test - Output Pressure vs Time....35
Figure 21. Lockup Test - Vent Emissions vs Time....36
Figure 22. Relief Test – Outlet Pressure vs Time....39
Figure 23. Relief Test – Vent Emission Volume vs Time....39
Figure 24. Relief Test – Emissions Flow Rate vs Outlet Pressure....40
Figure 25. Relief Test – Emissions Flow Rate vs Outlet Pressure (Focus View of Relief Point at 12-20 IWC)....40
Figure 26: Methane sensor array with sensors positioned around the regulator vent....44
Figure 27: Positioning of methane sensors in concentric circles around the regulator vent....44
Figure 28: Shed enclosure for the test setup....45
Figure 29: Data logger and power supply for the methane sensor array....45

Figure 30: IRV Regulator – Part 2 Normal Conditions Lockup Testing 46
Figure 31: Gas plume heatmap for vent limiting regulator (both diaphragms torn) highest readings after OPSO engaged. 47
Figure 32: Gas plume dissipating for vent limiting regulator (both diaphragms torn) after OPSO engaged. 48
Figure 33: Methane sensor housing in downward position, with the cavity highlighted by a yellow arrow. 49
Figure 34: Gas plume heatmap for vent limiting regulator (lever disconnect) highest readings after OPSO engaged. 50
Figure 35: Gas plume dissipating for vent limiting regulator (lever disconnect) after OPSO engaged. 50

List of Tables

Table 1. Summary of Relevant MSA Clearance Requirements 15
Table 2. Summary of Part 1 Individual Tests Completed 19
Table 3. Summary of Part 2 Individual Tests Completed 20
Table 4. Pressure drop (Left: flow meter; Right: ¼″-diameter tubing 12″ length) 21
Table 5: Tests included in Part 1 32
Table 6: Modified Lockup Test Summary at 7 IWC Inlet Pressure; Average Emission Volume [SCF] 36
Table 7: Modified Lockup Test Summary at 7 IWC Inlet Pressure; Average Emission Rate [SCFH] 37
Table 8: Modified Lockup Test Summary at 2-psig Inlet Pressure; Average Emission Volume [SCF] 37
Table 9: Modified Lockup Test Summary at 2-psig Inlet Pressure; Average Emission Rate [SCFH] 38
Table 10: Relief Test Summary at 7 IWC Inlet Pressure; Average Emission Volume [SCF] 41
Table 11: Relief Test Summary at 7 IWC Inlet Pressure; Average Emission Rate [SCFH] 41
Table 12: Relief Test Summary at 2-psig Inlet Pressure; Average Emission Volume [SCF] 42
Table 13: Relief Test Summary at 2-psig Inlet Pressure; Average Emission Rate [SCFH] 42
Table 14: Tests included in Part 2. 43
Table 15: Single-Lockup Test highest readings recorded at various distances for 7 IWC set point. 51
Table 16: Single-Lockup Test highest readings recorded at various distances for 2 psig set point. 52
Table 17: Multi-Lockup Test highest readings recorded at various distances for 7 IWC set point. 52
Table 18: Multi-Lockup Test highest readings recorded at various distances for 2 psig set point. 52
Table 19: Highest reading after the OPSO engaged on the OPSO for 7 IWC set point 53
Table 20: Highest reading after the OPSO engaged on the OPSO for 2 psig set point. 53

Executive Summary

This project is co-funded by DOT PHMSA with an objective to provide natural gas utilities with data for additional options for the safe, outside installation of service regulators and meter sets. The objective of the project is to perform research on newer "vent limiting" gas service regulators to determine safe clearance allowances and installation practices that will provide a gas utility with more options for outside installation. The objectives of the project included:

- Review the existing industry practices for "vent limiting" service regulators, including those in other countries.
- Perform comparative emissions testing for "vent limiting" gas service regulators.
- Provide installation recommendations on safe distance allowances to the industry.

Some local codes, industry standards, and utility procedures require a minimum clearance distance from the service regulator vent to building openings (doors and windows), vents, and possible ignition sources. In certain scenarios, there is difficulty to find safe clearance distances and therefore making it less desirable to install new or relocate existing indoor meters and regulators on the outside of the building. However, new vent limiting service regulators are now available on the market with an overall smaller footprint with less or no clearance requirements. This project evaluated these new vent limiting regulators and worked to create data that can be used in guidelines and recommendations for the safe reduction of the minimum clearance distances, therefore, improving the ability of the service regulator to be installed outside.

This project reviewed existing practices and performed comparative service regulator testing that resulted in data that can be used for guidance to the natural gas industry on "vent-limiting" service regulators. The data results may provide more options for a gas utility to install or move the service regulator and/or meter set to the outside of the structure. The project measured the level of natural gas produced from "vent-limiting" service regulators as compared to traditional IRV service regulators to determine safe clearance distance requirements. Experimental testing has determined that "vent-limiting" service regulators offer more options for outside installation by having a smaller footprint that includes the ability to install at reduced clearance distances as compared to traditional internal relief valve (IRV) service regulators. The safe distance allowances can be determined through the testing data results for the amount of gas vented during various regulator operating flow conditions (normal and abnormal) and failure modes, including diaphragm ruptures.

The project provided scientific data demonstrating that newer vent limiting gas service regulators with an over pressure shut off (OPSO) vent less gas emissions as compared to traditional IRV during abnormal conditions. The test plan provides a list of gas service

regulators that were tested as part of this project, however the manufacturer and model for each of the regulators is not listed in the results section of the public report.

Introduction

Project Objective

This project titled "Design and Placement of Compact Service Regulators" has the objective to review existing practices and perform comparative service regulator testing. The objective included analyzing the results to provide recommendations and guidance to the natural gas industry on "vent-limiting" service regulators. The project's goal with the results of the testing was to provide more options for a gas utility to install or move the service regulator and/or meter set to the outside of the structure. The project measured the level of natural gas produced from "vent-limiting" service regulators as compared to traditional internal relieve valve (IRV) regulators to determine safe clearance distance requirements. The project verified some of the benefits that newer "vent-limiting" service regulators can offer the industry by providing more options for outside installation by having a smaller footprint that includes the ability to install at reduced clearance distances as compared to traditional IRV service regulators. The safe distance allowances were determined by creating and implementing a test plan that measured the amount of gas vented during various regulator operating flow conditions and failure modes, including diaphragm ruptures.

Background, Industry Need & Business Value

Relocation of meter set assemblies (MSAs) to the outdoors has been a focus of gas utilities and has been increased due to a recent apartment building incident in Silver Spring, Maryland in 2016. The probable cause reported for the gas release was a failed indoor service regulator and an unconnected vent line in the meter room that allowed natural gas into the meter room where it accumulated and ignited from an unknown ignition source. The National Transportation Safety Board (NTSB) investigation of the incident has resulted in the following recommendations:

- Require that all new service regulators be installed outside occupied structures. (P-19-001).
- Require existing interior service regulators be relocated outside occupied structures whenever the gas service line, meter, or regulator is replaced. In addition, multifamily structures should be prioritized over single-family dwellings. (P-19-002).

General requirements for the placement of gas meters and regulators are provided in the Code of Federal Regulations 49 CFR Part 192. For the placement of service regulators, these requirements include:

- Indoor service regulators must be located as near as practical to the point of service entrance.
- Where feasible, upstream regulators in a series must be located outside the building, unless it is located in a separate metering or regulating building.
- Service regulator vents and relief vents must terminate outdoors, and the outdoor terminal must be located at a place where gas from the vent can escape freely into the atmosphere.
- Service regulator vents and relief vents must terminate outdoors, and the outdoor terminal must be rain and insect resistant, be located at a place where gas from the vent can escape freely into the atmosphere and away from any opening into the building.

Natural gas utilities prefer to install new MSAs outdoors, however, finding appropriate locations with sufficient clearances from building openings (doors and windows), vents, and potential ignition sources can create challenges. In addition, gas utilities are relocating existing inside MSAs (meters and/or regulators) to the outdoors, but this is not always feasible due to space constraints (especially in congested urban environments), local building codes restricting their outdoor placement, landmark / historic district restrictions, equipment security, and sensitive building designations.

A gas utility field crew is tasked with the challenge of finding a space to install MSAs, including the regulator and regulator vent on the outside of a building that satisfies the clearance distance requirements. The National Fuel Gas Code (NFGC), ANSI Z223.1/NFPA 54 section 5.8.5, has a 3-ft clearance requirement for indoor regulator vent outlets and many gas utilities have set a 3-ft minimum distance to a source of ignition for both indoor and outdoor meters. These clearance distances were created with standard Internal Relief Valve (IRV) regulators in mind. IRV regulators have an internal relief valve that is designed to relieve the downstream gas pressure at a set spring point. The internal relief valve is designed to open and vent the excess gas pressure to the atmosphere through the regulator vent line.

Since in some situations, the established clearance distance cannot be found, some gas utilities have established special permits (waivers) with their state commerce commissions pertaining to the regulator venting distance requirements and the use of "vent limiting" gas service regulators. The manufacturers of these "vent limiting" regulators claim that they emit a much smaller quantity of natural gas as part of their pressure regulating operation and some have specified that clearances from building openings are not required.

Some gas utilities have been successful in installing these vent limiting regulators with slam-shut features and have demonstrated a reduction in methane emissions and decreased operations and maintenance costs, thus improving system safety and performance. Several manufacturers incorporate overpressure shut-off (OPSO) and under-pressure shut-off (UPSO) systems. These regulators may also incorporate excess flow valve shut-off abilities that could be effective to

stop the flow in the event of large amounts of gas escaping into a structure. These regulators have been manufactured with a vent limiter that is compliant with ANSI Z21.80/CSA 6.22 to keep the vent flow to less than 2.5 SCFH in the event of diaphragm failure, and therefore if installed properly, the belief is that the natural gas that is escaping is limited from becoming hazardous.

This project was needed to validate the performance and capabilities and bring awareness to "vent limiting" service regulator technology and to advance the industry by providing more options for safe MSA installations. Currently, an industry standard that measures regulator gas emissions to determine safe clearance distances does not exist. A test plan is needed that can validate and determine safe clearance distances.

Project Approach

This project defines a "vent-limiting" gas service regulator as compliant with ANSI Z21.80/CSA 6.22 and noted that this standard is not appliable to gas service regulators. The standard is applicable for line pressure regulators that are located between the gas service regulator and the gas utilization equipment. Line pressure regulators are designed with a lower MAOP and lower inlet pressures (typically less than 10 psig) as compared to gas service regulators and would not be able to accommodate some of the higher pressures found in a distribution system. Equipment manufacturers have designed and tested new gas service regulators to this standard to improve safety in the event of diaphragm failure.

The following tasks were performed as part of this project:

- Project Scoping and Establishing a Technical Advisory Panel (TAP): several meetings were held with PHMSA and a Technical Advisory Panel (TAP) to review the project scope, approach, and approve a test plan. The TAP consisted of local gas distribution companies, regulator manufacturers and industry subject-matter experts (SMEs) on regulator design and installation.
- Identify Service Regulators with "Vent Limiting" Capabilities: a product search was performed to find gas service regulators with "vent limiting" capabilities that are currently commercially available in the US market.
- Develop a Test Plan to Measure Emissions and Clearances: a test plan was created and distributed to the TAP for input. The TAP approved the test plan that was implemented for this project that included a list and comparison of new vent limiting regulators to traditional IRV regulators.
- Service Regulator Installation Procedures and Clearance Distance Requirements: the project reviewed service regulator installation procedure documentation provided by regulator manufacturers and clearance requirements by governing bodies, various standards, and gas utilities.
- Comparative Testing of Safety Clearances and Environmental Conditions: the two-part test plan focused on evaluation of both the volume of gas emitted from the regulator

vent, the concentration, and dispersion of methane at various distances from the regulator vent port.

- Development of Best Practice Guidelines and Recommendations: based on the data obtained from the test plan, conclusions were provided on minimum clearance distance requirements as they relate to the test data.

A challenge for the project was that there are no current standards for testing the emissions from a gas service regulator vent during normal and abnormal operation, and therefore a test plan and test rig would need to be developed to provide data pertaining to regulator vent gas flow, venting characteristics, and gas levels at various distances from the vent. The project team with the assistance from the TAP developed a two-part test plan that was implemented as part of this project based on the ANSI B109.4 standard (Part 1) and by creating a test rig for measuring gas LEL levels at various distances using gas sensors (Part 2). ANSI B109.4 is the standard for Self-operated Diaphragm-Type Natural Gas Service Regulators for nominal pipe sizes 1-1/4" (32mm) and smaller with outlet pressures of 2-psig (13.8 kPa) and less.

Gas Service Regulator Function

Venting Process

Natural gas service regulators are typically installed upstream of the gas meter and are used to decrease the supply pressure, to a pressure that can be safely used by a customer's in-house appliances (i.e., range ovens, water heaters, etc.). The inlet pressures for gas service regulators can vary and have a wide range based on the associated gas distribution system maintained by the gas utility. The typical outlet pressure (customer delivery pressure) that the gas service regulator needs to maintain for the customer's piping system will usually be 0.25 psig (7 inches water column) or 2 psig.

Traditional gas service regulators have an IRV that is designed to relieve (emit gas) at a set pressure through a vent as part of normal operation to maintain a target outlet pressure for the customer. The pressure that an IRV emits gas is set by spring tension on a diaphragm. As illustrated in Figure 1, the movement of a diaphragm in a single stage regulator opens and closes a valve (orifice and valve seat) to maintain a steady outlet pressure for the customer.

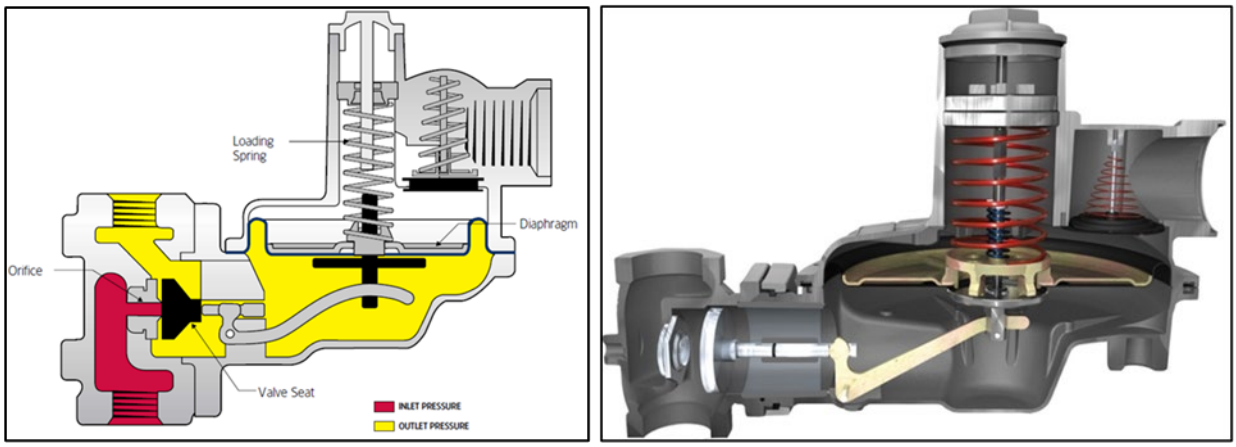
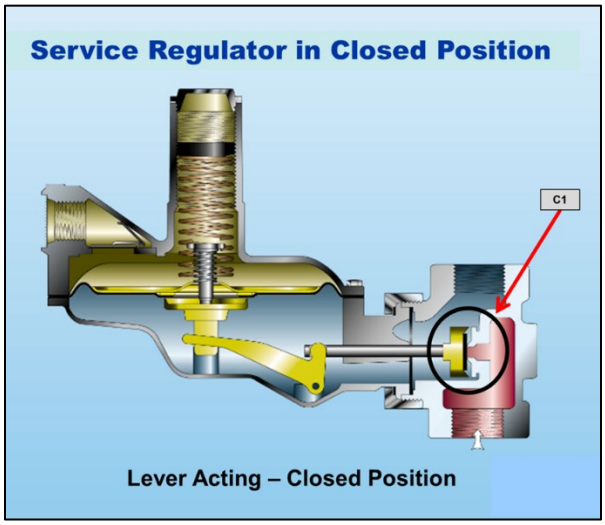


Figure 1. Single Stage Traditional IRV Gas Service Regulator Design.

When the downstream pressure decreases, such as when appliances (water heater, e.g.) are drawing gas, the diaphragm moves down along with the pin with the attached valve seat. This motion opens the path to allow more gas from the upstream (inlet) side to flow through the regulator and meet the customer's gas demand. Gas flow through the regulator will be allowed until the pressure is equalized and the diaphragm returns to its setpoint, controlled by the loading spring setting. In this traditional single-stage IRV gas service regulator, excess gas pressure higher than the loading spring set points pushes past the diaphragms to be released through the outside vent. Excess inlet gas pressure can occur when gas appliances are suddenly turned off and the pressure allowed past the valve seat increases past the IRV's spring set point.

This process occurs quickly and can sometimes result in a quick small burst of gas being emitted through the regulator vent. The following service regulator figures illustrate the step-by-step process of gas being emitted through the regulator vent.



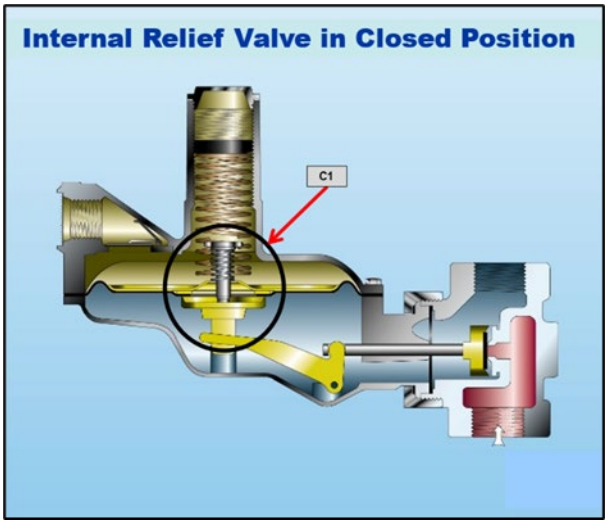
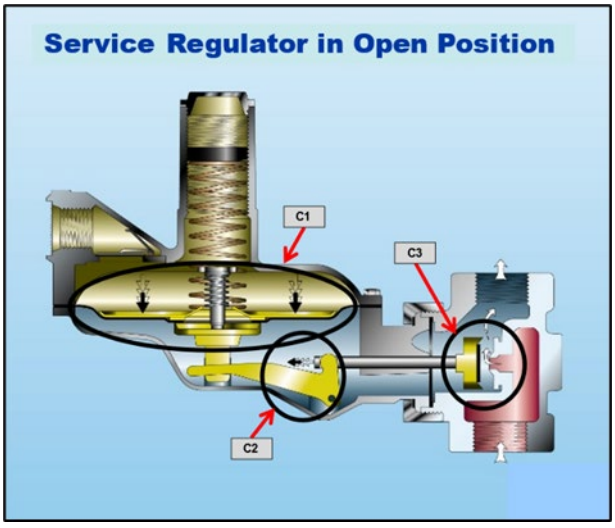


Figure 2. (left) No Gas Usage by Customer
Figure 3. (right) IRV is Closed



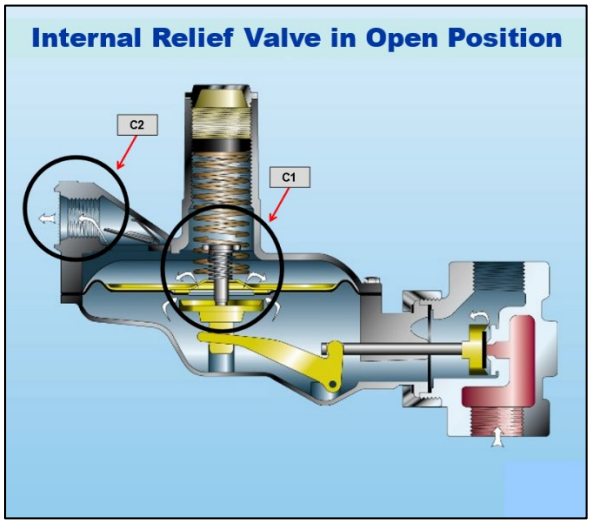


Figure 4. (left) Customer Using Gas
Figure 5. (right) Gas Usage Stops Raising Pressure Above IRV Set Point

The Figures illustrate the process of a gas service regulator venting gas:

- In **Figure 2**, the customer is not using any gas, and C1 highlights the lever holding the valve closed separating the inlet and outlet pressures.
- In **Figure 3**, C1 highlights that the IRV is also closed indicating that no gas is being emitted out through the vent.

- In **Figure 4**, the customer is using gas therefore lowering the outlet pressure that forces the diaphragm downward C1, pulling the lever C2, and opening the valve C3. The movement of the diaphragm pushes open the valve that is covering the orifice allowing for the higher pressure gas to enter for customer use. The flexing of the diaphragm back and forth, C1, will typically open and control the valve C3 maintaining a steady inlet pressure and without exceeding the IRV spring set point.
- In **Figure 5**, the higher pressure gas entering downstream of the regular exceeds the IRV spring set point, therefore the IRV opens allowing gas to vent. A condition that causes this type of venting to occur is when customer gas usage is high and then suddenly stops, the higher pressure traveling into the regulator exceeds the IRV set point and venting occurs.

In addition to the venting process outlined, if the diaphragm is damaged in any way, if the lever were to disconnect, or if debris gets in the way of the valve seat, an abnormal condition is created and gas will be continuously emitted from the vent. The gas vented from a service regulator could potentially accumulate in a confined space and/or cause a fire/explosion if in contact with an ignition source. The test plan created for this project worked to account for these extreme conditions to determine safe clearance distances for gas service regulators that are tested.

Another type of venting from gas service regulators discussed with gas utilities is a condition when the gas piping downstream from the regulator becomes heated, such as with sunlight or from the surrounding temperatures. The gas inside the downstream piping expands increasing the pressure beyond the IRV spring set point causing gas to vent. This venting condition observed with gas service regulators was discussed with subject matter experts at the gas utilities after the final approval of the test plan for this project, and therefore was out of scope for validating and testing.

Two-stage Gas Service Regulators

Dual-stage gas regulators differ from traditional single-stage or lever-style regulators since they have two separate stages of regulation in series as depicted on Figure 6. Inlet pressure enters the regulator and pressure is reduced to intermediate pressure by the first stage. The first stage is an independent, self-operated regulator that controls the intermediate pressure to roughly 5 psi above delivery pressure. The second stage of regulation is also a self-operated regulator that controls the final outlet delivery pressure. The two stages of pressure reduction improve safety and accuracy by reducing wear on the second stage of regulation and ensuring that the second stage receives a constant pressure, regardless of inlet pressure variations from the system.

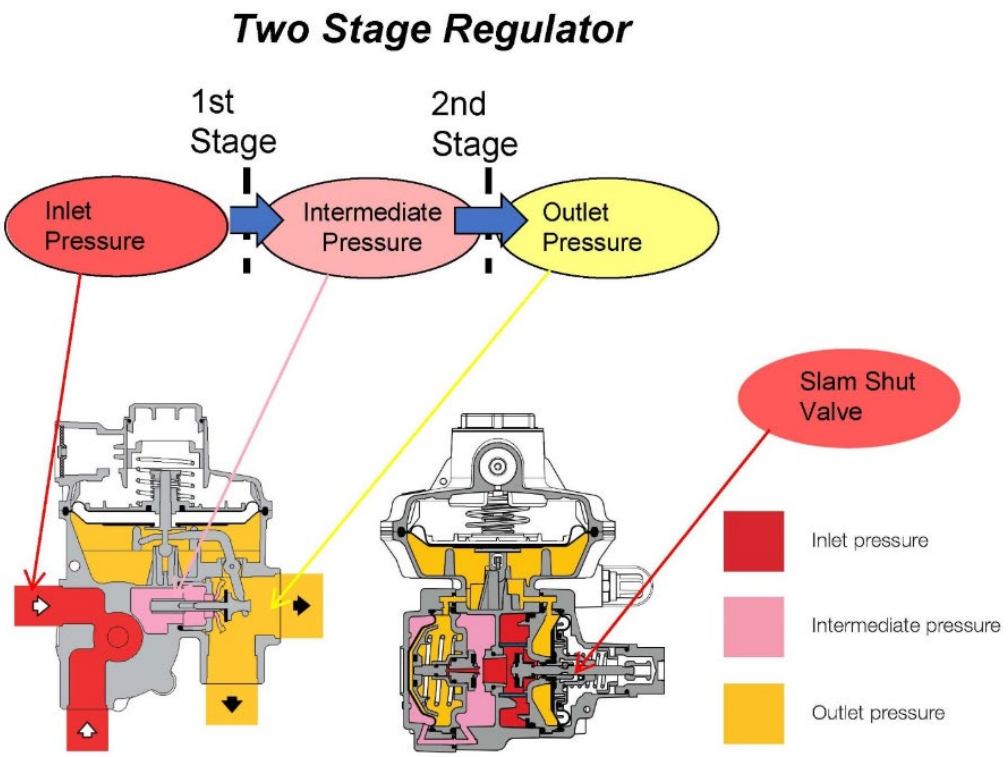


Figure 6. Two-stage Service Regulator

Dual-stage regulators offer a variety of safety features that have the benefit of lower emissions. These regulators can have a token IRV that allows less gas to escape as compared to full capacity IRVs. The slam-shut valve is designed as an Over Pressure Shut Off (OPSO) and these regulators have available options for an Under Pressure Shut Off (UPSO). Dual stage regulators are also available with double diaphragms on the second stage of regulation where a safety/secondary diaphragm acts as a backup if the main diaphragm fails. During a failure, this safety diaphragm contains the gas and allows the regulator to continue operating as normal. The safety diaphragm has a small vent built in that allows a minimal amount of gas to escape to indicate an abnormal condition. An example of regulator function is if outlet pressure (customer pressure) is set to 7" w.c. and the outlet pressure exceeds 13" w.c. the token IRV will vent, and then if the outlet pressure (customer pressure) exceeds 19" w.c. the slam shut will activate stopping inlet flow into the customer piping.

Clearance Procedures

Component Definitions

Meter set assemblies (MSA) are necessary for providing natural gas service to a customer's building. In industry procedures, the word "clearance" can be used to describe multiple different distances of components related to the MSA. The word "clearance" used in this report is referencing the distancing of the gas service regulator vent to ignition sources, ventilation ports, and/or air intakes to buildings. An MSA is generally composed of the following components:

a) **Riser** – Transitions service from the inground service pipeline to the associated piping in a building.
b) **Gas Meter** (diaphragm, rotary, ultrasonic, etc.) – equipment that measures gas usage.
c) **Service Regulator** (Single/double diaphragm with and internal relief valve (IRV), vent-limited, etc,) – the equipment used to lower the distribution gas pressure to a usable pressure for equipment inside the building. A vent is installed on a regulator that allows gas to escape as part of a regulator's normal operation and for adverse operating conditions.
d) **Shutoff Valve** – Allows for the manual shutoff of gas service to the customer. Usually is the first fitting after the riser transitions from the ground.
e) **Meter Bar** – Prefabricated component with swivel fittings to allow utilities to install MSA's more efficiently.
f) **Entrance to Building** – The point of entry of the gas pipe into the customer's building or dwelling.

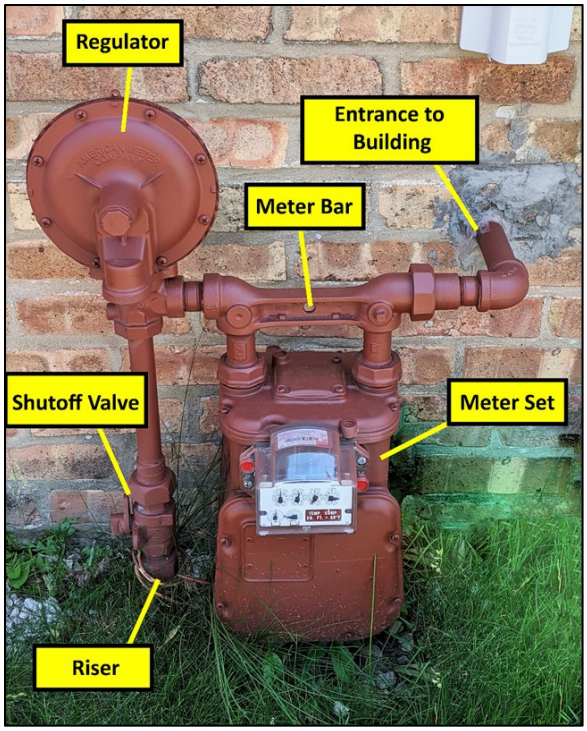


Figure 7. MSA Installed Outside

Ideally, the preference is to install all the MSA components outside of the building similar to **Figure 7**, therefore no gas utility owned components are inside the building that require inspection and maintenance. There are conditions and situations where all or some of the MSA components are installed inside of the building. If MSA components are installed in a building, the preference is that they are installed inside the building wall at the gas service pipe entry point. When the regulator is installed indoors, the utility is required to ensure that the regulator vent is piped outdoors (as seen in **Figure 8**). In some situations, with indoor meter sets, the regulator is installed outside of the building (as seen in **Figure 9**).

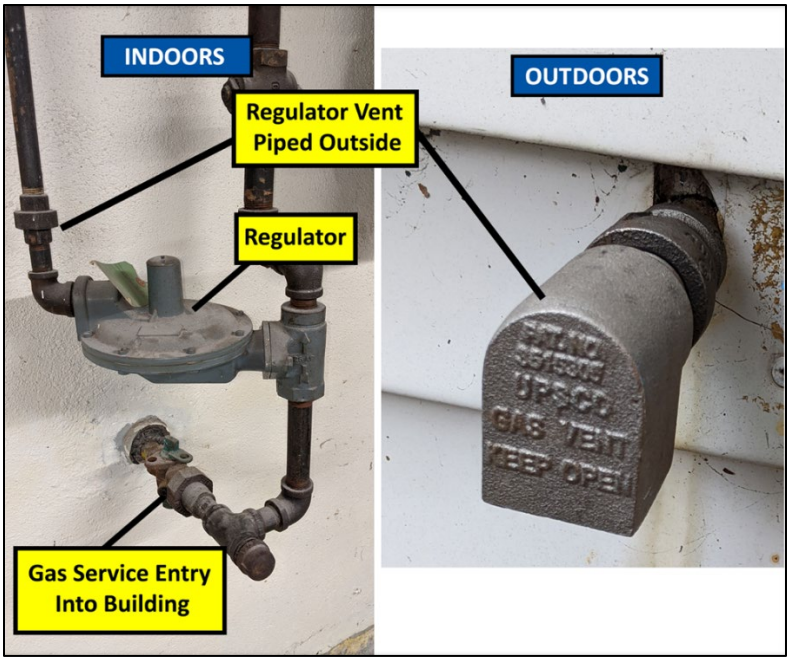


Figure 8. Regulator Installed Indoors with Vent Outdoors



Figure 9. Regulators Installed Outdoors and Gas Meters Installed Indoors

An example of an illustration of a gas utility procedure related to the proper installation of MSAs can be seen in **Figure 10**. Many gas utilities have specific MSA clearance distance requirements.

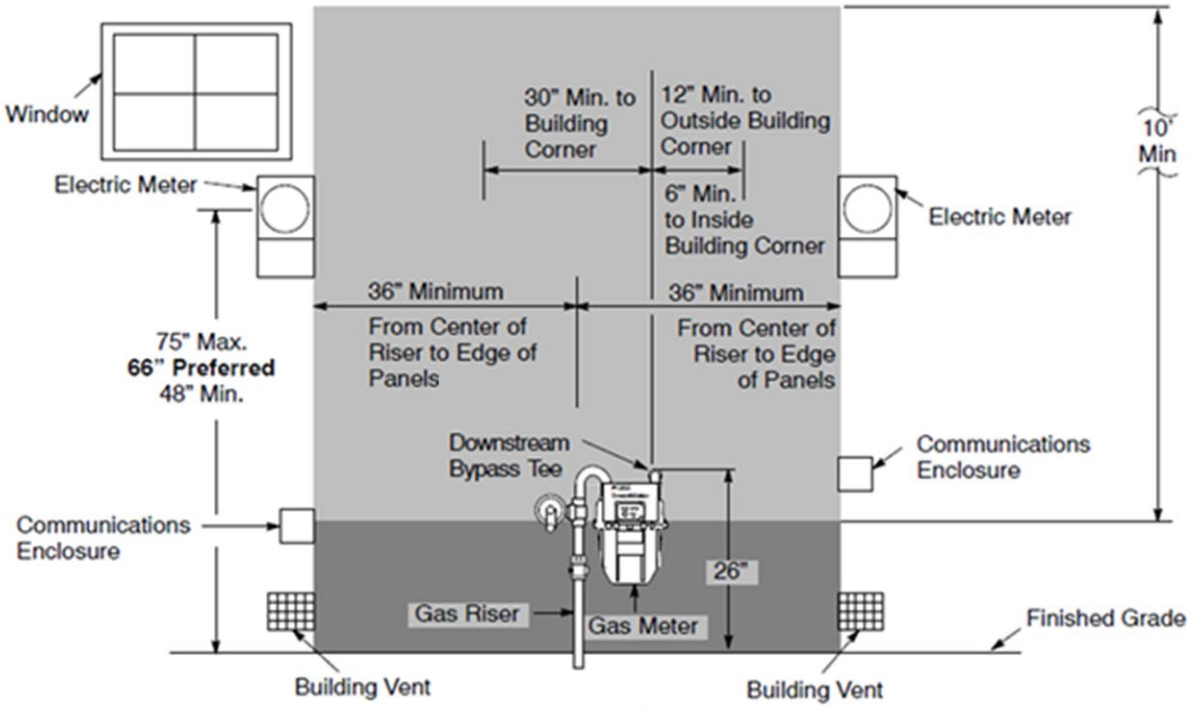
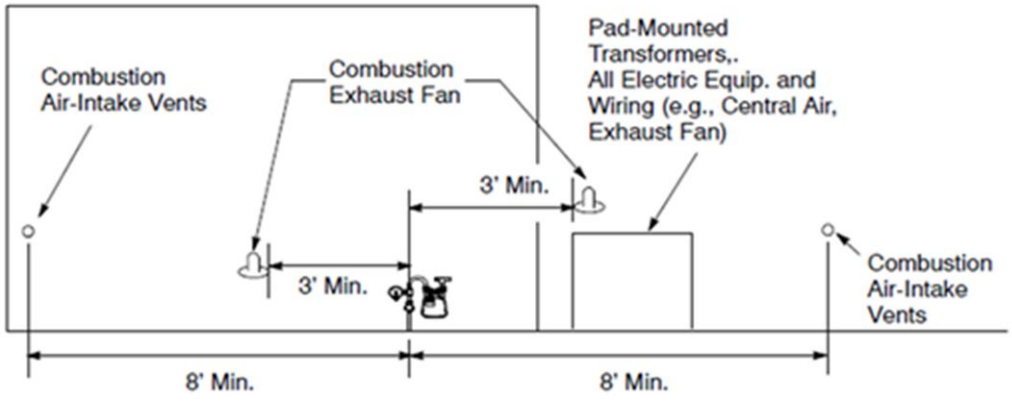


Figure 3
Gas Meter Set Separations



Gas Regulator Set Clearance Requirement from Sources of Ignition

Figure 10. Example of a Gas Utility Clearance Procedure

Regulatory and Procedure Requirements

Gas utilities base and develop their procedures on standards, regulatory requirements, and industry best practices. As of 2023, the 49 CFR Part 192 does not provide any clearance distances for outside MSAs. 192.353, 192.355, and 192.357 provide some direction and pertain to gas service regulator location, protection from damage, and installation, referenced:

§ 192.351 Scope.

This subpart prescribes minimum requirements for installing customer meters, service regulators, service lines, service line valves, and service line connections to mains.

§ 192.353 Customer meters and regulators: Location.

(a) Each meter and service regulator, whether inside or outside a building, must be installed in a readily accessible location and be protected from corrosion and other damage, including, if installed outside a building, vehicular damage that may be anticipated. However, the upstream regulator in a series may be buried.

(b) Each service regulator installed within a building must be located as near as practical to the point of service line entrance.

(c) Each meter installed within a building must be located in a ventilated place and not less than 3 feet (914 millimeters) from any source of ignition or any source of heat which might damage the meter.

(d) Where feasible, the upstream regulator in a series must be located outside the building, unless it is located in a separate metering or regulating building.

§ 192.355 Customer meters and regulators: Protection from damage.

(a) Protection from vacuum or back pressure. If the customer's equipment might create either a vacuum or a back pressure, a device must be installed to protect the system.

(b) Service regulator vents and relief vents. Service regulator vents and relief vents must terminate outdoors, and the outdoor terminal must -

(1) Be rain and insect resistant;

(2) Be located at a place where gas from the vent can escape freely into the atmosphere and away from any opening into the building; and

(3) Be protected from damage caused by submergence in areas where flooding may occur.

(c) Pits and vaults. Each pit or vault that houses a customer meter or regulator at a place where vehicular traffic is anticipated, must be able to support that traffic.

§ 192.357 Customer meters and regulators: Installation.

(a) Each meter and each regulator must be installed so as to minimize anticipated stresses upon the connecting piping and the meter.

(b) When close all-thread nipples are used, the wall thickness remaining after the threads are cut must meet the minimum wall thickness requirements of this part.

(c) Connections made of lead or other easily damaged material may not be used in the installation of meters or regulators.

(d) Each regulator that might release gas in its operation must be vented to the outside atmosphere.

As seen in the excerpts from the federal code, the only clearance distance requirement included in the code is in section 192.353 (c) pertaining to the clearance for an inside meter. The federal code also does not provide a minimum clearance distance for the outside regulator vent termination point from air intake ports or vent openings. The project team performed a review of various federal/state/local requirements, and gas utility company procedure requirements that pertain to MSA clearance distances and that research is summarized in **Table 1**. It should be noted that many of these clearances specifically provide a "point of measurement" for a distance from the gas service regulator relief vent.

Table 1. Summary of Relevant MSA Clearance Requirements

Reference Standard / Code	Clearance Distance Measure Used	Definition of Ignition Sources	Exact Point of Measurement	Additional Vent Clearance Considerations
Federal Code 49 CFR 192.353	3 feet (applicable to indoor meter only)	"Any source of ignition or any source of heat which might damage the meter"	Not mentioned	"must be vented to the outside atmosphere."
Gas Utility A	3 feet radially from ignition source or building openings. 10 feet radially from forced air intake	"Electrical equipment, air conditioning unit, electric meter, electric outlet"	Relief Vent Termination	It may be acceptable for reduced clearances from building openings and potential sources of ignition when approved limited vent service regulators are installed.

Gas Utility B	36 inches horizontally from sources of ignition and openings into the building. The clearance area will extend 10 feet above and 36 inches below the regulator vent termination. 8 feet laterally from forced air intake.	Not mentioned	Relief Vent Termination	Vents for all natural gas regulator and gas monitor diaphragm equipment must terminate above a reasonable flood level.
Gas Utility C	3 feet from any sources of ignition. 18 inches horizontally from an opening into the building if that opening is less than 6 feet vertically from the vent. 10 feet of horizontal clearance from forced air intake.	Not mentioned	Relief Vent Termination	It is preferred that regulator vents be installed at a height 18 inches above grade, however, the minimum allowable vent height shall be 12 inches above final grade. Regulator / relief vent terminus shall face down. The regulator / relief vent terminus shall be protected from damage caused by submergence in areas where flooding or ice accumulation may occur.
Gas Utility D	3 feet radial distance from any source of ignition	Electric meter, air conditioning condensing unit, electrical outlet, electrical disconnect	Relief Vent Termination	The relief vent should not be installed below, above, or within 12" horizontally to the side of a basement or first floor window (that can opened), door, stairs, dryer vents, furnace intakes/ exhausts, or other potential air inlet to the house.
Gas Utility E	3 feet radial distance from any source of ignition required. 10 feet desired.	Electric meter, air conditioner, electric outlet.	Relief Vent Termination	3-foot minimum clearance also applies to area in front of meter. Windows that cannot be opened are exempt from clearance requirements. Exhaust vents shall not be located directly above the meter set in addition to 3-foot minimum clearance. Telephone and cable boxes are not sources of ignition. No part of the MSA should be within 30-inch working space in front of the electric meter.

Maine PUC chapter 420	At least 5 feet away from any existing source of ignition. 3 feet horizontally or 8 feet vertically from building openings above vent.	Electrical meters, openings into direct-vent appliances, or mechanical ventilation air intakes.	Relief Vent Termination	Vents on pressure regulators installed after July 1, 2011, with over-pressure protection that vent gas to atmosphere must be at least three feet horizontally, or eight feet vertically, away from any existing building opening above the vent, and at least five feet away from any existing source of ignition (e.g., electrical meters, openings into direct-vent (sealed combustion system) appliances, or mechanical ventilation air intakes). Pressure regulators that utilize over-pressure shutoff (OPSO) technology or otherwise effectively eliminate venting gas to atmosphere need not abide by the above distance restrictions.
NYC Fuel Gas Code Section 410.3	18 inches above grade, not under an opening to the building or overhang.		Vent terminal	A vent to the outdoors is not required for regulators less than 1 1/4 inches (31.7 mm) NPS equipped with and labeled for utilization with approved vent-limiting devices installed in accordance with the manufacturer's instructions.
Illinois State Section 501.110	Only for indoor meters - minimum three feet from any ignition source or source of heat.	Not mentioned	Meter	Utilities should not install meters in locations where expected temperatures are likely to exist outside the range recommended by the meter manufacturer.
New Hampshire PUC 506.1 (n)				Utilities shall not install or operate a gas regulator that could release gas closer than 3 feet to a source of ignition, an opening into a building, an air intake into a building or any electrical source not intrinsically safe, as follows: (1) 3-foot clearance from a source of ignition shall be measured from the vent or source of release (discharge port), not from the physical location of the meter set assembly; and (2) For encroachment within the required 3-foot clearance caused by an action of the property owner or occupant after the initial installation, the encroachment shall be resolved by extending the regulator vent to meet this requirement within 90 days of discovery"

As seen in in **Table 1**, clearance distance requirements can vary between gas utilities and some of the MSA requirements can vary by state. Most utilities procedures currently do not differentiate between "vent-limited" regulators and traditional IRV regulators. The New York City Fuel Gas Code and the State of Maine PUC both state special exceptions for clearance distances in situations when vent-limited gas service regulators are used.

Testing Plan

Background

The project team with the assistance from the TAP developed a two-part test plan that was implemented as part of this project based on the ANSI B109.4 standard (Part 1) and by creating a test rig for measuring gas LEL levels at various distances using gas sensors (Part 2). The test plan is designed to compare vent emissions from "vent-limiting" style service regulators to the results from traditional IRV service regulators. The results from the testing should be able to assist in providing recommendations on safe clearance allowances for these types of regulators, potentially providing more scientifically proven options for gas service regulator placement. Based on the test data, the project will determine the safe clearance allowances for vent-limiting regulators in situations where space is limited while installing a MSA in an area with crowded utilities and obstacles (doors, windows, A/C units, etc.). The scope of the two-part test plan worked to include Part 1 for determining the volume of gas emitted from the regulator vent during some of the most extreme conditions that could potentially happen to a gas service regulator installed in the field and a Part 2 to measure the methane levels at various distances from the regulator vent. The following **Table 2** and **Table 3** provides a summary of the number of individual tests completed as part of the project for Part 1 and Part 2 testing. In addition, there were some retests performed based on subject matter expert input and manufacturer input.

Table 2. Summary of Part 1 Individual Tests Completed

Test Conditions	Tests	Total Regulators	Number of Inlet Pressures Tested	Individual Tests Completed
Normal	Set Point	18	1	18
	Modified Lockup	18	3	54
	Relief	18	3	54
Lever Disconnect	Relief	18	3	54
	Internal Relief Valve Performance	18	3	54
	Modified Lockup	8	3	24
Primary Diaphragm Slit	Relief	18	3	54
	Internal Relief Valve Performance	18	3	54
	Modified Lockup	8	3	24
Secondary Diaphragm Slit	Relief	10	3	30
	Internal Relief Valve Performance	10	3	30
Blocked Vent	Modified Lockup	18	3	54
			Cumulative	504

Table 3. Summary of Part 2 Individual Tests Completed

Test Conditions	Tests	Total Regulators	Number of Inlet Pressures Tested	Number of Sensor 1 Distances	Individual Tests Completed
Normal	Single Lockup	18	1	2	36
	Multi-Lockup	18	1	2	36
	OPSO Performance	10	1	1	10
Lever Disconnect	OPSO Performance	10	1	1	10
Primary Diaphragm Slit	OPSO Performance	10	1	1	10
Secondary Diaphragm Slit	OPSO Performance	10	1	1	10
			Cumulative		112

The test plan was created and approved by the TAP and finalized on June 22, 2022, and is included in the appendix of this report. After the final approval of the test plan and the start of testing, there have been several recommendations to improve on the testing including the introduction of a heat chamber to simulate potential field conditions (thermal expansion) and further backpressure type relief testing. Some of these recommendations are lessons learned for future testing and included in the conclusion of this report.

Testing Design

The purpose of this study is to measure the volume of natural gas that is emitted from service regulators in both normal and abnormal operating conditions. The motivation behind this study is the claim that vent-limited, dual-diaphragm service regulators emit a smaller volume of natural gas as compared to the traditional, single diaphragm IRV service regulators. The results of this study will assist with determining the clearance distance requirements for vent-limited regulators.

This test plan is composed of two parts, as follows:

Part 1: Vent Emission Measurement – Using compressed air in a lab setting, measuring the volume emitted by the regulator vent in various inlet pressures and downstream flow rates. The variable flow testing rig allows for the automation and continuous data logging of all pressure transducers, flow meters, motorized ball valves, and pressure controllers. The Set Point, and internal relief valve performance tests are not modified from the ANSI B109.4 test standard. The Modified Lockup and Modified relief tests were taken from the standard and then modified to test emission rates. The following are modifications to the original standard:

The modification to the lockup test is the addition of the vent flow meter. An Omega FMA1828A-ST thermal mass flow meter was used to quantify the emissions from the regulator

vent. A ¼" clear, plastic tube was used to connect the flow meter to the vent, refer to the test plan for exact configuration. The subsequent pressure drop of this addition was calculated and added into the table below.

Table 4. Pressure drop (Left: flow meter; Right: ¼"-diameter tubing 12" length)

Flow (SCFH)	Pressure drop (InWC)
21.19	1
42.38	14
63.57	34
105.94	90

Flow (SCFH)	Pressure drop (InWC)
21.19	0.1
42.38	0.5
63.57	1.02
105.94	1.68

As indicated in **Table 4**, the pressure drop from using the flow meter and tubing was found to be negligible for measuring flows less than 2.5 SCFH to the low flow rate from the vent, which is significantly below 21.19 SCFH.

5.3.3 Set Point Test

For the purposes of developing a uniform testing procedure and comparison, the set point shall be established with the following parameters:

a) Inlet Pressure: 40 psig (276 kPa) or the maximum allowable inlet pressure per the manufacturer's specification if less than 40 psig (276 kPa).
b) Outlet Pressure Ranges:

TABLE IV

Outlet Pressure Range	Set Point Tolerance
X ≤ 14 inches w.c. gauge (3.48 kPa gauge)	+/- 0.1 inches w.c. gauge (0.025 kPa gauge)
14 inches w.c. gauge (3.48 kPa gauge) < X ≤ 1 psig (6.89 kPa gauge)	+/- 0.2 inches w.c.gauge (0.050 kPa gauge)
1 psig (6.89 kPa gauge) < X ≤ 2 psig (13.8 kPa gauge)	+/- 0.03 psig (0.2 kPa gauge)

c) Flow Rate: 39 scf/h (1.1 m3/h) of air to be set by slowly increasing the flow rate from zero for a period of five seconds.

During tests to check the set point, the regulator should be stable with no evidence of hunting or chattering. Other pressures and flow rates may be used to demonstrate compliance with this standard for alternative requirements. NOTE: Inlet and outlet conditions other than those specified above will affect the performance of the regulator and could produce varying results.

5.3.5 Lock-Up

When the demand for flow from the regulator is shut off, the flow of gas should be stopped against the maximum inlet pressure recommended by the manufacturer for the applicable orifice. The outlet pressure under no-flow conditions, or "lock-up pressure," shall be checked using the following test method:

a) Set the regulator as described in section 5.3.3.
b) Close the outlet valve at a constant speed over five seconds. Allow outlet pressure to stabilize and record lock-up pressure. Wait an additional 30 seconds and ensure the reads are comparable within the measurement system accuracy.
c) Ensure that the lock-up pressure is no greater than 3 inches w.c. (0.75 kPa) above the original set pressure for set points of 14 inches w.c. or less (3.48 kPa). For set points greater than 14 inches w.c. (3.48 kPa), lock-up pressure shall not be greater than 115% of set point. See Section 5.3.3.

Modified Lock-Up Test

When the demand flow from a regulator is turned off, there is a rapid spike in outlet pressure. During this pressure spike, the IRV of the regulator discharges a small volume of gas. The magnitude of the discharge volume is proportional to the outlet flow rate right before the outlet valve is closed, and it is measuring the combination of the diaphragm movement and the gas being relieved. The flow rates of these vent emissions were checked using an automated test script conformed to the following test method.

a) Install the flow meter at the vent of the regulator so that it is continually data logging. The thermal mass flow meter has a range of 0-105.94 scf/h (3.0 m3/h) and a connection size of ¼" NPT. There must be at least 12" (30.48 cm) of straight pipe before the flow meter to ensure laminar flow.
b) Set the inlet pressure accordingly, either 10, 60, or 100 psig.
c) Open the outlet valve to induce a flow rate of 100 scf/h (2.83 m3/h). The script will automatically proceed to step c when the outlet flow meter reads equal to or greater than 100 scf/h.
d) Close the outlet valve at a constant speed over five seconds. The valve will automatically reopen when the outlet flow meter reads less than or equal to 3 scf/h.
e) For each subsequent lockup, the outlet valve is opened further. Such that the induced outlet flow is 100 scf/h greater than the previous.
f) Repeat steps c,d, and e until the outlet flow rate has reached the maximum flow rate specified by the Manufacturer.

5.3.8 Relief Set Point

TABLE VI

Set Point	IRV – Start-to-Discharge Range (Over Set-Point)	Minimum IRV Reseat Above Lock-Up
Set ≤ 14 inches w.c. gauge (3.48 kPa	6 – 12 inches w.c.	2 inches w.c.
14 inches w.c. gauge (3.48 kPa gauge) < Set < 1 psig	7 – 21 inches w.c.	2 inches w.c.
1 psig ≤ Set ≤ 2 psig	2.0 psi max	0.1 psi

For regulators equipped with an internal relief valve, the following design verification test shall be performed for each orifice size available:

a) Set outlet pressure as described in Section 5.3.3, "Set Point."
b) Once outlet pressure stabilizes, close the downstream valve allowing the regulator to go into lockup.
c) Slowly apply a controlled backpressure of air into the outlet side of the regulator to yield a flow rate of approximately one cubic foot an hour.
d) The relief valve should begin to relieve as downstream pressure rises above the lock-up point of the regulator. After the regulator has been pressurized, the start-to- relieve point can be detected by:
    - applying a leak-detection solution to the regulator vent,
    - placing the vent discharge into a maximum water seal of one-inch w.c. (0.25 kPa),
    - or other acceptable means.

e) To determine the relief-valve reseat point, remove the backpressure on the outlet side of the regulator and observe the pressure at which the relief valve ceases to release pressure. The relief valve shall reseat according to the values in the Table VI. The reseat pressure should be checked to see that it remains constant for a minimum of 10 seconds.

Modified Relief Point Test

The following test was developed to quantify the IRV discharge rate during a backpressure event. The vent emission rate is directly proportional to the backpressure supplied at the outlet. This test was performed with regulators under normal operating conditions and all major failure modes.

a) Install the flow meter at the vent of the regulator so that it is continually data logging. The thermal mass flow meter has a range of 0-105.94 scf/h (3.0 m3/h) and a connection

size of ¼" NPT. There must be at least 12" (30.48 cm) of straight pipe before the flow meter to ensure laminar flow.

b) Set the inlet pressure accordingly, either 10, 60, or 100 psig.
c) Once outlet pressure stabilizes, close the downstream valve allowing the regulator to go into lockup.
d) Slowly apply a controlled backpressure of air into the outlet side of the regulator. Increase the back pressure until it surpasses the OPSO trip point of the regulator or the maximum allowable pressure is reached 5 psig (138.4"w.c.).
e) Slowly decrease back pressure to 0 psig.

5.3.9 Internal Relief-Valve Performance Test

This section is only for regulators equipped with an internal relief valve. The internal relief-valve capacity for each orifice size available shall be tested as follows:

a) Cause the regulator to fail by disconnecting the linkage between the diaphragm and valve mechanism or the most severe failure condition that yields the highest build-up pressure.
b) Disconnect any vent piping to allow the regulator to vent the flow of gas freely and unrestricted to the atmosphere.
c) Close the valve downstream of the regulator so that there is no flow of gas through the regulator.
d) Note the outlet pressure while slowly increasing the inlet pressure from 0 psig to the maximum inlet pressure recommended by the manufacturer for the orifice installed. Record the outlet pressure at the maximum inlet pressure after the system reaches a steady-state condition. Refer to Appendix A for how to display the result.

TABLE VII

Set Point	Maximum Outlet Buildup
Set ≤ 14 inches w.c. gauge (3.48 kPa gauge)	2 psi
14 inches w.c. gauge (3.48 kPa gauge) < Set < 1 psig	5 psi
1 psig ≤ Set ≤ 2 psig	5 psi

The user shall evaluate all downstream equipment limits and design considerations when selecting the relief performance. The maximum outlet pressure shall not exceed those guidelines established by governing standards and regulations. Table VIII shows typical equipment allowable limits. However applicable codes and standards shall be additionally considered.

Part 2: Methane Concentration Measurement – Replicating field conditions, measuring the concentration of natural gas at various distances away from the regulator vent, or source of natural gas emission. There are three main tests:

1) Single lockup test,
2) Multi-lockup test,
3) and OPSO performance test.

The lockup tests were performed using a solenoid valve configured to a Python script to ensure all tests for each regulator were performed consistently. The solenoid valve is located 12 feet downstream of the regulator, the outlet flow rate while the solenoid valve was in the open position was 384 SCFH for 7"w.c. regulators and 1260 SCFH for 2 PSIG regulators. The natural gas was supplied to the regulator at a pressure of 60 PSIG.

The following describes the tests as they were performed on the testing rig and the manner in which they were conducted.

Single lockup Test

a) Install regulator into test chamber.
b) Initialize data log of the outlet pressure transducer.
c) Pressurize and use a soap solution to ensure there are no leaks from the connections.
d) Set the distance between methane sensor 1 and regulator vent: less than 1" (2.54 cm). An additional test must be done with a 6" (15.24 cm) distance between the vent and methane sensor 1.
e) Run the test script: Open valve for 3 seconds, close valve, wait 20 seconds, repeat 4 more times. Refer to **Figure 11** to see a graph showing outlet pressure during the Single lockup test that was repeated for each regulator.

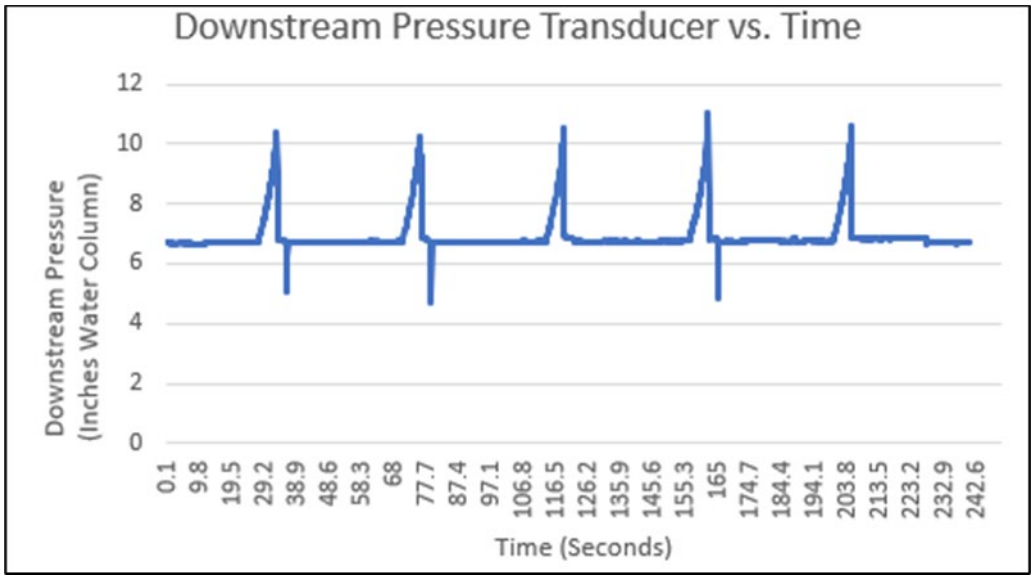


Figure 11. Part 2 Outlet Pressure Repeated for Each Single Lockup Test

Multi-lockup Test

a) Install regulator into test chamber.
b) Initialize data log of the methane sensor array and outlet pressure transducer.
c) Pressurize and use a soap solution to ensure there are no leaks from the connections.
d) Set the distance between methane sensor 1 and regulator vent: less than 1" (2.54 cm). An additional test must be done with a 6" (15.24 cm) distance between the vent and methane sensor 1.
e) Run the test script: Open valve for 3 seconds, close valve, open valve for 0.5 seconds, close valve, repeat 3 times. After the 3rd repetition add 1 lockup to a maximum of 4. Refer to the **Figure 12** to see a graph showing outlet pressure during the multi-lockup test that was repeated for each regulator.

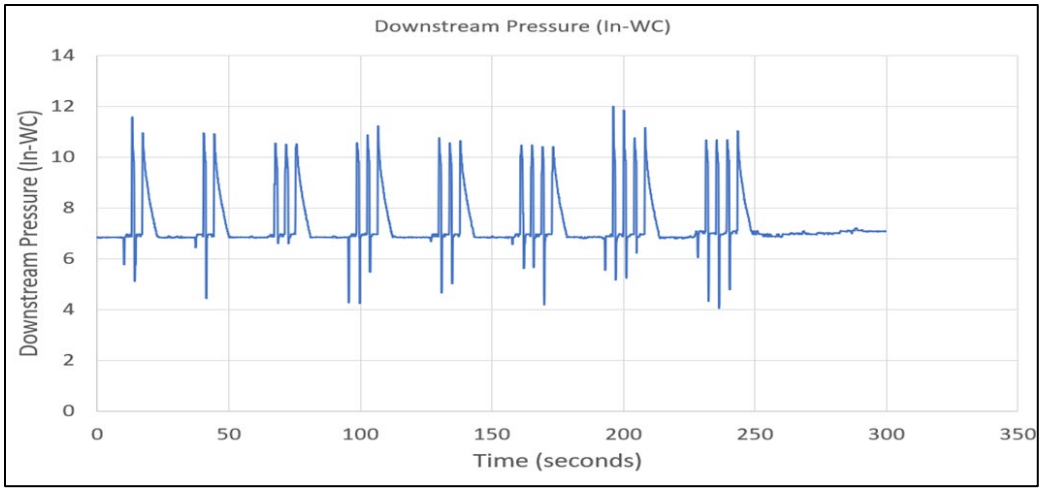


Figure 12. Part 2 Outlet Pressure Repeated for Each Mult-Lockup Test

OPSO performance test (only for regulators with OPSO)

a) Cause the regulator to fail by either Lever disconnect, Single diaphragm tear, or Double diaphragm tear.
b) Install regulator into test chamber.
c) Initialize data log of the methane sensor array.
d) Open the inlet pressure valve.
e) Wait for 10 minutes.
f) Close inlet pressure valve.

Procedure for creating regulator failures

Lever disconnect

a) Open the body of the regulator by loosening and removing the screws.
b) Unhook the diaphragm linkage from the lever, allowing for the removal of the diaphragm, (**Figure 13**).
c) Using a hack saw or rotary cutter, cut off the linkage that connects the diaphragm assembly to the lever, (**Figure 14**).
d) Reassemble diaphragm assembly, making sure that the diaphragm and spring are correctly aligned within the body of the regulator.
e) Close the regulator body and tighten the screws, label the respective failure mode on the outside of the regulator.
f) Pressure test regulator to ensure no leaks.

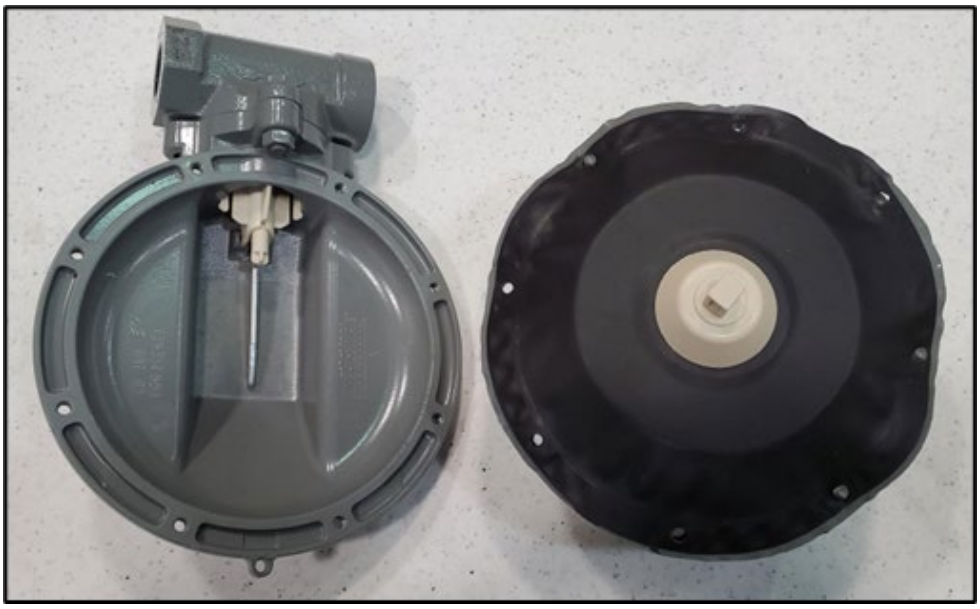


Figure 13. Inside Regulator (Lever and Diaphragm)

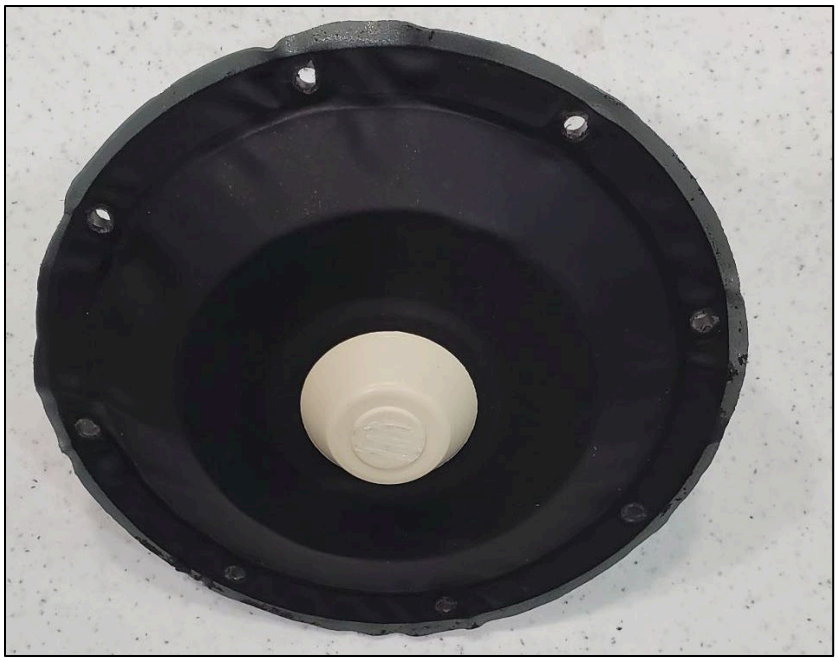


Figure 14. Linkage Cutoff the Diaphragm

Diaphragm slit

a) Open the body of the regulator by loosening and removing the screws.
b) Unhook the diaphragm linkage from the lever, allowing for the removal of the diaphragm.

c) For primary diaphragm slits, separate the primary diaphragm from the secondary diaphragm. For primary and secondary diaphragm slits, both diaphragms can be cut simultaneously. **Figure 15** displays the diaphragm and the cutting guide used for consistent cuts for each regulator tested.
d) Align outer ridge of the diaphragm with the radial gap of the cutting guide, as shown in **Figure 16** and **Figure 17** .
e) Using a razor blade, cut the diaphragm through the slot of the cutting guide and mark the slit with a silver marker.
f) Measure cut length using calipers and ensure the cut length is 1 inch (2.54 cm), extend cut if needed, see **Figure 18**.
g) Reassemble diaphragm assembly and reconnect the diaphragm linkage to the lever, making sure that the diaphragm and spring are correctly aligned within the body of the regulator.
h) Close the regulator body and tighten the screws, label the respective failure mode on the outside of the regulator.
i) Pressure test regulator to ensure no leaks.



Figure 15. Diaphragm and Cutting Guide



Figure 16. Primary and Secondary Diaphragm (Cutting Guide)



Figure 17. Diaphragm and Cutting Guide



Figure 18. Consistent Cut and Location for Each Diaphragm

Regulator Models Included in Testing

The following regulator models were included in this evaluation and listed in the test plan:

1. Pietro Fiorentini FE
2. Pietro Fiorentini FEX
3. Cavagna Group / MESURA Model S7
4. Cavagna Group / MESURA Model S9
5. Honeywell 1843B2-VL
6. Honeywell 1813C
7. Itron B42R
8. Sensus 143-80
9. Fisher-Emerson HSR

Summary of Results (Part 1: Emission Volume Measurement)

The tests conducted in Part 1 of this evaluation are listed in **Table 5**. Further details on the test setup can be found in the Test Plan. The full results of all tests for Part 1 are in the Appendix of this report.

Table 5: Tests included in Part 1.

Test	Sub-test	Standard /Procedure reference	Conditions	Test Criteria	Parameters
Pressure Regulating Characteristics (Normal Operating Conditions)	Set Point Test	ANSI B109.4 - [5.3.3]	Temperature: Ambient; Inlet pressure: 40 psig; Flow 50 SCFH GAS or 39 SCFH AIR	Outlet pressure 7"±0.1 iwc 2±0.03 psig (2 psig reg.)	Set point [iwc]
	Modified Lock-Up Test	ANSI B109.4 - [5.3.5]	Temperature: Ambient; Inlet pressure: 60, 100 psig; Flow: 100, 200, 300, until maximum manufacturer specifications [SCFH Air]	Outlet pressure Max 9"±0.5 iwc 2.15±0.15 psig (2psig reg.)	Lock up [iwc]
				Flow rate at vent 2.5 SCFH (vent limited) 100 SCFH (IRV)	Vent flow rate [SCFH]
	Modified Relief Point Test	ANSI B109.4 - [5.3.8]	Temperature: Ambient; Inlet pressure: 10, 60, 100 psig; Outlet pressure: slowly increase until slam shut closes or maximum allowable pressure reached	Outlet pressure MAX 17"±0.5 iwc; 3.3±0.15iwc psig (2psig reg.)	Relief point [iwc]
				Flow rate at vent 2.5 SCFH (vent limited) 100 SCFH (IRV)	Vent flow rate [SCFH]
Pressure Regulating Characteristics (Abnormal Operating Conditions) **Full Lever disconnect**	Set Point Test	ANSI B109.4 - [5.3.3]	Temperature: Ambient; Inlet pressure: 40 psig; Flow 50 SCFH GAS or 39 SCFH AIR	Outlet pressure 7"±0.1 iwc 2±0.03 psig (2 psig reg.)	Set point [iwc]
	Modified Lock-Up Test	ANSI B109.4 - [5.3.5]	Temperature: Ambient; Inlet pressure: 60, 100 psig; Flow: 100, 200, 300, until maximum manufacturer specifications [SCFH Air]	Outlet pressure Max 9"±0.5 iwc 2.15±0.15 psig (2psig reg.)	Lock up [iwc]
				Flow rate at vent 2.5 SCFH (vent limited) 100 SCFH (IRV)	Vent flow rate [SCFH]
	Modified Relief Point Test	ANSI B109.4 - [5.3.8]	Temperature: Ambient; Inlet pressure: 60, 100 psig; Outlet pressure: slowly increase until slam shut closes or maximum allowable pressure reached	Outlet pressure MAX 17"±0.5 iwc; 3.3±0.15iwc psig (2psig reg.)	Relief point [iwc]
				Flow rate at vent 2.5 SCFH (vent limited) 100 SCFH (IRV)	Vent flow rate [SCFH]
	Internal Relief-Valve Performance Test	ANSI B109.4 - [5.3.9]	Temperature: Ambient; Inlet Pressure: 0-60 psig or the maximum manufacturer specifications	Max Outlet pressure buildup 2psig (7iwc reg.) 5 psig (2psig reg.)	Droop pressure [iwc]

				Flow rate at vent 2.5 SCFH (vent limited) 100 SCFH (IRV)	Vent flow rate [SCFH]
Pressure Regulating Characteristics (Abnormal Operating Conditions) . Diaphragm slit (in primary diaphragm)	Set Point Test	ANSI B109.4 - [5.3.3]	Temperature: Ambient; Inlet pressure: 40 psig; Flow 50 SCFH GAS or 39 SCFH AIR	Outlet pressure 7"±0.1 iwc 2±0.03 psig (2 psig reg.)	Set point [iwc]
	Modified Lock-Up Test	ANSI B109.4 - [5.3.5]	Temperature: Ambient; Inlet pressure: 60, 100 psig; Flow: 100, 200, 300, until maximum manufacturer specifications [SCFH Air]	Outlet pressure Max 9"±0.5 iwc 2.15±0.15 psig (2psig reg.)	Lock up [iwc]
				Flow rate at vent 2.5 SCFH (vent limited) 100 SCFH (IRV)	Vent flow rate [SCFH]
	Modified Relief Point Test	ANSI B109.4 - [5.3.8]	Temperature: Ambient; Inlet pressure: 60, 100 psig; Outlet pressure: slowly increase until slam shut closes or maximum allowable pressure reached	Outlet pressure MAX 17"±0.5 iwc; 3.3±0.15iwc psig (2psig reg.)	Relief point [iwc]
				Flow rate at vent 2.5 SCFH (vent limited) 100 SCFH (IRV)	Vent flow rate [SCFH]
	Internal Relief-Valve Performance Test	ANSI B109.4 - [5.3.9]	Temperature: Ambient; Inlet Pressure: 0-60 psig or the maximum manufacturer specifications	Max Outlet pressure buildup 2psig (7iwc reg.) 5 psig (2psig reg.)	Droop pressure [iwc]
				Flow rate at vent 2.5 SCFH (vent limited) 100 SCFH (IRV)	Vent flow rate [SCFH]
Pressure Regulating Characteristics (Abnormal Operating Conditions) . Diaphragm slit (in both diaphragms)	Set Point Test	ANSI B109.4 - [5.3.3]	Temperature: Ambient; Inlet pressure: 40 psig; Flow 50 SCFH GAS or 39 SCFH AIR	Outlet pressure 7"±0.1 iwc 2±0.03 psig (2 psig reg.)	Set point [iwc]
	Modified Lock-Up Test	ANSI B109.4 - [5.3.5]	Temperature: Ambient; Inlet pressure: 60, 100 psig; Flow: 100, 200, 300, until maximum manufacturer specifications [SCFH Air]	Outlet pressure Max 9"±0.5 iwc 2.15±0.15 psig (2psig reg.)	Lock up [iwc]
				Flow rate at vent 2.5 SCFH (vent limited) 100 SCFH (IRV)	Vent flow rate [SCFH]
	Modified Relief Point Test	ANSI B109.4 - [5.3.8]	Temperature: Ambient; Inlet pressure: 60, 100 psig; Outlet pressure: slowly increase until slam shut closes or maximum allowable pressure reached	Outlet pressure MAX 17"±0.5 iwc; 3.3±0.15iwc psig (2psig reg.)	Relief point [iwc]
				Flow rate at vent 2.5 SCFH (vent limited) 100 SCFH (IRV)	Vent flow rate [SCFH]
	Internal Relief-Valve Performance Test	ANSI B109.4 - [5.3.9]	Temperature: Ambient; Inlet Pressure: 0-60 psig or the maximum manufacturer specifications	Max Outlet pressure buildup 2psig (7iwc reg.) 5 psig (2psig reg.)	Droop pressure [iwc]
				Flow rate at vent 2.5 SCFH (vent limited) 100 SCFH (IRV)	Vent flow rate [SCFH]

Pressure Regulating Characteristics (Abnormal Operating Conditions) **Blocked regulator vent**	Set Point Test	ANSI B109.4 - [5.3.3]	Temperature: Ambient; Inlet pressure: 40 psig; Flow 50 SCFH GAS or 39 SCFH AIR	Outlet pressure 7"±0.1 iwc 2±0.03 psig (2 psig reg.)	Set point [iwc]
	Modified Lock-Up Test	ANSI B109.4 - [5.3.5]	Temperature: Ambient; Inlet pressure: 60, 100 psig; Flow: 100, 200, 300, until maximum manufacturer specifications [SCFH Air]	Outlet pressure Max 9"±0.5 iwc 2.15±0.15 psig (2psig reg.)	Lock up [iwc]
				Flow rate at vent 2.5 SCFH (vent limited) 100 SCFH (IRV)	Vent flow rate [SCFH]
	Modified Relief Point Test	ANSI B109.4 - [5.3.8]	Temperature: Ambient; Inlet pressure: 60, 100 psig; Outlet pressure: slowly increase until slam shut closes or maximum allowable pressure reached	Outlet pressure MAX 17"±0.5 iwc; 3.3±0.15iwc psig (2psig reg.)	Relief point [iwc]
				Flow rate at vent 2.5 SCFH (vent limited) 100 SCFH (IRV)	Vent flow rate [SCFH]
	Internal Relief-Valve Performance Test	ANSI B109.4 - [5.3.9]	Temperature: Ambient; Inlet Pressure: 0-60 psig or the maximum manufacturer specifications	Max Outlet pressure buildup 2psig (7iwc reg.) 5 psig (2psig reg.)	Droop pressure [iwc]
				Flow rate at vent 2.5 SCFH (vent limited) 100 SCFH (IRV)	Vent flow rate [SCFH]

Note: Since some of the vent-limited regulators have "uni-vents," blocking the vent outlet on these models can lead to additional failures. The "blocked vent" tests were added to investigate the effect of a blocked vent on regulator performance and to observe any resulting failure modes. Vent emissions cannot be measured when the vent is blocked, so these measurements are not available. Charts of other flow characteristics during tests where the regulator vent was blocked, however, can be seen in the Appendices of this report.

Lockup Test Results

During the modified lockup tests, the vent flow rate was measured using an Omega FMA mass flow meter. The following data graphs are examples and were plotted for each Part 1 Test:

- Outlet Flow vs Time, **Figure 19**
- Outlet Pressure vs Time, **Figure 20**
- Vent Emissions Volume vs Time, **Figure 21**

The data was recorded over the series of regulator lockups to measure the flow rate and volume of emission from the regulator vent. The reported flow rate of the vent emissions was calculated

dividing the total volume emitted over the course of the test by the duration of the test, and then converting to a vent emission rate in SCFH.

During the lockup tests, the vent relieves in multiple, intermittent successions. The "Vent Emissions Over Time" graph depicts the volume emitted each time that the outlet flow changes. An alternative method for calculating the vent emission rate would be to calculate the emission volume of every single separate emission and divide it by the time that elapsed during each specific separate emission.

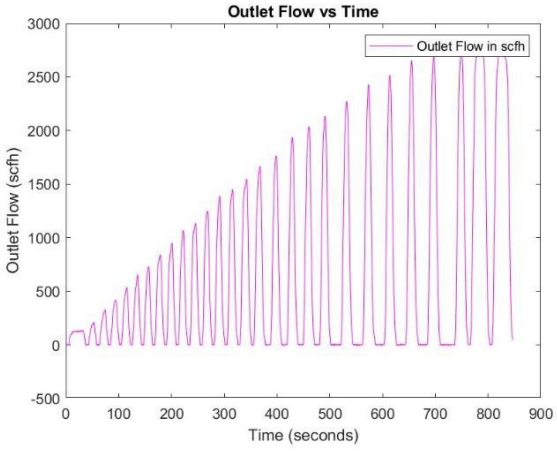


Figure 19. Lockup Test - Output Flow vs Time

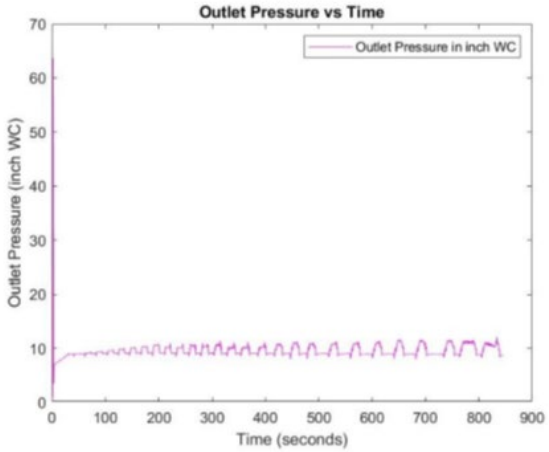


Figure 20. Lockup Test - Output Pressure vs Time

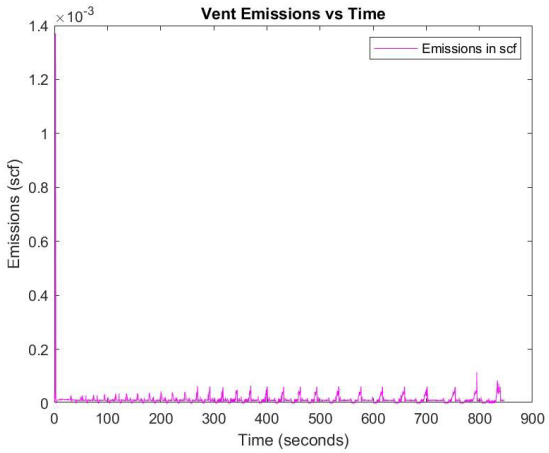


Figure 21. Lockup Test - Vent Emissions vs Time

The summarized results for the Modified Lockup and Relief Tests (Emission Volume and Emission Flow Rate) can be seen in the following tables. The entries are color coded to provide more context. Full results with charts of each specific test conducted can be seen in the Appendix of this report. Due to the variability in total time elapsed for each test, the average emission rate (SCFH) is the most comparable metric between regulator models. In addition, average emission volume is included for comparison.

	Flow surpassed flow meter range
	OPSO tripped during first lock-up

Table 6: Modified Lockup Test Summary at 7 IWC Inlet Pressure; Average Emission Volume [SCF]

Modified Lockup Test Results Summary, Average Emission Volume [SCF]	Outlet Set Point = 7 IWC								
	Type			Diaphragm Tear			Lever Disconnect		
Regulators	10-psig	60-psig	100-psig	10-psig	60-psig	100-psig	10-psig	60-psig	100-psig
VL1	0.02	0.02	0.02						
VL2	0.01	0.06	0.01						
VL3	0.14	0.11	0.15						
VL4	0.01	0.01	0.01						
VL5	0.01	0.01	0.01						
IRV1	0.06	0.13	0.14	3.44	2.88	3.42	3.71	0.37	0.36
IRV2	0.12	0.02	0.04	1.14	3.23	4.56	2.17	0.50	
IRV3	0.06	0.09	0.11						
IRV4	0.09	0.10	0.19	2.20	2.36	3.36	0.11	0.02	0.02

Table 7: Modified Lockup Test Summary at 7 IWC Inlet Pressure; Average Emission Rate [SCFH]

Modified Lockup Test Results Summary, Average Emission Rate [SCFH]	Outlet Set Point = 7 IWC								
	Type			Diaphragm Tear			Lever Disconnect		
Regulators	10-psig	60-psig	100-psig	10-psig	60-psig	100-psig	10-psig	60-psig	100-psig
VL1	0.10	0.11	0.10						
VL2	0.12	0.51	0.09						
VL3	1.02	0.59	0.56						
VL4	0.09	0.09	0.07						
VL5	0.04	0.04	0.04						
IRV1	0.90	0.55	0.61	54.10	79.78	75.14	59.12	87.36	80.69
IRV2	0.38	0.15	0.15	21.80	24.35	23.80	51.39	84.71	
IRV3	0.55	0.48	0.46						
IRV4	1.02	0.37	0.37	25.90	17.02	27.04	1.25	1.86	2.55

The summary for vent emissions for the regulator lockup tests with a 7 IWC set point are as follows:

- **Normal Conditions**: none of the regulators exceeded 2.5 SCFH during normal conditions.
- **Vent Limited Regulators**: all the vent limited regulators with an OPSO successfully closed during the first lock-up during an abnormal condition (1st diaphragm tear, both diaphragm tears, and lever disconnect).
- **Non-Vent Limited Regulators**: all the non-vent limited regulators significantly exceeded 2.5 SCFH with a diaphragm tear. All the non-vent limited regulators significantly exceeded 2.5 SCFH with the lever disconnect, except for the one.

	Flow surpassed flow meter range
	OPSO tripped during first lock-up
	NA - No samples tested

Table 8: Modified Lockup Test Summary at 2-psig Inlet Pressure; Average Emission Volume [SCF]

Modified Lockup Test Results Summary, Average Emission Volume [SCF]	Outlet Set Point = 2 psig								
	Type			Diaphragm Tear			Lever Disconnect		
Regulators	10-psig	60-psig	100-psig	10-psig	60-psig	100-psig	10-psig	60-psig	100-psig
VL1	0.01	0.10	0.09						
VL2	0.08	0.19	0.18						
VL3	NA	NA	NA	NA	NA	NA	NA	NA	NA
VL4	0.02	0.02	0.02						
VL5	0.01	0.01	0.01						
IRV1	0.04	0.11	0.15	2.93	1.01	0.25	1.80	0.29	0.29
IRV2	0.03	0.04	0.05	0.36	0.34	0.43	1.99	0.50	
IRV3	0.06	0.10	0.15						
IRV4	NA	NA	NA	NA	NA	NA	NA	NA	NA

Table 9: Modified Lockup Test Summary at 2-psig Inlet Pressure; Average Emission Rate [SCFH]

Modified Lockup Test Results Summary, Average Emission Rate [SCFH]	Outlet Set Point = 2 psig								
	Type			Diaphragm Tear			Lever Disconnect		
Regulators	10-psig	60-psig	100-psig	10-psig	60-psig	100-psig	10-psig	60-psig	100-psig
VL1	0.11	0.10	0.09						
VL2	0.33	0.19	0.18						
VL3	NA	NA	NA	NA	NA	NA	NA	NA	NA
VL4	0.21	0.12	0.13						
VL5	0.07	0.05	0.04						
IRV1	0.65	0.63	0.62	66.42	85.98	83.68	43.56	81.10	79.46
IRV2	0.44	0.25	0.22	5.56	1.99	1.60	39.97	90.54	
IRV3	1.26	0.62	0.64						
IRV4	NA	NA	NA	NA	NA	NA	NA	NA	NA

The summary for vent emissions for the regulator lockup tests with a 2-psig set point are as follows:

- **Normal Conditions**: none of the regulators tested exceeded 2.5 SCFH during normal conditions.
- **Vent Limited Regulators:** all the vent limited regulators with an OPSO successfully closed during the first lock-up of an abnormal condition (1st diaphragm tear, both diaphragm tears, and lever disconnect) when input pressure exceeded the set point.
- **Non-Vent Limited Regulators**: one of the IRV exceeded 2.5 SCFH during both abnormal conditions (diaphragm tear and lever disconnect). One IRV only exceeded 2.5 SCFH during the lever disconnect.

Relief Test Results

During the relief tests, the vent flow rate was measured using an Omega FMA mass flow meter. The following data graphs are examples and were plotted for each Part 1 Test:

- Outlet Pressure vs Time, **Figure 22**
- Vent Emission Volume vs Time, **Figure 23**
- Vent Emissions Flow Rate vs Time, **Figure 24** and **Figure 25** (focused view of relief point)

Pressure is increased on the regulator's outlet piping in order to cause a relief emission from the regulator vent. The relief emission is a momentary event and does not constitute a constant flow rate. During the testing, the relief event occurs for 30-40 seconds. The relief test involves applying a backpressure to the regulator's outlet piping and this condition is possible in the field if the piping downstream of the regulator increases pressure, such as if the piping were to increase in temperature. Given that VL regulators incorporate the OPSO device on the inlet side,

the execution of this test effectively resulted in the circumvention of the Over-Pressure Shut-Off (OPSO) mechanism.

Initially, the vent flow rate was calculated by measuring the total volume emitted from the vent, and then dividing this value by the total length of time that of the test (approximately 180 seconds). Since the regulator relieves only for a portion of this time, the calculation was modified to only consider the flow rate during the actual emission event.

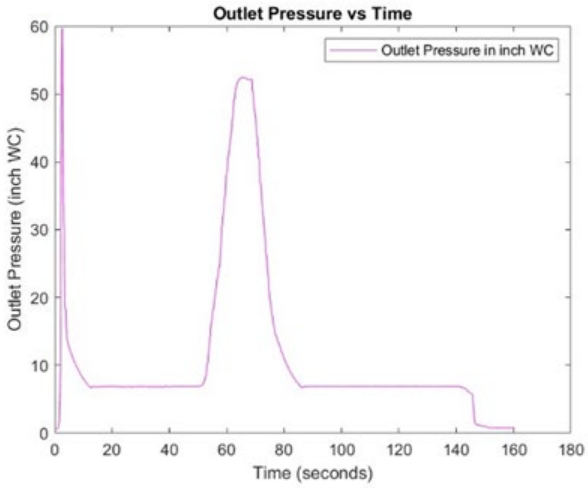


Figure 22. Relief Test – Outlet Pressure vs Time

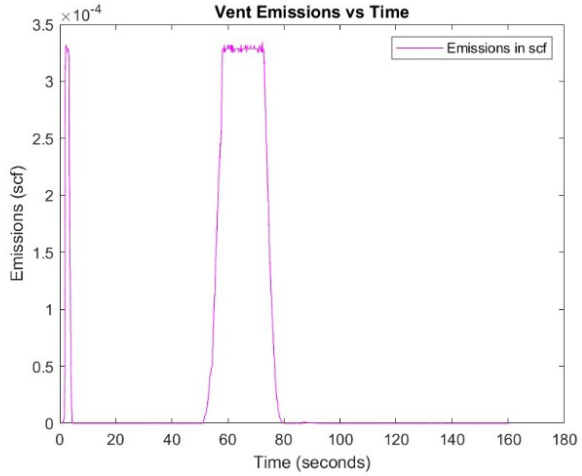


Figure 23. Relief Test – Vent Emission Volume vs Time

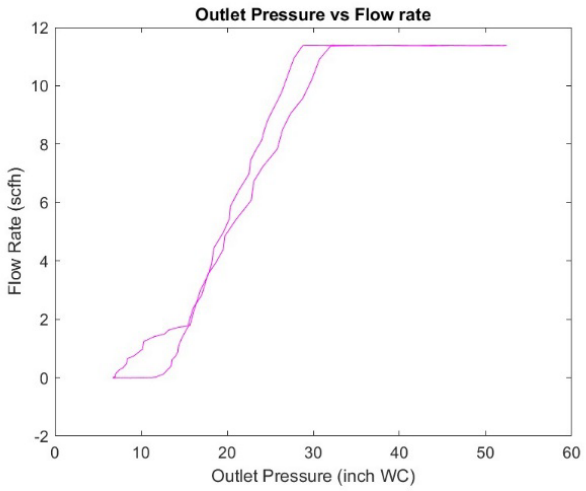


Figure 24. Relief Test – Emissions Flow Rate vs Outlet Pressure

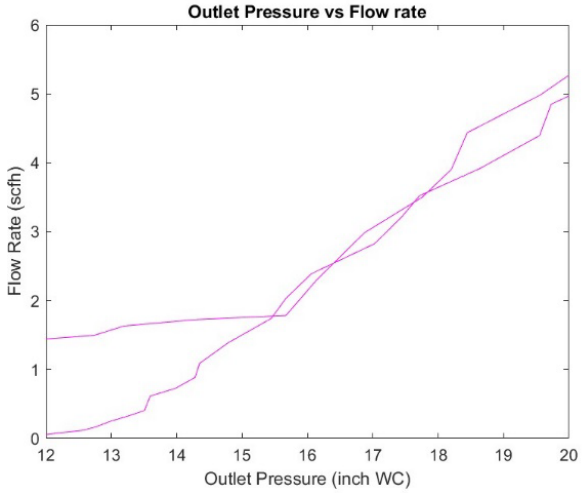


Figure 25. Relief Test – Emissions Flow Rate vs Outlet Pressure (Focus View of Relief Point at 12-20 IWC)

	Flow surpassed flow meter range
*	NA - No samples tested, single diaphragm regulator

Table 10: Relief Test Summary at 7 IWC Inlet Pressure; Average Emission Volume [SCF]

Relief Test Results Summary, Average Emission Volume [SCF]	Outlet Set Point = 7 IWC											
	Type			1st Diaphragm Tear			Both Diaphragm Tears			Lever Disconnect		
Regulators	10-psig	60-psig	100-psig	10-psig	60-psig	100-psig	10-psig	60-psig	100-psig	10-psig	60-psig	100-psig
VL1	0.07	0.07	0.06	0.07	0.07	0.07	0.41	0.43	0.42	0.00	0.00	0.00
VL2	0.06	0.08	0.08	0.08	0.09	0.09	0.84	0.95	1.60	0.81	0.64	0.80
VL3	0.06	0.03	0.03	1.04	1.05	0.96	NA*	NA*	NA*	0.58	0.56	0.68
VL4	0.08	0.11	0.10	0.09	0.11	0.11	0.71	1.03	0.78	0.00	0.00	0.00
VL5	0.14	0.13	0.14	0.33	0.32	0.30	0.91	0.88	1.00	0.28	0.28	0.29
IRV1	0.62	0.71	0.57	1.74	1.51	1.47	NA*	NA*	NA*	1.13	0.38	0.34
IRV2	0.07	0.08	0.08	2.01	2.05	2.25	NA*	NA*	NA*	1.39		
IRV3	0.07	0.07	0.08				NA*	NA*	NA*			
IRV4	0.65	1.04	1.12	1.42	1.69	2.60	NA*	NA*	NA*	0.02	0.02	0.02

Table 11: Relief Test Summary at 7 IWC Inlet Pressure; Average Emission Rate [SCFH]

Relief Test Results Summary, Average Emission Rate [SCFH]	Outlet Set Point = 7 IWC											
	Type			1st Diaphragm Tear			Both Diaphragm Tears			Lever Disconnect		
Regulators	10-psig	60-psig	100-psig	10-psig	60-psig	100-psig	10-psig	60-psig	100-psig	10-psig	60-psig	100-psig
VL1	1.37	1.32	1.27	2.67	1.86	1.82	1.45	2.94	2.52	0.00	0.00	0.00
VL2	0.83	1.42	1.12	2.19	2.02	1.89	21.34	22.24	16.46	1.12	0.38	0.27
VL3	3.33	3.92	4.94	22.74	24.89	25.11	NA*	NA*	NA*	9.80	11.92	12.15
VL4	7.77	8.46	7.62	11.56	11.50	10.88		25.29	21.60	0.00	0.00	0.00
VL5	6.50	6.13	5.77	13.56	13.36	13.26	9.67	11.28	8.95	10.24	10.14	10.50
IRV1	10.88	8.54	8.85				NA*	NA*	NA*	32.86	27.75	
IRV2	8.25	7.79	7.65			11.585	NA*	NA*	NA*			
IRV3	3.00	3.46	3.53				NA*	NA*	NA*			
IRV4	14.10	8.44	11.95	16.92	19.61	17.59	NA*	NA*	NA*	28.54	21.96	

The summary for vent emissions for the regulator relief tests with a 7 IWC set point are as follows; all regulators tested exceeded 2.5 SCFH, except for two of the vent limited regulators tested remained below 2.5 SCFH under normal conditions. These same two regulators also remained below 2.5 SCFH during the abnormal conditions of the 1st Diaphragm Tear and the Lever Disconnect. It is worth mentioning that the data of the 1st diaphragm include the IRV vent capacity plus the vent capacity of the safety diaphragm.

Table 12: Relief Test Summary at 2-psig Inlet Pressure; Average Emission Volume [SCF]

Relief Test Results Summary, Average Emission Volume [SCF]	Outlet Set Point = 2psig											
	Type			1st Diaphragm Tear			Both Diaphragm Tears			Lever Disconnect		
Regulators	10-psig	60-psig	100-psig	10-psig	60-psig	100-psig	10-psig	60-psig	100-psig	10-psig	60-psig	100-psig
VL1	0.04	0.03	0.04	0.04	0.05	0.04				0.01	0.00	0.00
VL2	0.05	0.05	0.05	0.03	0.03	0.03				0.03	0.03	0.03
VL3	NA	NA	NA	NA	NA	NA	NA*	NA*	NA*	NA	NA	NA
VL4	0.01	0.23	0.30	0.32	0.35	0.35				0.01	0.01	0.00
VL5	0.17	0.18	0.19	0.34	0.37	0.37				0.19	0.18	0.19
IRV1	0.38	0.34	0.38	0.81	0.26	0.27	NA*	NA*	NA*	3.19	0.31	0.29
IRV2	0.53	0.50	0.52	0.67	0.87	0.76	NA*	NA*	NA*	3.13		
IRV3	1.07	0.94	1.05				NA*	NA*	NA*			
IRV4	NA	NA	NA	NA	NA	NA	NA*	NA*	NA*	NA	NA	NA

Table 13: Relief Test Summary at 2-psig Inlet Pressure; Average Emission Rate [SCFH]

Relief Test Results Summary, Average Emission Rate [SCFH]	Outlet Set Point = 2psig											
	Type			1st Diaphragm Tear			Both Diaphragm Tears			Lever Disconnect		
Regulators	10-psig	60-psig	100-psig	10-psig	60-psig	100-psig	10-psig	60-psig	100-psig	10-psig	60-psig	100-psig
VL1	2.25	1.49	1.35	3.76	3.43	4.21				0.10	0.06	0.03
VL2	2.94	2.70	3.03	1.36	1.03	2.24				0.19	0.19	0.15
VL3	NA	NA	NA	NA	NA	NA	NA*	NA*	NA*	NA	NA	NA
VL4	0.21	11.27	11.14	23.63	22.51	24.74				0.03	0.28	0.15
VL5	12.64	12.63	12.49	8.47	4.48	8.57				11.95	18.54	18.31
IRV1	6.36	6.44	6.36	69.30	71.69	54.38	NA*	NA*	NA*	29.45		42.13
IRV2	10.55	10.21	10.85	12.06	12.96	11.51	NA*	NA*	NA*	16.32		
IRV3	10.26	9.57	9.92				NA*	NA*	NA*			
IRV4	NA	NA	NA	NA	NA	NA	NA*	NA*	NA*	NA	NA	NA

The summary for vent emissions for the regulator relief tests with a 2-psig set point are as follows; all regulators tested exceeded 2.5 SCFH, except for one of the vent limited regulators tested remained below 2.5 SCFH under all normal conditions.

Summary of Results (Part 2: Methane Concentration Measurement)

The testing performed in Part 2 consisted of the tests listed in **Table 14**:

Table 14: Tests included in Part 2.

Test	Standard /Procedure reference	Conditions	Test Criteria	Parameters
Single Lock-Up Test	ANSI B109.4 -[5.3.5]	Temperature: Ambient; Inlet pressure: 60 psig; Flow Rate: 390 SCFH (7 iwc reg.) 1260 SCFH (2 psig reg.) Lockup condition: One lock up induced, wait 30 seconds for gas concentration dissipate to 0% LEL, repeat 10 times.	Outlet pressure Max 9"±0.5 iwc (7 iwc reg.) 2.15±0.15 psig (2psig reg.)	Lock up pressure [iwc]
			Methane concentration at vent 0% LEL (vent limited) 3% LEL (IRV)	Methane Concentration [% LEL]
Multi Lock-Up Test	ANSI B109.4 -[5.3.5]	Temperature: Ambient; Inlet pressure: 60 psig; Flow Rate: 390 SCFH (7 iwc reg.) 1260 SCFH (2 psig reg.) Lockup condition: Two lock ups induced in quick succession, wait 30 seconds for gas concentration dissipate to 0% LEL, repeat 3 times, after 3 repetitions increase the number of lockups by 1 to a maximum of 4.	Outlet pressure Max 9"±0.5 iwc (7 inWC reg.) 2.15±0.15 psig (2psig reg.)	Lock up pressure [inWC]
			Methane concentration at vent 0% LEL (vent limited) 3% LEL (IRV)	Methane Concentration [% LEL]

The purpose of Part 2 of the test design was to measure the methane concentration at various distances away from the regulator vent during normal and abnormal operating conditions. This was done by constructing a methane sensor array that was composed of 24 separate methane sensors (0-100% LEL). These sensors were mounted onto a fixture and spaced in concentric rings at distances 6-inches, 1-foot, 2-feet, and 3-feet away from the regulator vent, as seen in **Figure 26.** Each sensor position and distance from the regulator vent was measured to align with the schematic in **Figure 27**. A pressure transducer was also installed downstream of the regulator to monitor the setpoint pressure as tests were run. The area where these tests were conducted was a contained space (enclosed shed), as seen in **Figure 28**, with a removable tarp on the top to allow for venting of gas after each test. All sensors were supplied power and connected to a data logger inside of the shed, as seen in **Figure 29**.

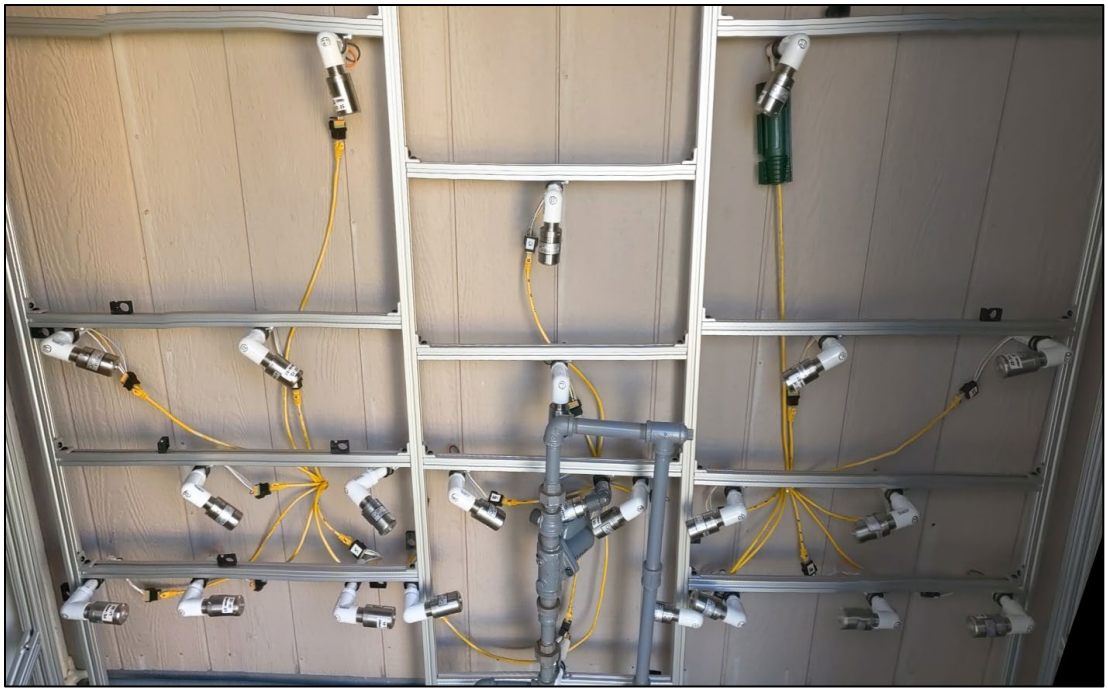


Figure 26: Methane sensor array with sensors positioned around the regulator vent.

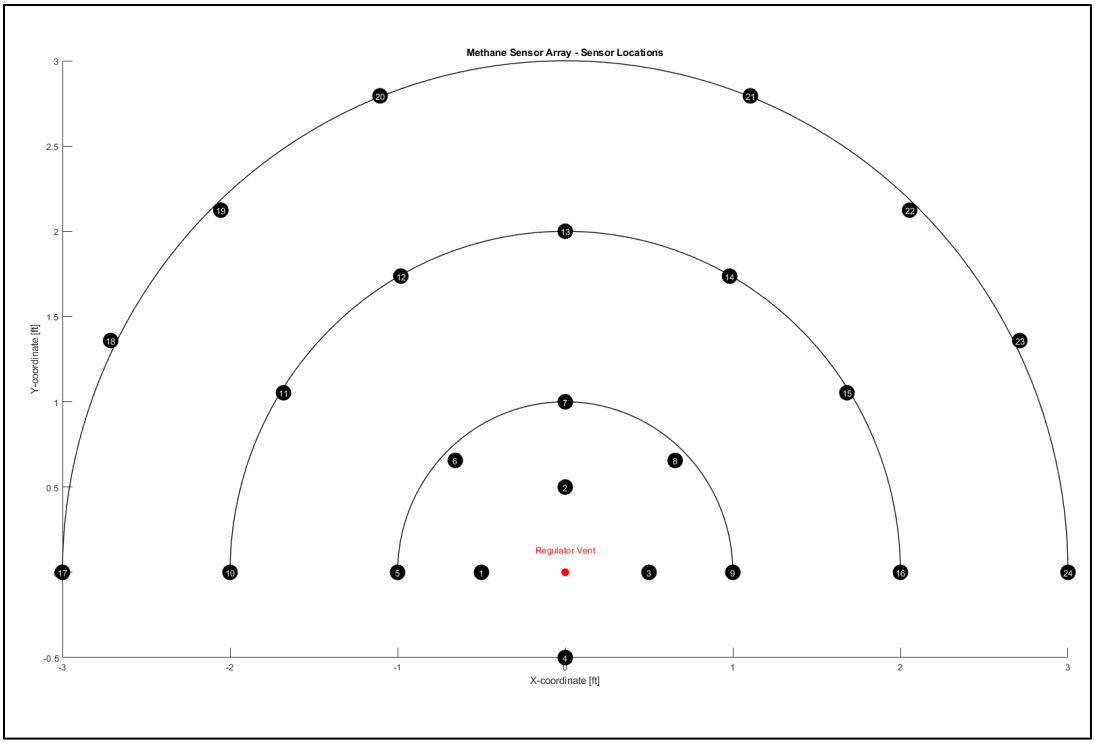


Figure 27: Positioning of methane sensors in concentric circles around the regulator vent

GTI ENERGY



Figure 28: Shed enclosure for the test setup.

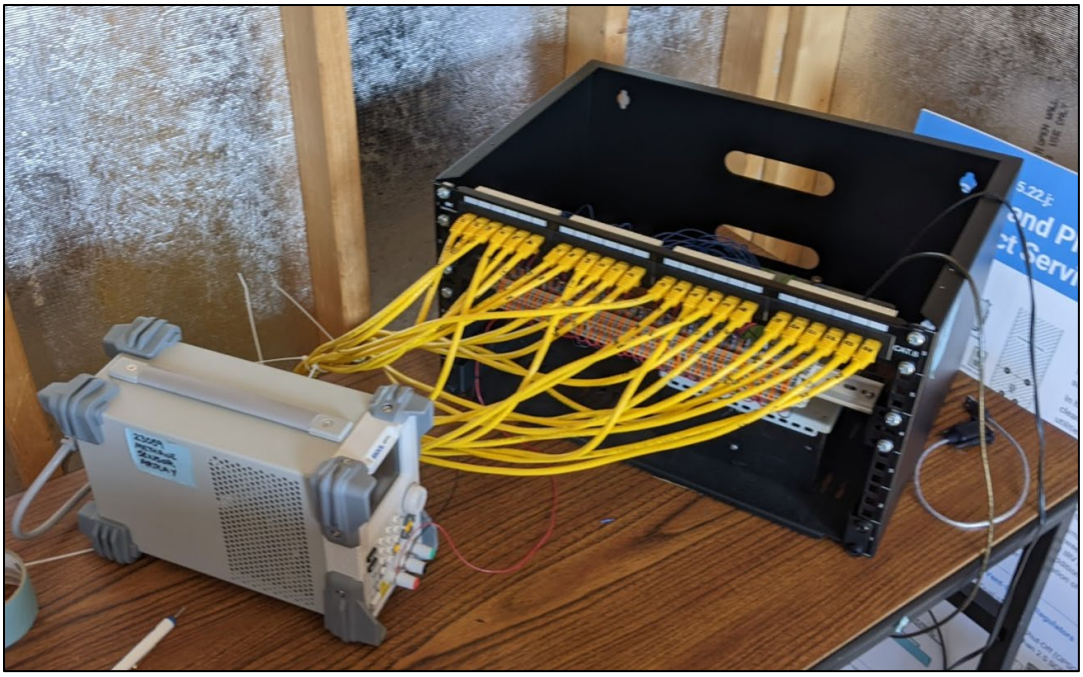


Figure 29: Data logger and power supply for the methane sensor array

To simulate common gas distribution pressure, all regulators tested were supplied with 60-psig inlet pressure. For lockup tests, downstream lockups were controlled using an automated valve that opened and closed in a repeatable succession to simulate downstream gas demand. The automated valve was used to create a consistent and repeatable test to provide a comparison between regulator models. As in Part 1, abnormal operating conditions for regulators were also tested (hole in the regulator diaphragm and a complete lever disconnect).

To visualize the plume of natural gas emitted from the regulator vent, all the data from the methane sensors was compiled to create a heatmap using MATLAB. For the most conservative estimation of the gas plume, the maximum methane reading over the course of each test was used to create these heatmaps. Since data was only available at the locations where a sensor was fixtured, the concentrations in the spaces between sensors were interpolated using a Gaussian kernel method to approximate the shape of the natural gas plume.

Examples of gas plume approximations can be seen in **Figure 30**. Each test was performed three times, and below is a typical result of a traditional IRV regulator with a 7-IWC setpoint operating normally in a muti-lockup test. Occasional venting of gas registered as relatively low concentrations (<10% LEL) of methane measured near (<1-ft) of the regulator vent. The red dot represents the regulator vent location, and the concentric rings denote the radial distance from the vent and the arrow shows the location of the sensor (and associated methane reading). The methane plume is color-scaled as well, to depict the relative concentration of methane at a given location.

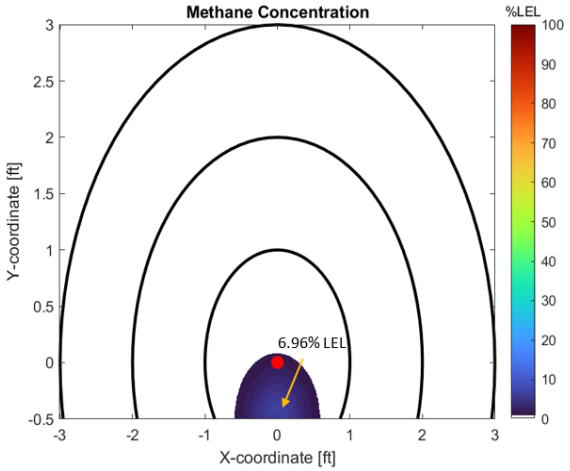


Figure 30: IRV Regulator – Part 2 Normal Conditions Lockup Testing

Clearance distance requirements, however, must consider scenarios where the regulator operation has failed. The traditional IRV regulators tested with torn diaphragms or disconnected levers continuously vented gas and quickly created a dangerous test environment. Traditional IRV regulators that had been altered to malfunction were not tested with live gas in Part 2 due

to safety concerns. Vent-limited regulators, however, have safety features such as OPSO and the abnormal conditions were tested in Part 2.

A gas plume plot and a methane array plot were created for each regulator tested in Part 2. **Figure 31** and **Figure 32** are plot examples of a vent limited regulator with both diaphragms torn and illustrate the maximum concentration of gas recorded before the vent-limited regulator OPSO engaged and to stop the flow of gas. This can be observed from the accompanying methane array plot, where the concentration of methane "spikes" in the beginning and then dissipates the following 2-3 minutes. Note **Figure 31** indicates the highest readings obtained at the sensors and **Figure 32** indicates that the gas readings quickly lowered over time after the OPSO engaged.

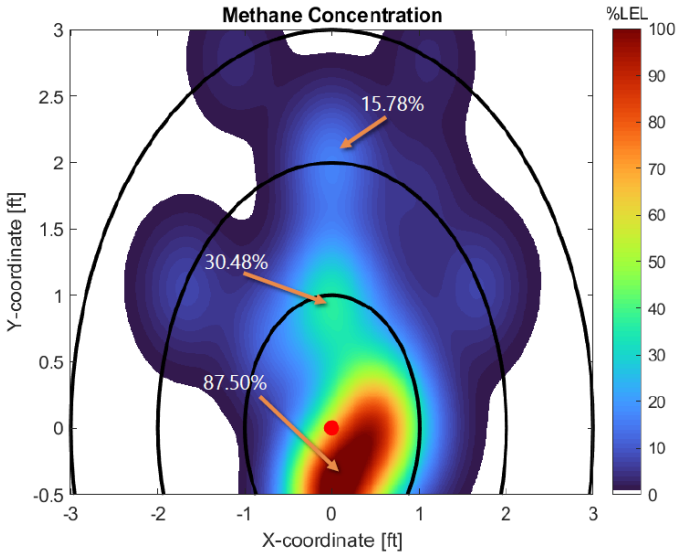


Figure 31: Gas plume heatmap for vent limiting regulator (both diaphragms torn) highest readings after OPSO engaged.

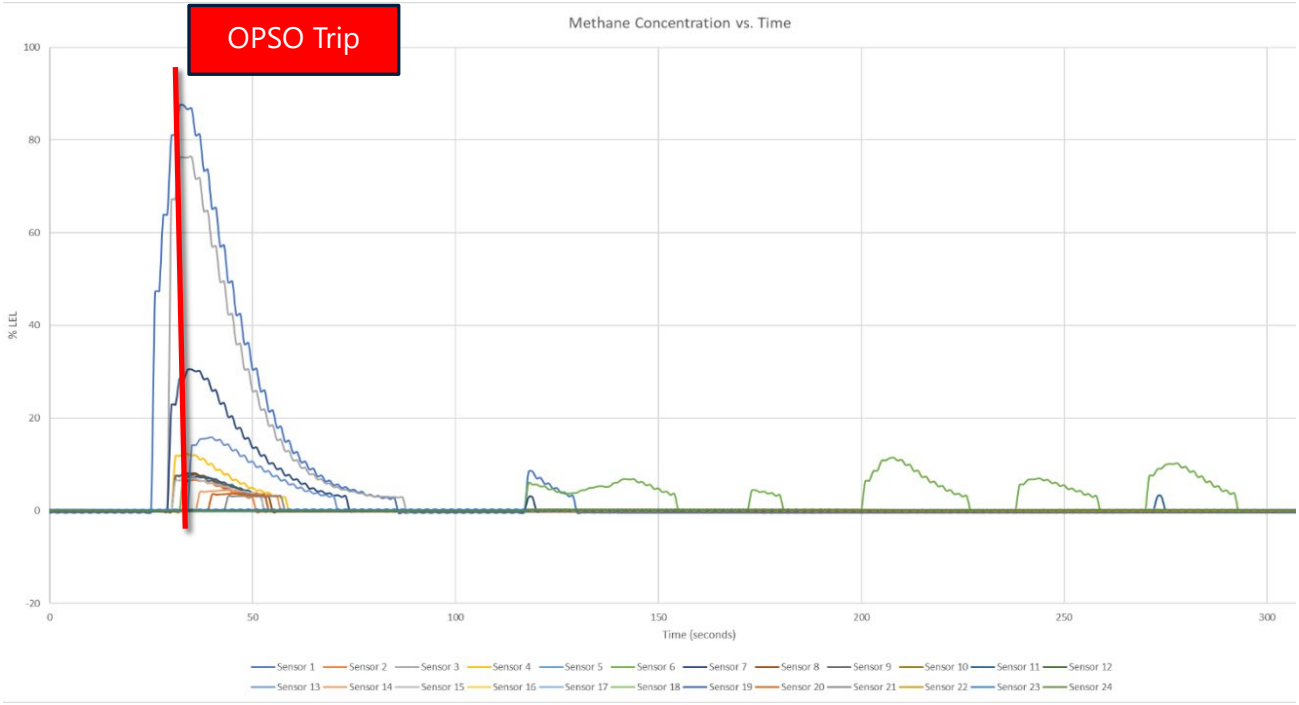


Figure 32: Gas plume dissipating for vent limiting regulator (both diaphragms torn) after OPSO engaged.

The properties of natural gas, (being lighter than air), cause gas to rise and will accumulate underneath structures. Each of the methane sensors in the array were installed with outdoor rated, intrinsically safe housings, as seen in Figure 33. These housings have a cavity feature that, when installed so that the sensor is pointing down, can have a "cupping" effect that catches the natural gas as it rises. This causes a slightly higher methane reading in the locations where the sensors are pointed downward and are located directly above the regulator vent. The project team learned to angle the methane sensor so gas passes by the sensor head and does not get trapped underneath the sensor causing a higher reading as compared to allowing the gas to dissipate freely. When the methane sensor was pointed exactly downward during the testing, the project team observed gas accumulating below the sensor's surface causing a higher gas reading as compared to placing the sensor on an angle. The observance of the accumulation of gas underneath the sensor's surface demonstrated the importance of a difference clearance needed pertaining to gas rising directly above the vent. A sensor placed directly below the vent would always indicate a smaller reading as compared to a sensor placed the same distance above the vent.



Figure 33: Methane sensor housing in downward position, with the cavity highlighted by a yellow arrow.

The following figures are examples of the lever disconnect abnormal condition for vent-limited regulators with an OPSO. The plot in **Figure 34** demonstrates the highest LEL readings observed by the methane sensors at various distances away from the vent (1 ft, 2ft, and 3ft). Note that for this abnormal regulator condition these are the highest gas LEL readings observed prior to the gas dissipating back to zero after the OPSO engaged. The plot for **Figure 35** demonstrates the LEL readings for each methane sensor (numbered 1 – 24) over time. Note that the readings spike and then after the OPSO engages the readings immediately start lowering to zero indicating that the gas is dissipating in the air. The project team noted that some of the LEL readings seem to be heavier on the left and was believed to be caused due to a small air current in the enclosed testing room.

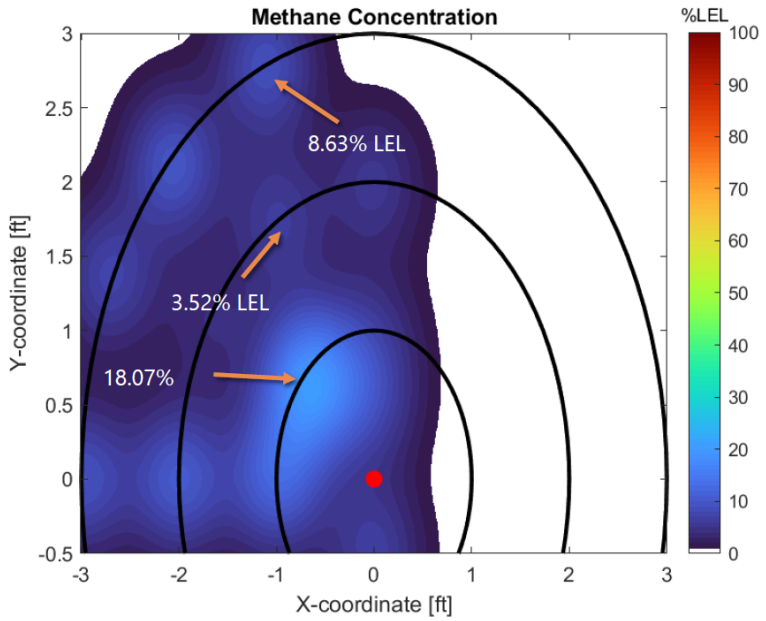


Figure 34: Gas plume heatmap for vent limiting regulator (lever disconnect) highest readings after OPSO engaged.

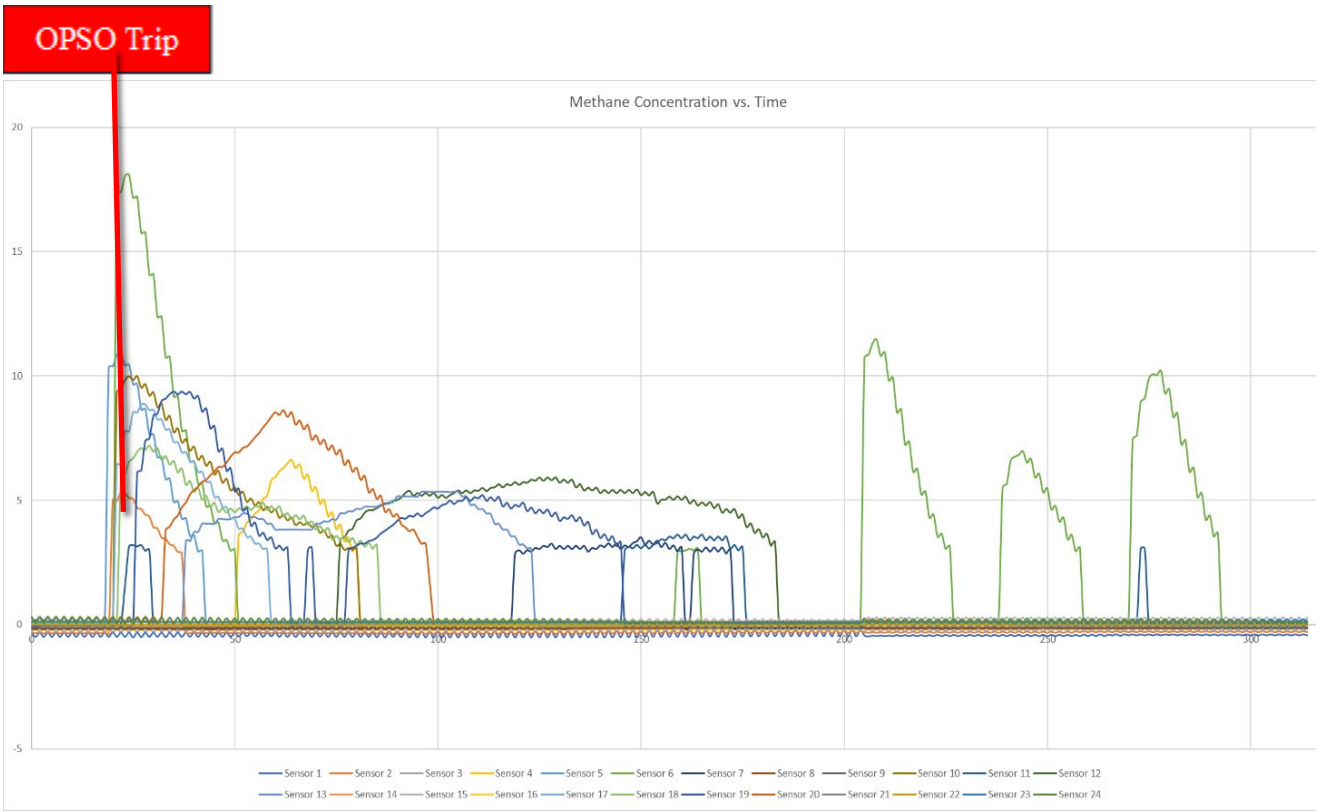


Figure 35: Gas plume dissipating for vent limiting regulator (lever disconnect) after OPSO engaged.

GTI ENERGY

Part 2 Clearance Results – Max LEL at 12 in, 24 in, & 36 in

The following data illustrates the highest readings from the regulator vents at various distances for the Part 2 testing during normal regulator conditions. Note that all the LEL readings from the vents for normal regulator conditions are less than the explosive limit. The testing under normal conditions illustrated in Tables 15 through 18 produced situations where the vent limited regulators and traditional IRV regulators produce small bursts of gas. The testing results indicate that each gas service regulator tested emitted gas lower than the explosive limit within 12 inches of the regulator vent (except for VL5 @ 7" w.c.). The gas emitted averaged less than 15% LEL within 12 inches of the regulator vent, would dissipate over time, and dissipate over distance from the vent. One of the vent limited regulators tested slightly exceeded a peak of 15% LEL at 24 inches from the vent.

Table 15: Single-Lockup Test highest readings recorded at various distances for 7 IWC set point.

Single-Lockup Test	Normal Condition		
7 IWC			
Regulators	Highest % LEL at 12"	Highest % LEL at 24"	Highest % LEL at 36"
VL1	10.20%	3.05%	0.35%
VL2	10.20%	3.05%	0.35%
VL3	11.45%	3.05%	0.36%
VL4	10.20%	3.05%	0.00%
VL5	0.06%	4.67%	0.36%
IRV1	10.20%	3.05%	0.37%
IRV2	10.20%	3.05%	0.36%
IRV3	10.20%	3.05%	0.34%
IRV4	10.20%	3.05%	0.36%

Table 16: Single-Lockup Test highest readings recorded at various distances for 2 psig set point.

Single-Lockup Test	Normal Condition		
2 psig			
Regulators	Highest % LEL at 12"	Highest % LEL at 24"	Highest % LEL at 36"
VL1	10.20%	3.05%	0.35%
VL2	10.20%	3.05%	0.36%
VL3	NA	NA	NA
VL4	10.20%	3.05%	0.37%
VL5	10.20%	3.05%	0.34%
IRV1	10.20%	3.05%	0.39%
IRV2	10.20%	3.05%	0.36%
IRV3	10.20%	3.05%	0.34%
IRV4	NA	NA	NA

Table 17: Multi-Lockup Test highest readings recorded at various distances for 7 IWC set point.

Multi-Lockup Test	Normal Condition		
7 IWC			
Regulators	Highest % LEL at 12"	Highest % LEL at 24"	Highest % LEL at 36"
VL1	0.11%	0.27%	0.34%
VL2	0.11%	0.31%	0.35%
VL3	8.35%	0.31%	0.36%
VL4	11.45%	3.39%	0.36%
VL5	68.70%	15.78%	0.36%
IRV1	0.11%	0.25%	0.36%
IRV2	0.11%	0.31%	0.36%
IRV3	0.10%	0.31%	0.34%
IRV4	0.08%	0.31%	0.36%

Table 18: Multi-Lockup Test highest readings recorded at various distances for 2 psig set point.

Multi-Lockup Test	Normal Condition		
2 psig			
Regulators	Highest % LEL at 12"	Highest % LEL at 24"	Highest % LEL at 36"
VL1	4.75%	0.27%	0.36%
VL2	0.11%	0.29%	0.36%
VL3	NA	NA	NA
VL4	3.33%	0.16%	0.36%
VL5	0.09%	3.43%	0.36%
IRV1	0.08%	0.30%	0.38%
IRV2	0.11%	0.31%	0.36%
IRV3	5.29%	0.31%	0.36%
IRV4	NA	NA	NA

The following data in Tables 19 and 20 illustrates the highest readings from the regulator vents at various distances for the Part 2 testing during abnormal regulator conditions. Note that the IRV regulators would continually vent gas during abnormal regulator conditions and would reach hazardous levels of gas in the Part 2 testing environment. The testing for the IRV

regulators would immediately stop prior to the Part 2 testing environment becoming filled with gas to a hazardous point and are not listed. The following are the highest readings obtained from the vent limited regulators as the OPSO engaged and gas levels dissipate (see **Figure 35**).

Table 19: Highest reading after the OPSO engaged on the OPSO for 7 IWC set point.

OPSO Performance Test	Single Diaphragm Tear (DT1)			Both Diaphragms Torn (DT2)			Lever Disconnect		
7 IWC									
Regulators	LEL at 12"	LEL at 24"	LEL at 36"	LEL at 12"	LEL at 24"	LEL at 36"	LEL at 12"	LEL at 24"	LEL at 36"
VL1	11.45%	3.05%	0.34%	13.03%	7.38%	0.39%	11.45%	3.05%	0.34%
VL2	23.35%	3.57%	0.35%	23.78%	11.18%	9.64%	11.45%	3.05%	0.34%
VL3	110.00%	110.20%	91.70%	NA*	NA*	NA*	11.45%	7.71%	8.09%
VL4	94.00%	49.46%	35.33%	95.20%	42.39%	19.72%	18.07%	12.82%	10.33%
VL5	11.45%	14.88%	7.44%	110.00%	35.20%	3.35%	21.44%	11.07%	10.89%

Table 20: Highest reading after the OPSO engaged on the OPSO for 2 psig set point.

OPSO Performance Test	Single Diaphragm Tear (DT1)			Both Diaphragms Torn (DT2)			Lever Disconnect		
2-psig									
Regulators	LEL at 12"	LEL at 24"	LEL at 36"	LEL at 12"	LEL at 24"	LEL at 36"	LEL at 12"	LEL at 24"	LEL at 36"
VL1	39.52%	12.45%	6.36%	30.48%	15.78%	3.61%	11.45%	3.05%	0.34%
VL2	11.45%	3.05%	0.37%	55.01%	37.03%	30.11%	11.45%	3.05%	0.34%
VL3	NA	NA	NA	NA	NA	NA	NA	NA	NA
VL4	110.00%	110.00%	16.73%	22.56%	18.86%	10.04%	11.45%	3.05%	0.34%
VL5	109.90%	13.72%	7.67%	11.45%	11.97%	10.08%	17.00%	26.82%	10.45%

When the abnormal conditions of a slit diaphragm or disconnected lever were introduced to the traditional IRV regulators the lower explosive limit was exceeded at the maximum measurements of 36 inches from the vent and the testing was stopped due to safety. During the same abnormal condition testing, the vent limited regulators slam shuts would immediately engage to stop gas flow and the LEL levels were observed to peak and dissipate. As noted in the data results, none of the vent limited regulators with OPSO exceeded a peak of 100% LEL at 36 inches, and there was one that was tested that exceeded 100% LEL at 24 inches. Gas utilities can use the data from this project to assist with their clearance requirements, however as noted in the conclusion of this report there are other gas service regulator scenarios that were not tested and were later recommended after the final approval of the test plan.

Conclusions

This project provided natural gas utilities with testing data on newer vent limited gas service regulators that can be used to determine safe clearance distances, however more testing is recommended. The intent of the test plan was to develop a worst-case scenario and simulate the most extreme conditions that the regulators would experience in the field and take gas readings at various distances. It is believed that thermal expansion of the gas on the customer piping can create an extreme condition that causes gas to be vented and therefore this condition needs to be tested to include in the decision for determining safe clearance distances and Best Practice Guidelines. Thermal expansion testing to simulate the extremes in the field will create more data on regulator vent emission to assist with determining safe clearance distances.

The project evaluated and compared the emissions of traditional IRV regulators and newer vent-limited regulators and created a test plan to help determine safe clearance distance requirements for these types of regulators. The testing is referencing and using the ANSI Z21.80/CSA 6.22 specification of 2.5 SCFH for a torn diaphragm, since that is the only standard that provides any venting information pertaining to regulators. Throughout the course of implementing the test plan and reviewing the test results, the project team made several observations and conclusions:

Normal Conditions Lock-up Tests, Part 1 and Part 2 Testing: During normal regulator conditions both traditional IRV and vent-limited regulators tested had vent emissions below 2.5 SCFH and there was a minor difference observed that the dual-stage vent limited regulators had lower vent emissions.

Abnormal Conditions Lock-up Tests, Part 1 and Part 2 Testing: During abnormal regulator conditions, the vent limited regulators OPSO immediately engaged. It was observed that several of the vent limited regulators tested had vent emissions that spiked above 100% LEL within 12 inches of the vent. These gas LEL spikes were observed in the data and dissipated quickly to safe levels once the OPSO engaged.

Though the data obtained found that some vent-limited regulators did emit from the vent at a flow rate greater than 2.5 SCFH during abnormal conditions, such as dual diaphragm failure, the emission event only lasted a few seconds before the OPSO was engaged and emissions from the vent were stopped. The data pertaining to vent-limited gas service regulators, equipped with OPSO functionality, indicates that the enhanced safety features integrated into the regulator design minimize the volume of gas vented in the event of an abnormal condition such as a diaphragm tear or internal lever disconnect within the regulator. In addition, these gas service regulators will protect the customer from over-pressurization events. The vent-limited

regulators, with an abnormal condition, such as a torn diaphragm or lever disconnect, will only have a small burst of initial hazardous level gas prior to the slam shut engaging. In comparison, on a traditional IRV regulator, an abnormal condition, such as a torn diaphragm or lever disconnect, can result in gas reading levels reaching hazardous levels rapidly.

Once the test plan was approved and testing started there were additional requests for the test plan that were found to be important, however could not be added as the testing had started. If testing were to be repeated, one aspect of the test plan would be to refine the methodology for the modified relief point test. Specifically, the test plan would aim to have a more replicable procedure by incorporating a motorized ball valve to consistently apply back pressure to the regulator. With this addition, we would reduce the variability between each test.

Another recommendation is to consult with the industry to develop an agreed-upon standardized test protocol to include in the ANSI B109 standard for measuring the vent emission rate from regulator models. Some of this protocol was developed with the TAP as part of this project. A vent emissions testing item to address would be to develop a method of measuring vent emissions without affecting regulator performance by creating a flow restriction in the vent outlet piping where a flow meter would need to be placed.

In addition, ANSI Z21.80/CSA 6.22 states that a vent limiter emission rate should not exceed 2.5 SCFH when a diaphragm is torn. The project team recommends that more clarification be added to the CSA standard to define the following:

- The operating conditions in which vent emissions should be measured.
- The method and configuration of measuring the vent emissions so as not to interfere with the regulator's ability to maintain normal operation.

During the Part 1 relief testing, two of the 7" set point dual diaphragm regulators stayed below 2.5 SCFH in all the normal and abnormal condition testing except during dual diaphragm failures, and one of the 2 psig set point dual diaphragm regulators stayed below 2.5 SCFH during the normal condition relief testing. As an important safety point, the dual diaphragm failure test is the only test where two components are required to fail. In comparison, the test illustrates the additional layers of safety as compared to the single diaphragm regulator. Also noted, the relief testing was not performed during the Part 2 testing due to safety concerns.

Subject matter experts discussed that temperature increases in the piping downstream of the regulator can cause backpressure and relief conditions, therefore a test needs to be created to determine worst case scenarios and measure the emissions to determine a safe clearance. Calculations can be performed to estimate pressure buildup in pipe upstream of the regulator, then the amount of emissions could be estimated based on those calculations.

References

American Gas Association. Fact Sheet: 3-Ft Distance to Ignition Source. Rev 2.11.2020.

Code of Federal Regulations 49 CFR, Part 192: Sections 351-357.

National Grid. Document CMS06001: Inspecting High Pressure Service Regulating Equipment.

National Grid. Blue Book: Specifications and Requirements for Gas Installations. State of Massachusetts. 2020.

New York City Fuel Gas Code. Chapter 4. 410.3.

Nisource. Gas Standard 6500.105: Service Regulator Requirements Residential and Commercial. page 4.

PG&E. J-16: Gas Design Standard, Gas Meter Room.

State of Illinois Admin. Code. Title 83 Part 501: Section 110.

State of Maine, Public Utilities Commission. Chapter 420: Safety Standards for Natural Gas and Liquefied Natural Gas Facility Operators.

Wisconsin Public Services. WPSC Service Manual. Section 4: Gas Metering. June 2022.

List of Acronyms

Acronym	Description
IRV	Internal Relief Valve
LD	Lever Disconnect
DT	Diaphragm Tear
VL	Vent-Limited
OPSO	Over Pressure Shutoff
MSA	Meter Set Assembly

Appendix A – Test Plan



PHMSA / OTD 5.22.J: DESIGN AND PLACEMENT OF COMPACT SERVICE REGULATORS CONTRACT ID: 693JK32110001POTA

Final Test Plan

Updated: 06/30/2022

GTI ENERGY

Table of Contents

Introduction 2
Industry Standards 3
Regulators to Test 3
Test Plan 8
Part I: Measurement of Emission from Regulator Vent 8
Part II: Methane Concentration Measurement 18
Instrumentation Needed 26

List of Tables

Table 1: Consistent Conditions for Part 1 and Part 2 Testing 4
Table 2: Examples of Gas Service "Vent Limited" Regulators Proposed for Testing 5
Table 3: Examples of Gas Service Traditional IRV Regulators Proposed for Testing 5
Table 4: Comprehensive List of Gas Service Regulators to be Tested 6
Table 5: Test Rig Setup per ANSI B109.4 11
Table 6: Regulator Set Point per ANSI B109.4 13
Table 7: Lock-Up Test per ANSI B109.4 15
Table 8: Relief Set Point per ANSI B109.4 15
Table 9: Part 1 Test Plan Summary 17

Table of Figures

Figure 1: Pietro Fiorentini "uninvent" 8
Figure 2: Flow Test Rig Illustration 9
Figure 3: ANSI B109.4 Straight Body Configuration 9
Figure 4: Left: GTI Test Rig Inside Temperature Chamber; Right: Flow Meter Installed on Regulator Vent 10
Figure 5: GTI Test Rig Flow Control Valve and Outlet Flow Meter 10
Figure 6: Dynament infrared methane sensor and plot of resolution on 0-100% gas scale 19
Figure 7: Campbell CR23X Data Logger 20
Figure 8: Calibration of methane sensors using methane injection and reference methane sensor 20
Figure 9: Example of calibration curve of Dynament methane sensor voltage output vs. methane concentration measured with reference sensor 21
Figure 10: Four-walled structure surrounding the outdoor test site 21
Figure 11: Interpolated heat map of methane concentration during a defective regulator test 22
Figure 12: Proposed methane sensor array spacing of 6 inches 22
Figure 13: Top: Methane sensor spacing; Bottom: Aluminum frame designed to fit around the regulator and hold the methane sensor array 23
Figure 14: Different ventilation conditions can be simulated using fans and ventilation ports 25
Figure 15: Examples of soffit vent and Gable vent 25

PHMSA / OTD 5.22.j
Design and Placement of Compact Service Regulators

Introduction

The project will measure the level of natural gas produced from newer models of "vent-limiting" style service regulators as compared to traditional Internal Relief Valve (IRV) service regulators to determine safe clearance distance requirements. This project will determine whether "vent-limiting" style service regulators offer more options for outside installation by having a smaller footprint that includes the ability to install at reduced clearance distances as compared to traditional IRV service regulators. The safe distance allowances will be determined through testing the amount of gas vented during various regulator operating flow conditions and failure modes, including diaphragm ruptures.

Many gas utilities have set a 3-ft minimum distance to a potential source of ignition for both indoor and outdoor meters and regulators based on the National Fuel Gas Code's (NFGC) 3-ft requirement, therefore field crews are tasked with finding a space to install meter set assemblies, including the regulator on the outside of a building that satisfies the clearance distance requirements. These clearance distances were created with standard IRV regulators in mind. However, new "vent limiting" service regulators, typically with "slam shut" features, are now available from a few manufacturers and are being used in a limited fashion by some natural gas utilities. The manufacturers of these "vent limiting" regulators state that they exert a much smaller quantity of natural gas as part of their pressure regulating operation and some have specified that clearances from building openings are not required.

Natural gas utilities prefer to install new meter set assemblies outdoors, however, finding appropriate locations with sufficient clearances from building openings (doors and windows), vents, and potential ignition sources can create challenges. In addition, gas utilities are relocating existing inside meter set assemblies to the outdoors. This is not always feasible due to space constraints (especially in congested urban environments), due to local building codes restricting their outdoor placement, landmark and historic district restrictions, and security or sensitive building designations.

Relocation of meter set assemblies to the outdoors has been a focus of gas utilities and recently the NTSB recommended existing interior service regulators be relocated outside when the gas service line, meter, or regulator is replaced. The testing for this project is needed to prove and bring awareness to "vent limiting" service regulator technology and to advance the industry by providing more options for safe gas service regulator installations.

Goal of Testing: This project will test and verify the amount of gas that is released from "vent-limiting" style service regulators as compared to traditional IRV service regulators and determine safe clearance allowances (both outside, inside, and in confined space cabinets) for these types of regulators, potentially providing more scientifically proven options for service regulator placement. Based on the test data, this project will determine the safe clearance allowances for vent-limiting regulators in situations where space is limited while installing a meter set assembly in an area with crowded utilities

and obstacles (doors, windows, A/C units, etc.). The scope of this project's regulator testing pertains to determining the volume of gas emitted from the regulator vent during operation.

Industry Standards

There is not a specific gas service regulator industry standard that provides criteria for maximum emission amounts vented and specifically for gas service regulators there are not any standards defining a "vent-limited". The testing plan will utilize ANSI B109.4[1] and CSA/ANSI Z21.80 CSA 6.22:19[2] as reference documents when applicable.

- **ANSI B109.4** is the standard for Self-operated Diaphragm-Type Natural Gas Service Regulators for nominal pipe sizes 1-1/4" (32mm) and smaller with outlet pressures of 2-psig (13.8 kPa) and less. The relief set point requirements can be found in 5.3.8, however the standard does not provide information pertaining to maximum allowable emissions. Emissions are briefly discussed as a function of the regulator set point and downstream pressure in the definition of the internal relief valve:
    - *"Internal Relief Valve (IRV): A relief valve that relieves excessive outlet pressure through the diaphragm and vent assembly. The internal relief set point is a function of the regulator's set point and the maximum allowable build-up of downstream pressure."*
- **CSA/ANSI Z21.80 CSA 6.22:19** is the standard for Line Pressure Regulators and is applicable to building gas piping systems that are between the gas service regulator (defined in ANSI 109.4) to the gas utilization equipment. The standard is being referenced for this test plan because it provides a maximum allowable venting rate of 2.5 ft^3/hr (19.7 cm^3/s) for vent limiters used with regulators.
    - *"Vent limiter - a means that limits the flow of gas from the atmospheric diaphragm chamber to the atmosphere in the event of a diaphragm rupture. This may be either a limiting orifice or a limiting device."*

What definition for a "vent limiting" gas service regulator will be used for this test plan? The term "vent limiting" gas service regulator will be defined in this test plan as any gas service regulator that limits the emissions amount vented to a rate of 2.5 scfh (70 dm3/h) (19.7 cm^3/s) or less (including no internal relief) into the atmosphere by means of a limiting orifice or limiting device.

Regulators to Test

The project will test gas service regulators that are widely used by gas utilities and are selected by the project Technical Advisory Panel (TAP). The project team will procure a sample size of (3) of each model and configuration as documented in this test plan.

[1] ANSI B109.4 Self-Operated Diaphragm-Type Natural Gas Service Regulators, Revised October 2021
[2] CSA/ANSI Z81.80:19 CSA 6.21.19 Line Pressure Regulators, Revised June 2019

The following gas distribution and regulator configurations settings listed in **Table 1** will be used consistently for each test sample for both Part 1 and Part 2 testing:

Table 1: Consistent Conditions for Part 1 and Part 2 Testing

Test Condition	Test Condition Value
Regulator Direction Type	In-Line
Inlet Pressure	Testing to be performed at (3) different inlet pressures of 10-psig, 60-psig and 100-psig to simulate potential distribution pressures.
Inlet Size	¾" or 1" based on regulator availability (verify other inlet sizes up to 2" as appliable for higher volume usage regulators).
Outlet Pressure Set Points	7" wc. and 2-psig.
Outlet Size	¾", 1" or 1 ½" based on regulator availability
Vent Opening	½", ¾" or 1" based on regulator availability
Orifice Size	Appropriate size to be determined based on the inlet pressure according to manufacturer's specifications

Table 2 and **Table 3** illustrate examples of proposed gas service regulators of both vent-limiting and traditional IRV regulators that will be tested as part of this project. These brands offer different models for various operating pressures and applications and the associated regulator configurations/settings corresponding to **Table 1** will be selected for testing.

Table 2: Examples of Gas Service "Vent Limited" Regulators Proposed for Testing

American – Honeywell	Pietro Fiorentini	Cavagna Group - Mesura
	 	 

Table 3: Examples of Gas Service Traditional IRV Regulators Proposed for Testing

American	Itron	Fisher-Emerson
		

Table 4 lists the regulator models that are planned to be included in the comparative testing. There may be more gas service regulator models added based on TAP input and external stakeholder.

GTI ENERGY

Table 4: Comprehensive List of Gas Service Regulators to be Tested

Manufacturer	Model	Outlet Pressure (Spring Type - Color) And Inlet/Outlet size	Maximum outlet flow and orifice size at given inlet pressure		
			10 psi	60 psi	100 psi
Pietro Fiorentini	FE Vent Limited	• 7" wc (Yellow), IRV 13" wc, OPSO 19" wc (Yellow) • Inlet/Outlet: ¾" x 1"	Max: 885 scfh Orifice Size: 3/16"	Max: 885 scfh Orifice Size: 3/16"	Max: 885 scfh Orifice Size: 3/16"
		• 2-psig (Grey), IRV 2.7-psig, OPSO 3.3 psig (Violet) • Inlet/Outlet: ¾" x 1"	Max: 885 scfh Orifice Size: 3/16"	Max: 885 scfh Orifice Size: 3/16"	Max: 885 scfh Orifice Size: 3/16"
Pietro Fiorentini	FEX Vent Limited	• 7" wc (Yellow), IRV 13" wc, OPSO 19" wc (Yellow) • Inlet/Outlet: 1" x 1 ½"	Max: 3500 scfh Orifice Size: 3/16"	Max: 3500 scfh Orifice Size: 3/16"	Max: 3500 scfh Orifice Size: 3/16"
		• 2-psig (Grey), IRV 2.7-psig, OPSO 3.3 psig (Violet) • Inlet/Outlet: 1" x 1 ½"	Max: 3500 scfh Orifice Size: 3/16"	Max: 3500 scfh Orifice Size: 3/16"	Max: 3500 scfh Orifice Size: 3/16"
Cavagna Group (Mesura)	Model S7 Vent Limited	• 7" wc, IRV 13", OPSO 19" wc • Inlet/Outlet: ¾" x 1"	Max: 1539 scfh Orifice Size: ½" (2nd Stage)	Max: 1539 scfh Orifice Size: ½" (2nd Stage)	Max: 1539 scfh Orifice Size: ½" (2nd Stage)
		• 2 psig, IRV 2.7 psig, OPSO 3.3 psig • Inlet/Outlet: ¾" x 1"			
Cavagna Group (Mesura)	Model S9 Vent Limited	• 7" wc, IRV 13", OPSO 19" wc • Inlet/Outlet: 1" x 1-½"	Max: 1539 scfh Orifice Size: ½" (2nd Stage)	Max: 1539 scfh Orifice Size: ½" (2nd Stage)	Max: 1539 scfh Orifice Size: ½" (2nd Stage)
		• 2 psig, IRV 2.7 psig, OPSO 3.3 psig • Inlet/Outlet: 1" x 1-½"			
Honeywell	1843B2-VL Vent Limited	• 7" wc (Tan), OPSO 14"-35" wc • Inlet/Outlet: ¾" x 1"	Max: 1800 scfh Orifice Size: 9/16"	Max: 2500 scfh Orifice Size: 1/4"	Max: 2500 scfh Orifice Size: 3/16"
		• 2-psig (Red-Red), OPSO 1-3.5 psig • Inlet/Outlet: ¾" x 1"	Max: 1300 scfh Orifice Size: 9/16"	Max: 2500 scfh Orifice Size: 1/4"	Max: 2500 scfh Orifice Size: 3/16"

GTI ENERGY

Honeywell	1813C IRV	• 7" wc (Tan) • Inlet/Outlet: ¾" x 1"	Max: 1800 scfh Orifice Size: 9/16"	Max: 2500 scfh Orifice Size: 3/16"	Max: 2500 scfh Orifice Size: 3/16"
		• 2-psig (Red-Red) • Inlet/Outlet: ¾" x 1"	Max: 2300 scfh Orifice Size: 9/16"	Max: 2500 scfh Orifice Size: 3/16"	Max: 2500 scfh Orifice Size: 3/16"
Itron	B42R IRV	• 7" wc (Brown) • Inlet/Outlet: ¾" x 1"	Max: 1720 scfh Orifice Size: ½" x 9/16"	Max: 2500 scfh Orifice Size: ¼"	Max: 2500 scfh Orifice Size: 3/16"
		• 2-psig (Yellow/Black) • Inlet/Outlet: ¾" x 1"	Max: 1710 scfh Orifice Size: ½" x 9/16"	Max: 3130 scfh Orifice Size: ¼"	Max: 3000 scfh Orifice Size: 3/16"
Itron	B34S IRV	• 7" wc (Light green) • Inlet/Outlet: 2" x 2"	Max: 7500 scfh Orifice Size: 7/8"	Max: 7500 scfh Orifice Size: 3/8"	Max: 7500 scfh Orifice Size: 3/8"
		• 2-psig (White) • Inlet/Outlet: 2" x 2"	Max: 4000 scfh Orifice Size: 7/8"	Max: 7500 scfh Orifice Size: 3/8"	Max: 7500 scfh Orifice Size: 3/8"
Fisher-Emerson	HSR IRV	• 7" wc (Yellow) Black Cap • inlet/Outlet: ¾" x 1"	Max: 1600 scfh Orifice Size: 1/2"	Max: 3010 scfh Orifice Size: ¼"	Max: 2390 scfh Orifice Size: 3/16"
		• 2-psig (Light Blue) Red Cap • inlet/Outlet: ¾" x 1"	Max: 2000 scfh Orifice Size: ½"	Max: 3600 scfh Orifice Size: ¼"	Max: 4000 scfh Orifice Size: 3/16"
Sensus	143-80 IRV	• 7" wc (Blue) • Inlet/Outlet: ¾" x 1"	Max: 1180 scfh Orifice Size: 5/8"	Max: 2000 scfh Orifice Size: 1/4"	Max: 2100 scfh Orifice Size: 3/16"

		• 2-psig (Black/White) • Inlet/Outlet: ¾" x 1"	Max: 1180 scfh Orifice Size: 5/8"	Max: 2000 scfh Orifice Size: 1/4"	Max: 2100 scfh Orifice Size: 3/16"

Sample Size: Plan to use at least three regulators of each Brand, Model, and Configuration for repeatable testing.

Two-stage gas service regulators have two vents. The test plan will require that a connection be installed that will combine both vents into a single vent to test emissions. Pietro Fiorentini has a "uninvent" that allows a signal vent for testing and shown in **Figure 1.**

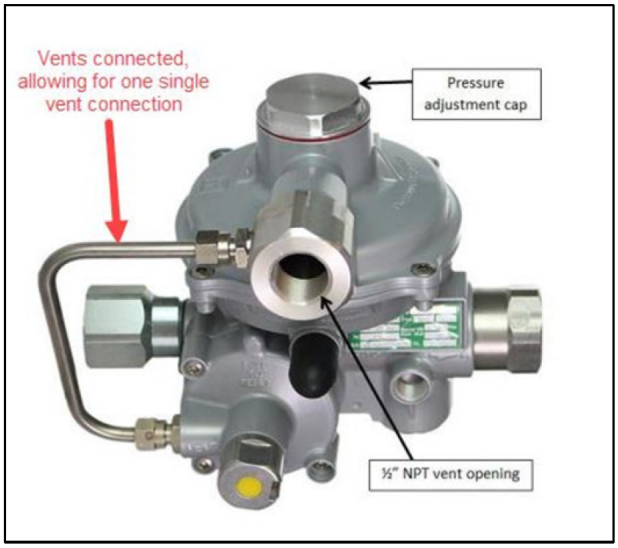


Figure 1: Pietro Fiorentini "uninvent"

Test Plan

Part I: Measurement of Emission from Regulator Vent

The equipment to be used for the measurement of the flow from the regulator vent is illustrated in **Figure 2** Flow Test Rig Illustration, **Figure 3** ANSI B109.4 Straight Body Configuration and **Figure 4 & 5** GTI Test Rig. Note that a flow meter will be added in **Figure 3** and **Figure 4** at the regulator vent. The regulator will be oriented vertically and placed within a temperature chamber (all tests will be performed at the same temperature). The flow tests on this rig will be performed using compressed air, while data logging the pressure and temperature of the air. Using this information, the data acquisition software converts the measured air values to equivalent natural gas values.

The following four (4) data points will be recorded during varying simulated customer flow conditions and analyzed.

1) Inlet Pressure (psig)
2) Outlet Pressure (iwc & psig)
3) Outlet Flow (scfh)
4) Regulator Vent Flow (scfh)

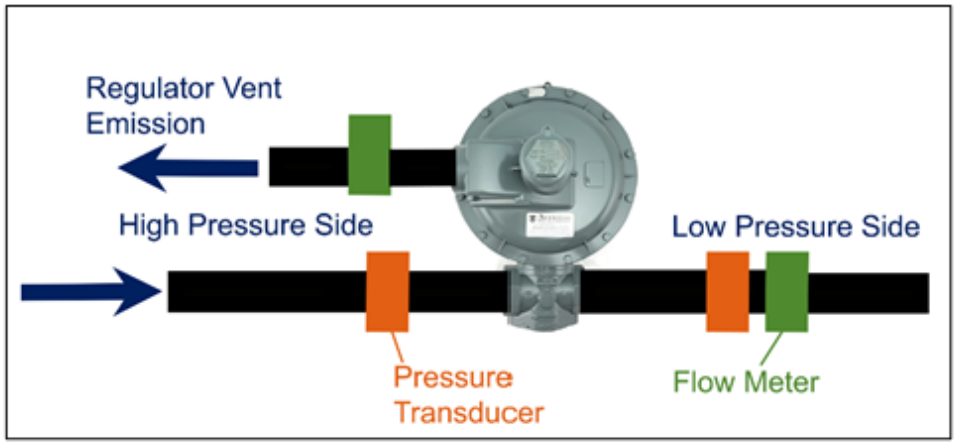


Figure 2: Flow Test Rig Illustration

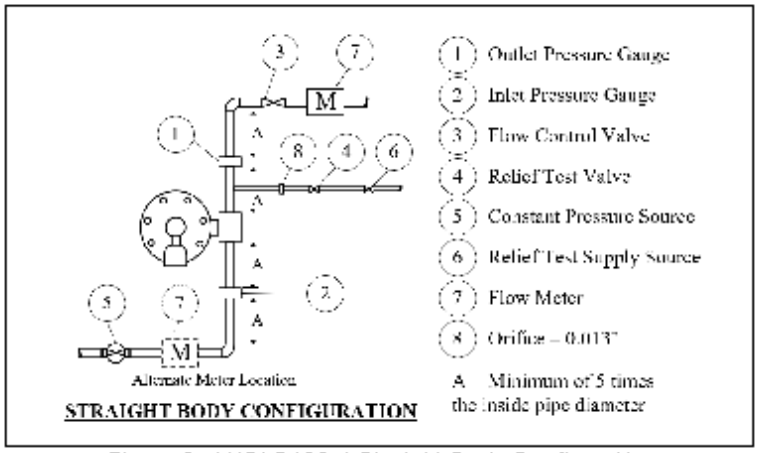


Figure 3: ANSI B109.4 Straight Body Configuration

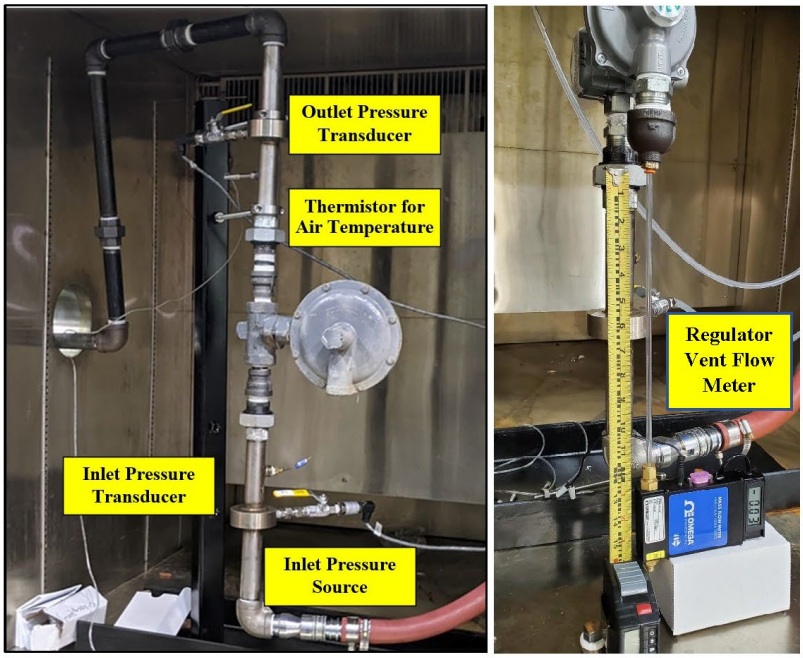


Figure 4: Left: GTI Test Rig Inside Temperature Chamber; Right: Flow Meter Installed on Regulator Vent

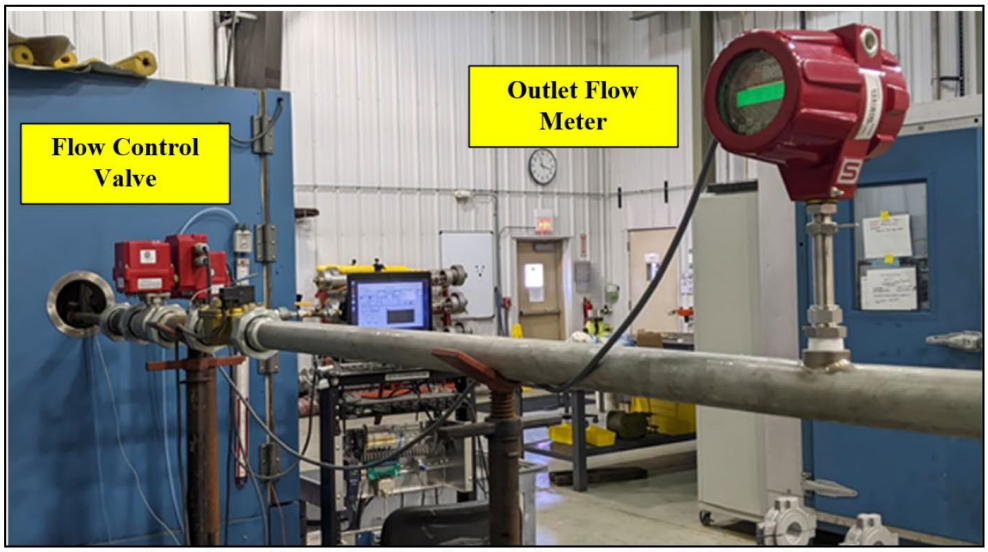


Figure 5: GTI Test Rig Flow Control Valve and Outlet Flow Meter

Assumptions: The test plan assumption is that all regulators used for this project will conform to the ANSI B109.4 standard. The goal of referencing this standard for testing is solely to record data for regulator features that have an impact on safe clearance distances for gas service regulator installation, that include the testing of flow and emissions from the gas service regulator vent opening. The test plan will adhere to ANSI B109.4 section 5.0 to section 5.2 with the addition of a flow meter located at the regulator vent pipe. As noted in section 5.1.2 (c), the flow meter at the regulator vent pipe should not obstruct flow and therefore a **Laminar Flow Meter** will be used at the regulator vent location for testing purposes. **Table 5** provides these sections from ANSI B109.4 for the test rig and regulator configurations of the test rig.

Table 5: Test Rig Setup per ANSI B109.4

5.0	**Qualification Test for Service Regulator Performance**	
5.1	**General** The purpose of the testing is to evaluate the regulator design for compliance with this standard. Designs shall be subjected to testing for regulator capacity, relief-valve capacity, set point, lock-up performance, material strength and other factors influencing the performance to the regulator.	
	5.1.1	A careful inspection of the regulator shall be made prior to testing to ensure that there is no foreign material present in the regulator.
	5.1.2	The regulator shall be tested in the following orientation (See **Figure 2** and **Figure 3a**): a) The regulator shall be installed in a vertical run of pipe. b) The diaphragm shall be in a vertical position. c) The vent shall be pointed downwards with unrestricted air flow.
	5.1.3	The regulator shall have an orifice selected for the appropriate operating conditions.
	5.1.4	All tests shall be conducted with air at room temperature unless specified otherwise.
	5.1.5	All tests shall be conducted under known and controlled conditions, wherein the accuracy of the containers, tapes, scales and other "state-of-the-art" measurement devices are traceable to the National Institute of Standards and Technology (NIST).
	5.1.6	The inlet air temperature shall be measured to an error not exceeding ± 2 F (± 1 C) of actual value. The inlet air temperature shall remain constant within ±5 F (±3 C) during the test run to record data for each specific test point.

GTI ENERGY

5.2	**Test Equipment**	
	5.2.1	Pressure Measurement Pressure gauges: Bourdon tube pressure gauges should have a dial face not less than four inches (10.2 cm) in diameter. The smallest graduation and uncertainty of the middle half of the scale should be in accordance with ANSI B40.100 Grade B, "Dial Type, Elastic Element Gauges." The gauge should be selected to provide readings in the middle half of its scale. Calibration of the gauge should be in accordance with ASME Power Test Code (PTC) 19.2. Manometers: A manometer should have scale graduations not greater than 0.1 inch (2.5 mm). Digital pressure transducers: A pressure transducer should have uncertainty of better than ±0.25% of full scale, taking into account linearity, repeatability and hysteresis. A digital display used in conjunction with the transducer should be updated a minimum of twice per second. It should have traceable calibration or be calibrated in accordance with ASME PTC 19.2.
	5.2.2	Pressure Sensing Positions: All pressure-sensing positions and connections should be as shown in **Figure 1**. Piezometer tubes: Body-sized piezometer tubes should be used to sense the inlet and the outlet pressures immediately upstream and downstream of the unit. Tubes larger or smaller than the pipe size of the regulator body should not be used. Their dimensions should correspond to the following ratios: a) Tube inlet: 5 Five pipe I.D. upstream of ring holes b) Tube outlet: Five pipe I.D. downstream of ring holes c) Ring holes: Up through one-inch NPT pipe: Six 1/16-inch holes equally spaced around the pipe, Greater than one-inch NPT: Eight 3/32-inch holes equally spaced around the pipe d) Gauge connection: 1/4-NPT registering through an 1/8-inch hole into the piezometer ring
	5.2.3	Flow Measurement Flow meters: Orifice meters, rotary meters or equivalents may be used to measure the flow of the regulator. The flow result given by the meter should be accurate to within ± 1.0% of flow rate.

All regulators used for testing will be set for 7" wc and 2-psig according to Section 5.3.3 found in **Table 6**.

Table 6: Regulator Set Point per ANSI B109.4

<table>
<tr>
<td></td>
<td>5.3.3</td>
<td>
Set Point

For the purposes of developing a uniform testing procedure and comparison, the set point shall be established with the following parameters:

a) Inlet Pressure: 40-psig (276 kPa) or the maximum allowable inlet pressure per the manufacturer's specification if less than 40-psig (276 kPa).

b) Outlet Pressure Ranges:
TABLE IV
<table>
<tr><th>Outlet Pressure Range</th><th>Set Point Tolerance</th></tr>
<tr><td>X ≤ 14 inches w.c. gauge (3.48 kPa gauge)</td><td>+/- 0.1 inches w.c. gauge (0.025 kPa gauge)</td></tr>
<tr><td>14 inches w.c. gauge (3.48 kPa gauge) < X ≤ 1 psig (6.89 kPa gauge)</td><td>+/- 0.2 inches w.c. gauge (0.050 kPa gauge)</td></tr>
<tr><td>1 psig (6.89 kPa gauge) < X ≤ 2 psig (13.8 kPa gauge)</td><td>+/- 0.03 psig (0.2 kPa gauge)</td></tr>
</table>
c) Flow Rate: 39 scf/h (1.1 m3/h) of air to be set by slowly increasing the flow rate from zero for a period of five seconds.

During tests to check the set point, the regulator should be stable with no evidence of hunting or chattering. Other pressures and flow rates may be used to demonstrate compliance with this standard for alternative requirements.

NOTE: Inlet and outlet conditions other than those specified above will affect the performance of the regulator and could produce varying results.
</td>
</tr>
</table>

The following flow conditions will be simulated during the testing:

Normal Operating Conditions:

Downstream flow rate will be adjusted to simulate different amounts of customer gas use and the emissions from the regulator vent will be monitored. The procedure for testing these scenarios is as follows:

1) Adjust a downstream valve to achieve a target flow rate (100, 200, 300 SCFH, until maximum manufacturer specifications). The control valves on GTI's test rig are programmable, so target flow rates can be achieved autonomously through a programmable PID loop to provide repeatability between tests.

2) Close the downstream valve to create a condition where the regulator will need to use upstream pressure to equalize downstream pressure by emitting gas (GTI to check the closing velocity and downstream buffer volume).

3) Measure the flow rate of gas emitted from the vent.

4) Measure the gas concentration at different distances from the regulator vent.

5) Repeat the valve operation multiple times to simulate intermittent gas use.

Abnormal Operating Conditions:

In addition to monitoring regulator vent emissions during normal operation, GTI will also simulate abnormal conditions that may occur. The abnormal operating conditions to be simulated during testing are as follows:

1) Regulator lockup conditions.

2) A full lever disconnect, (adhere to B109.4 Section 5.3.9). Disconnect the linkage between the diaphragm and valve mechanism if the regulator does not have a lever.

3) A back-pressure scenario where the gas pressure, higher than the regulator setpoint, is injected downstream of the regulator, (adhere to B109.4 Section 5.3.8).

4) Simulate a diaphragm break by making a slit in the diaphragm of the regulator. Some vent-limiting regulators are two-stage regulators, so we will need to test conditions where one diaphragm is damaged, and then create conditions for both diaphragms are damaged, etc.

5) A completely blocked regulator vent.

Modified Lock-Up Test: Sudden customer flow changes lead to the largest amounts of gas service regulator venting. To simulate the intermittent demand of gas appliances powering on and off, the test plan will incorporate sudden flow changes by opening/closing the outlet pressure valve. This action will create conditions for the largest emission release from the IRV through the regulator vent. The test will subject each gas service regulator to different operating conditions of varying outlet flows and closing of the outlet flow valve. The test will be repeated in increasing output flow increments until the maximum specified output flow for the regulator. The test data will be plotted for the amounts of gas emitted from the vent pipe over the time for the vent to completely relieve to a no flow condition.

The testing will include the verification of conformance of each regulator to the ANSI B109.4 standards as documented in **Table 7** and record the amounts (if any) of vented gas from the selected gas service regulators.

Table 7: Lock-Up Test per ANSI B109.4

	5.3.5	Lock-Up When the demand for flow from the regulator is shut off, the flow of gas should be stopped against the maximum inlet pressure recommended by the manufacturer for the applicable orifice. The outlet pressure under no-flow conditions, or "lock-up pressure," shall be checked using the following test method: a) Set the regulator as described in section 5.3.3. b) Close the outlet valve at a constant speed over five seconds. Allow outlet pressure to stabilize and record lock-up pressure. Wait an additional 30 seconds and ensure the reads are comparable within the measurement system accuracy. c) Ensure that the lock-up pressure is no greater than 3 inches w.c. (0.75 kPa) above the original set pressure for set points of 14 inches w.c. or less (3.48 kPa). For set points greater than 14 inches w.c. (3.48 kPa), lock-up pressure shall not be greater than 115% of set point. See Section 5.3.3.

Modified Relief Testing: A backpressure will be applied to the regulator at increasing increments and the venting emissions will be observed and recorded. The testing will be completed when the slam shut closes or to the maximum allowable pressure.

Table 8: Relief Set Point per ANSI B109.4

	5.3.8	Relief Set Point **TABLE VI** Set Point | IRV – Start-to-Discharge Range (Over Set-Point) | Minimum IRV Reseat Above Lock-Up Set ≤ 14 inches w.c. gauge (3.48 kPa gauge) | 6 – 12 inches w.c. | 2 inches w.c. 14 inches w.c. gauge (3.48 kPa gauge) < Set ≤ 1 psig | 7 – 21 inches w.c. | 2 inches w.c. 1 psig < Set ≤ 2 psig | 2.0 psi max | 0.1 psi For regulators equipped with an internal relief valve, the following design verification test shall be performed for each orifice size available: a) Set outlet pressure as described in Section 5.3.3, "Set Point." b) Once outlet pressure stabilizes, close the downstream valve allowing the regulator to go into lockup. c) Slowly apply a controlled backpressure of air into the outlet side of the regulator to yield a flow rate of approximately one cubic foot an hour.

<table>
<tr><td></td><td></td><td>d) The relief valve should begin to relieve as downstream pressure rises above the lock-up point of the regulator. After the regulator has been pressurized, the start-to- relieve point can be detected by:
applying a leak-detection solution to the regulator vent,
placing the vent discharge into a maximum water seal of one inch w.c. (0.25 kPa),
or other acceptable means.</td></tr>
<tr><td></td><td>5.3.9</td><td><u>Internal Relief-Valve Performance Test</u>

This section is only for regulators equipped with an internal relief valve. The internal relief-valve capacity for each orifice size available shall be tested as follows:

a) Cause the regulator to fail by disconnecting the linkage between the diaphragm and valve mechanism or the most severe failure condition that yields the highest build-up pressure.

b) Disconnect any vent piping to allow the regulator to vent the flow of gas freely and unrestricted to the atmosphere.

c) Close the valve downstream of the regulator so that there is no flow of gas through the regulator.

d) Note the outlet pressure while slowly increasing the inlet pressure from 0 psig to the maximum inlet pressure recommended by the manufacturer for the orifice installed. Record the outlet pressure at the maximum inlet pressure after the system reaches a steady-state condition. Refer to the Appendix A for how to display the result.

TABLE VII
<table><tr><th>Set Point</th><th>Maximum Outlet Buildup</th></tr><tr><td>Set ≤ 14 inches w.c. gauge (3.48 kPa gauge)</td><td>2 psi</td></tr><tr><td>14 inches w.c. gauge (3.48 kPa gauge) < Set ≤ 1 psig (6.89 kPa gauge)</td><td>5 psi</td></tr><tr><td>1 psig (6.89 kPa gauge) < Set ≤ 2 psig</td><td>5 psi</td></tr></table>
The user shall evaluate all downstream equipment limits and design considerations when selecting the relief performance. The maximum outlet pressure shall not exceed those guidelines established by governing standards and regulations. Table VIII shows typical equipment allowable limits. However applicable codes and standards shall be additionally considered.</td></tr>
</table>

By testing the regulator performance under both normal and abnormal operating conditions, GTI can provide a better understanding of methane concentration at various distances from the regulator vent. This will assist in providing insight for regulator clearance distance requirements with respect to the different scenarios that may occur during operation. The data used for this test will be used in the Part 2 testing that will utilize natural gas and studying the gas concentration at different distances away from the vent pipe.

Table 9: Part 1 Test Plan Summary

Test	Sub-test	Standard /Procedure reference	Conditions	Test Criteria	Parameters
Pressure Regulating Characteristics (Normal Operating Conditions)	Set Point Test	ANSI B109.4 - [5.3.3]	Temperature: Ambient; Inlet pressure: 40 psig; Flow 50 SCFH GAS or 39 SCFH AIR	Outlet pressure 7"±0.1 wc 2±0.03 psig (2 psig reg.)	Set point [iwc]
	Modified Lock-Up Test	ANSI B109.4 - [5.3.5]	Temperature: Ambient; Inlet pressure:10, 60, 100 psig; Flow: 100, 200, 300, until maximum manufacturer specifications [SCFH Air]	Outlet pressure Max 10" wc 2.3 psig (2psig reg.)	Lock up [iwc]
				Flow rate at vent 2.5 SCFH (vent limited)	Vent flow rate [SCFH]
	Modified Relief Point Test	ANSI B109.4 - [5.3.8]	Temperature: Ambient; Inlet pressure: 10, 60, 100 psig; Outlet pressure: slowly increase until slam shut closes or maximum allowable pressure reached	Outlet pressure range 6-12" wc; 2 psig max (2psig reg.) (Over set point)	Relief point [iwc]
				Flow rate at vent 2.5 SCFH (vent limited)	Vent flow rate [SCFH]
	Internal Relief-Valve Performance Test	ANSI B109.4 - [5.3.9]	Temperature: Ambient; Inlet Pressure: 0-60 psig or the maximum manufacturer specifications	Max Outlet pressure buildup 2psig (7iwc reg.) 5 psig (2psig) reg.)	Droop pressure [iwc]

Part II: Methane Concentration Measurement

Once the volume of emission has been measured for various flow conditions in the first phase of testing on the flow rig, then the same regulator conditions will be simulated in GTI's Pipe Farm outdoor leak setup. Methane sensors will be placed in an array around the regulator vent to measure methane concentration at various distances away from the vent. This will give an indication of the methane concentrations generated at known emission flow rates through the regulator vent.

The structure used for this testing will have four walls and an open top for safety. In between tests, the door will be opened to allow all the gas to be thoroughly vented before beginning the next test. Some tests may be done with a cover on the top that can be removed after the test, to simulate indoor venting conditions.

We will need to have a real-time measure of the flow rate of emitted gas to relate to the methane sensor readings. Depending on the size of the flow meter, we may attach the flow meter directly to the regulator vent. If the flow meter is affecting the dispersion of the vented gas, we will take a reading with the flow meter of the vent and then remove it before moving to the methane concentration measurement.

Methane sensor spacing and mesh shape is subject to change based on the methane concentrations measured in first rounds of testing.

GTI plans to use the same type of methane sensors and data logging equipment that was used in previous methane projects for measuring methane concentration, as outlined in the following sections.

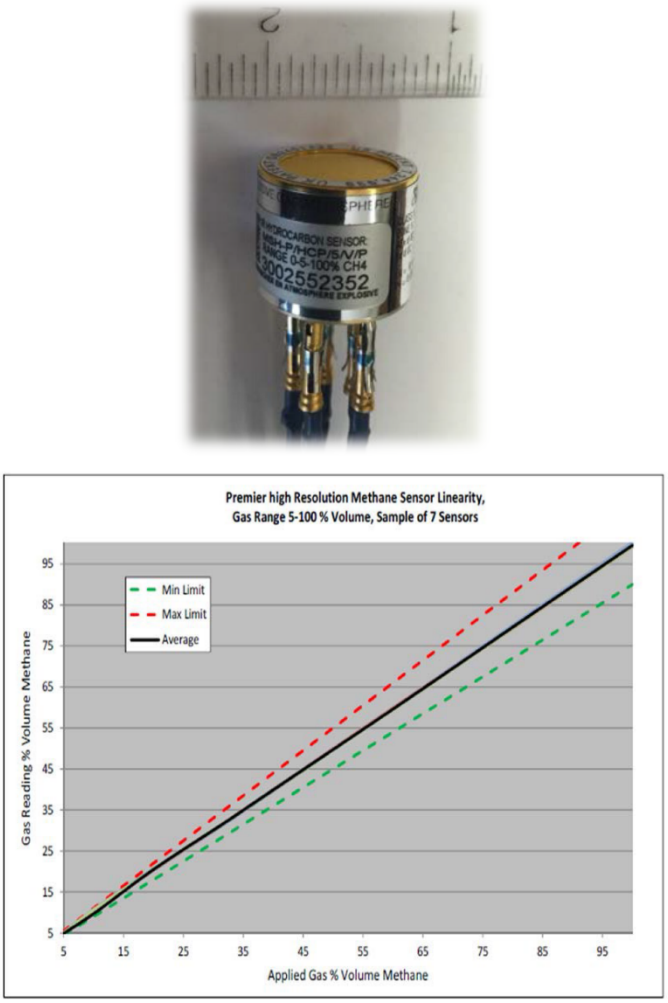


Figure 6: Dynament infrared methane sensor and plot of resolution on 0-100% gas scale

The Dynament Premier MSH-P (**Figure 6**) is an infrared sensor with a measurement range of 0-100% gas and a voltage output of 0-5 Volts. GTI will follow a regular lab calibration procedure for each individual sensor used for methane measurement (**Figure 8**). The voltage output of each sensor is recorded as methane is injected into the test chamber. The chamber's methane concentration is also recorded at various set points to produce a calibration curve, as seen in **Figure 9**.

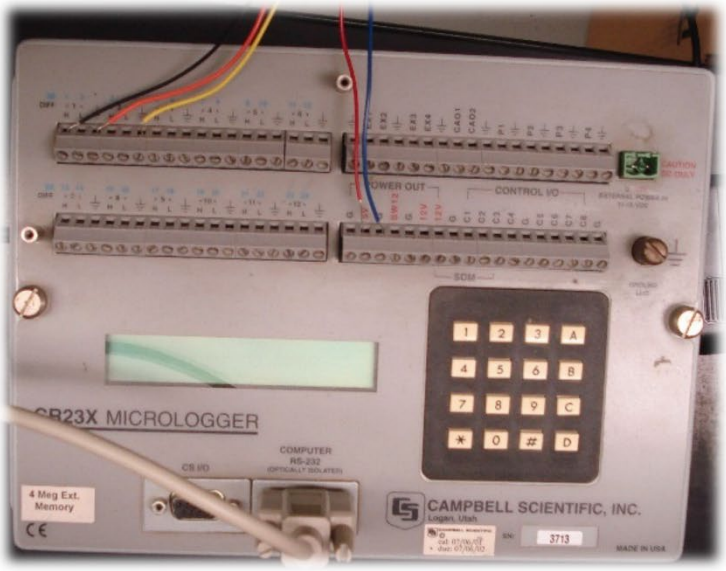


Figure 7: Campbell CR23X Data Logger



Figure 8: Calibration of methane sensors using methane injection and reference methane sensor

20

GTI ENERGY

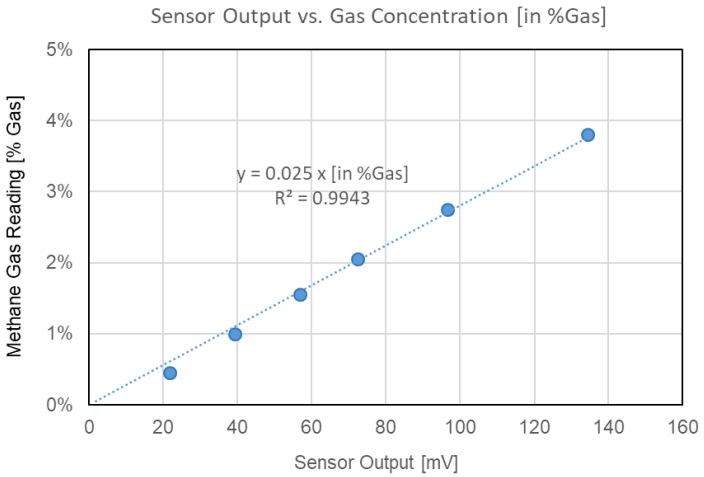


Figure 9: Example of calibration curve of Dynament methane sensor voltage output vs. methane concentration measured with reference sensor

Once all methane sensors have been properly calibrated, they will be placed in an array at various distances away from the regulator vent. The voltage output from each of the sensors will be simultaneously data logged as natural gas is emitted from the regulator vent. To minimize dispersion of the gas, the test apparatus will be surrounded on four sides with walls and the top of the test site will be open to the atmosphere (**Figure 10**). A temporary roof will be utilized during the testing to minimize any air current if the test conditions are first safely verified to be less than 100% LEL for the confined space.



Figure 10: Four-walled structure surrounding the outdoor test site

GTI ENERGY

The methane concentration data recorded during the test will be plotted as an interpolated heat map as seen in **Figure 11**, a test run from previous project work where a defective regulator was similarly test. These heat maps are generated using a program called *Grapher* and provide a visual indication of the size and shape of the plume of gas emitted from the regulator vent. The spacing of the methane sensors in the array can be modified to provide greater resolution near the regulator vent. GTI will start with a sensor spacing of 6 inches (**Figure 12**) and adjust as needed.

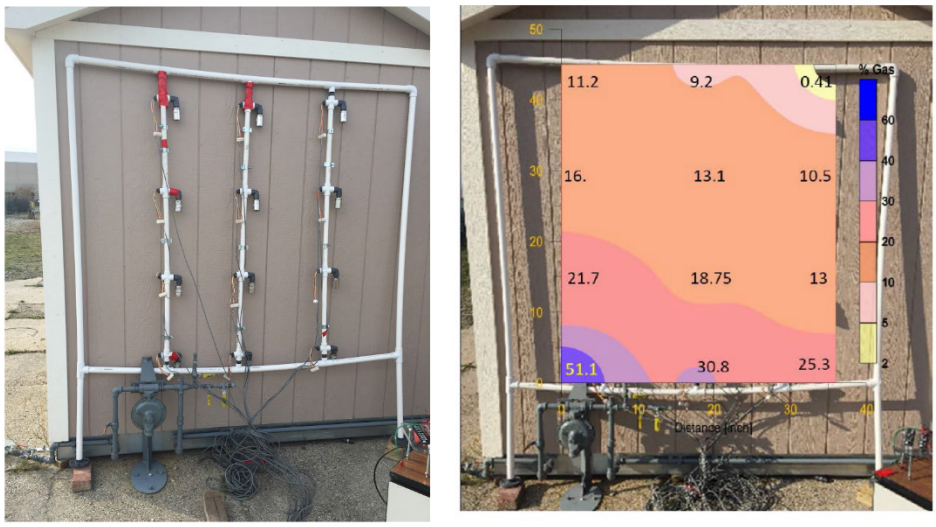


Figure 11: Interpolated heat map of methane concentration during a defective regulator test

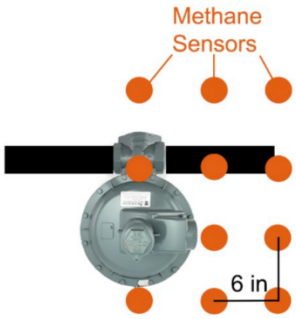


Figure 12: Proposed methane sensor array spacing of 6 inches

GTI ENERGY

To allow for adjustable distances between methane sensors, the sensor frame will be built using aluminum 80-20 extrusions, as seen in **Figure 13**. This is an improvement to the previous design that was made of PVC pipe. The sensors can also be moved more easily to allow for more flexible options when creating the sensor array. More sensors can be added to the array as well. The shape of the array is modelled after a series of rings that are distances of 6-in, 1-ft, 2-ft, and 3-ft away from the regulator vent.

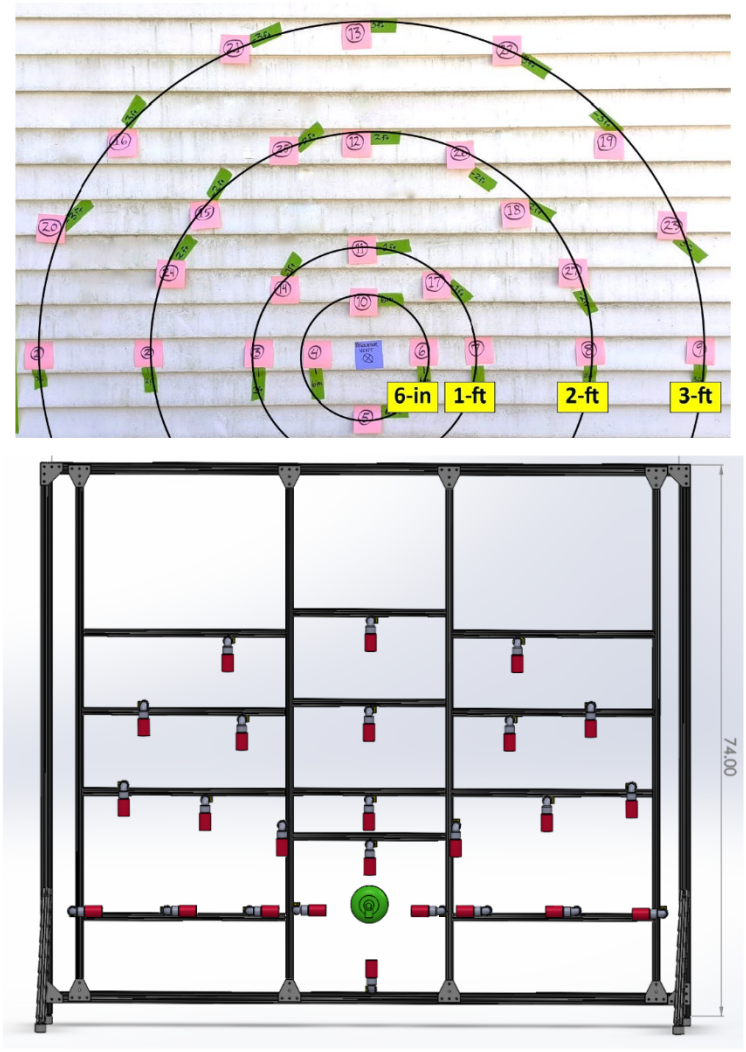


Figure 13: Top: Methane sensor spacing; Bottom: Aluminum frame designed to fit around the regulator and hold the methane sensor array

Flow conditions to be simulated during outdoor testing:

Normal Operating Conditions:

Downstream flow rate will be adjusted to simulate different amounts of customer gas use and the emissions from the regulator vent will be monitored. The procedure for testing these scenarios is as follows:

1. Adjust a downstream valve to achieve a target flow rate (100, 200, 300 SCFH, etc.).
2. Close the downstream valve to create a condition where the regulator will need to equalize pressure by emitting gas.
3. Measure the flow rate of gas emitted from the vent.
4. Measure the gas concentration at different distances from the regulator vent.
5. Repeat the valve operation multiple times to simulate intermittent gas use.

Abnormal Operating Conditions:

In addition to monitoring regulator vent emissions during normal operation, GTI will also simulate abnormal conditions that may occur. The abnormal operating conditions to be simulated during outdoor testing are as follows:

- A full lever disconnect or rip in the regulator diaphragm.
- A back-pressure scenario where gas pressure, higher than the regulator setpoint, is injected downstream of the regulator.
- Regulator lockup conditions.

By testing the regulator performance under both normal and abnormal operating conditions, GTI can provide a better understanding of methane concentration at various distances from the regulator vent. This will assist in providing insight for regulator clearance distance requirements with respect to the different scenarios that may occur during operation.

Other Considerations:

During outdoor testing, GTI can also simulate common ventilation conditions to observe the effect on methane concentration. For example, an indoor meter may be in an enclosed space with a ventilation port located nearby. By using an external fan, the effects of different levels of ventilation can be monitored during testing. **Figure 14** shows an example of how a ventilation port with fan can be added to the outdoor test setup.



Figure 14: Different ventilation conditions can be simulated using fans and ventilation ports

Another consideration for testing the methane concentration in different vent orientations will be the addition of a vent on the structure behind the test setup. A vent on the eave of the roof (also known as a Gable Vent) or a soffit vent will cause an increased amount of airflow into or out of the building. An additional methane sensor can be installed inside the vent to monitor methane that seeps inside of the building. The temperature gradient between the inside and outside of the structure will also be recorded at the time of testing, and insulation may be added to increase this temperature gradient.



Figure 15: Examples of soffit vent and Gable vent

Instrumentation Needed

For Flow Testing, we are using the existing flow testing rig in the Gray Lab. This rig is currently equipped to measure the following:

- Inlet Pressure
- Outlet Pressure
- Downstream Flow Rate
- Air Temperature in the Line for conversion to Natural Gas Equivalent Measurements

Additionally, we are going to need two flow meters to measure the regulator vent emission. We want to have two since the vent-limited regulators are dual-stage and have two separate vents. SignalX will also need to reconfigure the existing software to allow for data logging of the two additional flow meters. The current DAQ system already has room to fit the output signals from the two new flow meters, but the software will need to be configured to log their output signals.

For the methane concentration testing, we have a few options. We still have 12 infrared Dynament methane sensors that were used in previous project work. The DAQ system used in the past was a Campbell Scientific datalogger. This uses its own coding language for programming the datalogger and can also be used with a laptop to show the real-time output. We will need to re-calibrate the methane sensors, relating their voltage output to methane concentration. This was done in the past using an enclosure with a calibrated reference methane sensor. The voltage outputs were then logged in relation to the reference sensor readings to create a calibration curve for each of the sensors. We may want to add more sensors to our array.

Another option will be to investigate other sensors and DAQ systems that can be used.

END TEST PLAN.

Appendix B – VL1 & VL2 Manufacturer Test Data

GTI ENERGY
solutions that transform

REPORT
GTI ENERGY PROJECT NUMBER 23059

Comparison of Compact Service Regulators – Results of Testing

VL1 & VL2 Summary

GTI Energy Technical Contact:
Joe Carlstrom
Joseph Irwin, PE
Tom Bates
Jake Witecha

1700 S. Mount Prospect Rd.
Des Plaines, Illinois 60018
www.gti.energy

Introduction

This report was created to review data obtained during PHMSA project 693JK32110001 and OTD project 5.22.j - Design and Placement of Compact Service Regulators with subject matter experts from manufacturers. The following Part 1 and Part 2 matrix outlines the test methodology used to obtain data for analysis purposes for safe clearance distances.

Part 1 Test methodology

All testing was performed on the rig with air and software formula coefficients for natural gas.

Test	Standard/Procedure reference	Conditions	Test Criteria	Parameters
Modified Lock-Up Test	ANSI B109.4 -[5.3.5]	Temperature: Ambient; Inlet pressure: 10, 60, 100 psig; Flow: 100, 200, 300, until maximum manufacturer specifications [SCFH Air]	Outlet pressure Max 9"±0.5 iwc 2.15±0.15 psig (2psig reg.)	Lock up [iwc]
			Flow rate at vent 2.5 SCFH (vent limited) 100 SCFH (IRV)	Vent flow rate [SCFH]
Modified Relief Point Test	ANSI B109.4 -[5.3.8]	Temperature: Ambient; Inlet pressure: 10, 60, 100 psig; Outlet pressure: slowly increase until slam shut closes or maximum allowable pressure reached	Outlet pressure MAX 17"±0.5 iwc; 3.3±0.15iwc psig (2psig reg.)	Relief point [iwc]
			Flow rate at vent 2.5 SCFH (vent limited) 100 SCFH (IRV)	Vent flow rate [SCFH]

Part 2 Test Methodology

Testing was performed in an enclosed and controlled environment with natural gas. Safety rules were implemented to monitor and limit the amounts of natural gas. When an accumulation of natural gas greater than 100% LEL was detected by multiple sensors the natural gas source was terminated and the test concluded.

Single Lock-Up Test	ANSI B109.4 - [5.3.5]	**Temperature**: Ambient; **Inlet pressure**: 60 psig; **Flow Rate**: 390 SCFH (7 iwc reg.) 1260 SCFH (2 psig reg.) **Lockup condition**: One lock up induced, wait 30 seconds for gas concentration dissipate to 0% LEL, repeat 10 times.	Outlet pressure Max 9"±0.5 iwc (7 iwc reg.) 2.15±0.15 psig (2psig reg.)	Lock up pressure [iwc]
			Methane concentration at vent 0%LEL (vent limited) 3%LEL (IRV)	Methane Concentration [% LEL]
Multi Lock-Up Test	ANSI B109.4 - [5.3.5]	**Temperature**: Ambient; **Inlet pressure**: 60 psig; **Flow Rate**: 390 SCFH (7 iwc reg.) 1260 SCFH (2 psig reg.) **Lockup condition**: Two lock ups induced in quick succession, wait 30 seconds for gas concentration dissipate to 0%LEL, repeat 3 times, after 3 repetitions increase the number of lockups by 1 to a maximum of 4.	Outlet pressure Max 9"±0.5 iwc (7 inWC reg.) 2.15±0.15 psig (2psig reg.)	Lock up pressure [inWC]
			Methane concentration at vent 0%LEL (vent limited) 3%LEL (IRV)	Methane Concentration [% LEL]

Summary

Modified Lockup Tests

Average Emission Rate [SCFH], Normal Conditions, 7" WC

Model	10-psig inlet	60-psig inlet	100-psig inlet
VL1	0.1041	0.1070	0.0955
VL2	0.1180	0.5118	0.0883

*Under abnormal conditions, OPSO was triggered

Average Emission Rate [SCFH], Normal Conditions, 2-psig

Model	10-psig inlet	60-psig inlet	100-psig inlet
VL1	0.113	0.1039	0.0856
VL2	0.3254	0.1912	0.1832

*Under abnormal conditions, OPSO was triggered

Relief Tests

Average Emission Rate [SCFH], Normal Conditions, 7" WC

Model	10-psig inlet	60-psig inlet	100-psig inlet
VL1	1.3667	1.3200	1.2733
VL2	0.8333	1.4233	1.1200

Average Emission Rate [SCFH], Primary Diaphragm Tear, 7" WC

Model	10-psig inlet	60-psig inlet	100-psig inlet
VL1	2.6700	1.8600	1.8200
VL2	2.1933	2.0233	1.8900

Average Emission Rate [SCFH], Primary and Secondary Diaphragm Tear, 7" WC

Model	10-psig inlet	60-psig inlet	100-psig inlet
VL1	1.4533	2.9367	2.5167
VL2	21.3400	22.2350	16.4633

GTI ENERGY

Average Emission Rate [SCFH], Lever Disconnect, 7" WC

Model	10-psig inlet	60-psig inlet	100-psig inlet
VL1	0.000	0.000	0.000
VL2	1.1167	0.3833	0.2650

Average Emission Rate [SCFH], Normal Conditions, 2-psig

Model	10-psig inlet	60-psig inlet	100-psig inlet
VL1	2.2450	1.4933	1.3500
VL2	2.9400	2.6967	3.0300

Average Emission Rate [SCFH], Primary Diaphragm Tear, 2-psig

Model	10-psig inlet	60-psig inlet	100-psig inlet
VL1	3.7600	3.4250	4.2100
VL2	1.3550	1.0300	2.2400

*Flow rate exceeded flow meter range

Average Emission Rate [SCFH], Primary Diaphragm Tear, 2-psig

Model	10-psig inlet	60-psig inlet	100-psig inlet
VL1	N/A*	N/A*	N/A*
VL2	N/A*	N/A*	N/A*

*Flow rate exceeded flow meter range

Average Emission Rate [SCFH], Lever Disconnect, 2-psig

Model	10-psig inlet	60-psig inlet	100-psig inlet
VL1	0.0967	0.0600	0.0300
VL2	0.1900	0.1933	0.1500

VL1

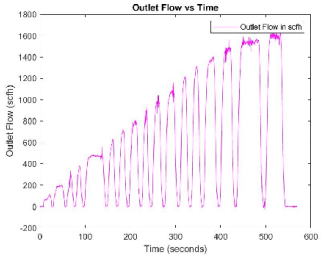
Modified Lockup Tests

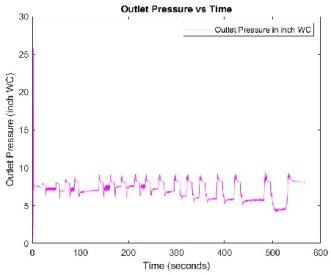
7" WC Outlet, 10-psig Inlet

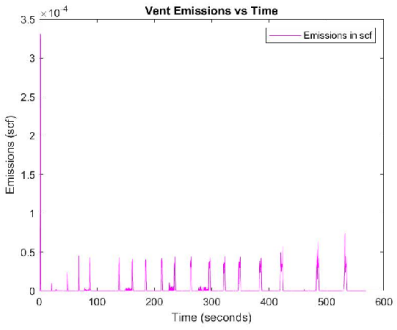
- 222489-013

The volume of total emissions in 568.96 seconds is 0.0151 scf.

The flow rate of emissions is 0.0957 scfh.

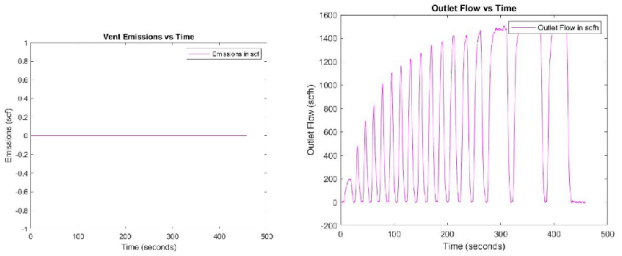


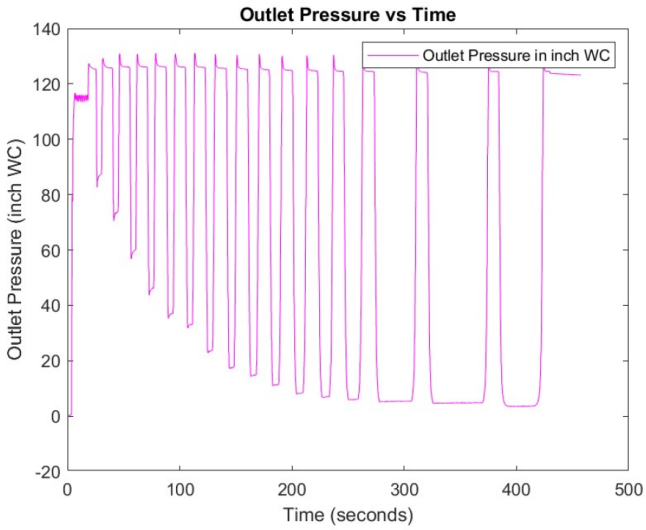




GTI ENERGY

- 222489-013 (Blocked Vent)
  The volume of total emissions in 457.24 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.



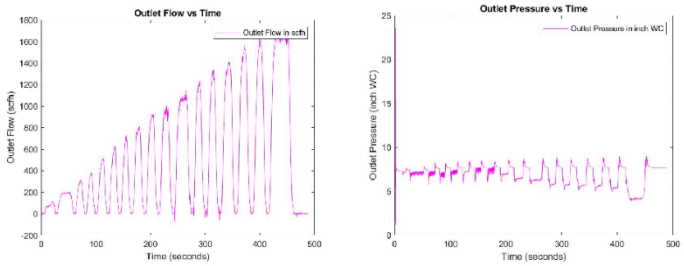


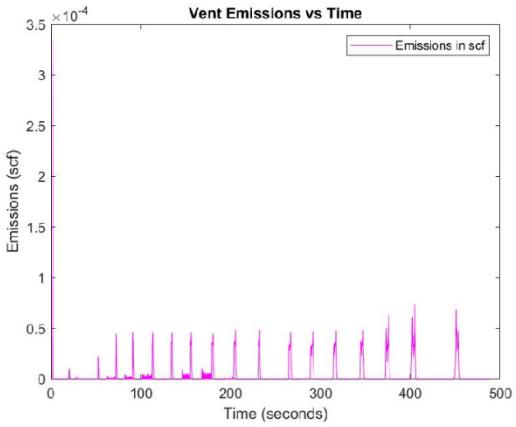
GTI ENERGY

- 222489-014

The volume of total emissions in 487.71 seconds is 0.0153 scf.

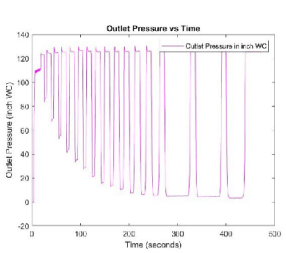
The flow rate of emissions is 0.1132 scfh.

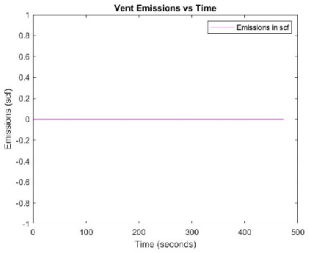


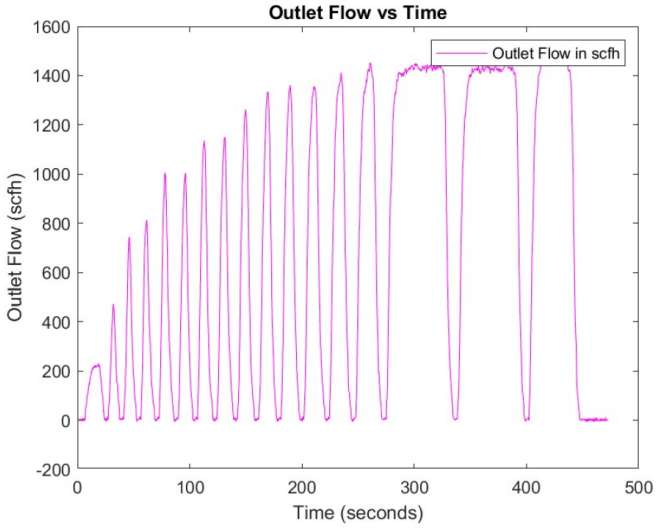


GTI ENERGY

- 222489-014 (Blocked Vent)
  The volume of total emissions in 473.03 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.





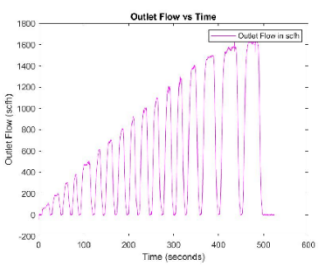


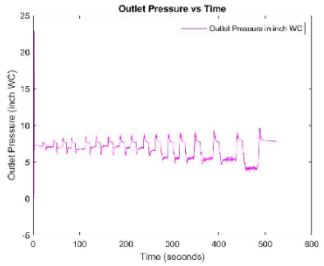
GTI ENERGY

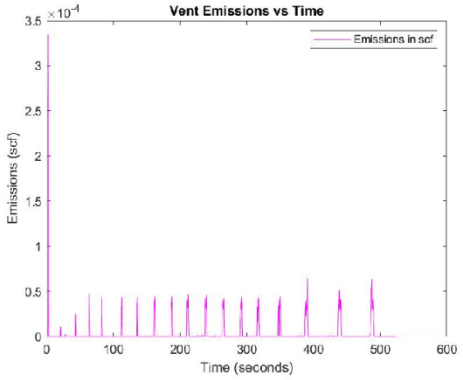
- 222489-015

The volume of total emissions in 523.96 seconds is 0.0151 scf.

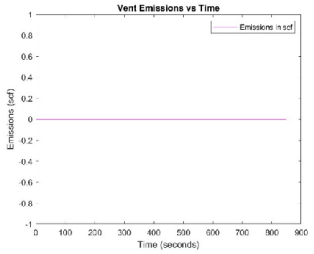
The flow rate of emissions is 0.1035 scfh.

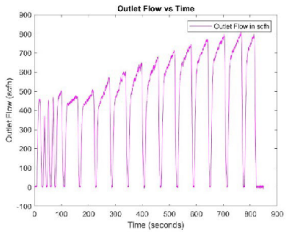


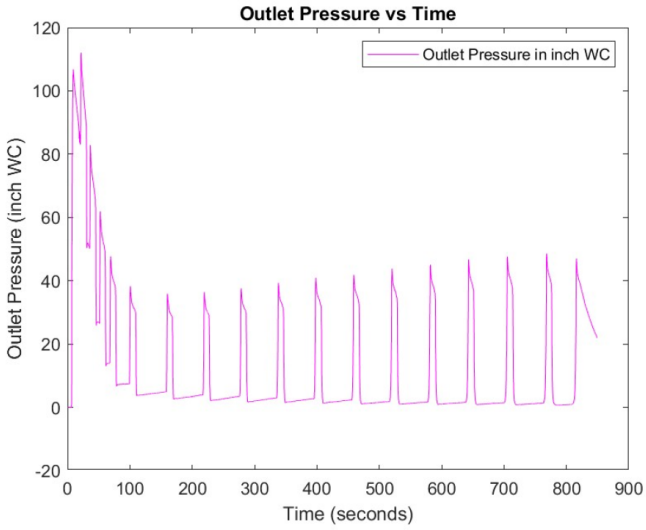




- 222489-015 (Blocked Vent)
  VL1_222489-015-BV_10_21_2022_12_10_56_1
  The volume of total emissions in 849.38 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.







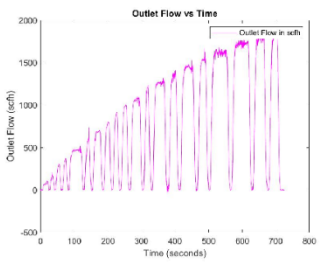
GTI ENERGY

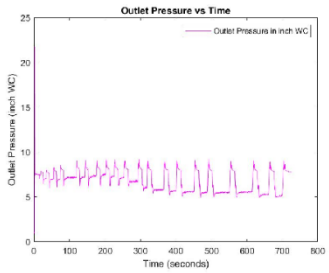
7″ WC Outlet, 60-psig Inlet

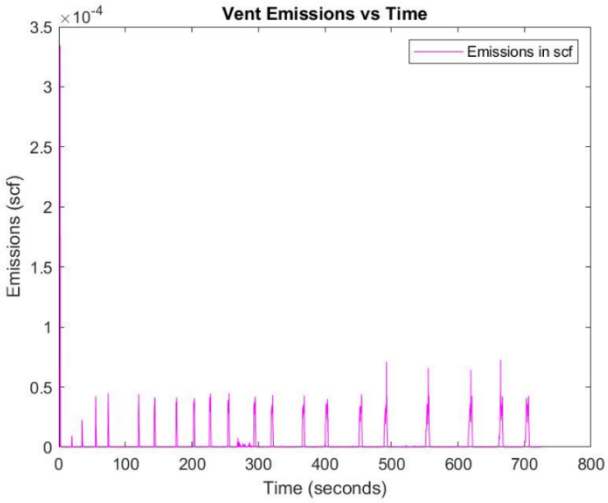
- 222489-013

The volume of total emissions in 725.21 seconds is 0.0184 scf.

The flow rate of emissions is 0.0916 scfh.





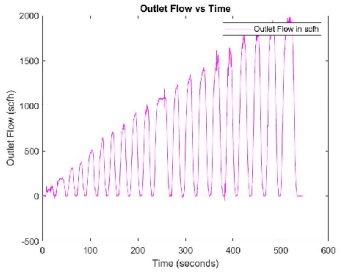


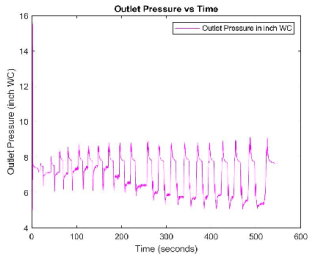
GTI ENERGY

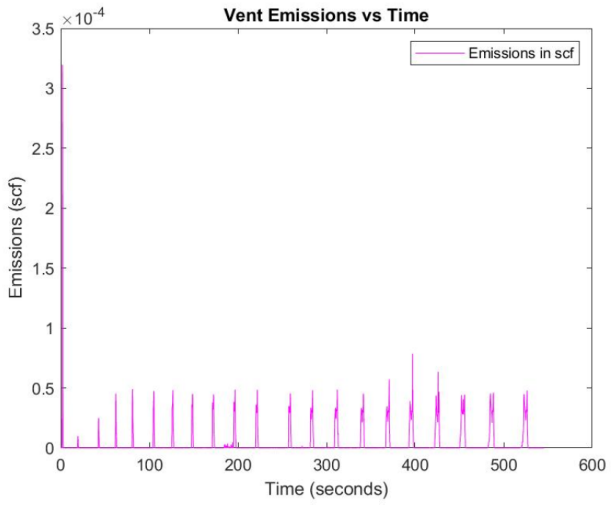
- 222489-014

The volume of total emissions in 545.43 seconds is 0.0187 scf.

The flow rate of emissions is 0.1232 scfh.





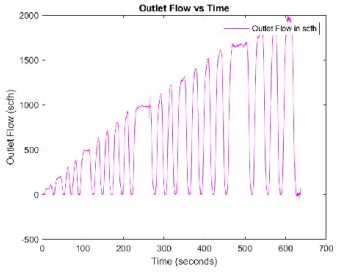


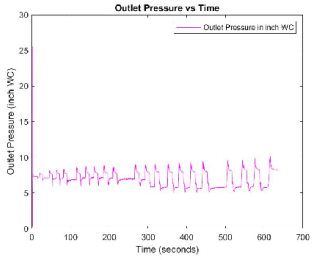
GTI ENERGY

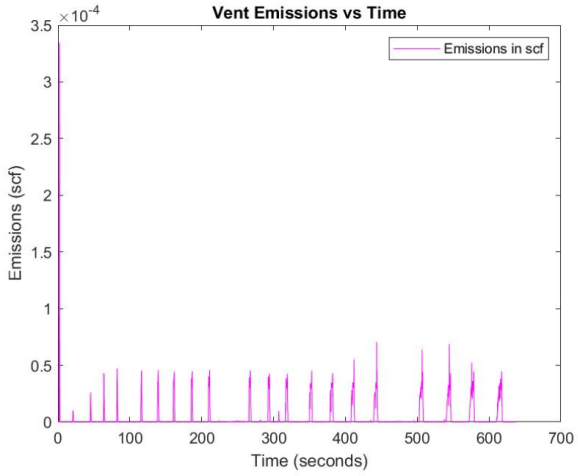
- 222489-015

The volume of total emissions in 636.52 seconds is 0.0188 scf.

The flow rate of emissions is 0.1062 scfh.







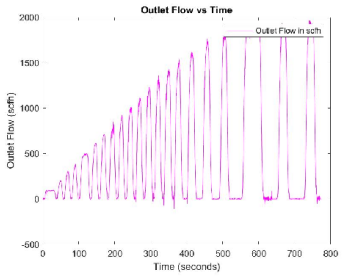
GTI ENERGY

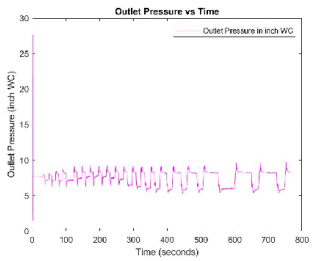
7" WC Outlet, 100-psig Inlet

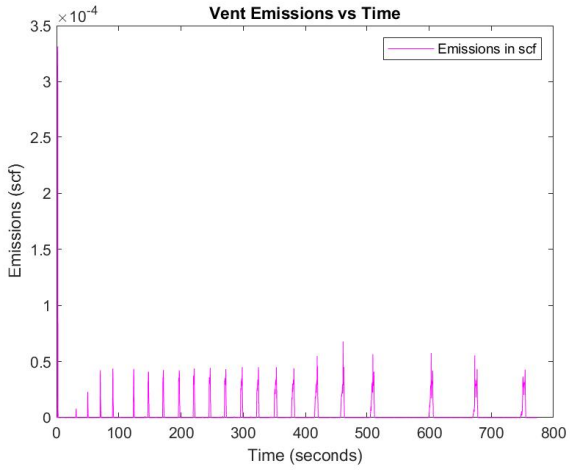
- 222489-013

The volume of total emissions in 773.26 seconds is 0.0191 scf.

The flow rate of emissions is 0.0888 scfh.





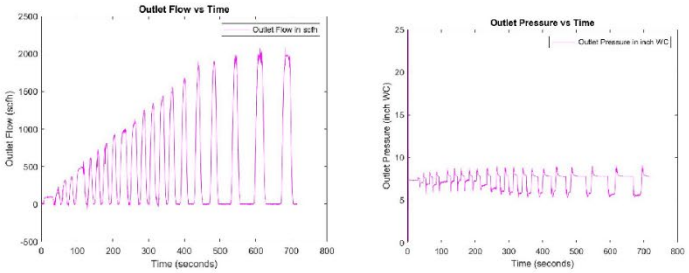


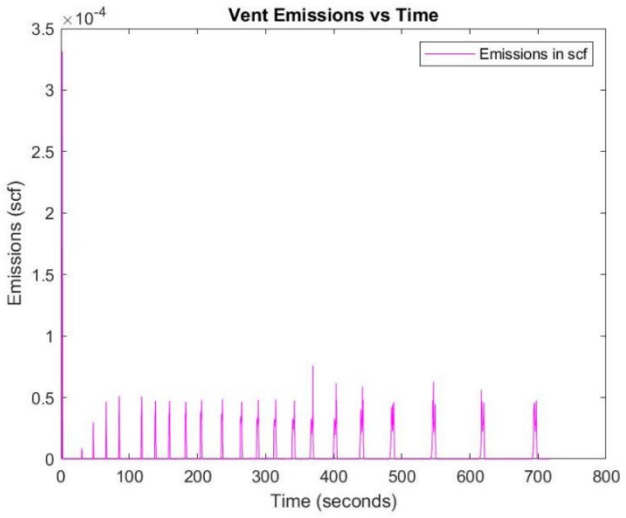
GTI ENERGY

- 222489-014

The volume of total emissions in 716.62 seconds is 0.0203 scf.

The flow rate of emissions is 0.1018 scfh.



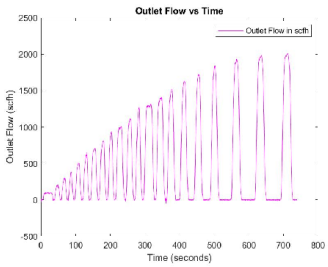


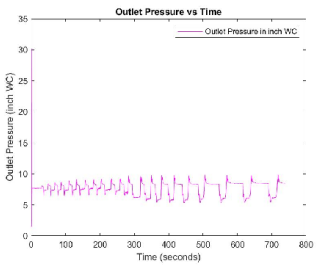
GTI ENERGY

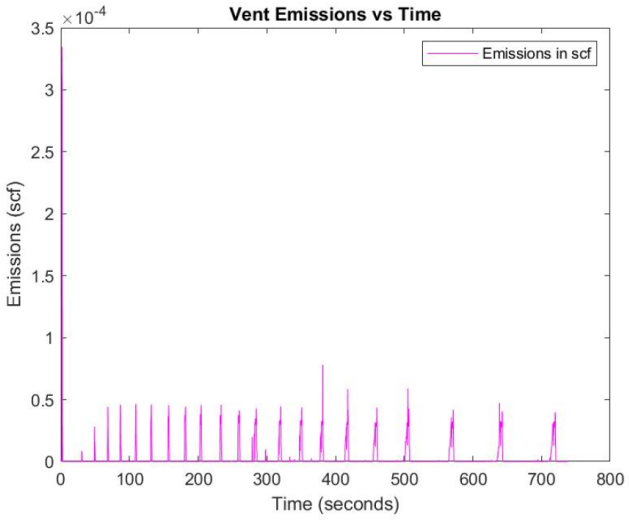
- 222489-015

The volume of total emissions in 738.82 seconds is 0.0197 scf.

The flow rate of emissions is 0.0959 scfh.







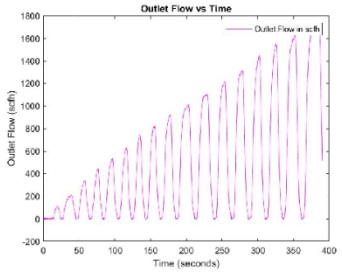
GTI ENERGY

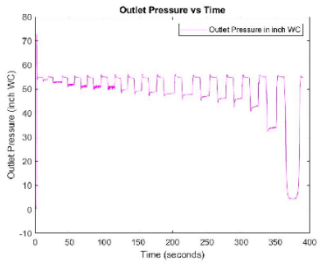
2-psig Outlet, 10-psig Inlet

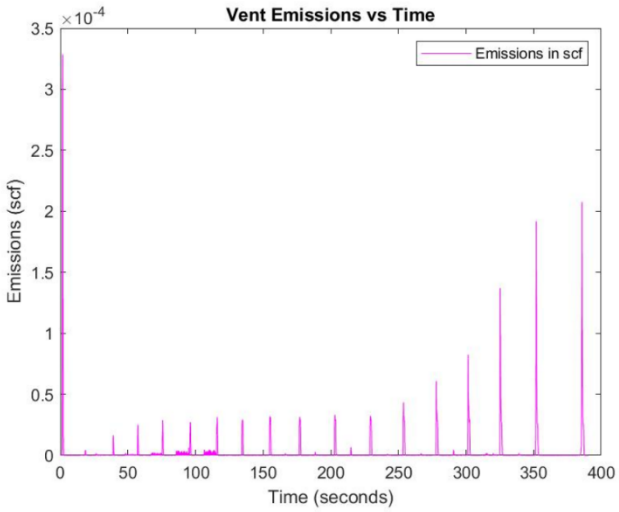
- 222489-016

The volume of total emissions in 390.51 seconds is 0.0090 scf.

The flow rate of emissions is 0.0828 scfh.

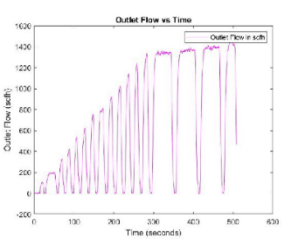


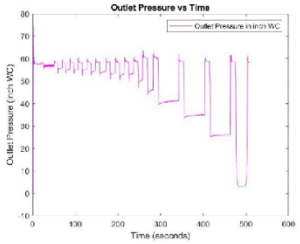


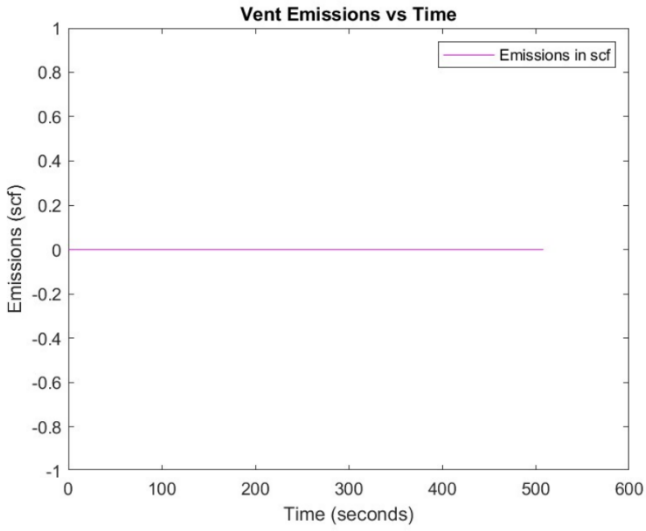


GTI ENERGY

- 222489-016 (Blocked Vent)
  The volume of total emissions in 508.41 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.





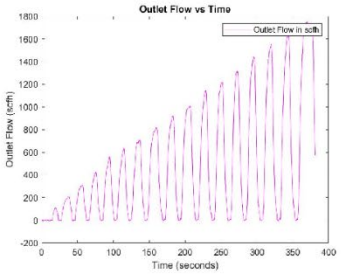


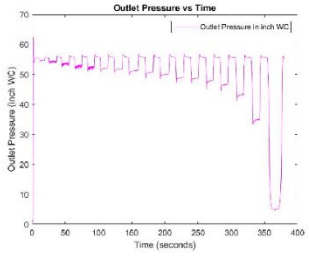
GTI ENERGY

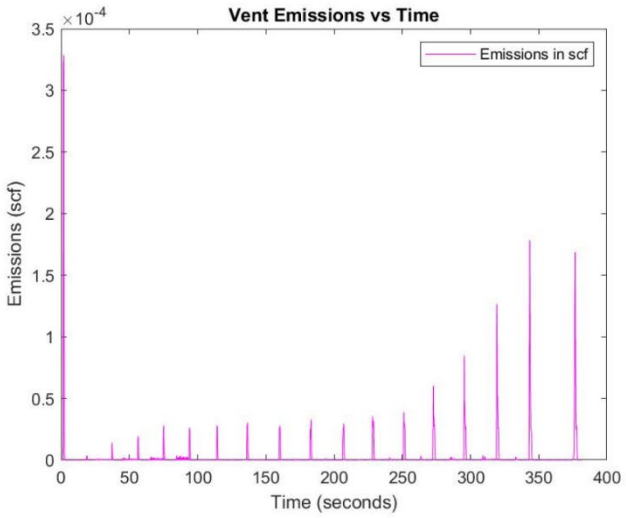
- 222489-017

The volume of total emissions in 381.44 seconds is 0.0084 scf.

The flow rate of emissions is 0.0792 scfh.

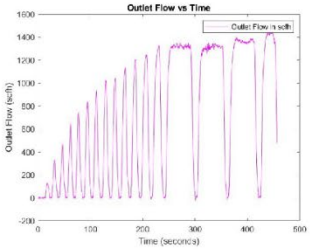


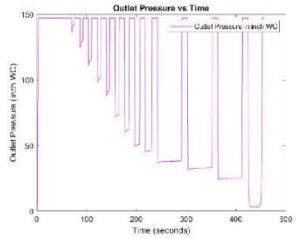


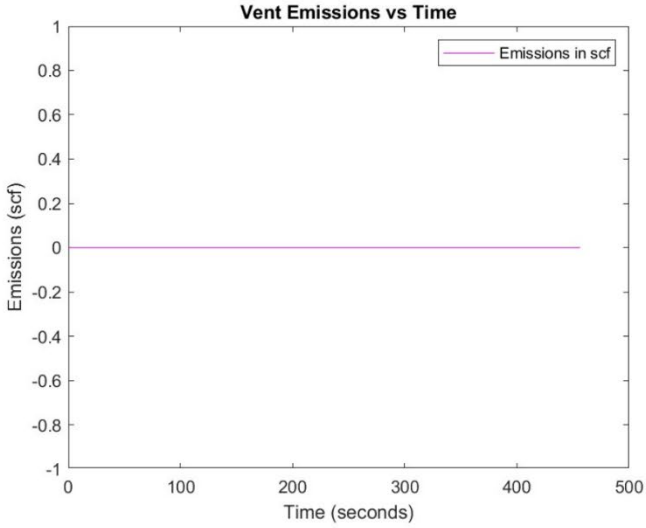


GTI ENERGY

- 222489-017 (Blocked Vent)
  The volume of total emissions in 456.42 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.





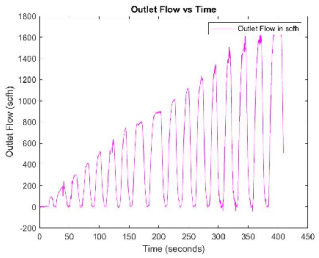


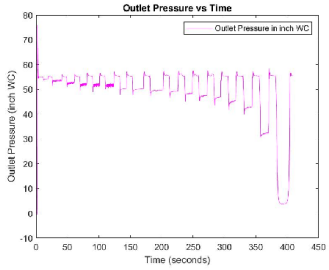
GTI ENERGY

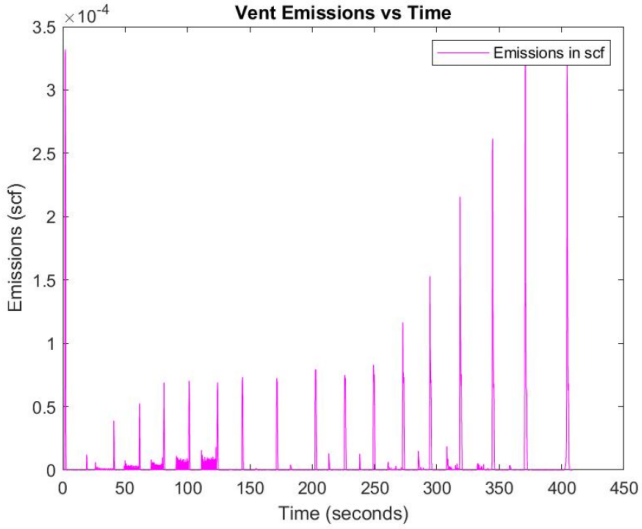
- 222489-018

The volume of total emissions in 409.22 seconds is 0.0201 scf.

The flow rate of emissions is 0.1770 scfh.

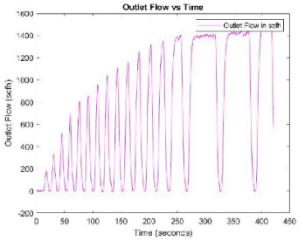


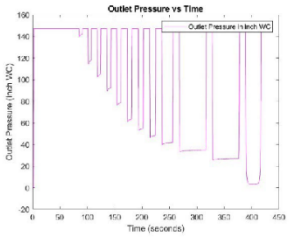


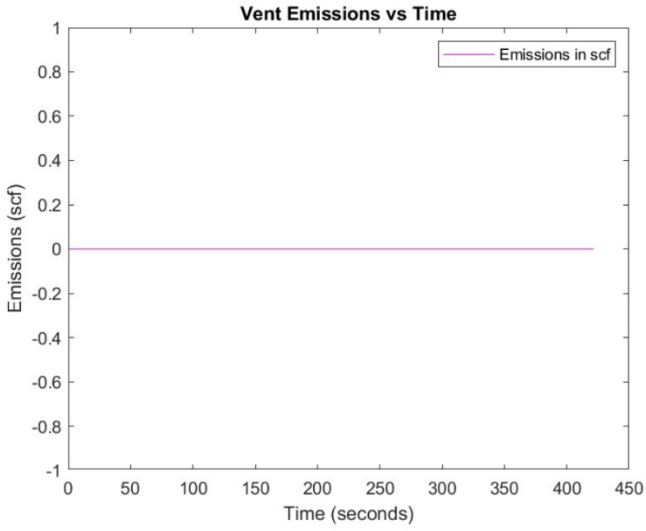


GTI ENERGY

- 222489-018 (Blocked Vent)
  VL1_222489-018-BV_11_08_2022_09_15_35_1
  The volume of total emissions in 421.63 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.







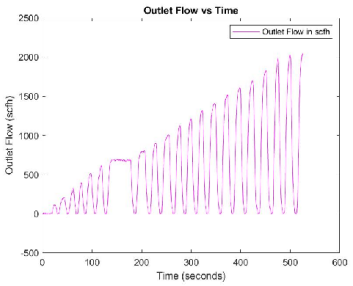
GTI ENERGY

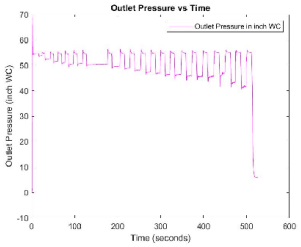
2-psig Outlet, 60-psig Inlet

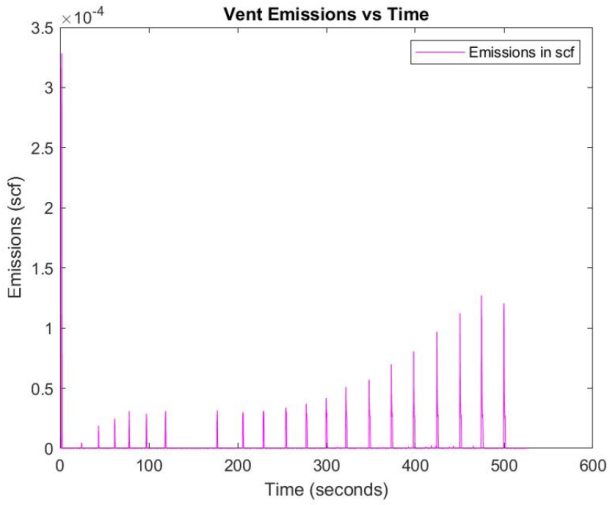
- 222489-016

The volume of total emissions in 526.49 seconds is 0.0100 scf.

The flow rate of emissions is 0.0685 scfh.

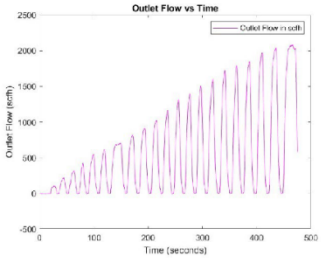


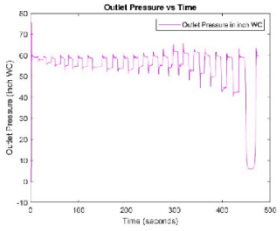


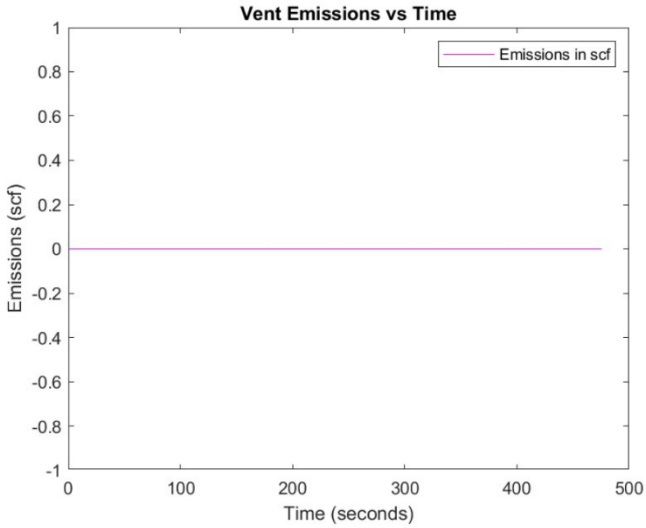


GTI ENERGY

- 222489-016 (Blocked Vent)
  The volume of total emissions in 475.60 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.





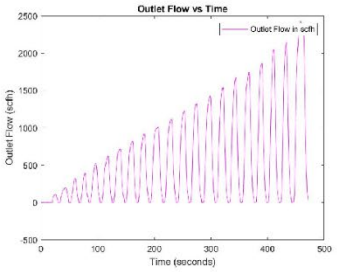


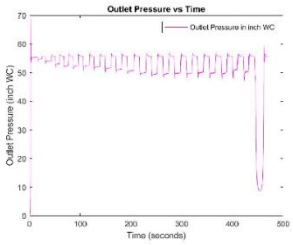
GTI ENERGY

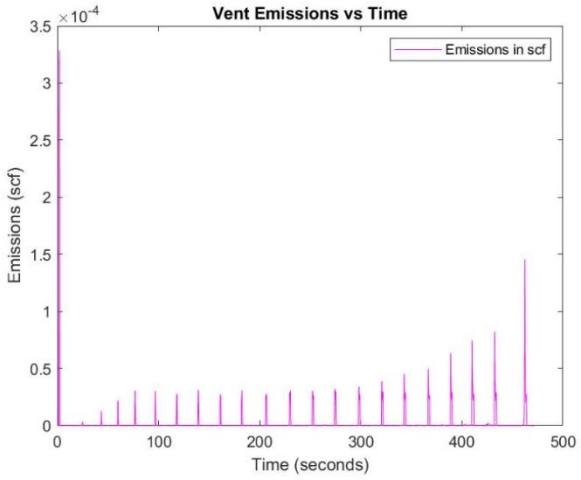
- 222489-017

The volume of total emissions in 471.31 seconds is 0.0091 scf.

The flow rate of emissions is 0.0695 scfh.

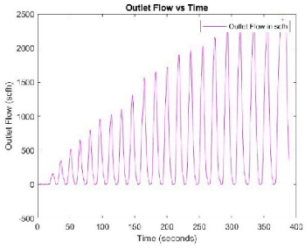


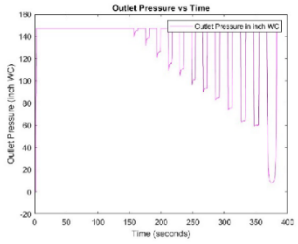


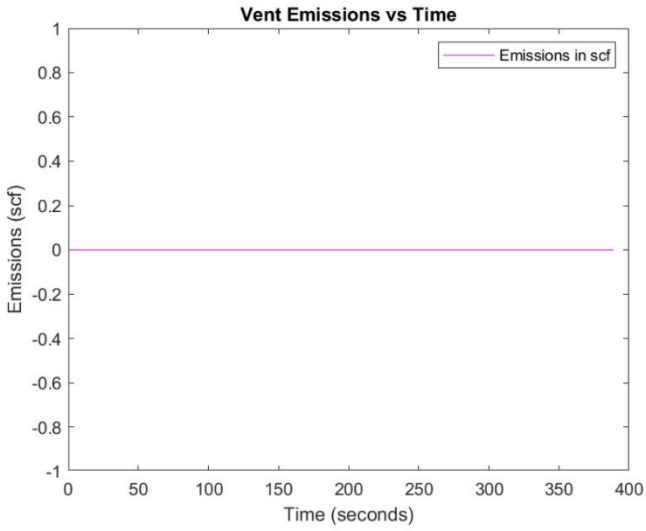


GTI ENERGY

- 222489-017 (Blocked Vent)
  The volume of total emissions in 389.03 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.





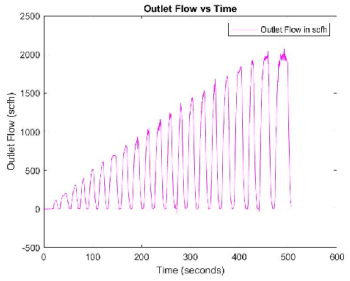


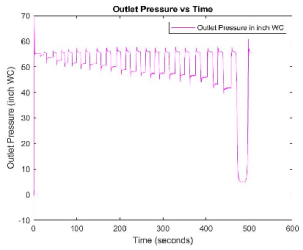
GTI ENERGY

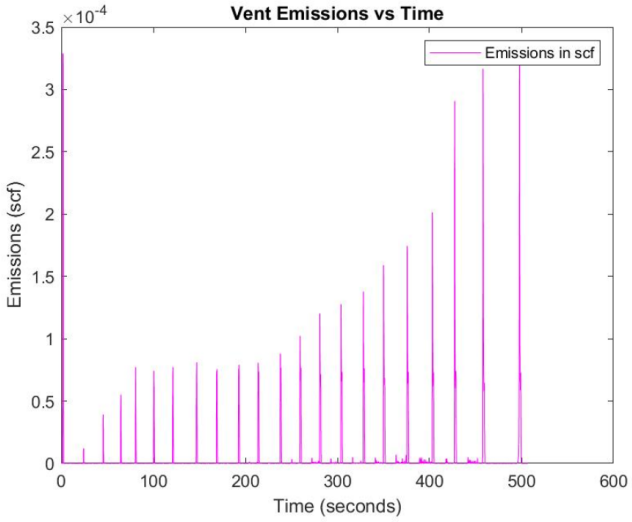
- 222489-018

The volume of total emissions in 507.12 seconds is 0.0245 scf.

The flow rate of emissions is 0.1737 scfh.

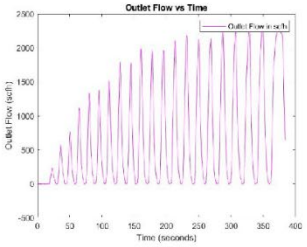


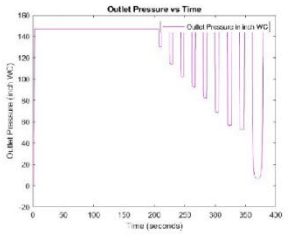


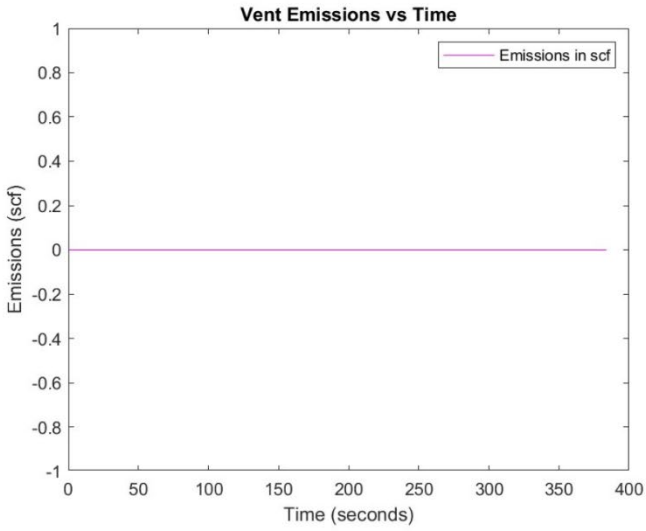


GTI ENERGY

- 222489-018 (Blocked Vent)
  The volume of total emissions in 383.91 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.





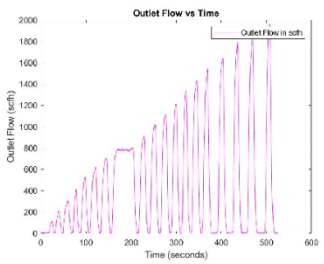


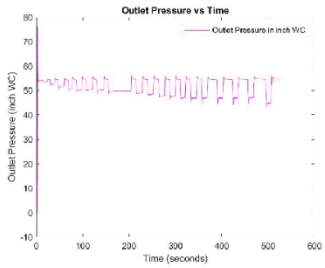
2-psig Outlet, 100-psig Inlet

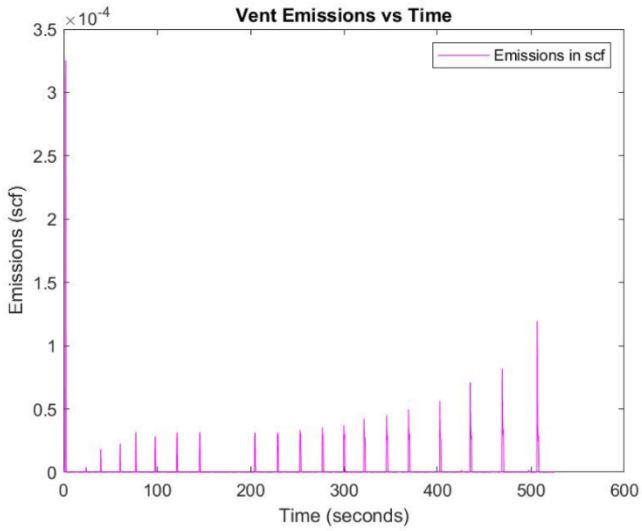
- 222489-016

The volume of total emissions in 525.63 seconds is 0.0084 scf.

The flow rate of emissions is 0.0573 scfh.

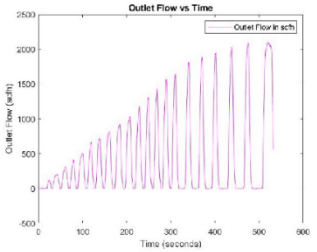


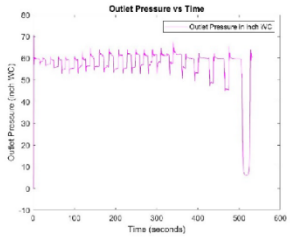


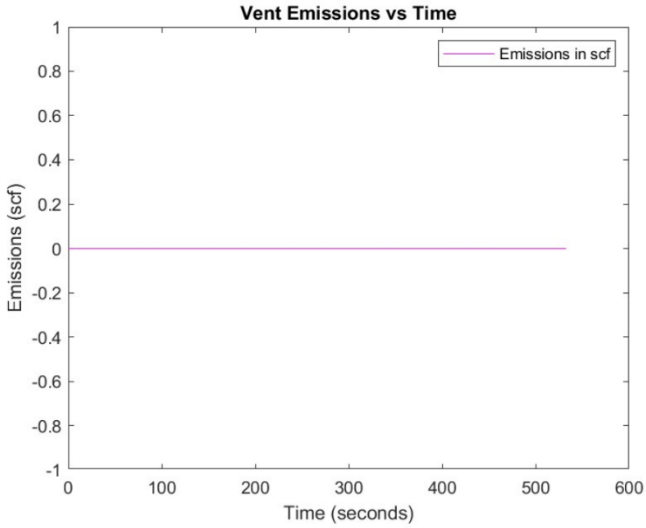


GTI ENERGY

- 222489-016 (Blocked Vent)
  The volume of total emissions in 532.58 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.





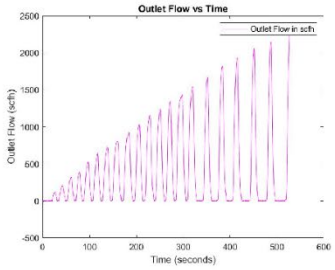


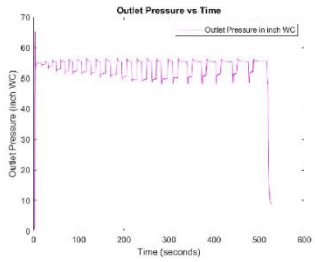
GTI ENERGY

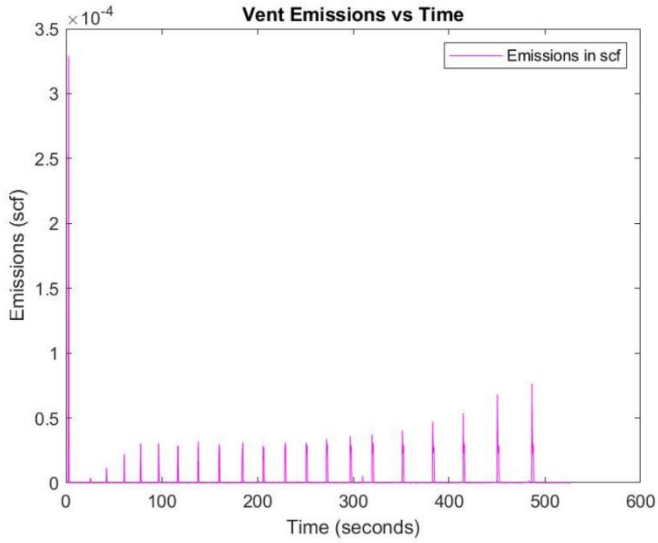
- 222489-017

The volume of total emissions in 527.13 seconds is 0.0079 scf.

The flow rate of emissions is 0.0537 scfh.

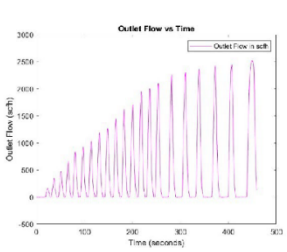


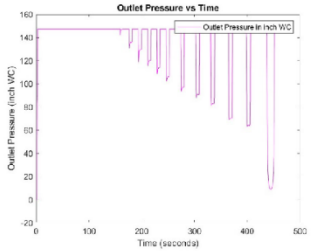


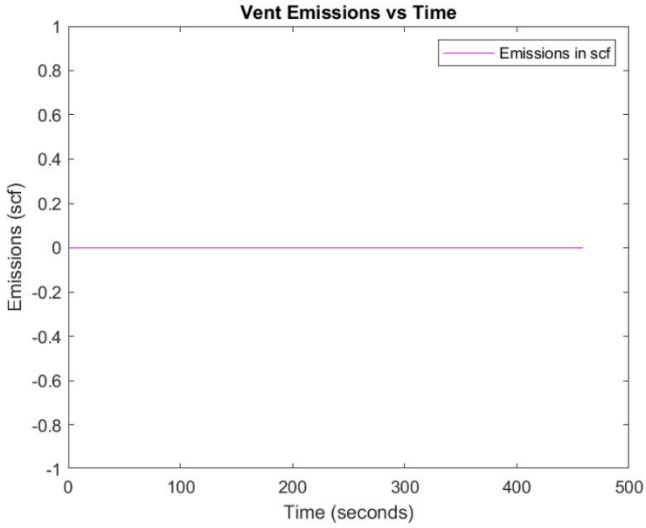


GTI ENERGY

- 222489-017 (Blocked Vent)
  The volume of total emissions in 459.06 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.





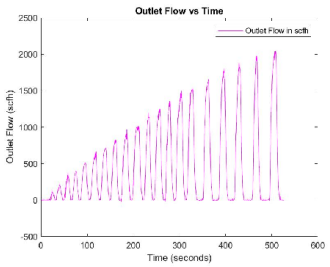


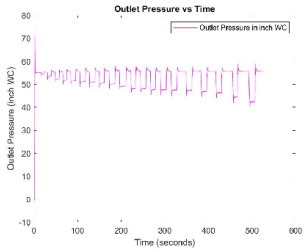
GTI ENERGY

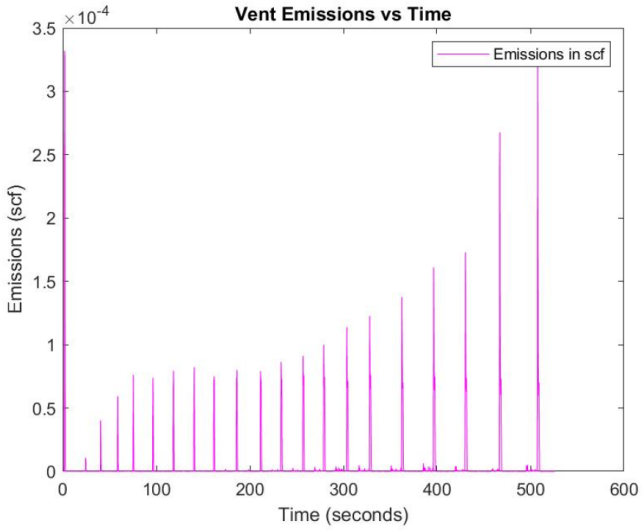
- 222489-018

The volume of total emissions in 525.76 seconds is 0.0213 scf.

The flow rate of emissions is 0.1458 scfh.





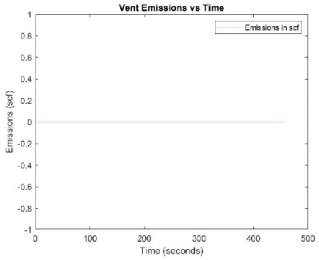


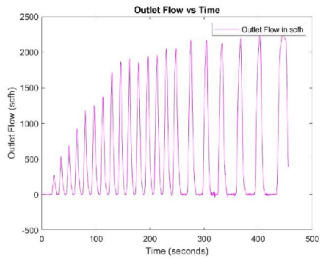
GTI ENERGY

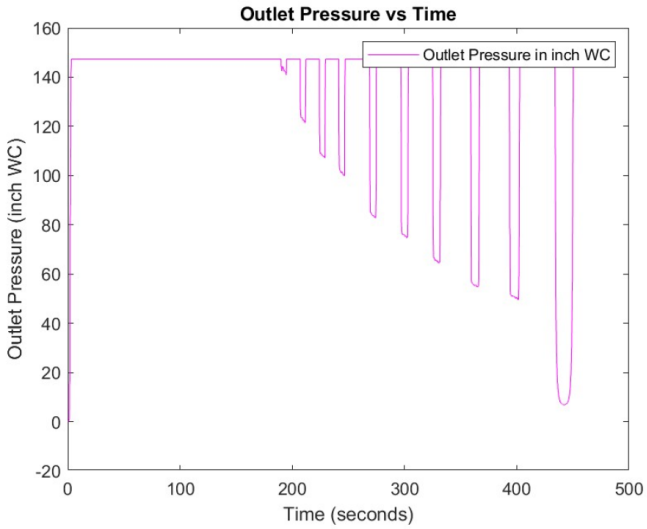
- 222489-018 (Blocked Vent)

The volume of total emissions in 455.99 seconds is 0.0000 scf.

The flow rate of emissions is 0.0000 scfh.







GTI ENERGY

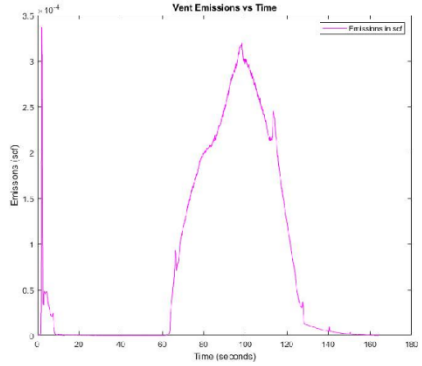
Relief Tests

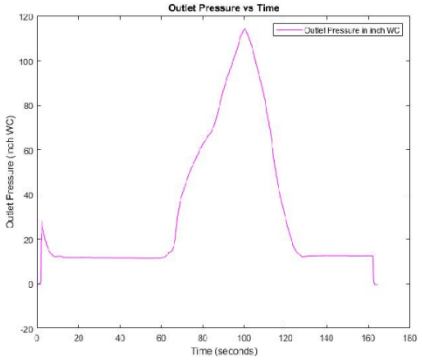
7" WC Outlet, 10-psig Inlet

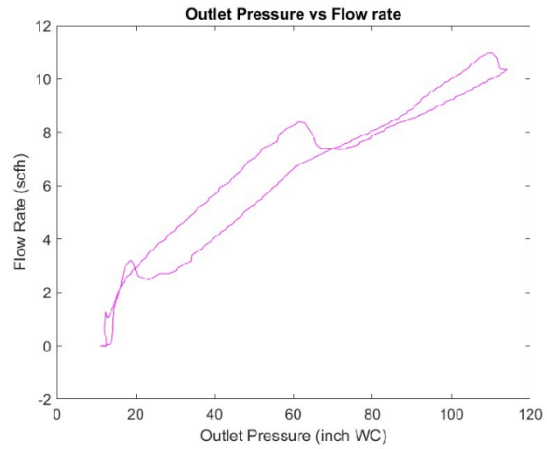
- 222489-013

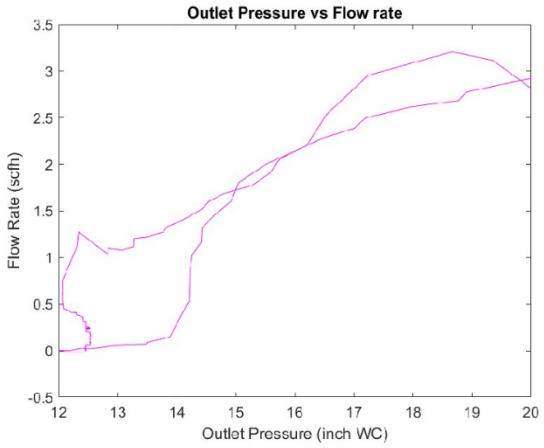
The volume of total emissions in 164.26 seconds is 0.1236 scf.

The average flow rate of emissions at 18 inches WC is 3.08 scfh.



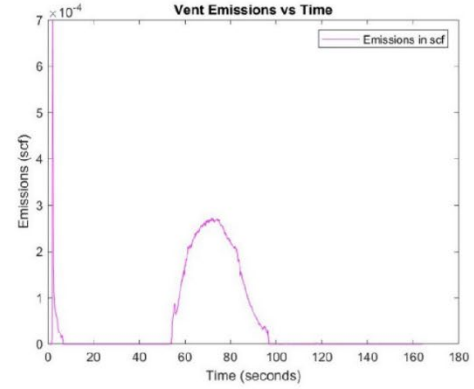


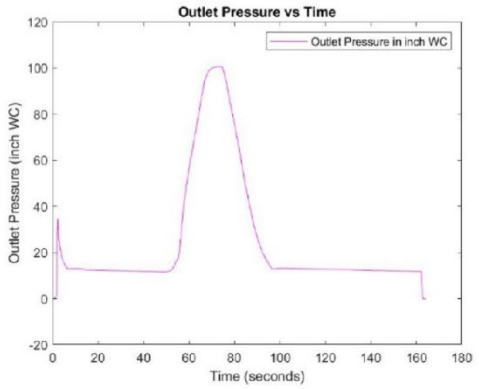

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
12
10
8
6
4
2
0
-2
0
20
40
60
80
100
120


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
12
13
14
15
16
17
18
19
20

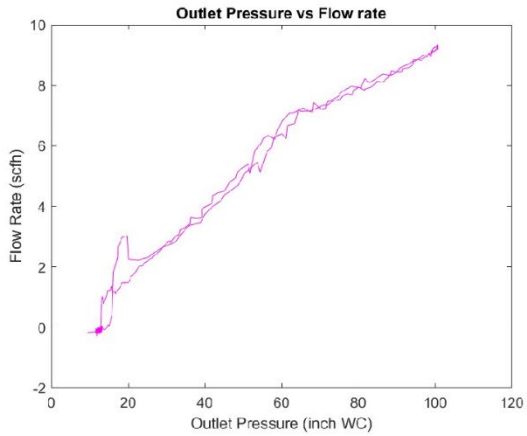
GTI ENERGY

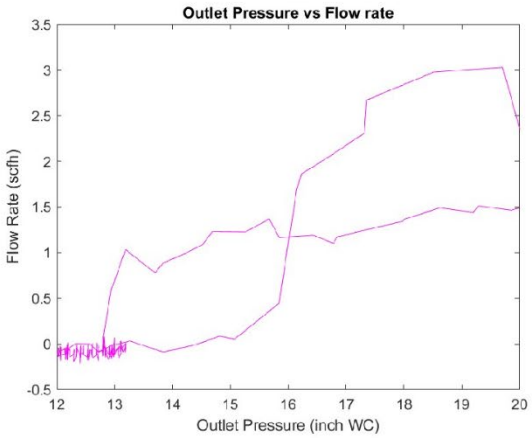
- 222489-013 DT1
  The volume of total emissions in 164.30 seconds is 0.0742 scf.
  The average flow rate of emissions at 18 inches WC is 1.89 scfh.





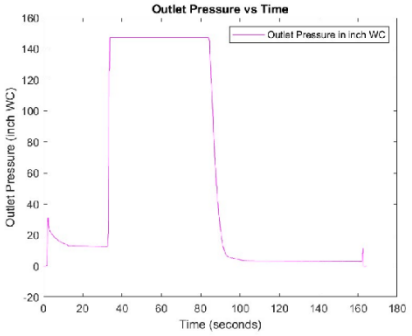
GTI ENERGY

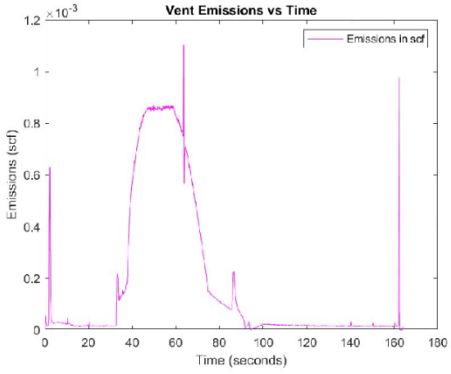

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
10
8
6
4
2
0
-2
0
20
40
60
80
100
120


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
12
13
14
15
16
17
18
19
20

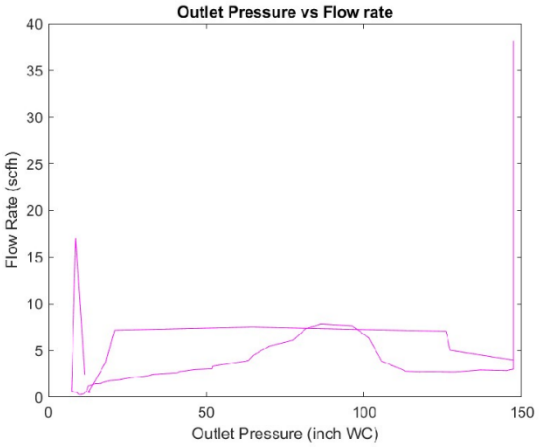
GTI ENERGY

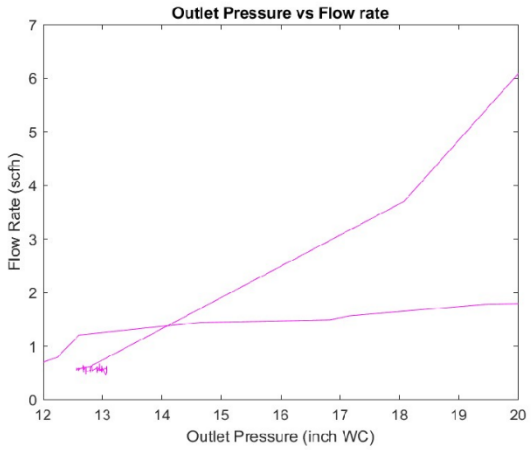
- 222489-013 DT2
  The volume of total emissions in 164.33 seconds is 0.2919 scf.
  The average flow rate of emissions at 18 inches WC is 1.29 scfh.





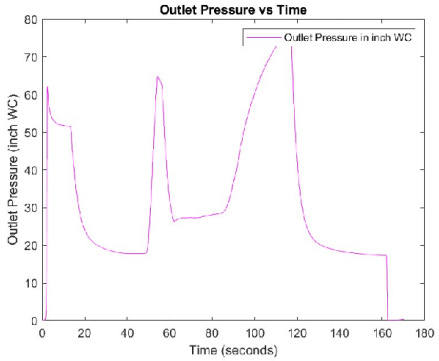
GTI ENERGY

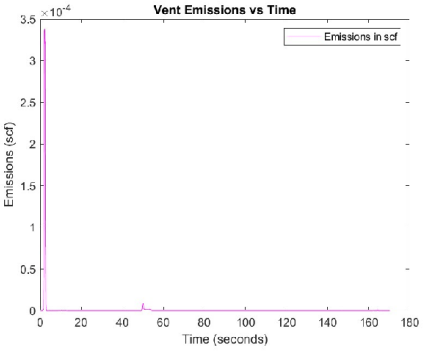

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
5
10
15
20
25
30
35
40
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
1
2
3
4
5
6
7
12
13
14
15
16
17
18
19
20

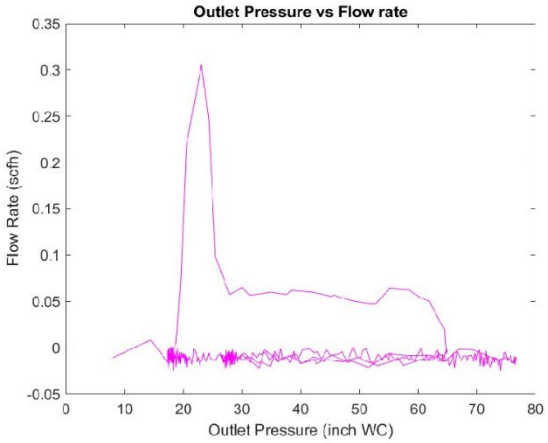
GTI ENERGY

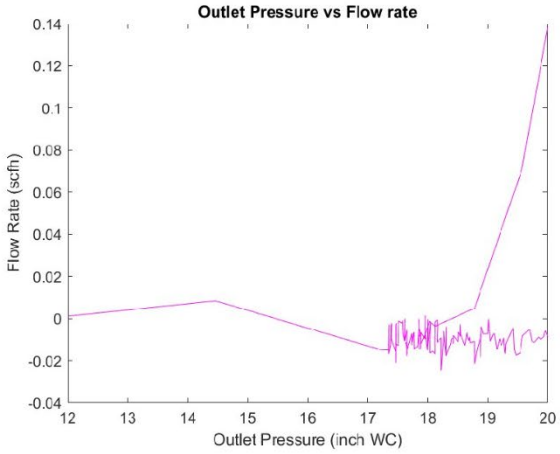
- 222489-013 LD
  The volume of total emissions in 170.30 seconds is 0.0024 scf.
  The average flow rate of emissions at 18 inches WC is -0.01 scfh.





GTI ENERGY

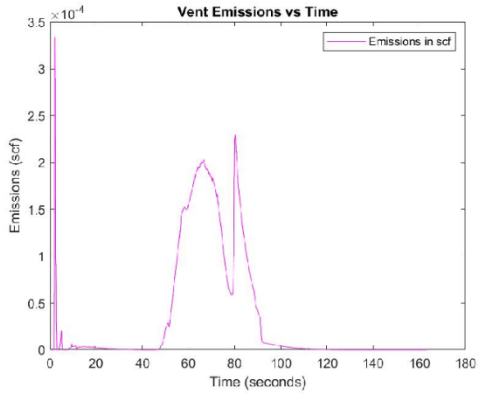

Outlet Pressure vs Flow rate
Flow Rate (scfh)
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
0
10
20
30
40
50
60
70
80
Outlet Pressure (inch WC)

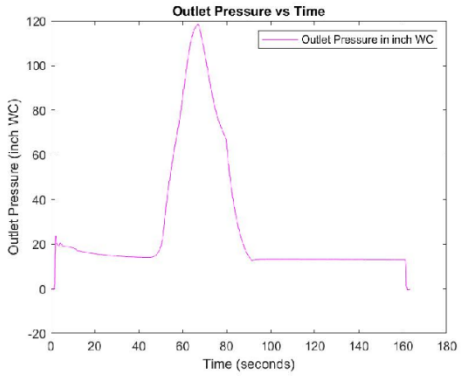

Outlet Pressure vs Flow rate
Flow Rate (scfh)
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
-0.02
-0.04
12
13
14
15
16
17
18
19
20
Outlet Pressure (inch WC)

- 222489-014

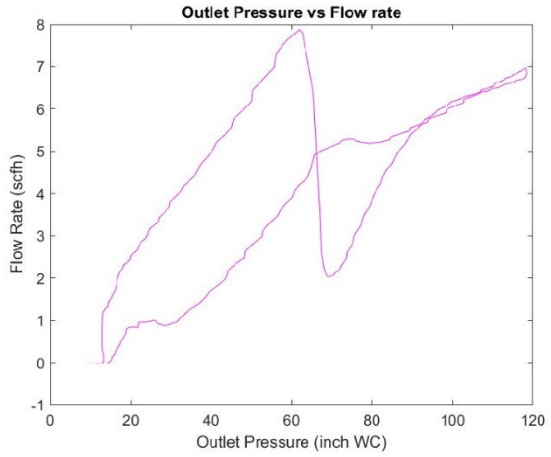
The volume of total emissions in 163.28 seconds is 0.0538 scf.

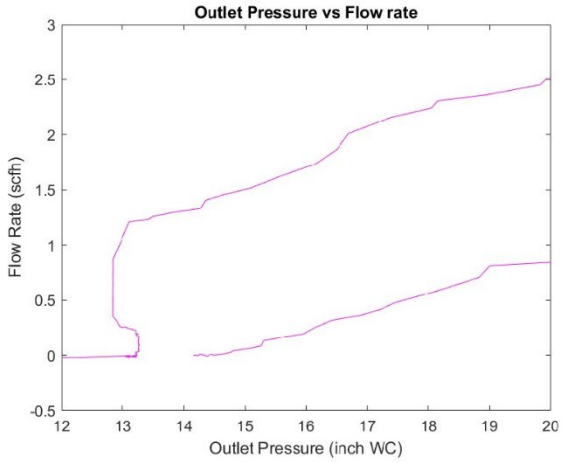
The average flow rate of emissions at 18 inches WC is 0.38 scfh.





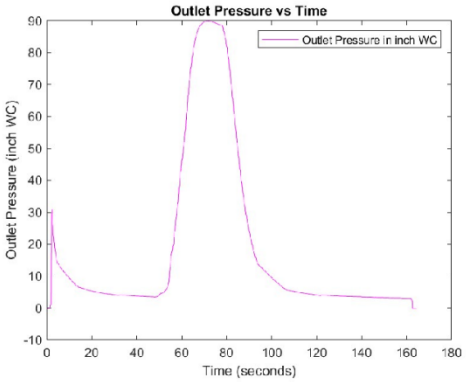
GTI ENERGY

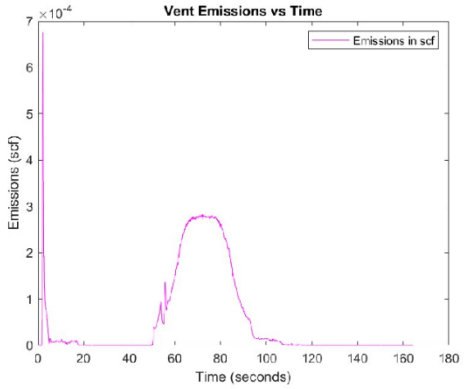

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
8
7
6
5
4
3
2
1
0
-1
0
20
40
60
80
100
120


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
3
2.5
2
1.5
1
0.5
0
-0.5
12
13
14
15
16
17
18
19
20

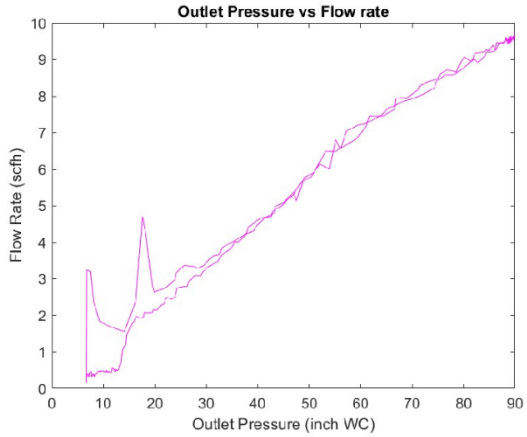
GTI ENERGY

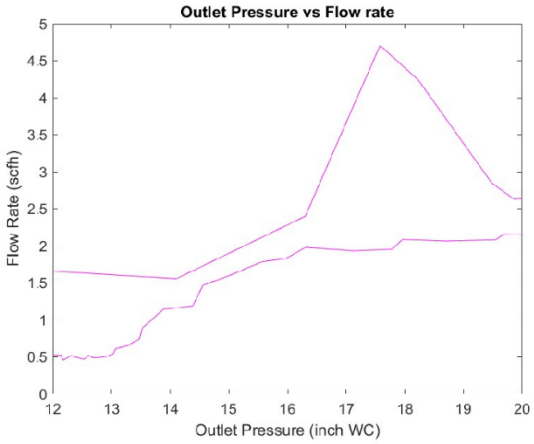
- 222489-014 DT1
  The volume of total emissions in 164.34 seconds is 0.0829 scf.
  The average flow rate of emissions at 18 inches WC is 4.64 scfh.



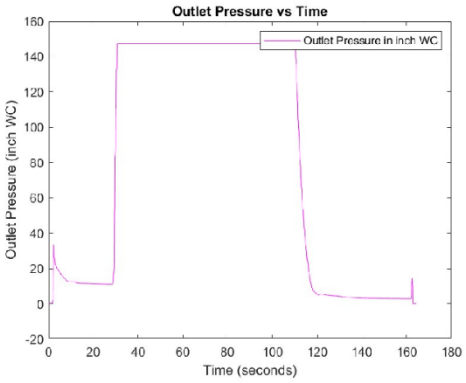


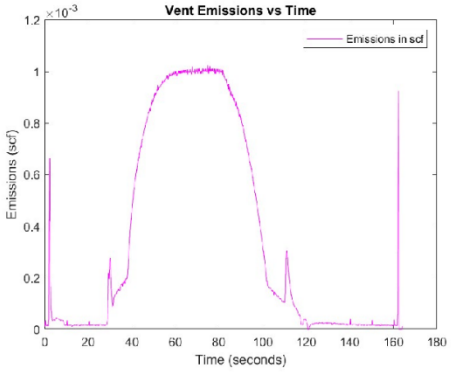
GTI ENERGY


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
1
2
3
4
5
6
7
8
9
10
0
10
20
30
40
50
60
70
80
90

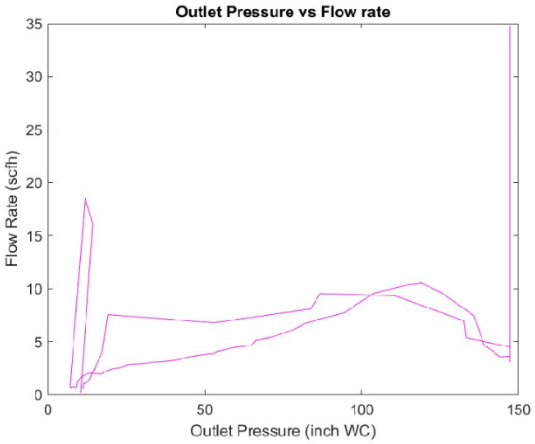

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
12
13
14
15
16
17
18
19
20

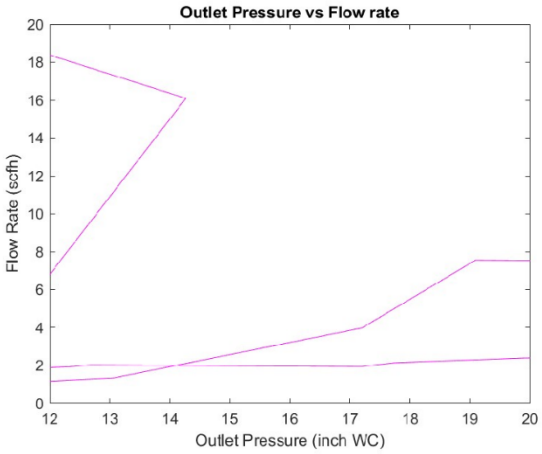
- 222489-014 DT2
  The volume of total emissions in 164.32 seconds is 0.5675 scf.
  The average flow rate of emissions at 18 inches WC is 1.86 scfh.





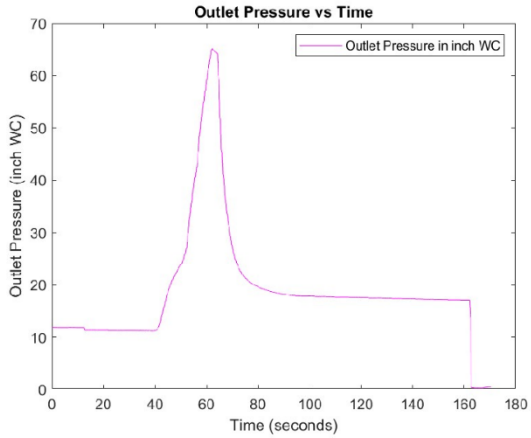
GTI ENERGY

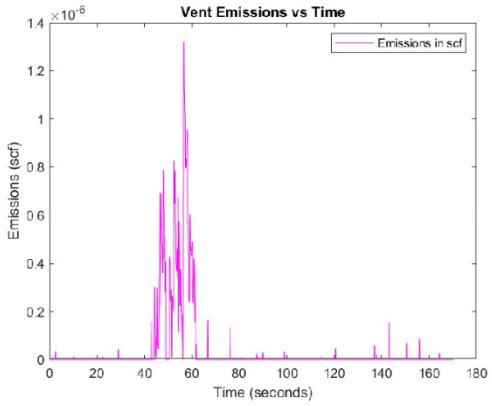

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
5
10
15
20
25
30
35
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
2
4
6
8
10
12
14
16
18
20
12
13
14
15
16
17
18
19
20

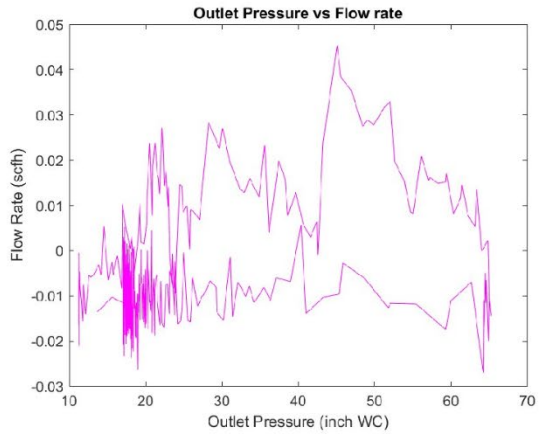
GTI ENERGY

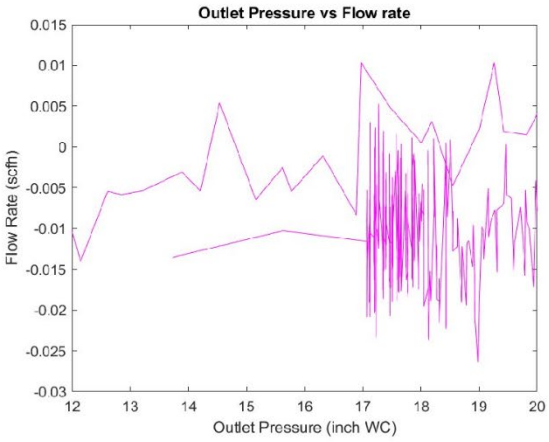
- 222489-014 LD
  The volume of total emissions in 170.32 seconds is 0.0001 scf.
  The average flow rate of emissions at 18 inches WC is -0.01 scfh.





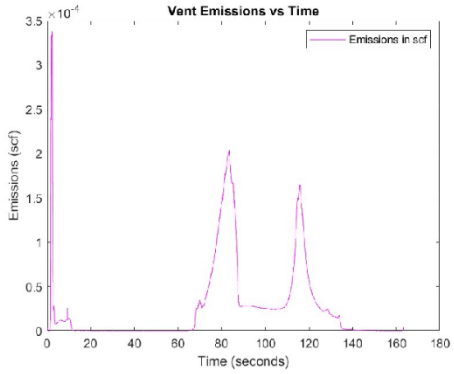
GTI ENERGY

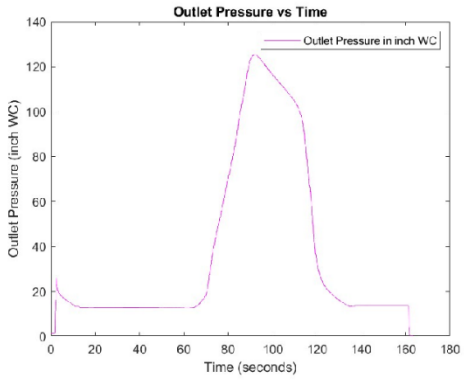

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0.05
0.04
0.03
0.02
0.01
0
-0.01
-0.02
-0.03
10
20
30
40
50
60
70


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0.015
0.01
0.005
0
-0.005
-0.01
-0.015
-0.02
-0.025
-0.03
12
13
14
15
16
17
18
19
20

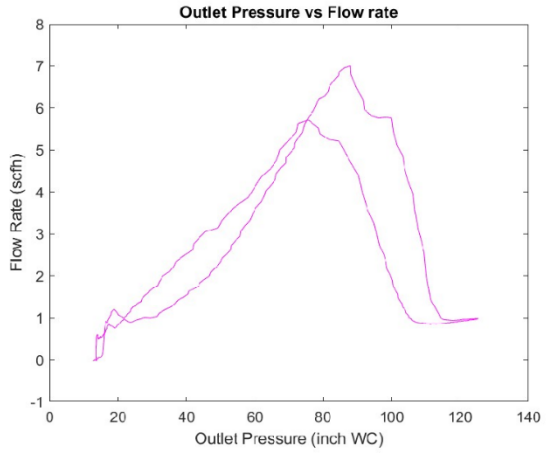
GTI ENERGY

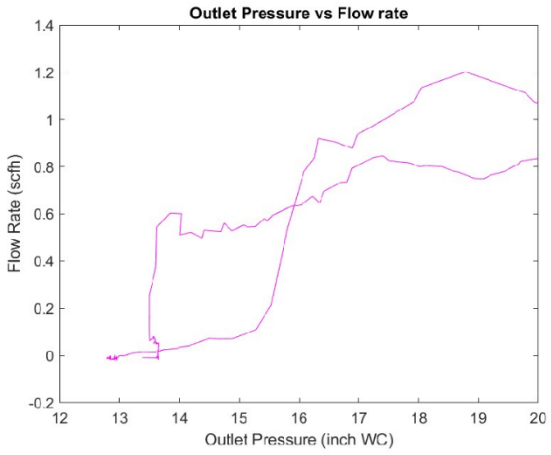
- 222489-015
  The volume of total emissions in 163.39 seconds is 0.0405 scf.
  The average flow rate of emissions at 18 inches WC is 0.64 scfh.



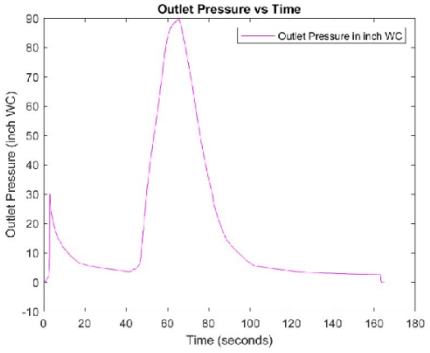


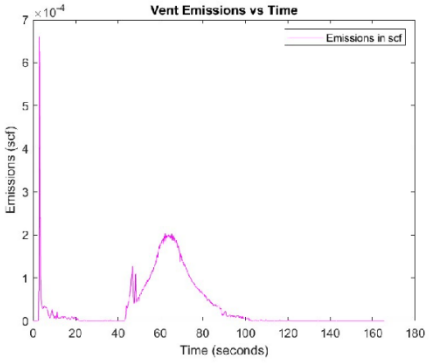
GTI ENERGY


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
8
7
6
5
4
3
2
1
0
-1
0
20
40
60
80
100
120
140

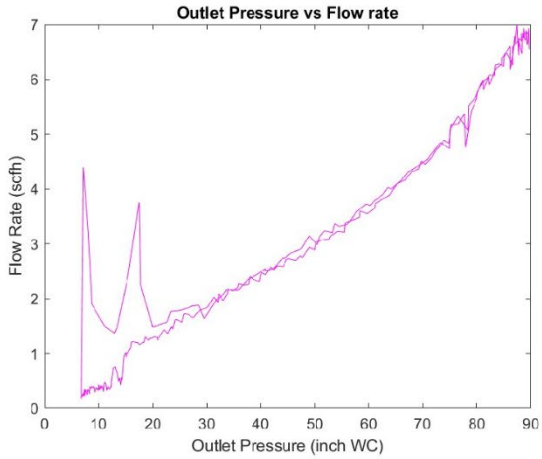

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
12
13
14
15
16
17
18
19
20

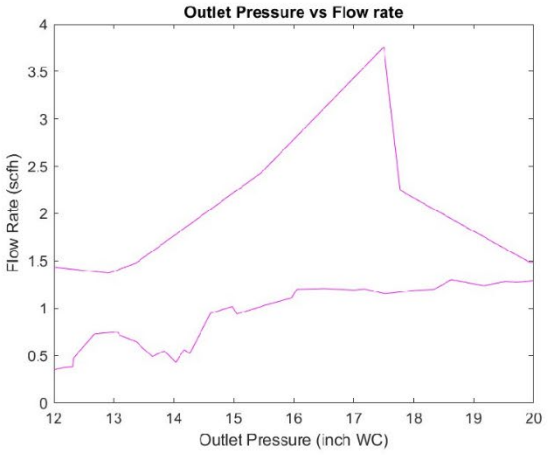
- 222489-015 DT1
  The volume of total emissions in 165.29 seconds is 0.0517 scf.
  The average flow rate of emissions at 18 inches WC is 1.48 scfh.



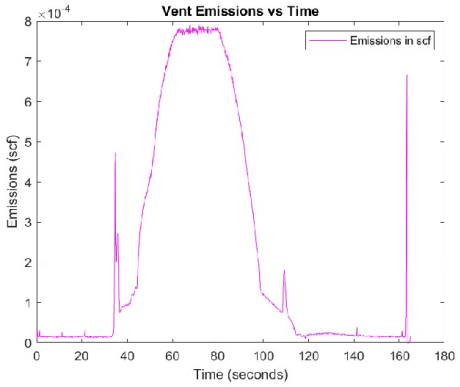


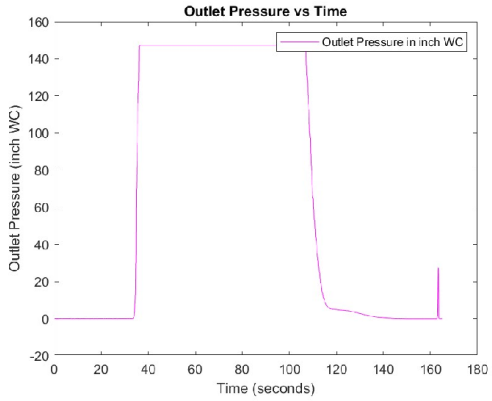
GTI ENERGY


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
1
2
3
4
5
6
7
0
10
20
30
40
50
60
70
80
90

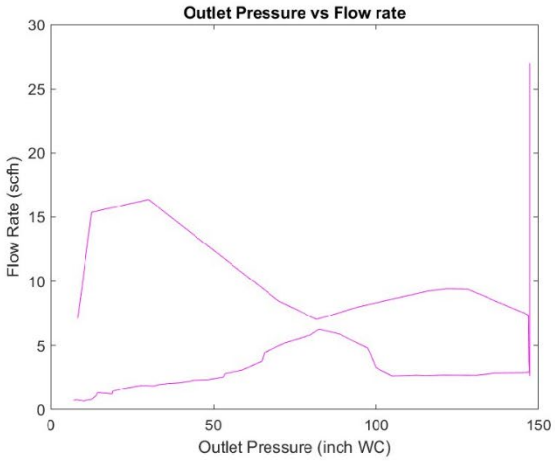

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
0.5
1
1.5
2
2.5
3
3.5
4
12
13
14
15
16
17
18
19
20

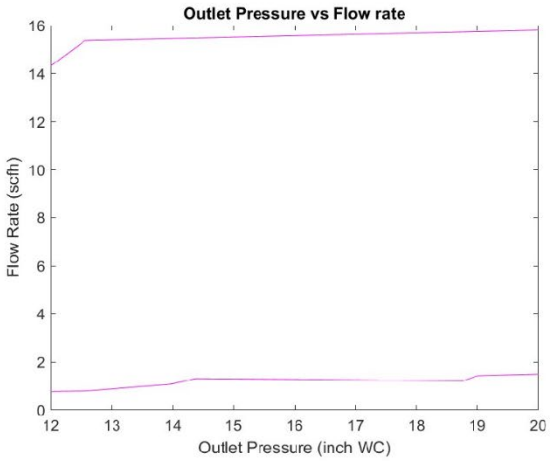
- 222489-015 DT2
  The volume of total emissions in 165.18 seconds is 0.3631 scf.
  The average flow rate of emissions at 18 inches WC is 1.21 scfh.





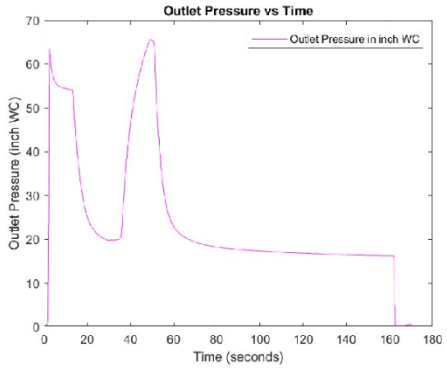
GTI ENERGY

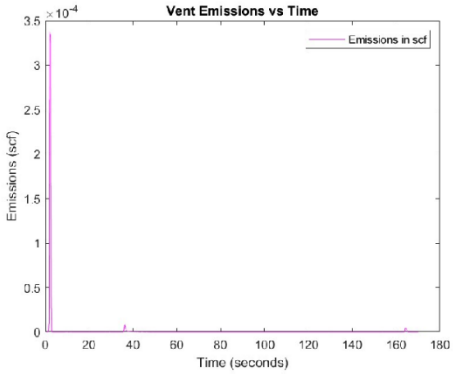

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
5
10
15
20
25
30
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
2
4
6
8
10
12
14
16
12
13
14
15
16
17
18
19
20

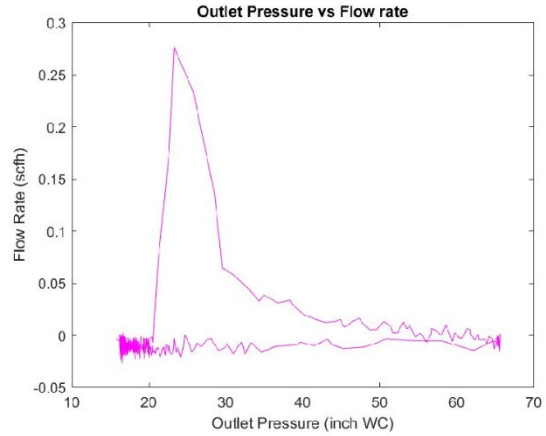
GTI ENERGY

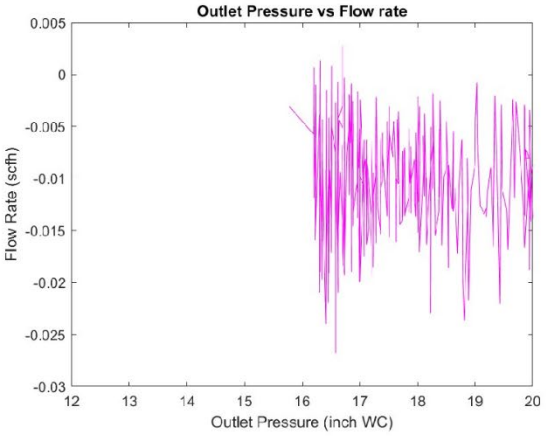
- 222489-015 LD
  The volume of total emissions in 170.27 seconds is 0.0024 scf.
  The average flow rate of emissions at 18 inches WC is -0.01 scfh.





GTI ENERGY


Outlet Pressure vs Flow rate
Flow Rate (scfh)
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
10
20
30
40
50
60
70
Outlet Pressure (inch WC)


Outlet Pressure vs Flow rate
Flow Rate (scfh)
0.005
0
-0.005
-0.01
-0.015
-0.02
-0.025
-0.03
12
13
14
15
16
17
18
19
20
Outlet Pressure (inch WC)

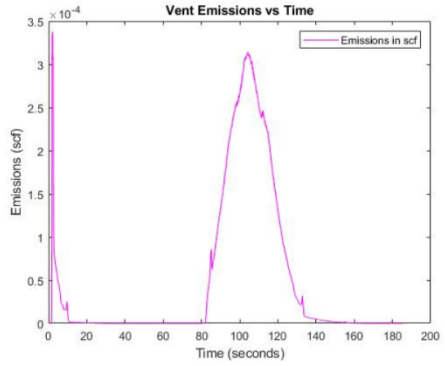
GTI ENERGY

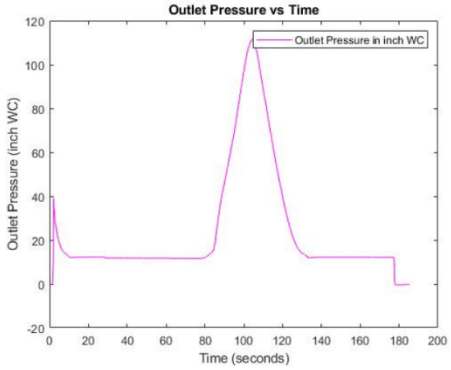
7″ WC Outlet, 60-psig Inlet

- 222489-013

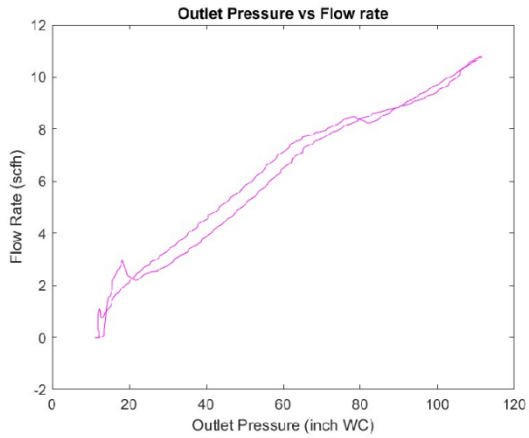
The volume of total emissions in 185.39 seconds is 0.0873 scf.

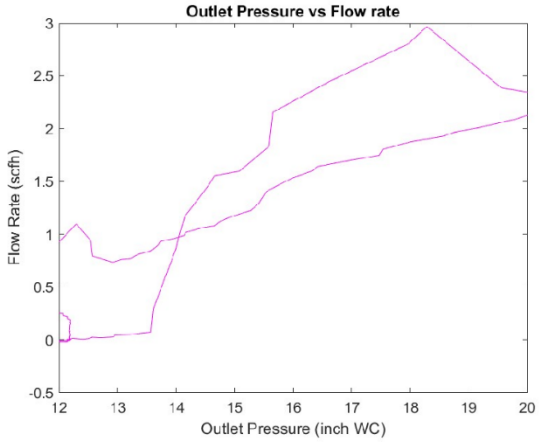
The average flow rate of emissions at 18 inches WC is 1.99 scfh.





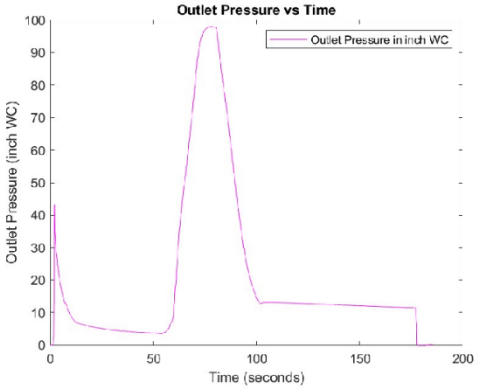
GTI ENERGY

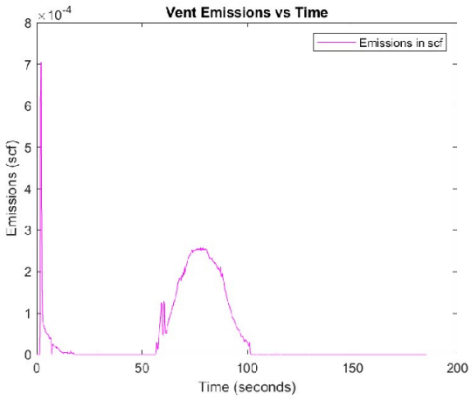

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
12
10
8
6
4
2
0
-2
0
20
40
60
80
100
120


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
3
2.5
2
1.5
1
0.5
0
-0.5
12
13
14
15
16
17
18
19
20

GTI ENERGY

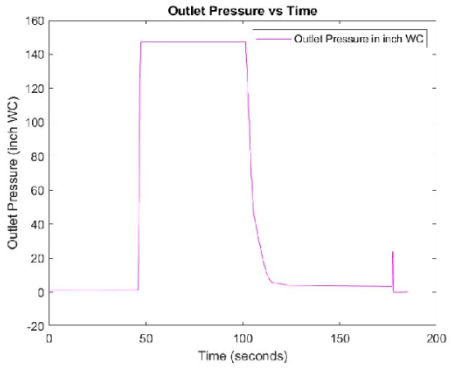
- 222489-013 DT1
  The volume of total emissions in 185.36 seconds is 0.0723 scf.
  The average flow rate of emissions at 18 inches WC is 2.12 scfh.

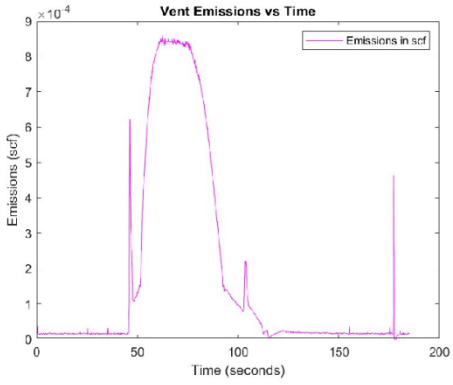




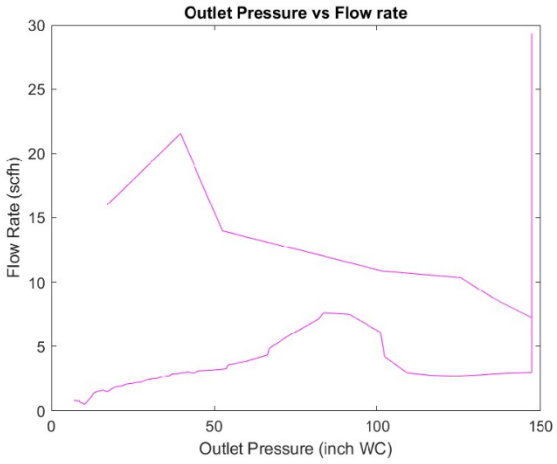
GTI ENERGY

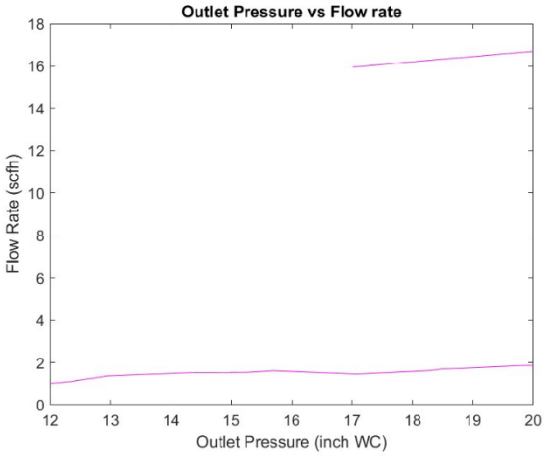
- 222489-013 DT2
  The volume of total emissions in 185.31 seconds is 0.3187 scf.
  The average flow rate of emissions at 18 inches WC is 5.18 scfh.





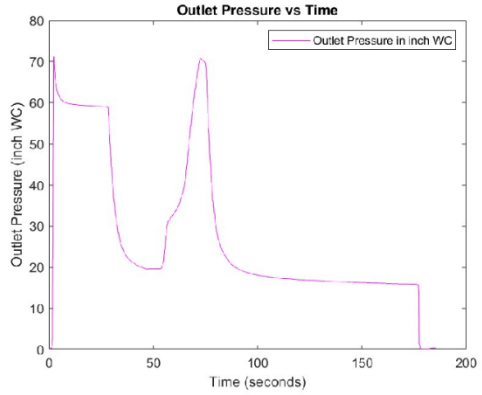
GTI ENERGY

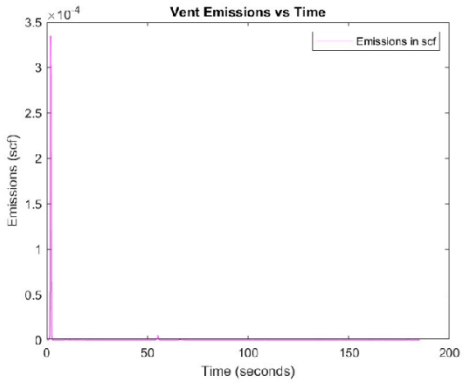

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
5
10
15
20
25
30
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
2
4
6
8
10
12
14
16
18
12
13
14
15
16
17
18
19
20

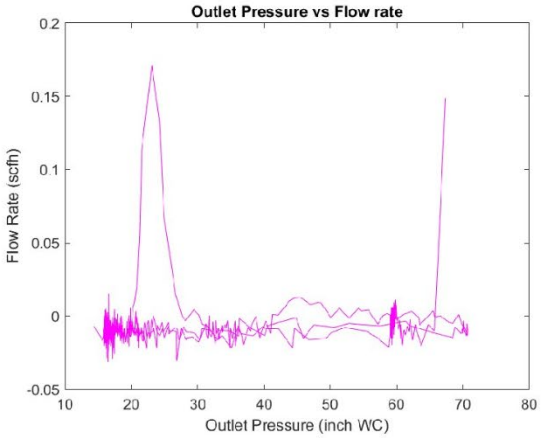
GTI ENERGY

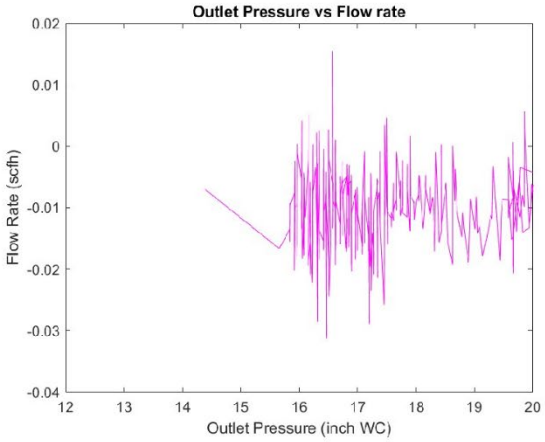
- 222489-013 LD
  The volume of total emissions in 185.35 seconds is 0.0022 scf.
  The average flow rate of emissions at 18 inches WC is -0.01 scfh.





GTI ENERGY


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0.2
0.15
0.1
0.05
0
-0.05
10
20
30
40
50
60
70
80

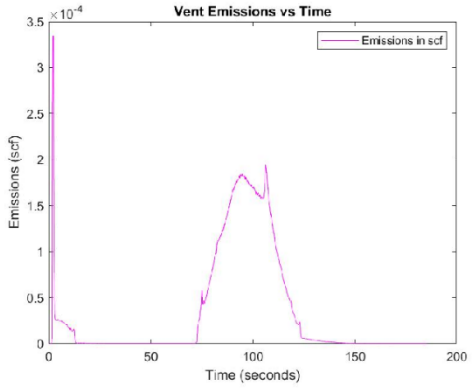

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0.02
0.01
0
-0.01
-0.02
-0.03
-0.04
12
13
14
15
16
17
18
19
20

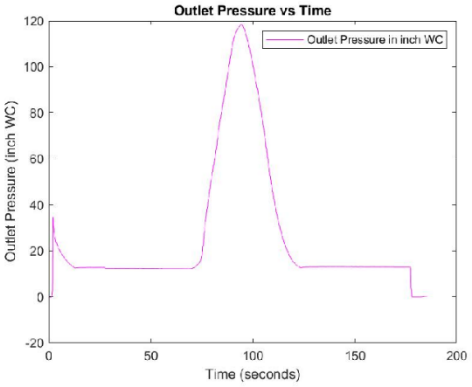
GTI ENERGY

- 222489-014

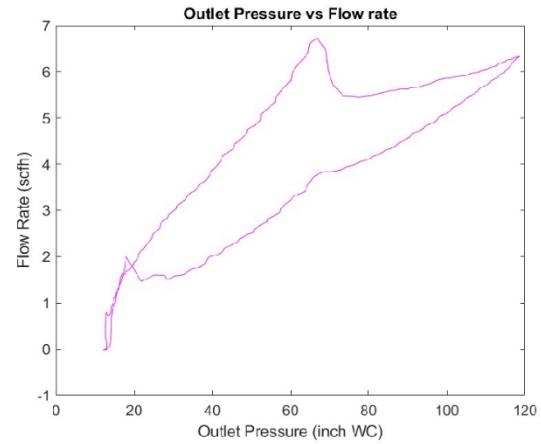
The volume of total emissions in 185.39 seconds is 0.0604 scf.

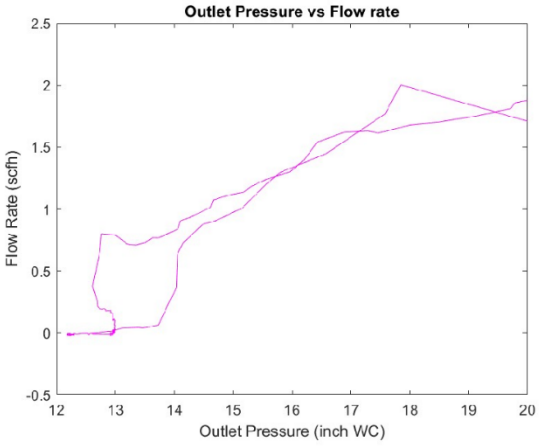
The average flow rate of emissions at 18 inches WC is 1.27 scfh.





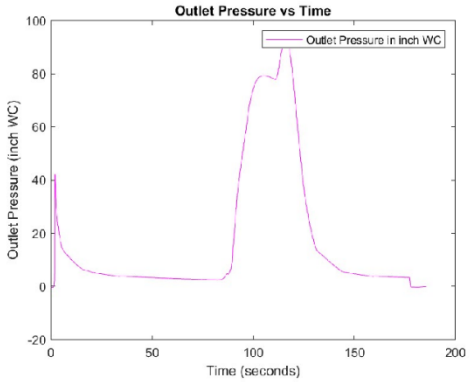
GTI ENERGY

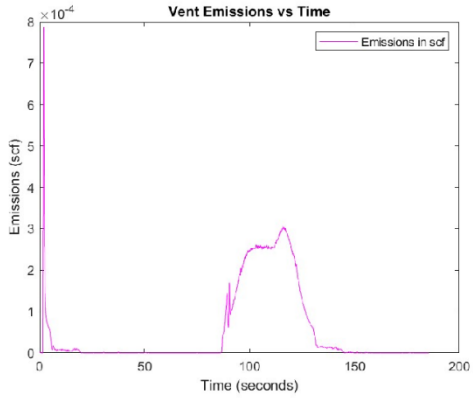

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
7
6
5
4
3
2
1
0
-1
0
20
40
60
80
100
120


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
2.5
2
1.5
1
0.5
0
-0.5
12
13
14
15
16
17
18
19
20

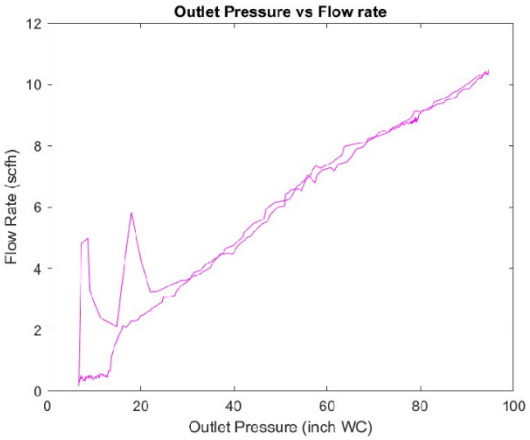
GTI ENERGY

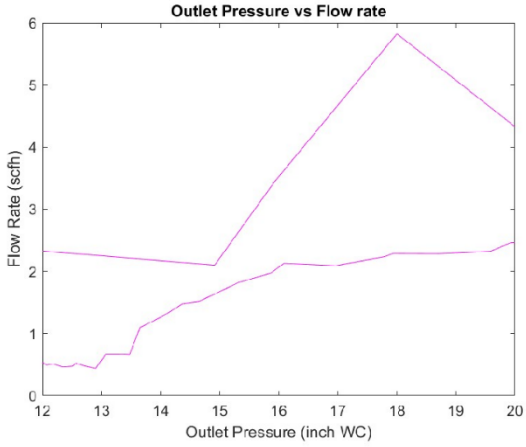
- 222489-014 DT1
  The volume of total emissions in 185.47 seconds is 0.0933 scf.
  The average flow rate of emissions at 18 inches WC is 2.94 scfh.





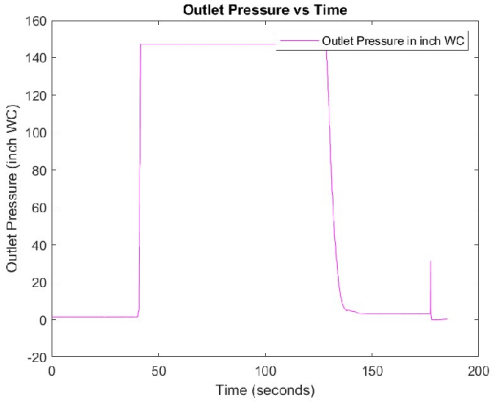
GTI ENERGY

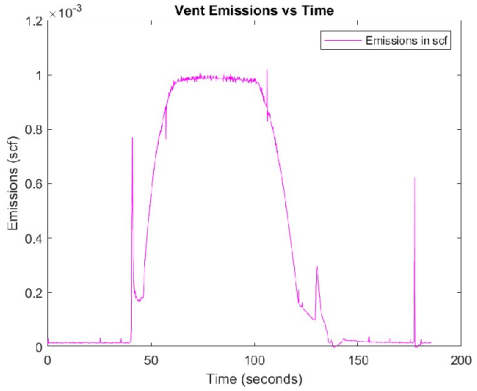

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
2
4
6
8
10
12
0
20
40
60
80
100


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
1
2
3
4
5
6
12
13
14
15
16
17
18
19
20

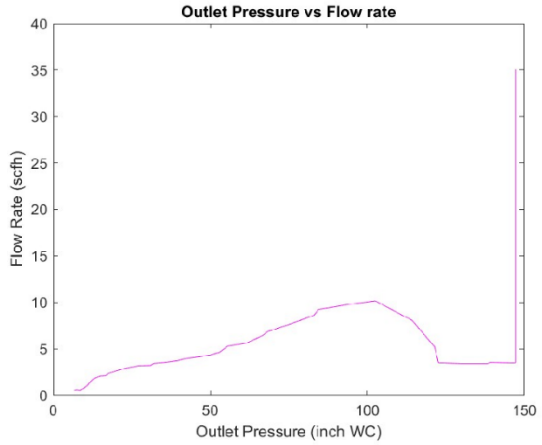
GTI ENERGY

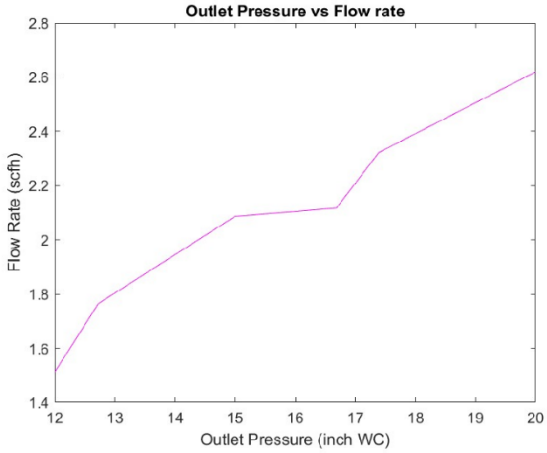
- 222489-014 DT2
  The volume of total emissions in 185.37 seconds is 0.6554 scf.
  The average flow rate of emissions at 18 inches WC is 2.32 scfh.



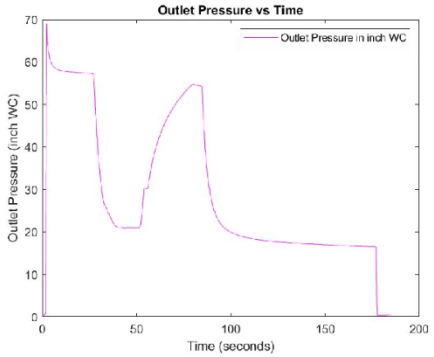


GTI ENERGY

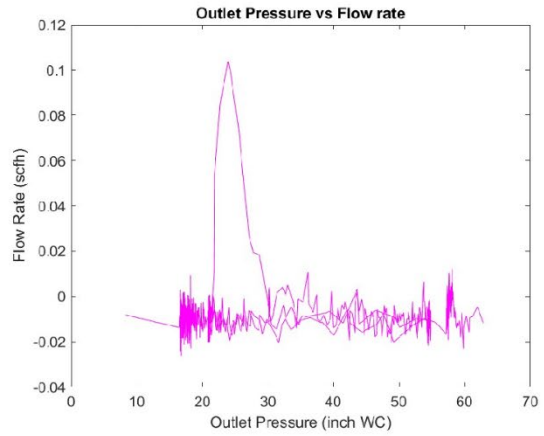

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
5
10
15
20
25
30
35
40
0
50
100
150

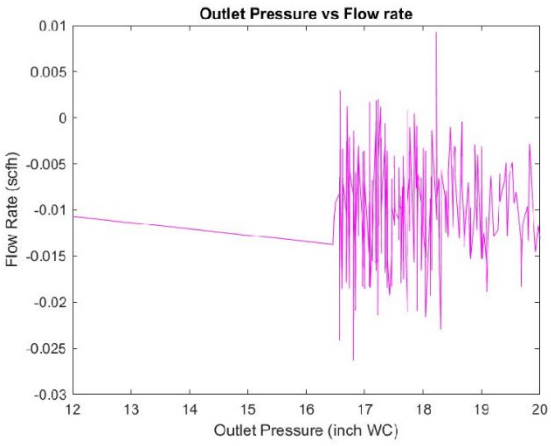

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
1.4
1.6
1.8
2
2.2
2.4
2.6
2.8
12
13
14
15
16
17
18
19
20

- 222489-014 LD
  The volume of total emissions in 185.32 seconds is 0.0022 scf.
  The average flow rate of emissions at 18 inches WC is -0.01 scfh.



GTI ENERGY


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0.12
0.1
0.08
0.06
0.04
0.02
0
-0.02
-0.04
0
10
20
30
40
50
60
70

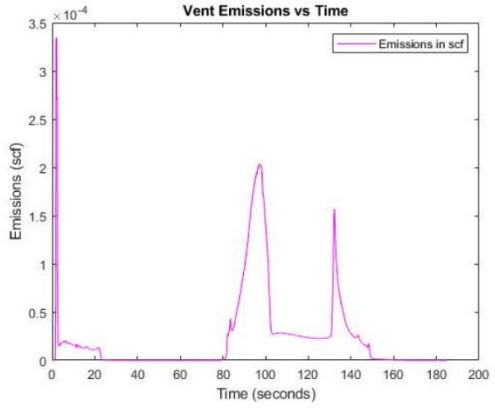

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0.01
0.005
0
-0.005
-0.01
-0.015
-0.02
-0.025
-0.03
12
13
14
15
16
17
18
19
20

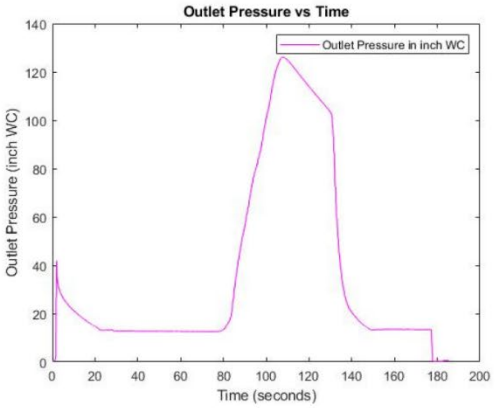
GTI ENERGY

- 222489-015

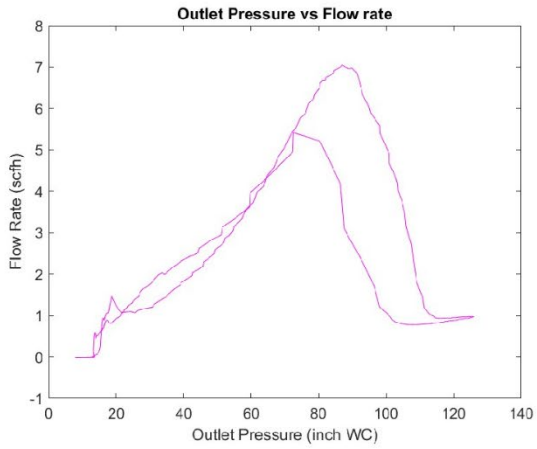
The volume of total emissions in 185.39 seconds is 0.0415 scf.

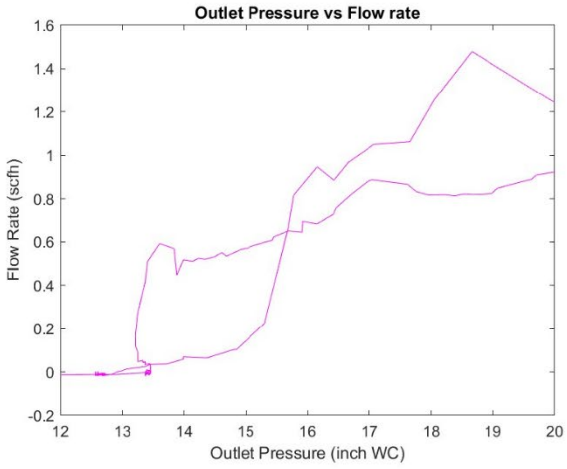
The average flow rate of emissions at 18 inches WC is 0.70 scfh.



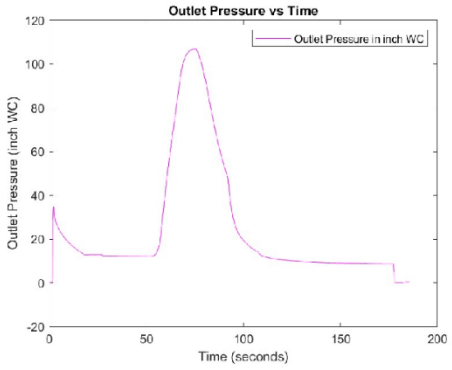


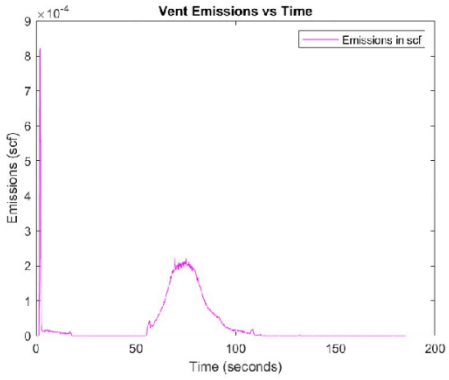
GTI ENERGY


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
8
7
6
5
4
3
2
1
0
-1
0
20
40
60
80
100
120
140

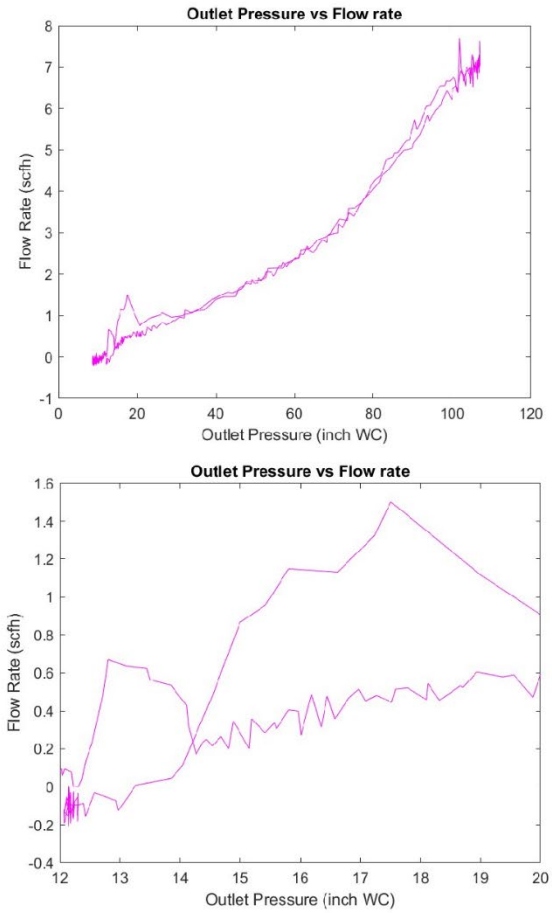

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
12
13
14
15
16
17
18
19
20

- 222489-015 DT1
  The volume of total emissions in 185.34 seconds is 0.0510 scf.
  The average flow rate of emissions at 18 inches WC is 0.52 scfh.



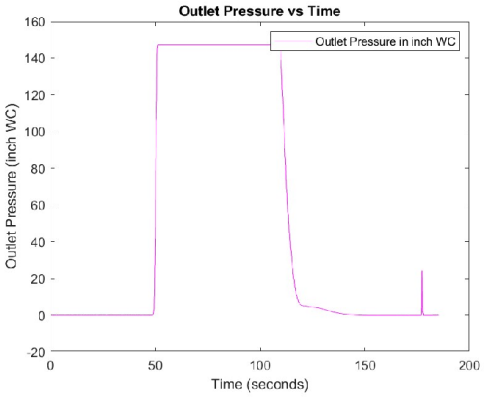


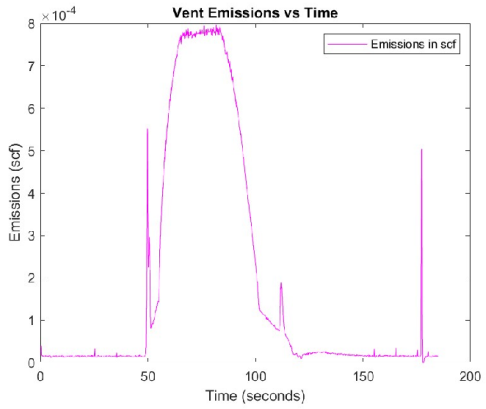
GTI ENERGY


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)

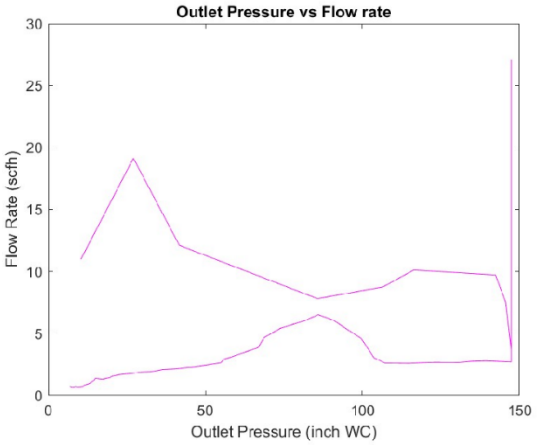
GTI ENERGY

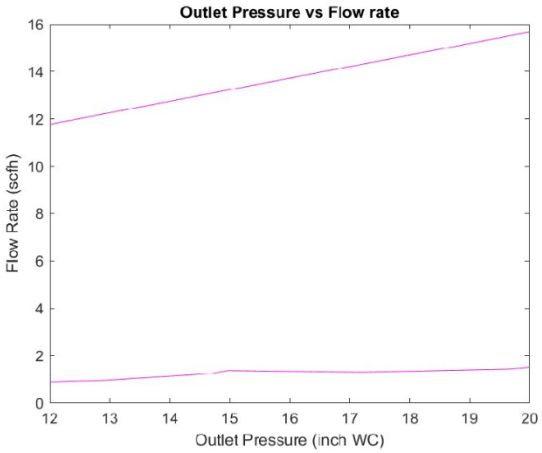
- 222489-015 DT2
  The volume of total emissions in 185.32 seconds is 0.3276 scf.
  The average flow rate of emissions at 18 inches WC is 1.31 scfh.





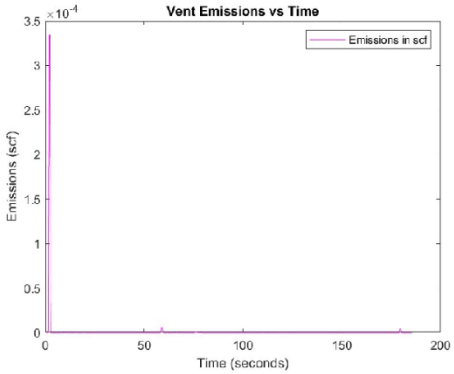
GTI ENERGY

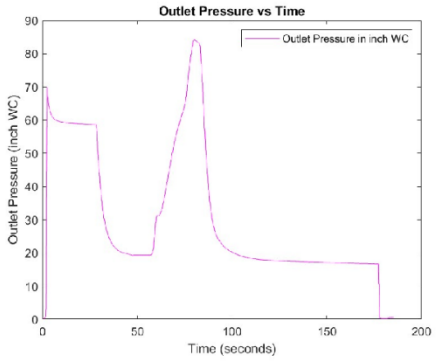

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
5
10
15
20
25
30
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
2
4
6
8
10
12
14
16
12
13
14
15
16
17
18
19
20

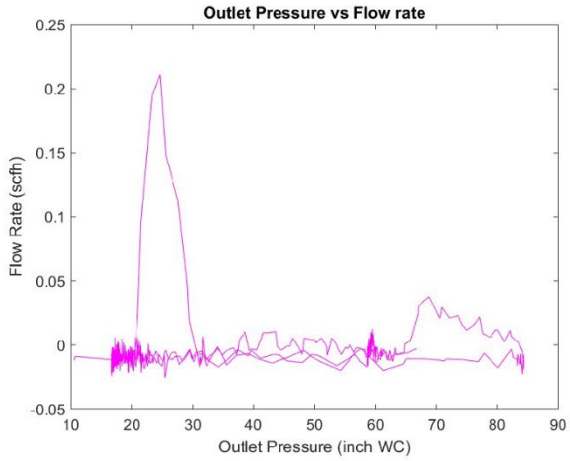
GTI ENERGY

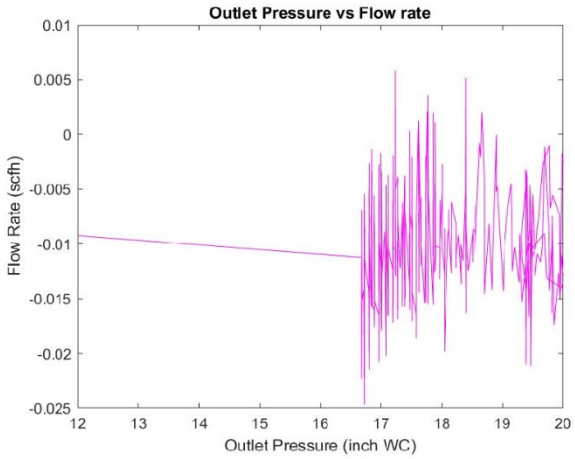
- 222489-015 LD
  The volume of total emissions in 185.49 seconds is 0.0023 scf.
  The average flow rate of emissions at 18 inches WC is -0.01 scfh.





GTI ENERGY


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0.25
0.2
0.15
0.1
0.05
0
-0.05
10
20
30
40
50
60
70
80
90


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0.01
0.005
0
-0.005
-0.01
-0.015
-0.02
-0.025
12
13
14
15
16
17
18
19
20

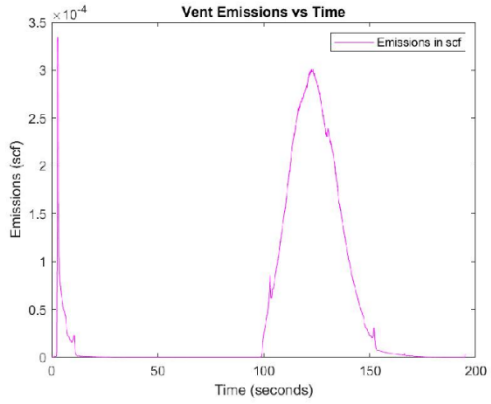
GTI ENERGY

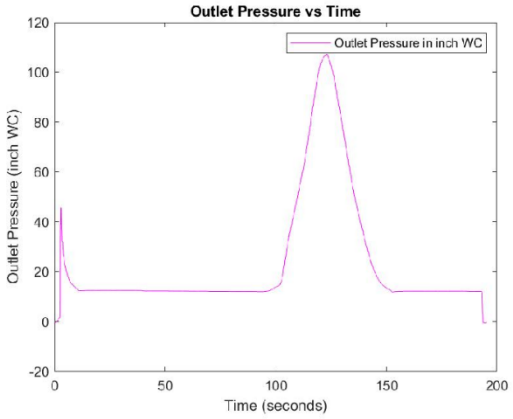
7″ WC Outlet, 100-psig Inlet

- 222489-013

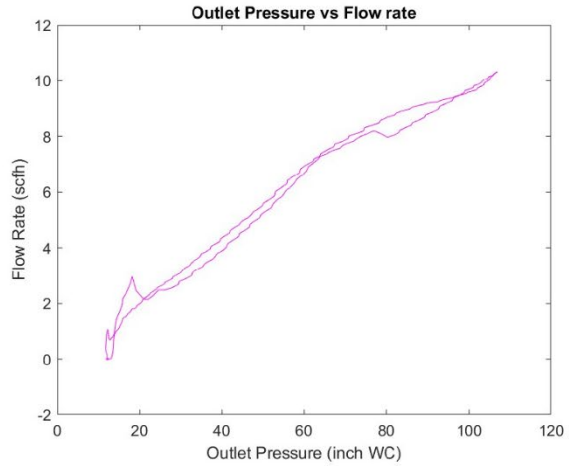
The volume of total emissions in 195.29 seconds is 0.0861 scf.

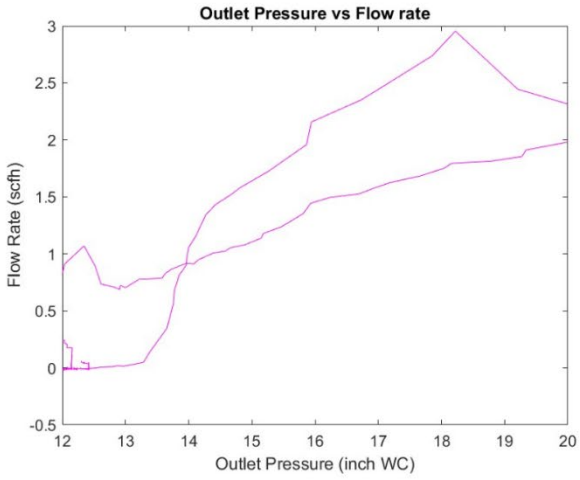
The average flow rate of emissions at 18 inches WC is 1.89 scfh.





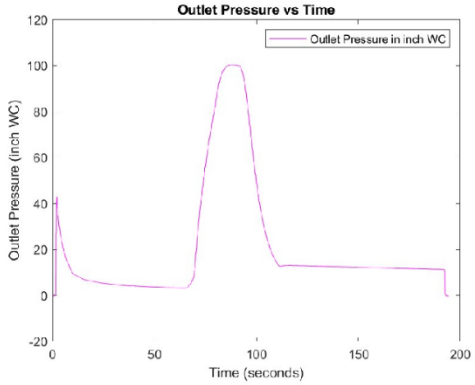
GTI ENERGY

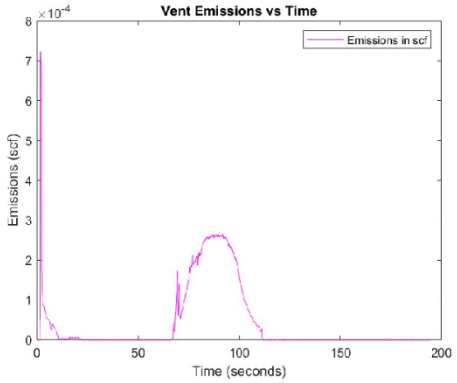

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
12
10
8
6
4
2
0
-2
0
20
40
60
80
100
120


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
3
2.5
2
1.5
1
0.5
0
-0.5
12
13
14
15
16
17
18
19
20

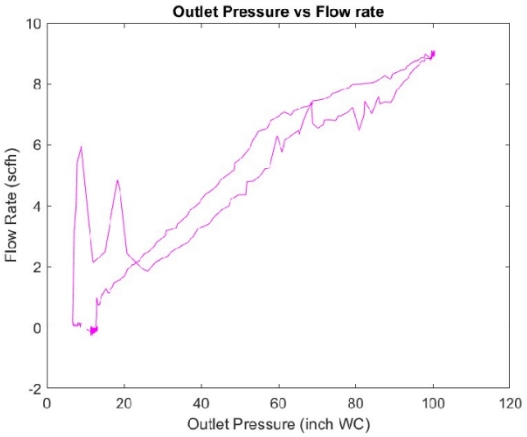
GTI ENERGY

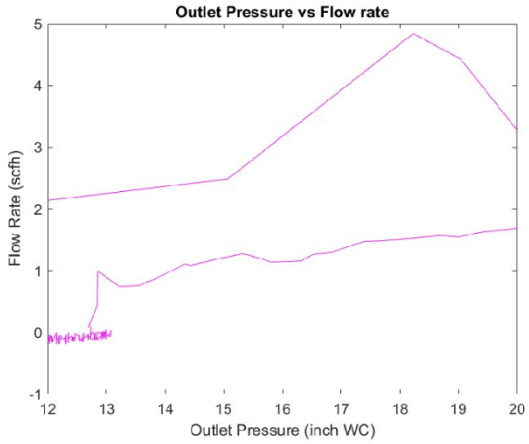
- 222489-013 DT1
  The volume of total emissions in 194.44 seconds is 0.0781 scf.
  The average flow rate of emissions at 18 inches WC is 1.95 scfh.





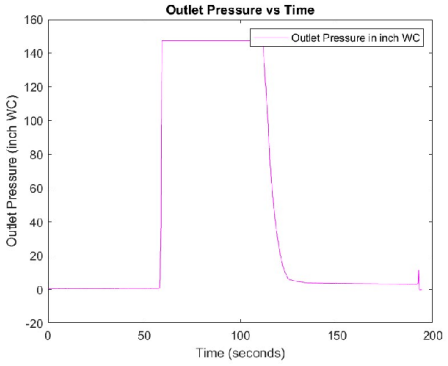
GTI ENERGY

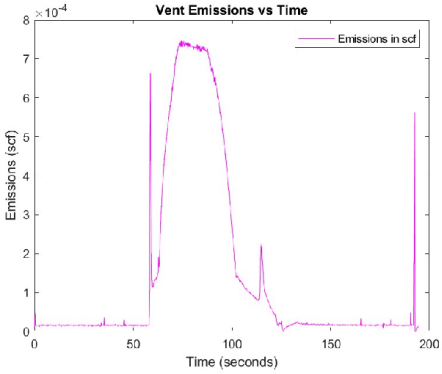

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
10
8
6
4
2
0
-2
0
20
40
60
80
100
120


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
5
4
3
2
1
0
-1
12
13
14
15
16
17
18
19
20

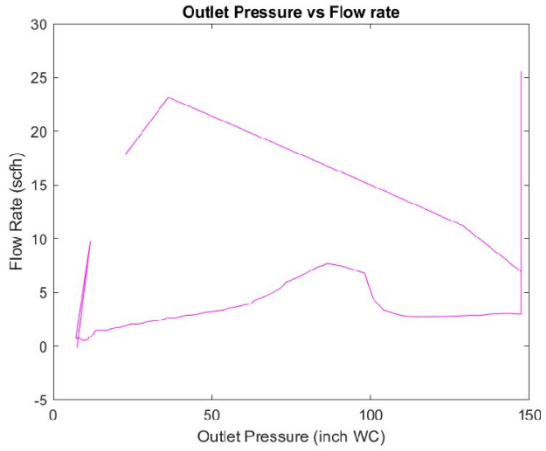
GTI ENERGY

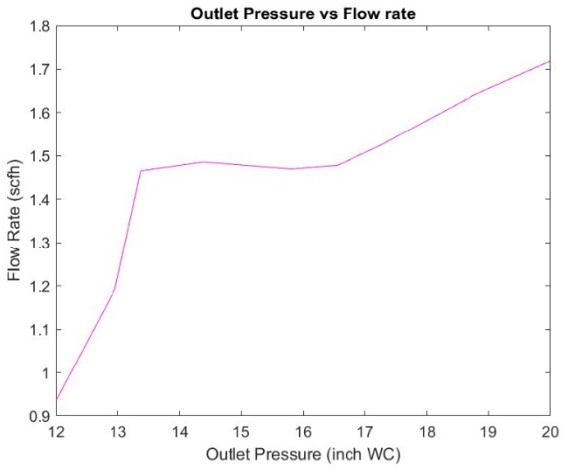
- 222489-013 DT2
  The volume of total emissions in 194.39 seconds is 0.2720 scf.
  The average flow rate of emissions at 18 inches WC is 1.58 scfh.





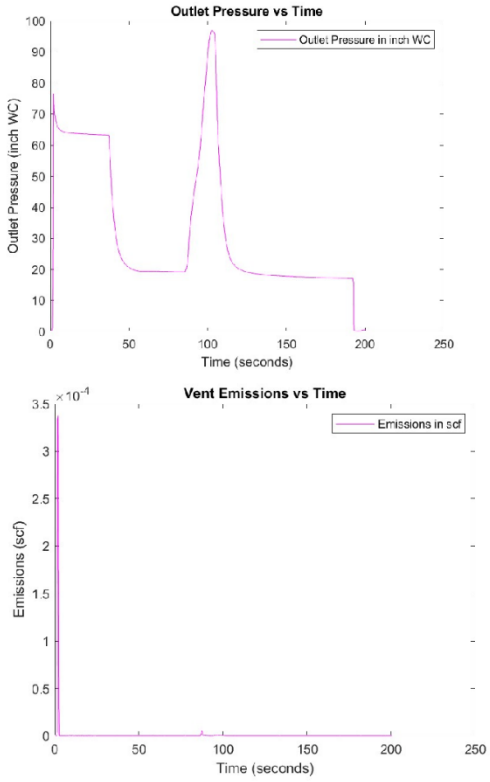
GTI ENERGY


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
30
25
20
15
10
5
0
-5
0
50
100
150

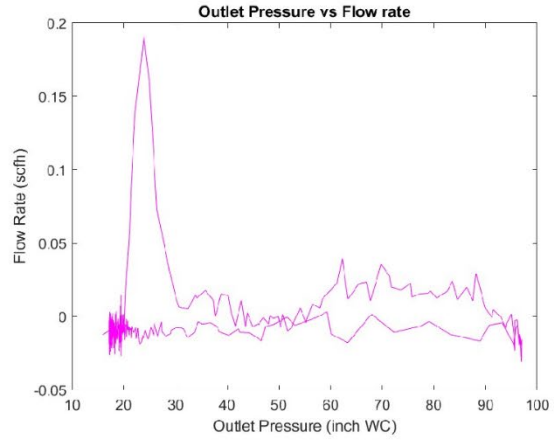

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
12
13
14
15
16
17
18
19
20

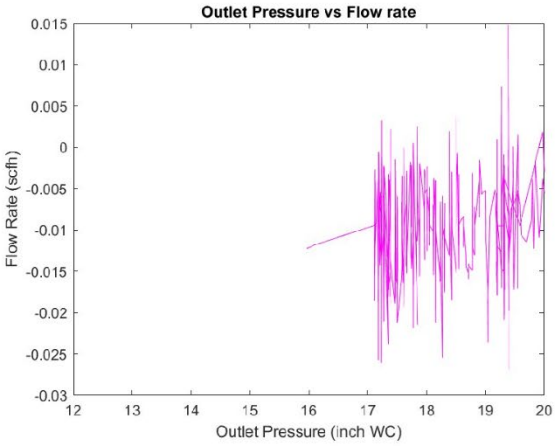
GTI ENERGY

- 222489-013 LD
  The volume of total emissions in 200.48 seconds is 0.0022 scf.
  The average flow rate of emissions at 18 inches WC is -0.01 scfh.



GTI ENERGY


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0.2
0.15
0.1
0.05
0
-0.05
10
20
30
40
50
60
70
80
90
100

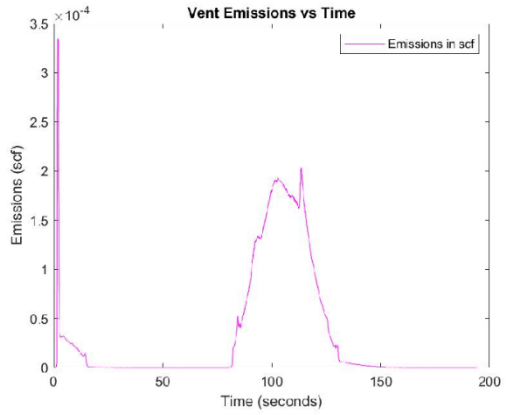

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0.015
0.01
0.005
0
-0.005
-0.01
-0.015
-0.02
-0.025
-0.03
12
13
14
15
16
17
18
19
20

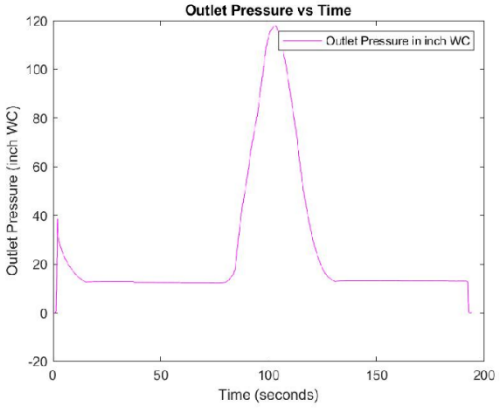
GTI ENERGY

- 222489-014

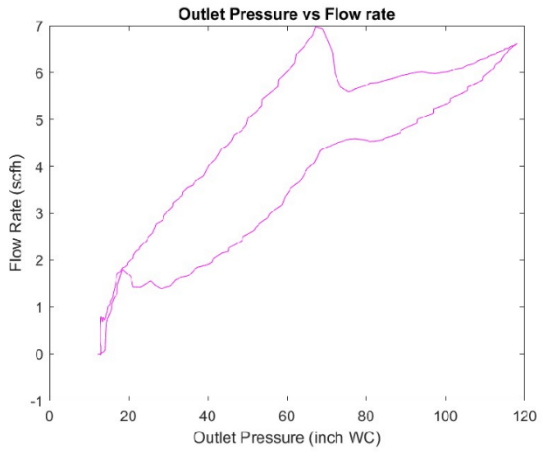
The volume of total emissions in 194.37 seconds is 0.0598 scf.

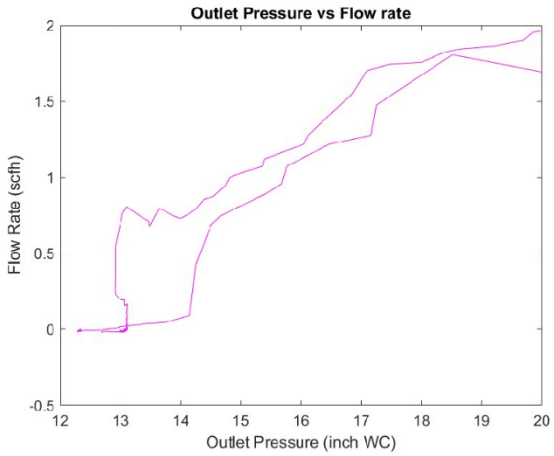
The average flow rate of emissions at 18 inches WC is 1.28 scfh.





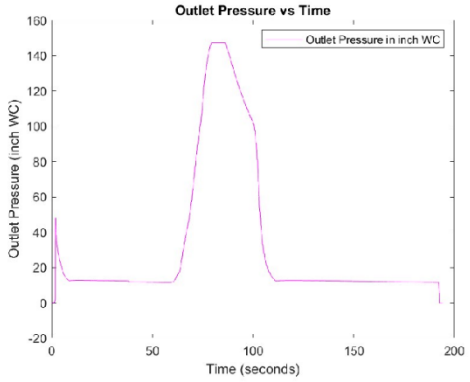
GTI ENERGY

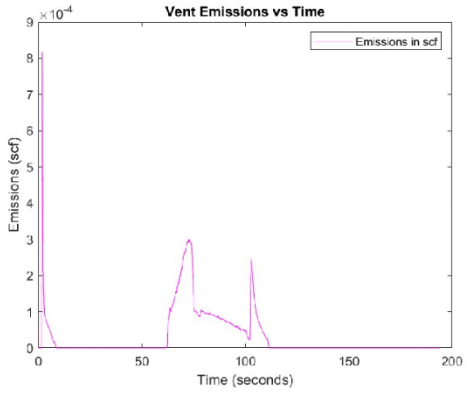

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
7
6
5
4
3
2
1
0
-1
0
20
40
60
80
100
120


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
2
1.5
1
0.5
0
-0.5
12
13
14
15
16
17
18
19
20

GTI ENERGY

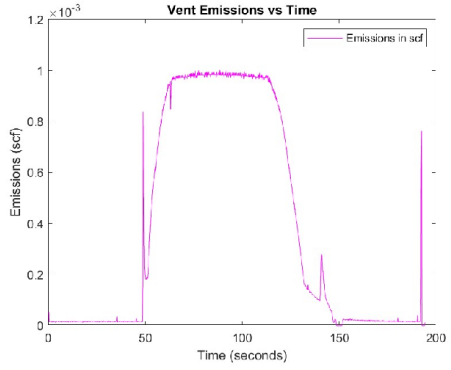
- 222489-014 DT1
  The volume of total emissions in 194.36 seconds is 0.0579 scf.
  The average flow rate of emissions at 18 inches WC is 2.29 scfh.

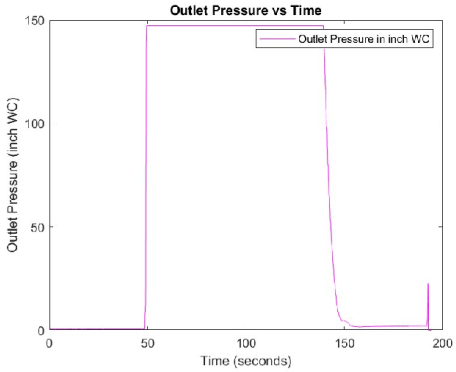




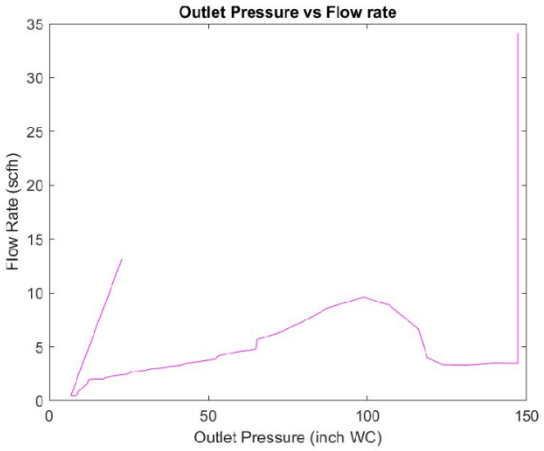
GTI ENERGY

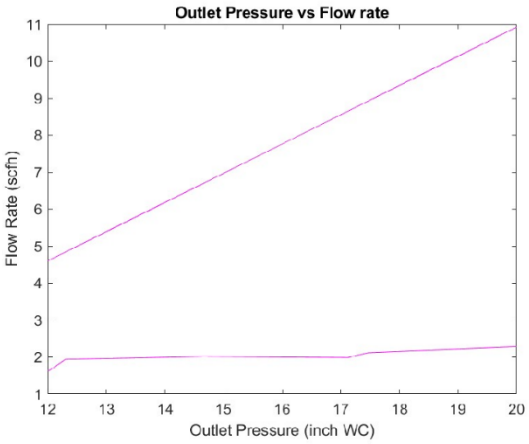
- 222489-014 DT2
  The volume of total emissions in 194.34 seconds is 0.7115 scf.
  The average flow rate of emissions at 18 inches WC is 2.05 scfh.





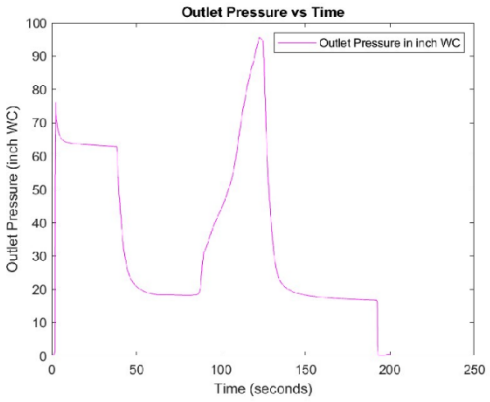
GTI ENERGY

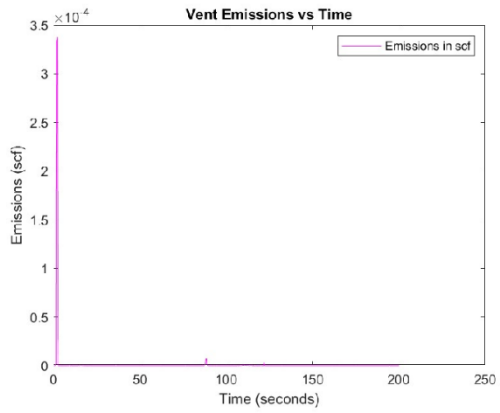

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
5
10
15
20
25
30
35
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20

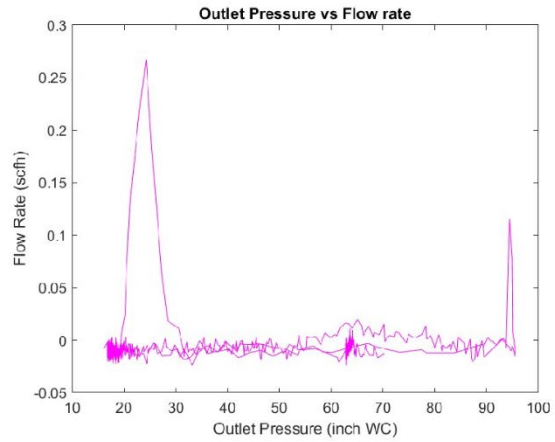
GTI ENERGY

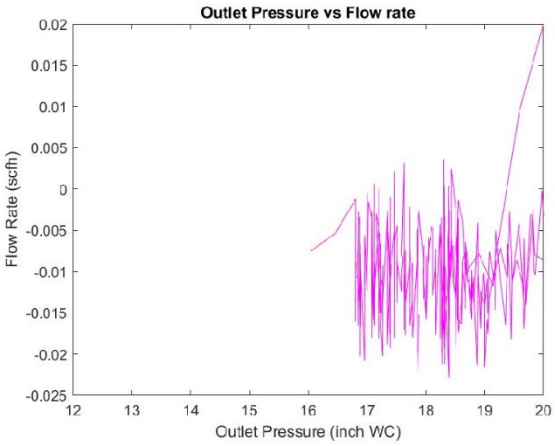
- 222489-014 LD
  The volume of total emissions in 200.39 seconds is 0.0023 scf.
  The average flow rate of emissions at 18 inches WC is -0.01 scfh.





GTI ENERGY


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
10
20
30
40
50
60
70
80
90
100

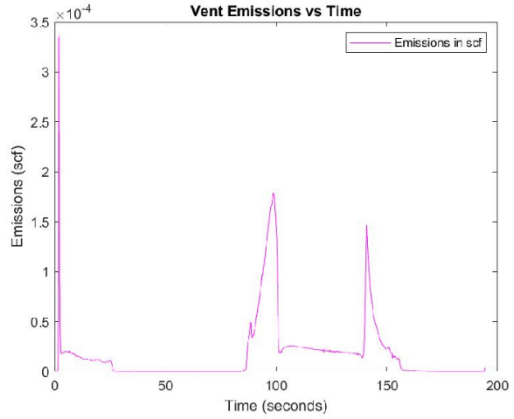

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0.02
0.015
0.01
0.005
0
-0.005
-0.01
-0.015
-0.02
-0.025
12
13
14
15
16
17
18
19
20

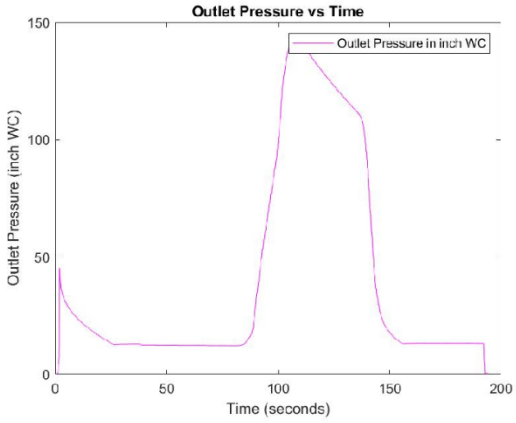
GTI ENERGY

- 222489-015

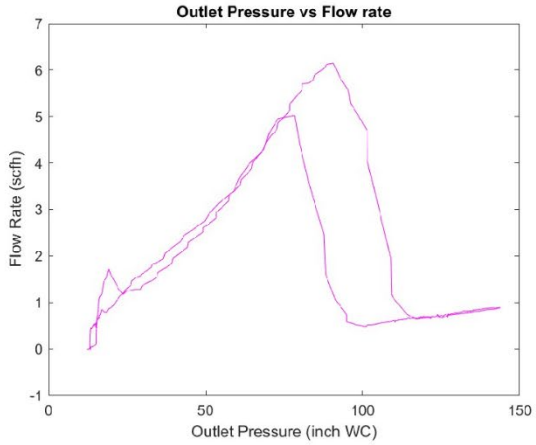
The volume of total emissions in 194.36 seconds is 0.0332 scf.

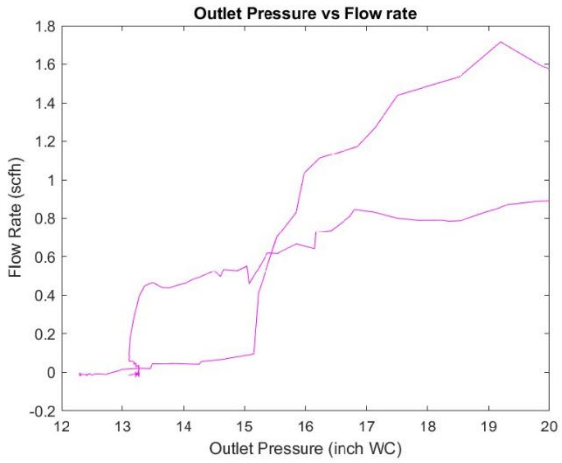
The average flow rate of emissions at 18 inches WC is 0.65 scfh.





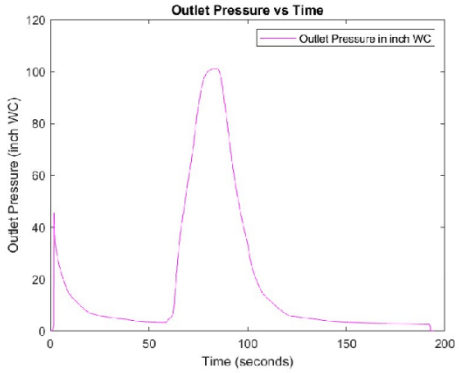
GTI ENERGY

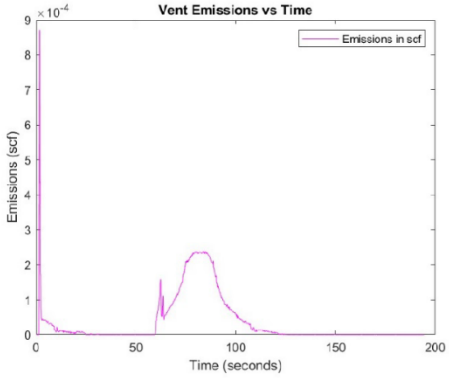

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
7
6
5
4
3
2
1
0
-1
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
12
13
14
15
16
17
18
19
20

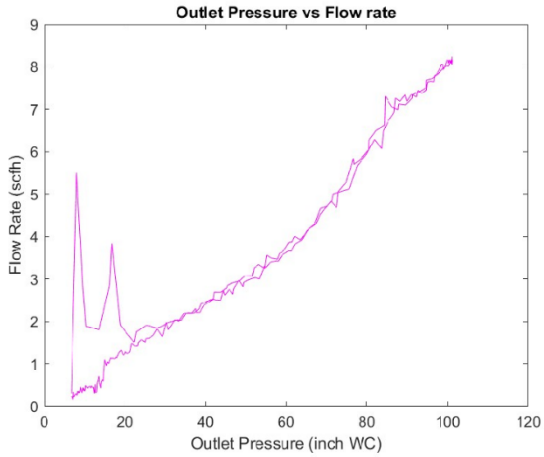
GTI ENERGY

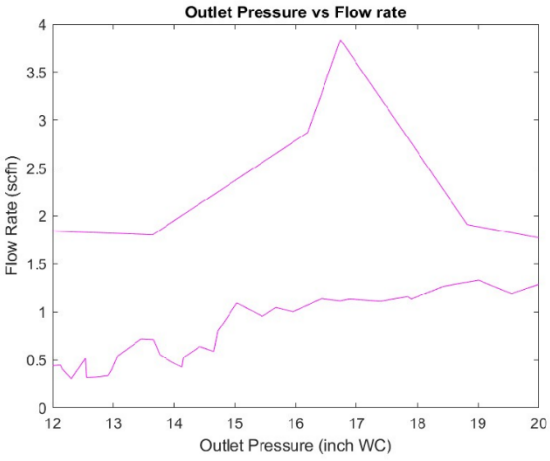
- 222489-015 DT1
  The volume of total emissions in 194.43 seconds is 0.0674 scf.
  The average flow rate of emissions at 18 inches WC is 1.22 scfh.





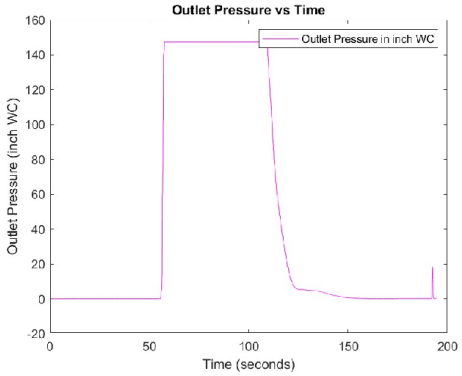
GTI ENERGY

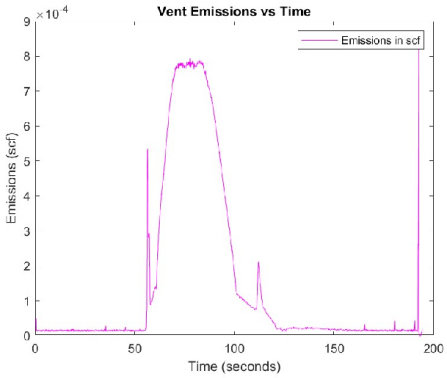

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
1
2
3
4
5
6
7
8
9
0
20
40
60
80
100
120


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
0.5
1
1.5
2
2.5
3
3.5
4
12
13
14
15
16
17
18
19
20

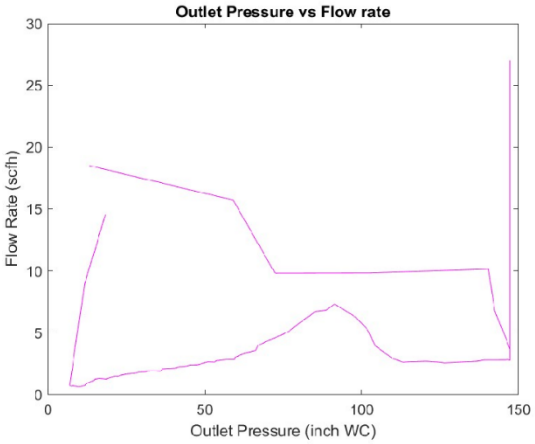
GTI ENERGY

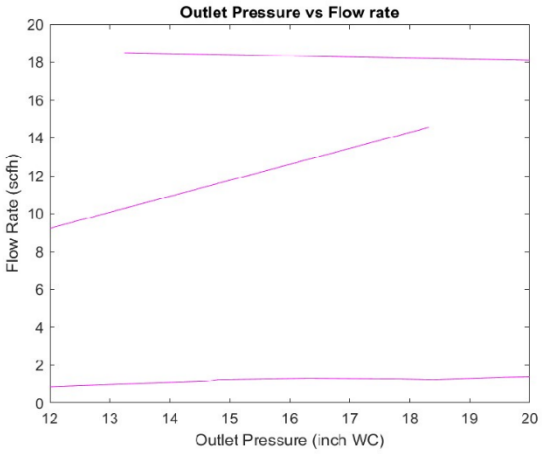
- 222489-015 DT2
  The volume of total emissions in 194.44 seconds is 0.2785 scf.
  The average flow rate of emissions at 18 inches WC is 3.92 scfh.





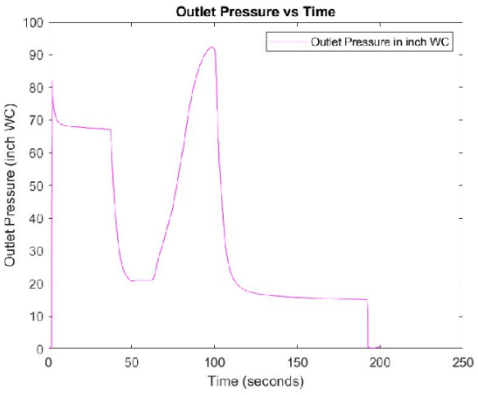
GTI ENERGY

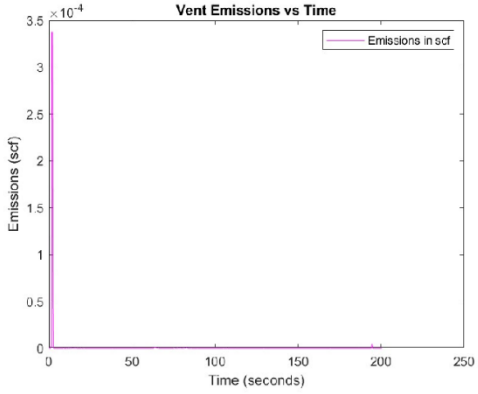

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
5
10
15
20
25
30
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
2
4
6
8
10
12
14
16
18
20
12
13
14
15
16
17
18
19
20

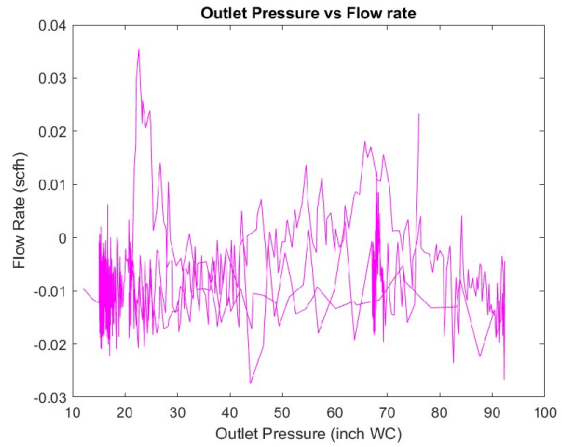
GTI ENERGY

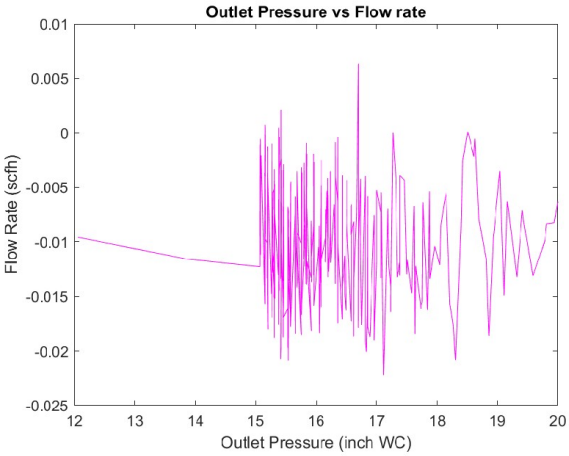
- 222489-015 LD
  The volume of total emissions in 200.50 seconds is 0.0022 scf.
  The average flow rate of emissions at 18 inches WC is -0.01 scfh.





GTI ENERGY

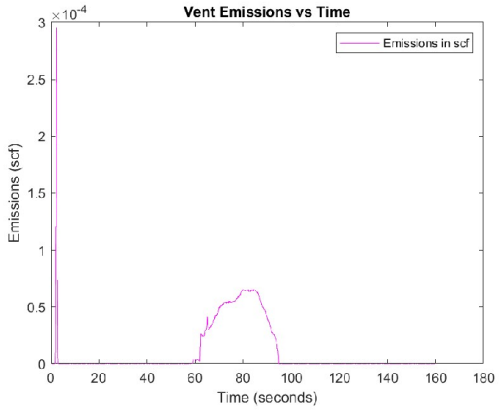

Outlet Pressure vs Flow rate
Flow Rate (scfh)
0.04
0.03
0.02
0.01
0
-0.01
-0.02
-0.03
10
20
30
40
50
60
70
80
90
100
Outlet Pressure (inch WC)

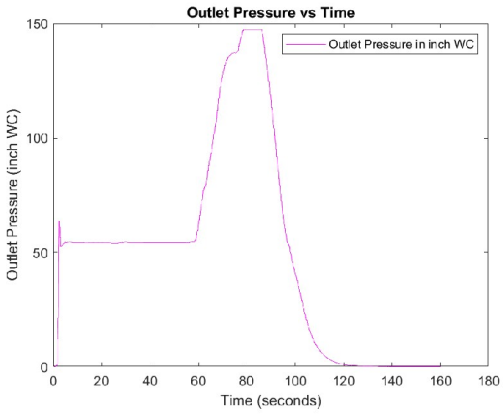

Outlet Pressure vs Flow rate
Flow Rate (scfh)
0.01
0.005
0
-0.005
-0.01
-0.015
-0.02
-0.025
12
13
14
15
16
17
18
19
20
Outlet Pressure (inch WC)

GTI ENERGY

2-psig Outlet, 10-psig Inlet

- 222489-016
  The volume of total emissions in 160.31 seconds is 0.0165 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 1.00 scfh.

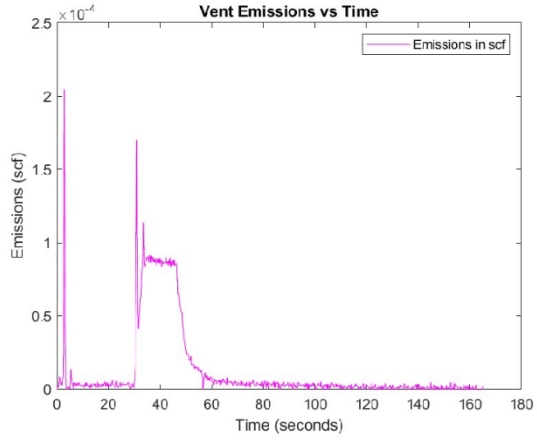


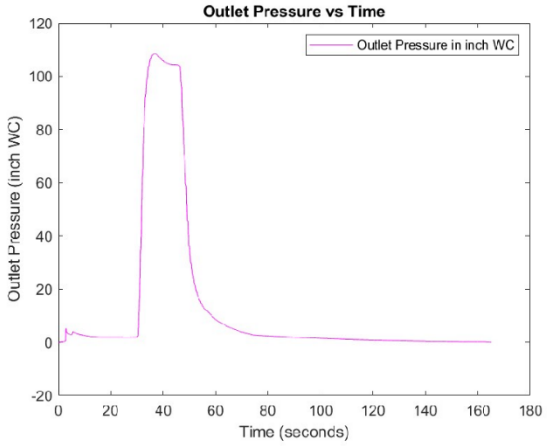


- 222489-016_DT1

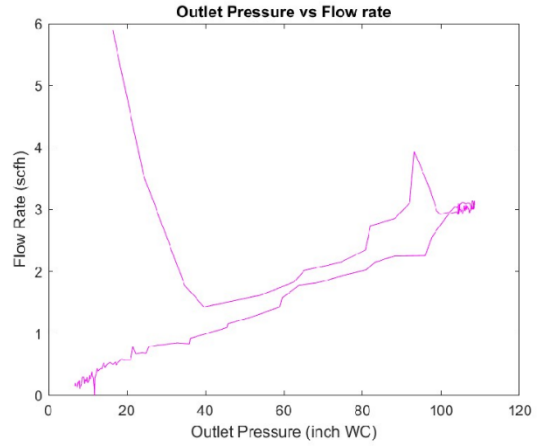
GTI ENERGY

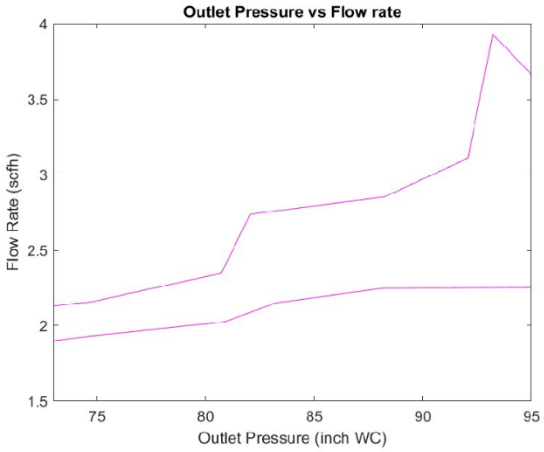
The volume of total emissions in 165.18 seconds is 0.0201 scf.
The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 2.55 scfh.





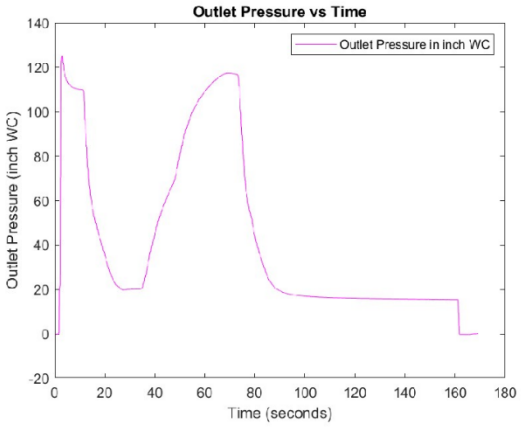
GTI ENERGY

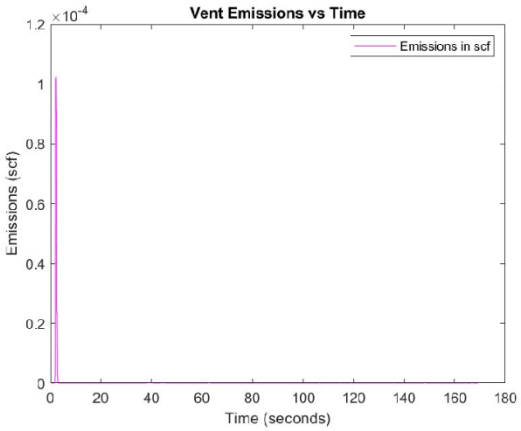

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
1
2
3
4
5
6
0
20
40
60
80
100
120


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
1.5
2
2.5
3
3.5
4
75
80
85
90
95

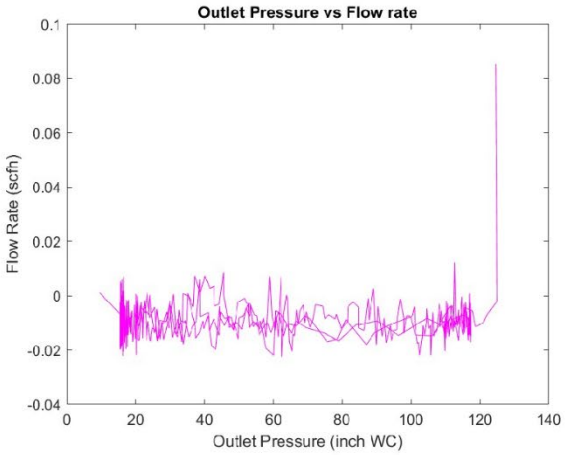
GTI ENERGY

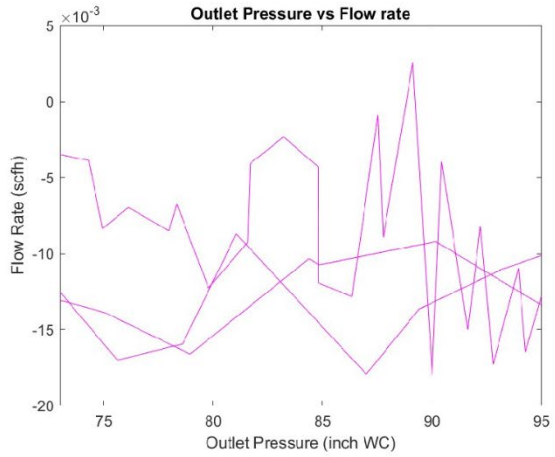
- 222489-016_LD
  The volume of total emissions in 169.37 seconds is 0.0004 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is -0.01 scfh.





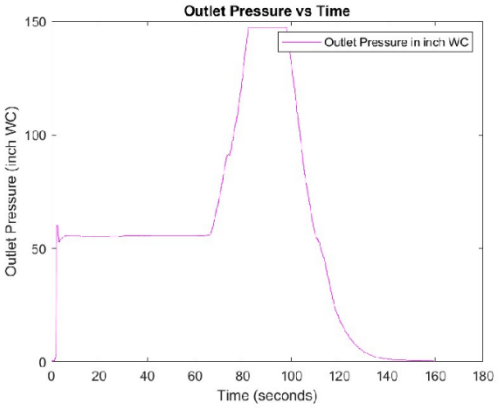
GTI ENERGY

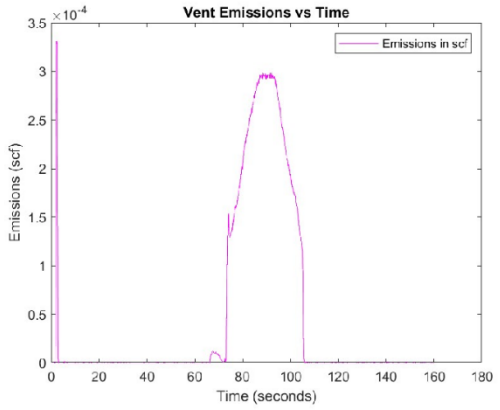

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0.1
0.08
0.06
0.04
0.02
0
-0.02
-0.04
0
20
40
60
80
100
120
140


Outlet Pressure vs Flow rate
×10^-3
Flow Rate (scfh)
Outlet Pressure (inch WC)
5
0
-5
-10
-15
-20
75
80
85
90
95

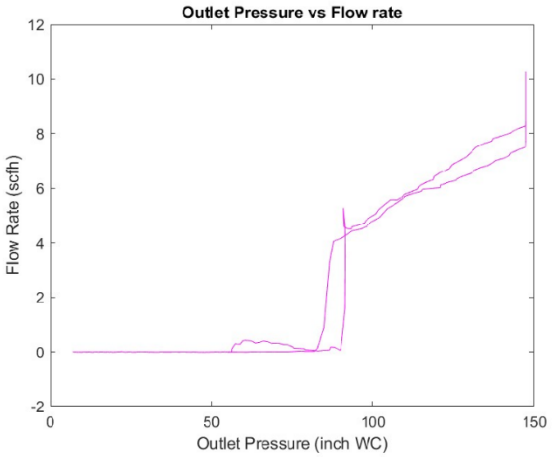
GTI ENERGY

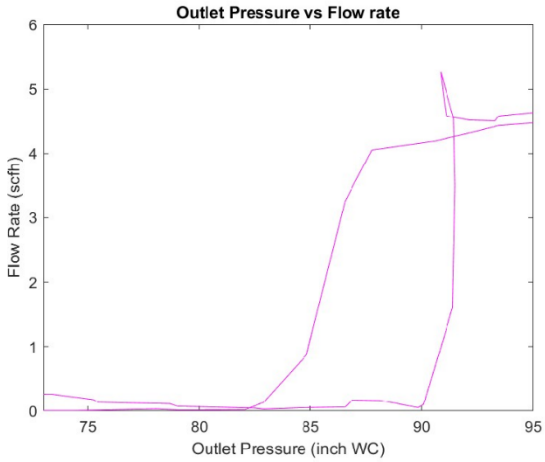
- 222489-017
  The volume of total emissions in 160.28 seconds is 0.0714 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 2.53 scfh.





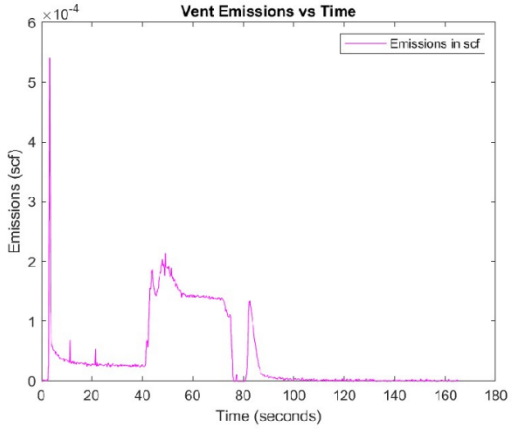
GTI ENERGY

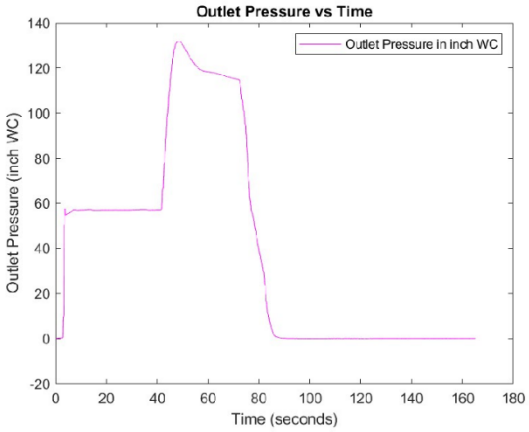

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
12
10
8
6
4
2
0
-2
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
6
5
4
3
2
1
0
75
80
85
90
95

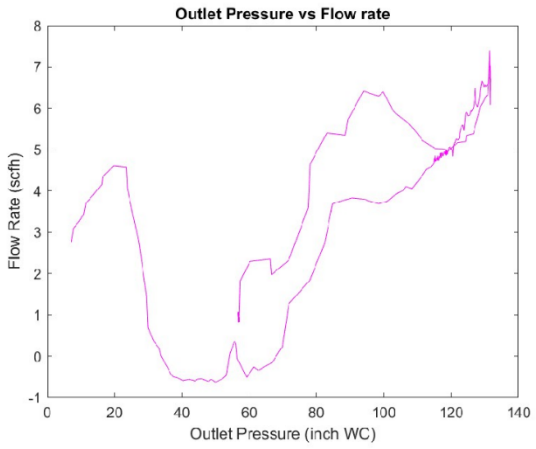
GTI ENERGY

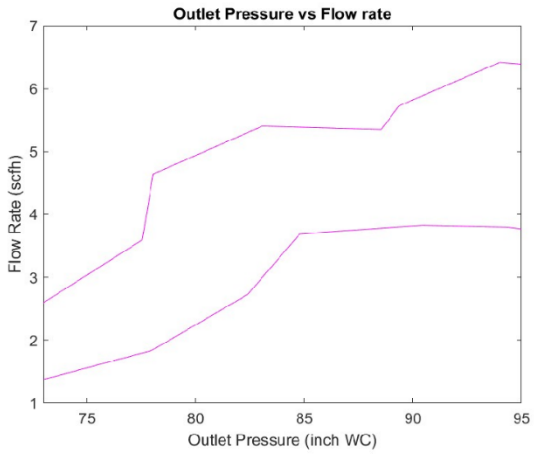
- 222489-017_DT1
  The volume of total emissions in 165.26 seconds is 0.0667 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 4.97 scfh.





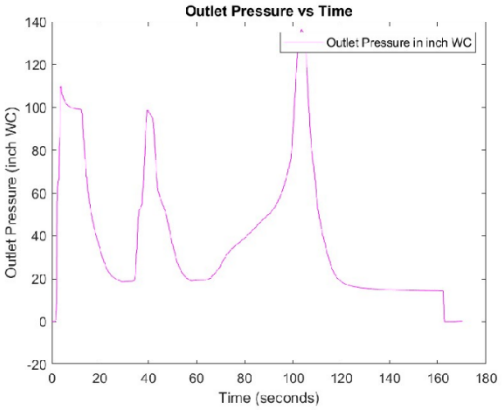
GTI ENERGY

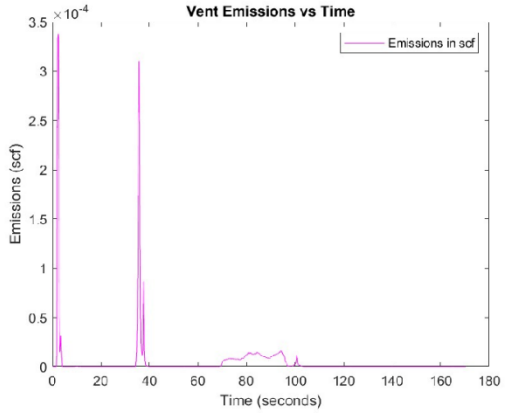

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
8
7
6
5
4
3
2
1
0
-1
0
20
40
60
80
100
120
140


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
7
6
5
4
3
2
1
75
80
85
90
95

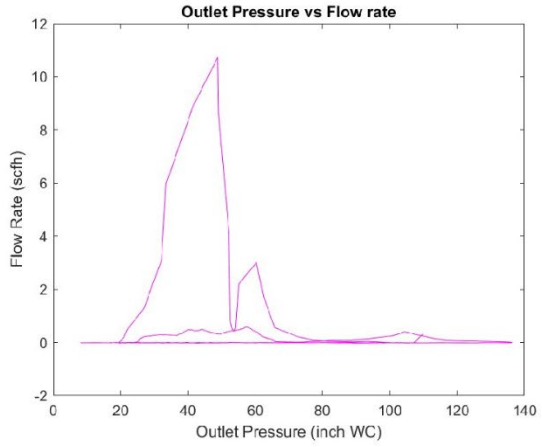
GTI ENERGY

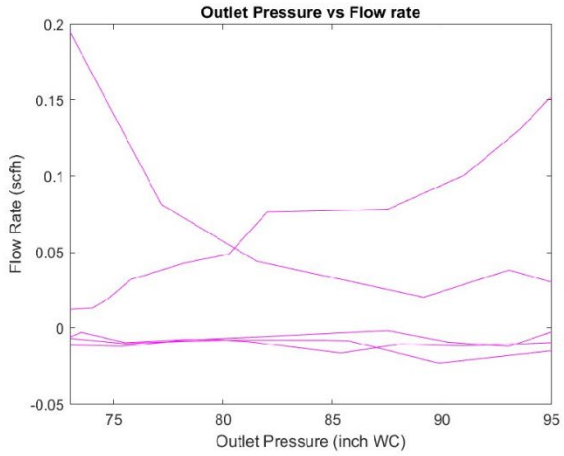
- 222489-017_LD
  The volume of total emissions in 170.36 seconds is 0.0087 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 0.09 scfh.





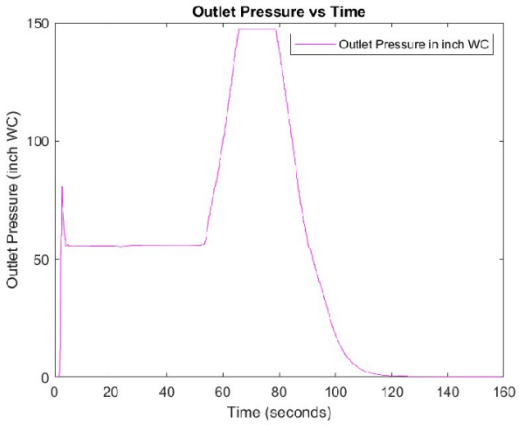
GTI ENERGY

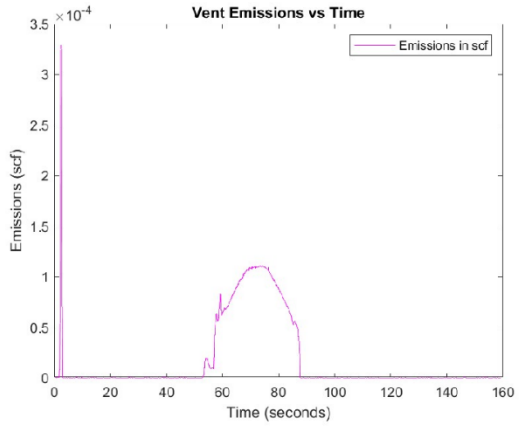

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
12
10
8
6
4
2
0
-2
0
20
40
60
80
100
120
140


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0.2
0.15
0.1
0.05
0
-0.05
75
80
85
90
95

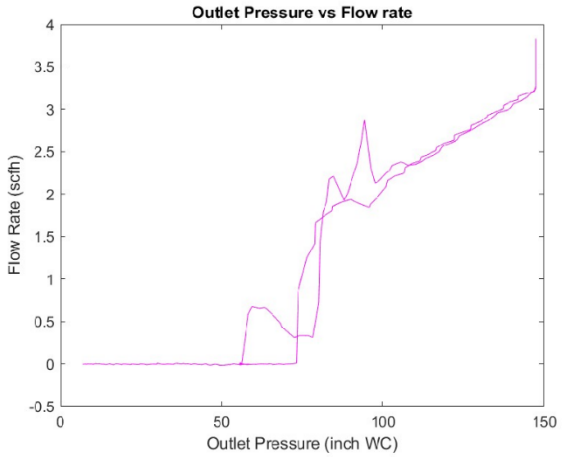
GTI ENERGY

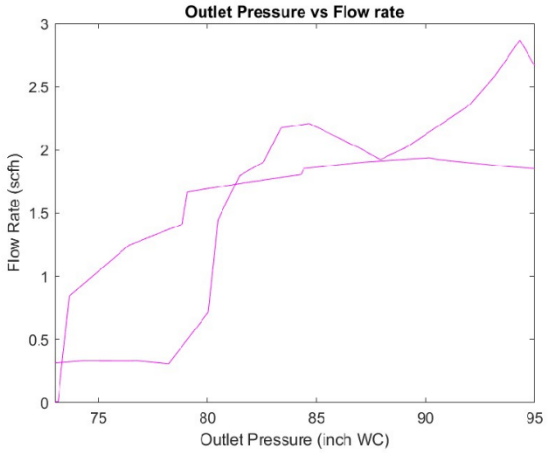
- 222489-018
  The volume of total emissions in 159.32 seconds is 0.0278 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 1.96 scfh.



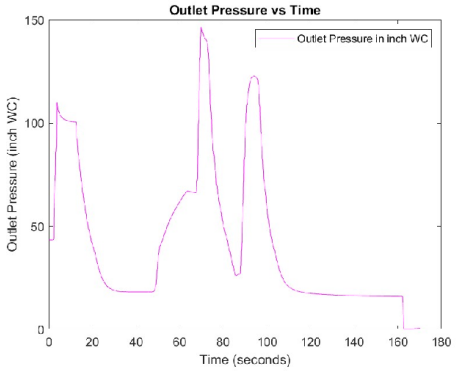


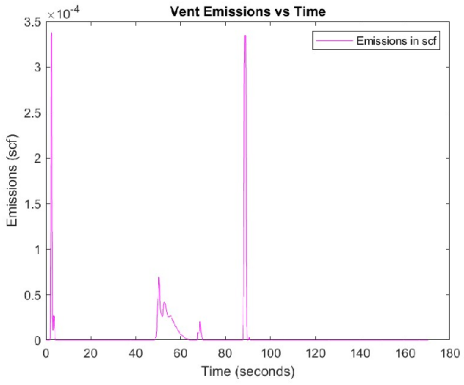
GTI ENERGY


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
4
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
0
50
100
150

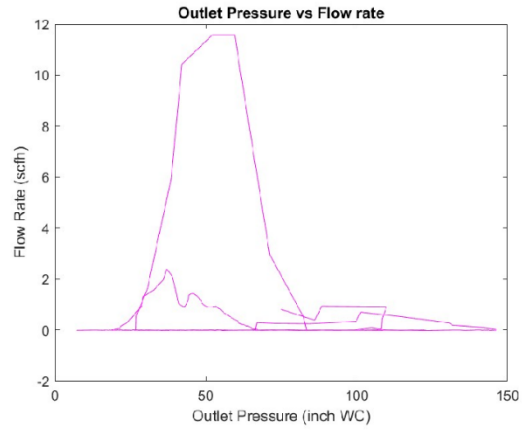

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
3
2.5
2
1.5
1
0.5
0
75
80
85
90
95

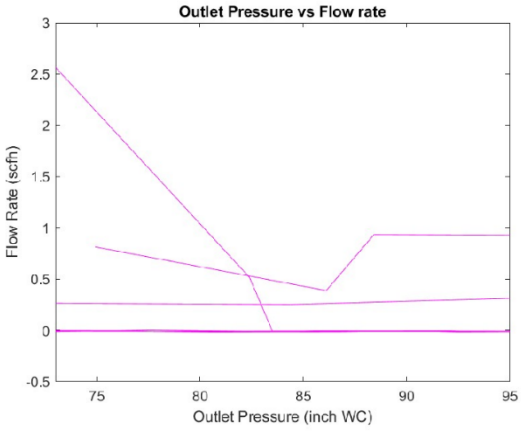
- 222489-018_LD
  The volume of total emissions in 170.37 seconds is 0.0083 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 0.21 scfh.





GTI ENERGY


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
12
10
8
6
4
2
0
-2
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
3
2.5
2
1.5
1
0.5
0
-0.5
75
80
85
90
95

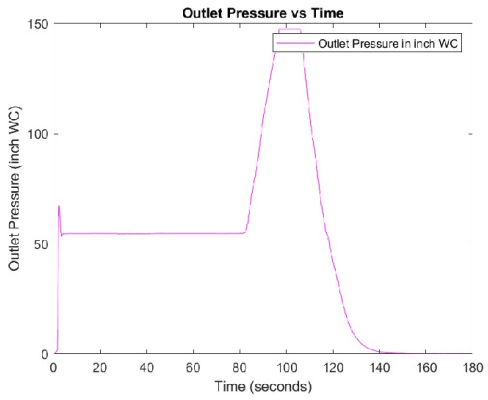
GTI ENERGY

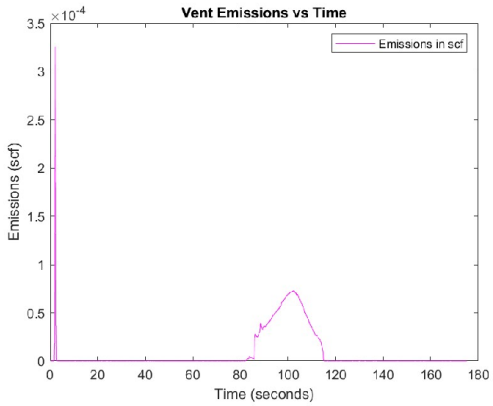
2-psig Outlet, 60-psig Inlet

- 222489-016

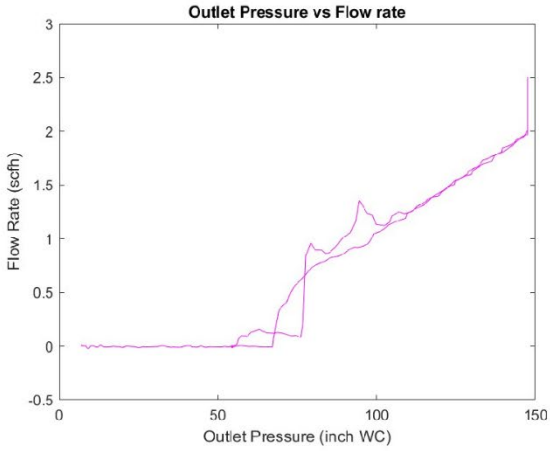
  The volume of total emissions in 175.36 seconds is 0.0147 scf.

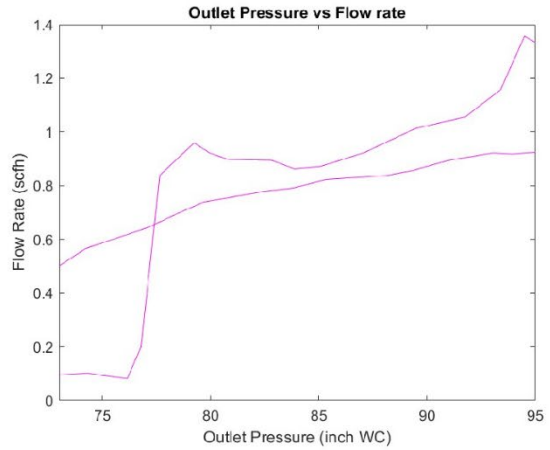
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 0.92 scfh.





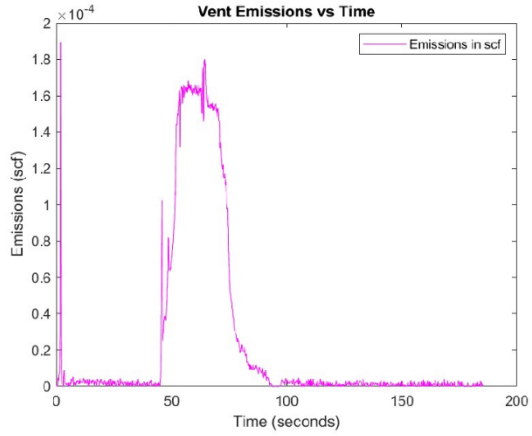
GTI ENERGY

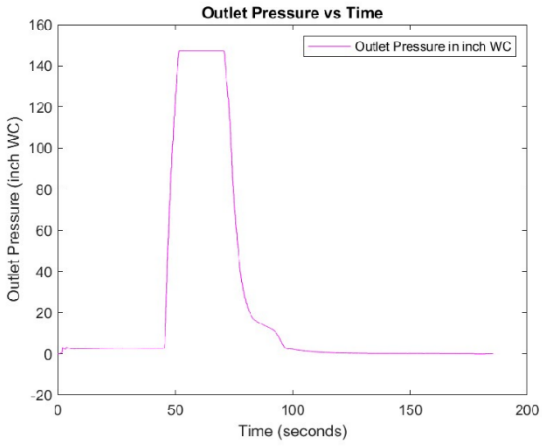

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
3
2.5
2
1.5
1
0.5
0
-0.5
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
75
80
85
90
95

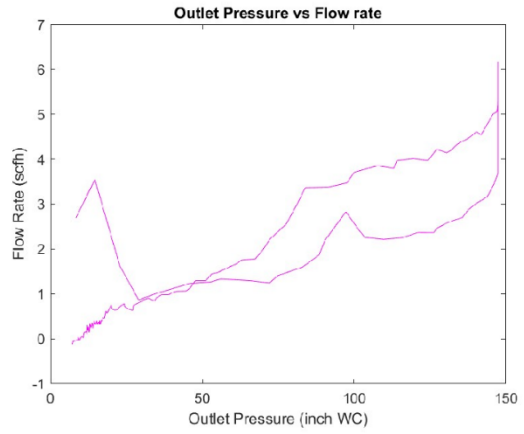
GTI ENERGY

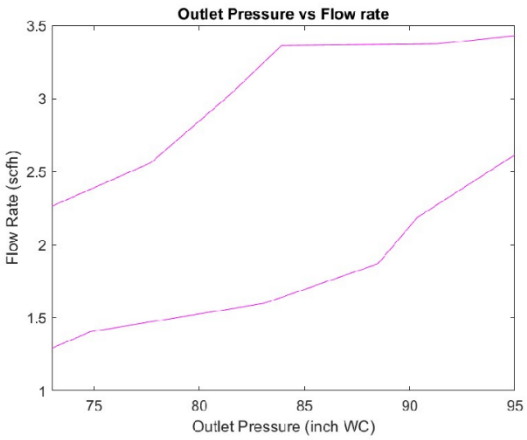
- 222489-016_DT1
  The volume of total emissions in 185.41 seconds is 0.0427 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 2.48 scfh.





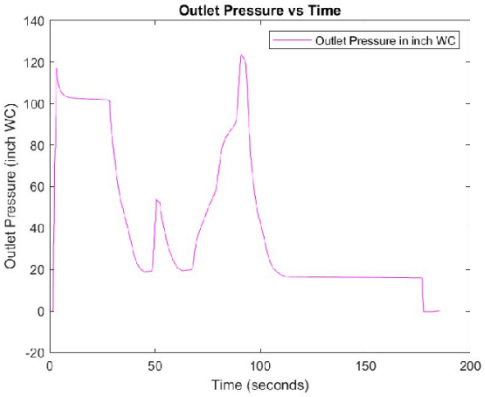
GTI ENERGY

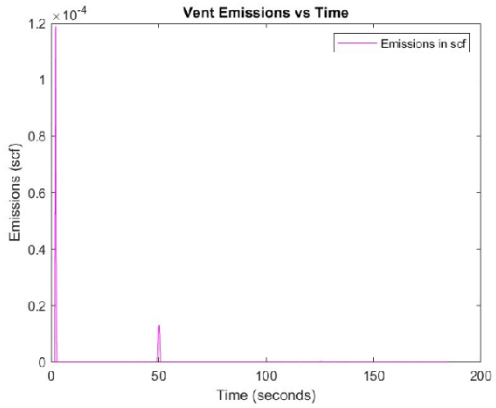

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
7
6
5
4
3
2
1
0
-1
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
3.5
3
2.5
2
1.5
1
75
80
85
90
95

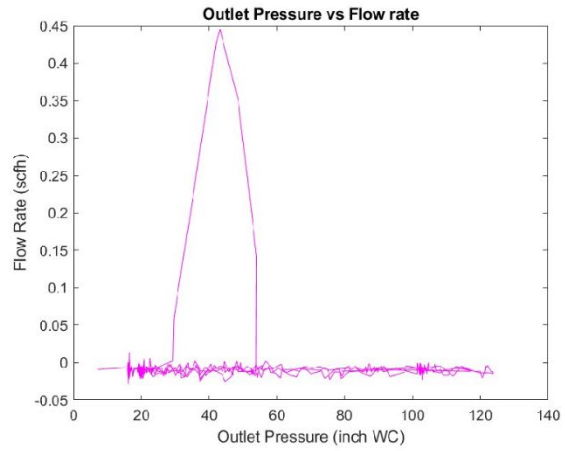
GTI ENERGY

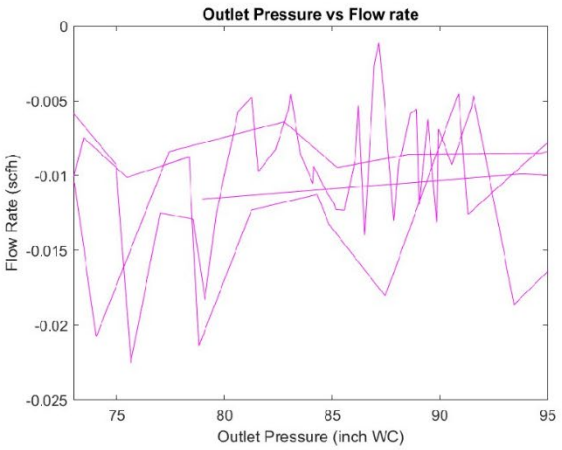
- 222489-016_LD
  The volume of total emissions in 185.42 seconds is 0.0005 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is -0.01 scfh.





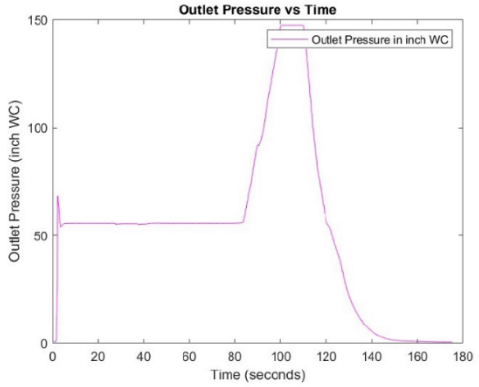
GTI ENERGY

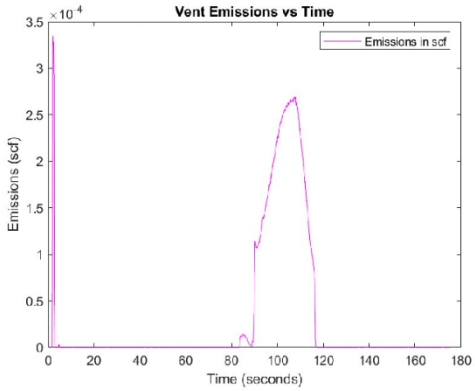

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
0
20
40
60
80
100
120
140


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
-0.005
-0.01
-0.015
-0.02
-0.025
75
80
85
90
95

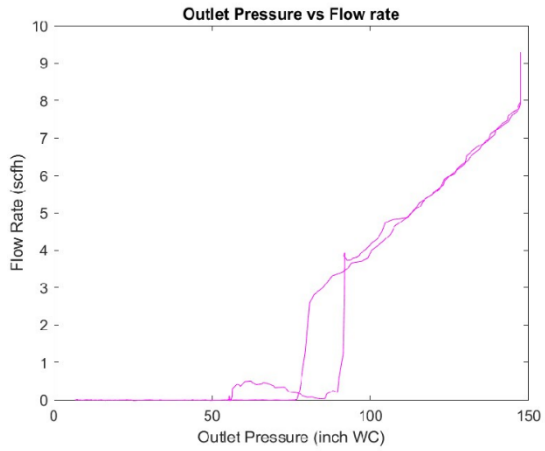
GTI ENERGY

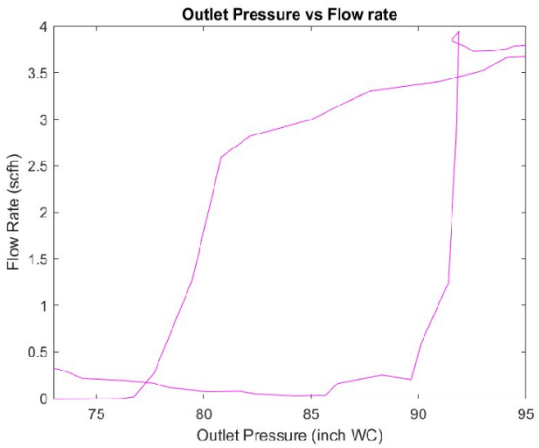
- 222489-017
  The volume of total emissions in 175.32 seconds is 0.0512 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 1.54 scfh.





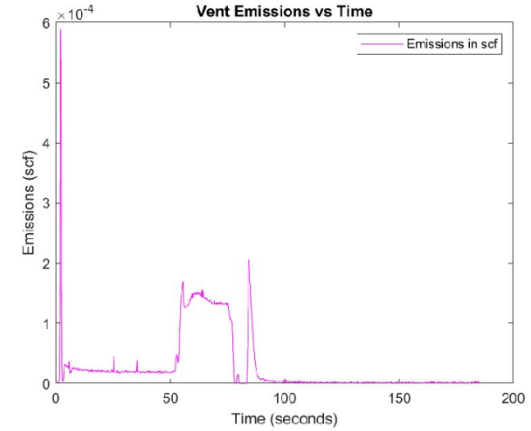
GTI ENERGY

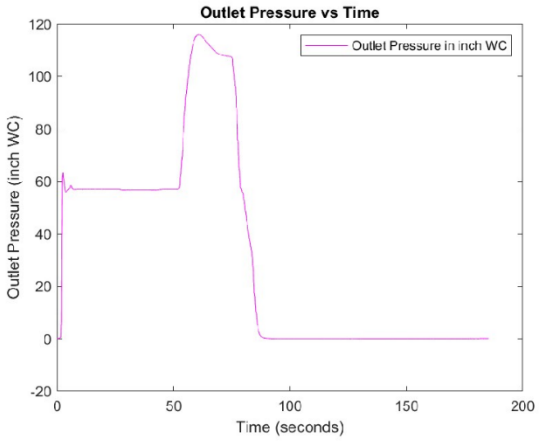

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
1
2
3
4
5
6
7
8
9
10
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
0.5
1
1.5
2
2.5
3
3.5
4
75
80
85
90
95

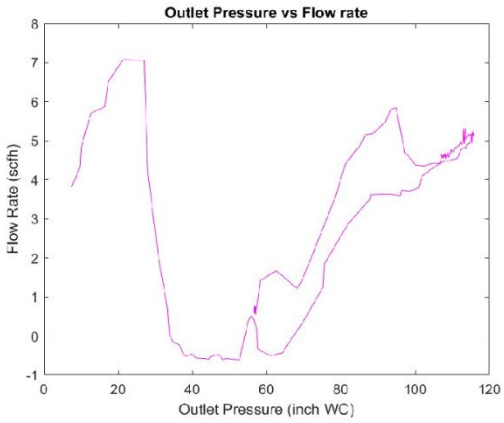
GTI ENERGY

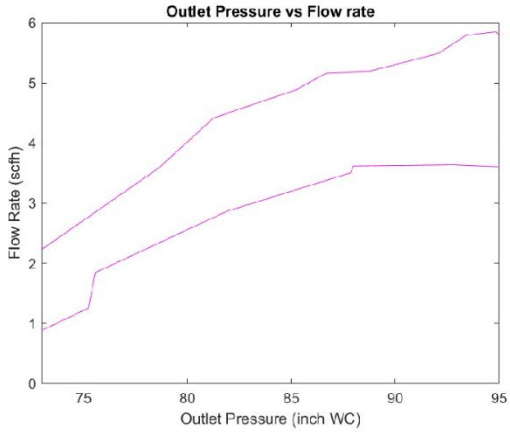
- 222489-017_DT1
  The volume of total emissions in 185.36 seconds is 0.0500 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 4.37 scfh.





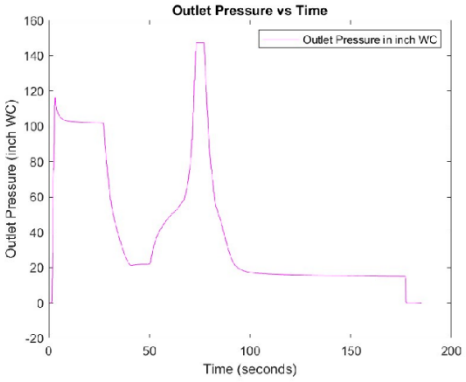
GTI ENERGY

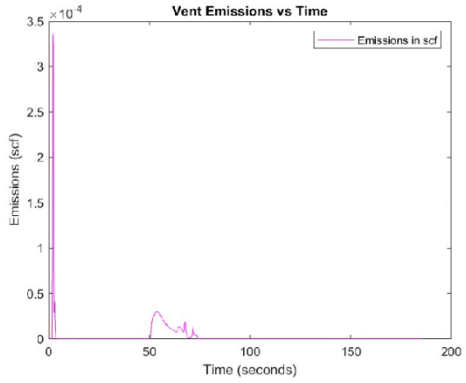

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
8
7
6
5
4
3
2
1
0
-1
0
20
40
60
80
100
120


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
6
5
4
3
2
1
0
75
80
85
90
95

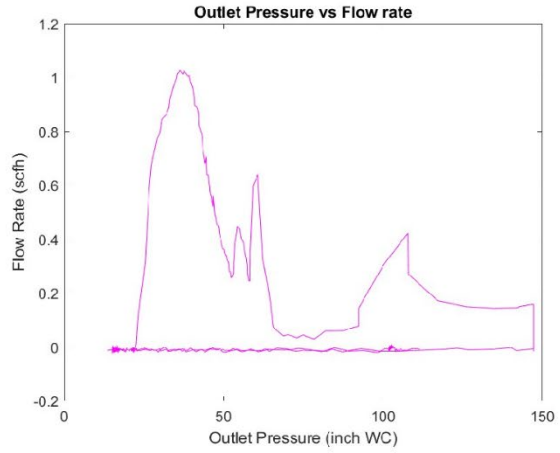
GTI ENERGY

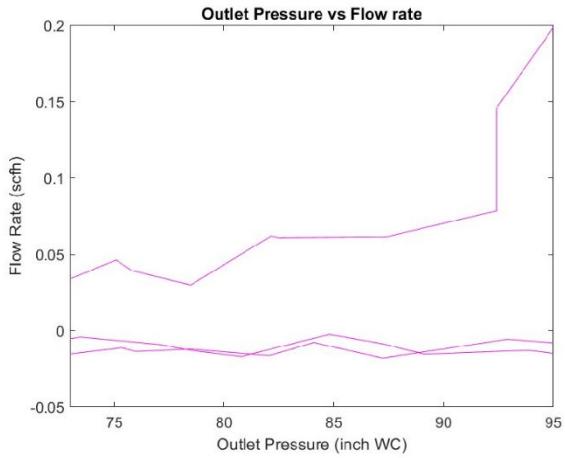
- 222489-017_LD
  The volume of total emissions in 185.34 seconds is 0.0055 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 0.20 scfh.



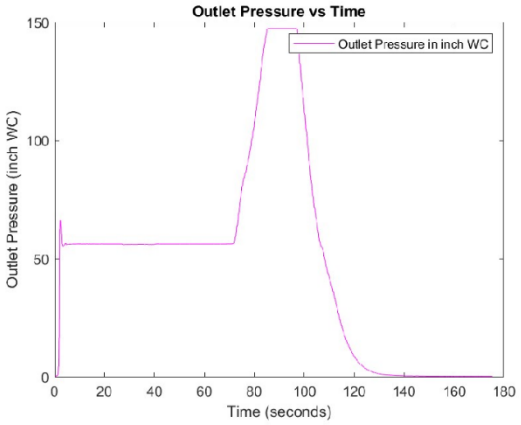


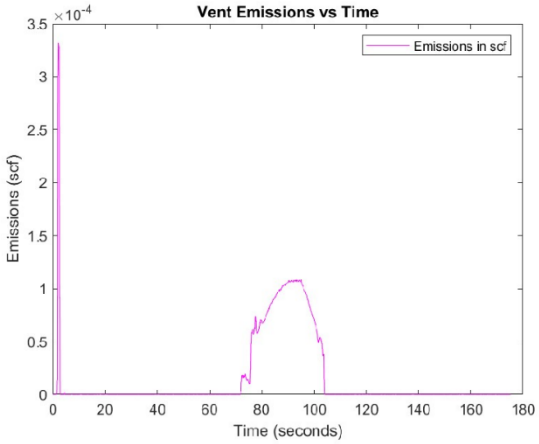
GTI ENERGY


Outlet Pressure vs Flow rate
Flow Rate (scfh)
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
0
50
100
150
Outlet Pressure (inch WC)

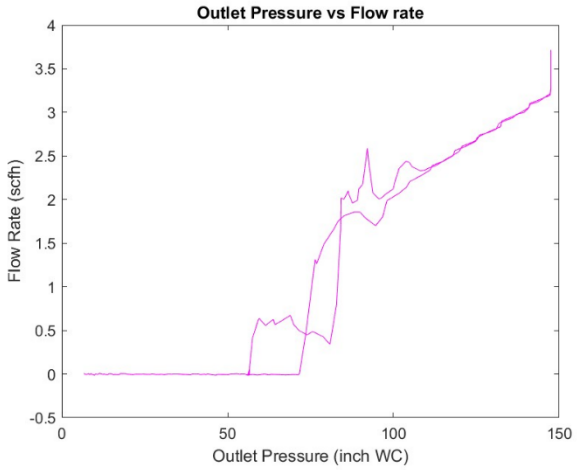

Outlet Pressure vs Flow rate
Flow Rate (scfh)
0.2
0.15
0.1
0.05
0
-0.05
75
80
85
90
95
Outlet Pressure (inch WC)

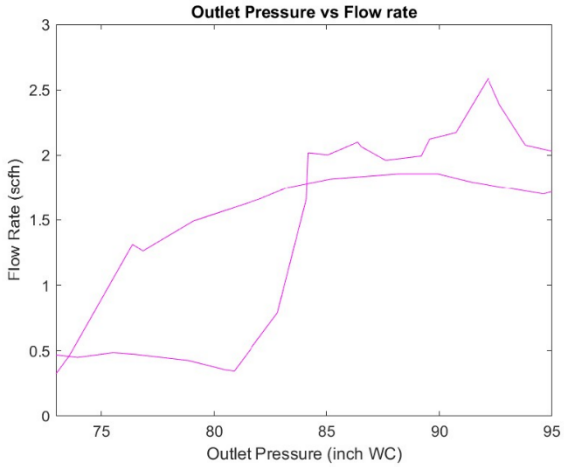
- 222489-018
  The volume of total emissions in 175.30 seconds is 0.0253 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 2.02 scfh.





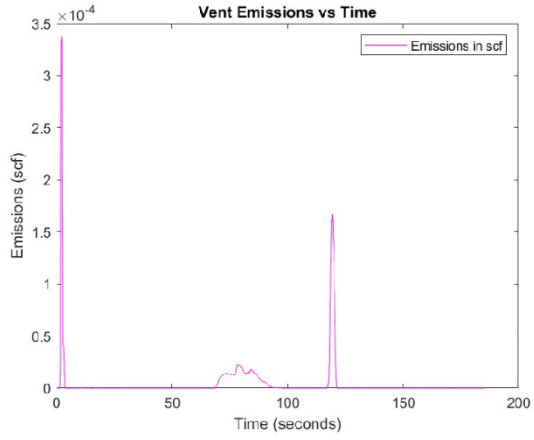
GTI ENERGY

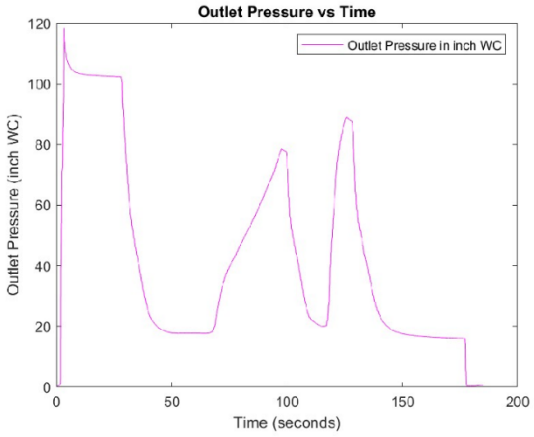

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
4
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
3
2.5
2
1.5
1
0.5
0
75
80
85
90
95

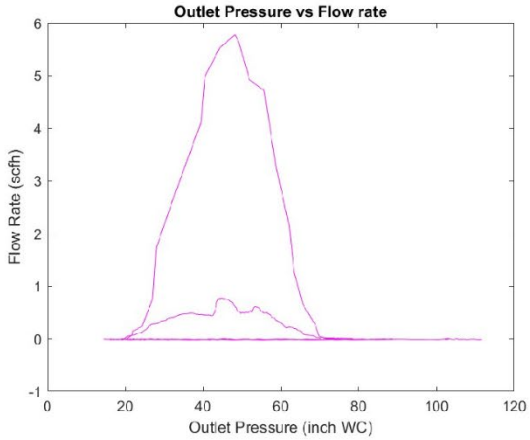
GTI ENERGY

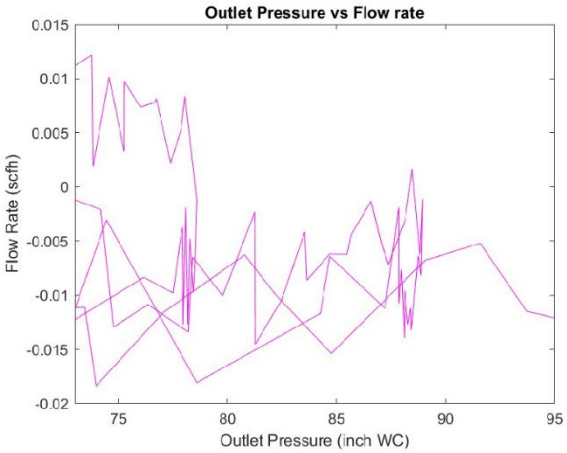
- 222489-018_LD
  The volume of total emissions in 185.34 seconds is 0.0085 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is -0.01 scfh.





GTI ENERGY


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
6
5
4
3
2
1
0
-1
0
20
40
60
80
100
120


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0.015
0.01
0.005
0
-0.005
-0.01
-0.015
-0.02
75
80
85
90
95

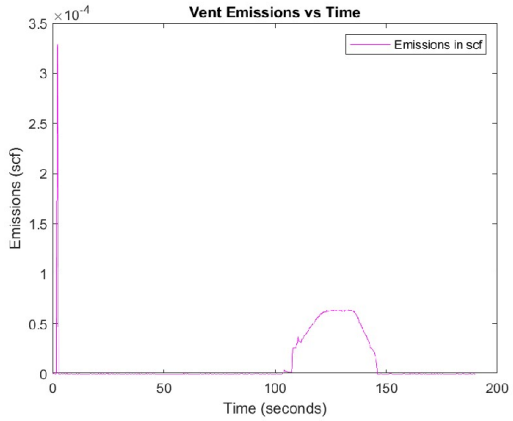
GTI ENERGY

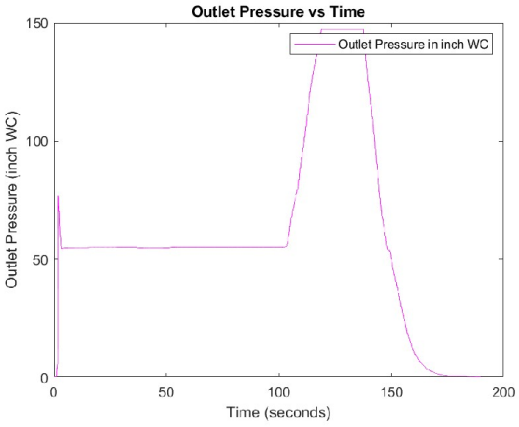
2-psig Outlet, 100-psig Inlet

- 222489-016

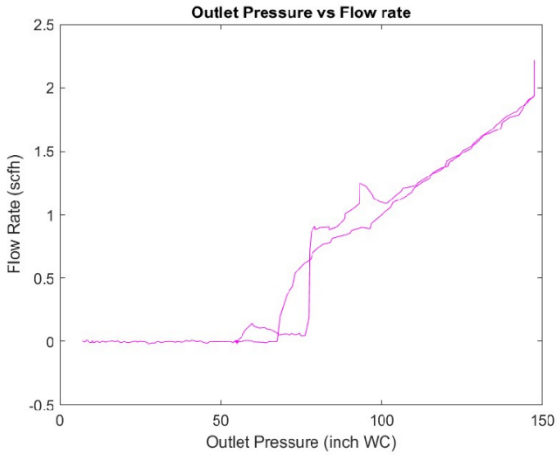
  The volume of total emissions in 190.24 seconds is 0.0197 scf.

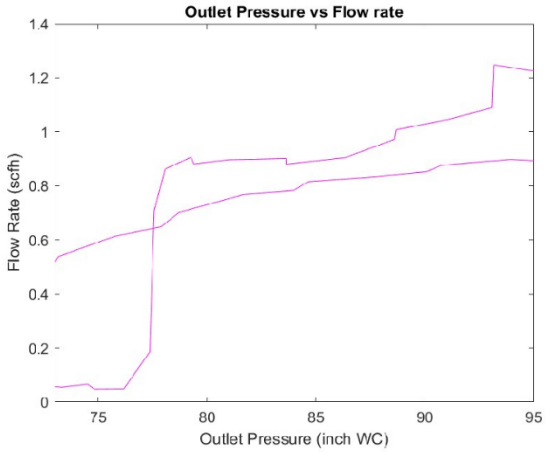
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 0.93 scfh.





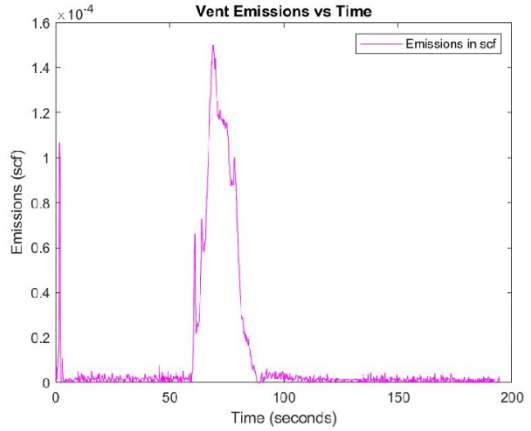
GTI ENERGY

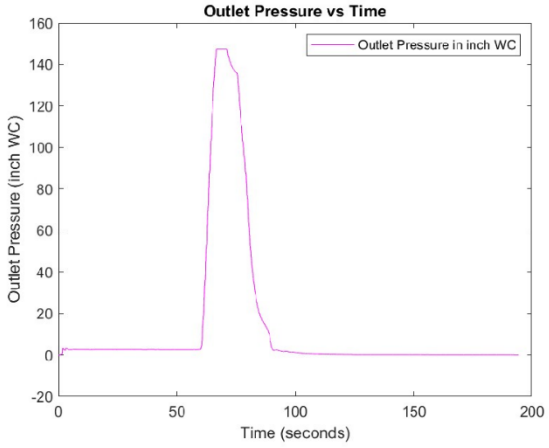

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
2.5
2
1.5
1
0.5
0
-0.5
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
75
80
85
90
95

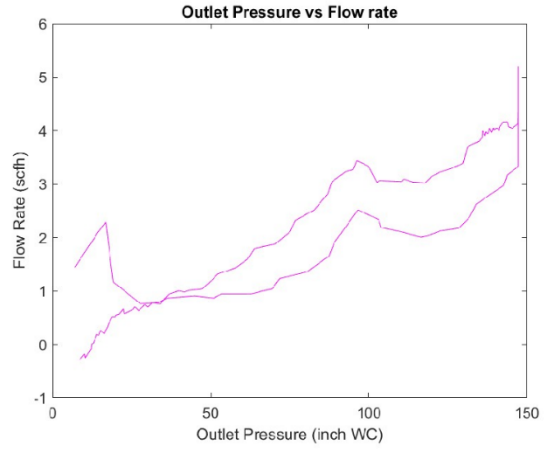
GTI ENERGY

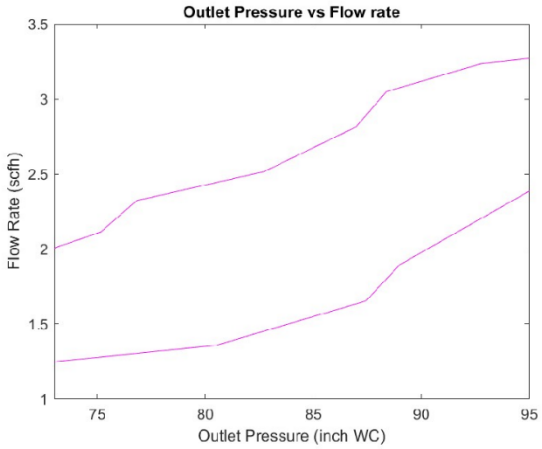
- 222489-016_DT1
  The volume of total emissions in 194.46 seconds is 0.0218 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 2.35 scfh.





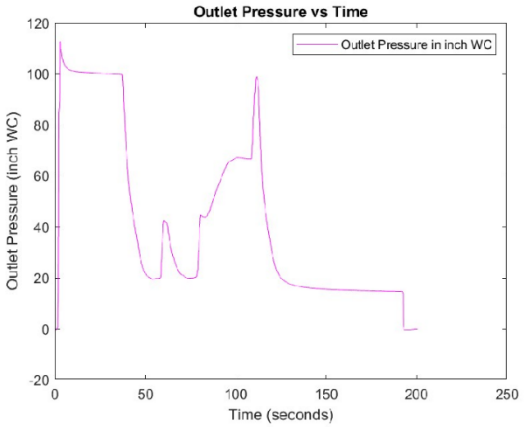
GTI ENERGY

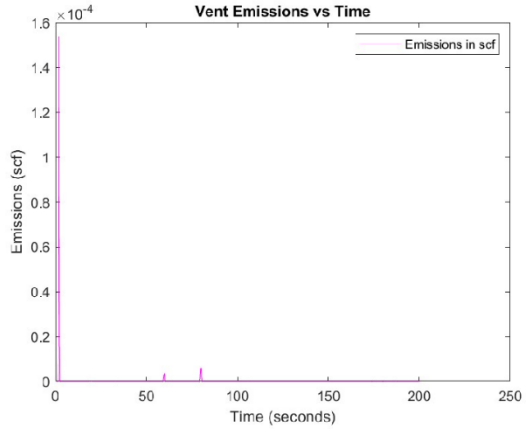

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
6
5
4
3
2
1
0
-1
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
3.5
3
2.5
2
1.5
1
75
80
85
90
95

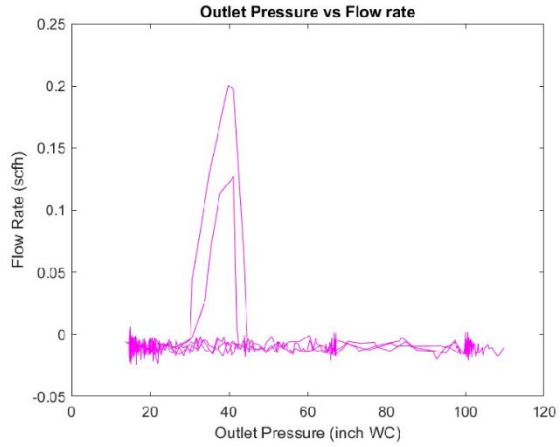
GTI ENERGY

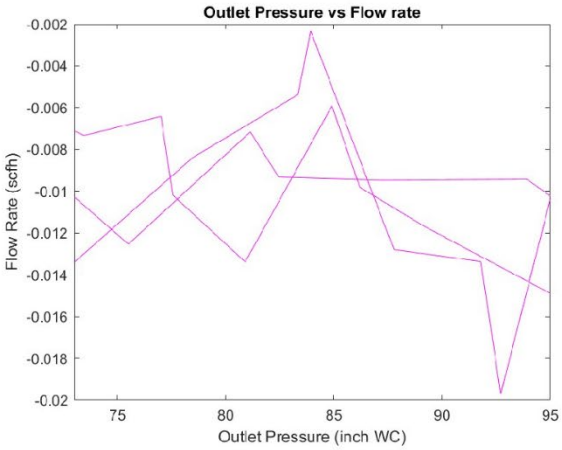
- 222489-016_LD
  The volume of total emissions in 200.42 seconds is 0.0005 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 0.09 scfh.





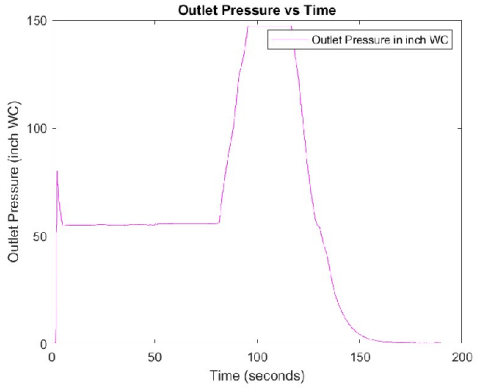
GTI ENERGY

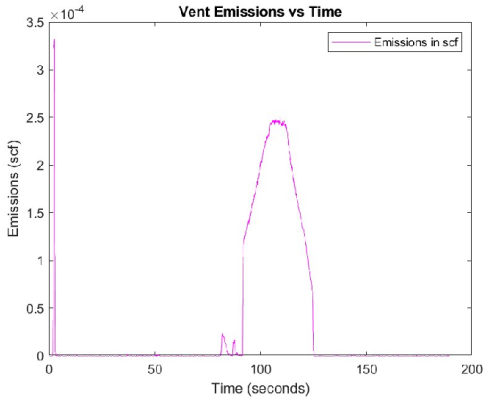

Outlet Pressure vs Flow rate
Flow Rate (scfh)
0.25
0.2
0.15
0.1
0.05
0
-0.05
0
20
40
60
80
100
120
Outlet Pressure (inch WC)


Outlet Pressure vs Flow rate
Flow Rate (scfh)
-0.002
-0.004
-0.006
-0.008
-0.01
-0.012
-0.014
-0.016
-0.018
-0.02
75
80
85
90
95
Outlet Pressure (inch WC)

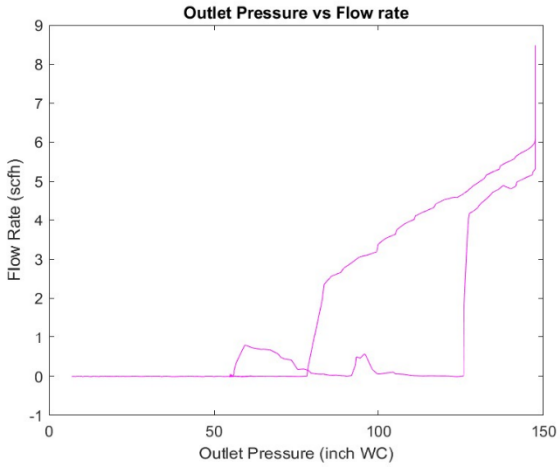
GTI ENERGY

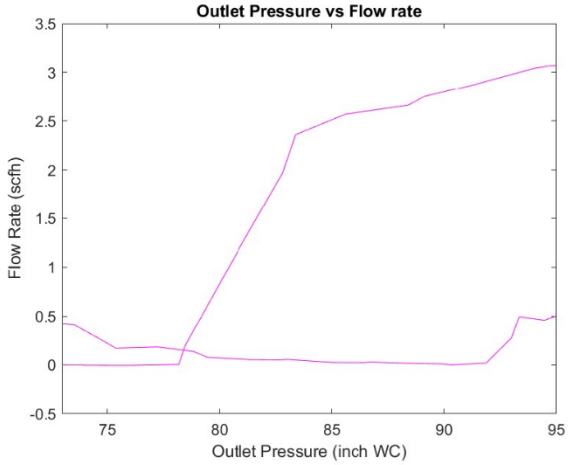
- 222489-017
  The volume of total emissions in 189.37 seconds is 0.0614 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 1.04 scfh.





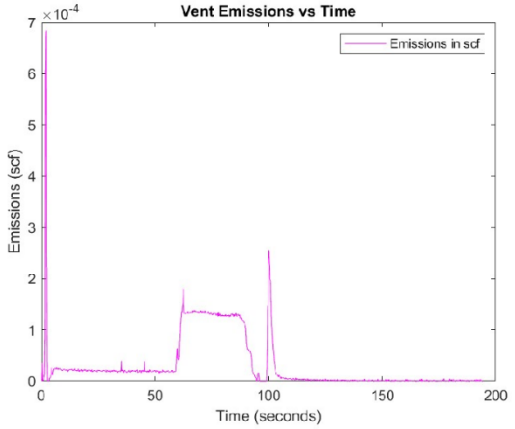
GTI ENERGY

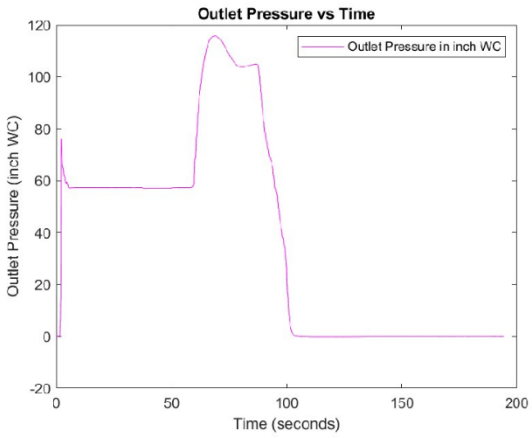

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
9
8
7
6
5
4
3
2
1
0
-1
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
75
80
85
90
95

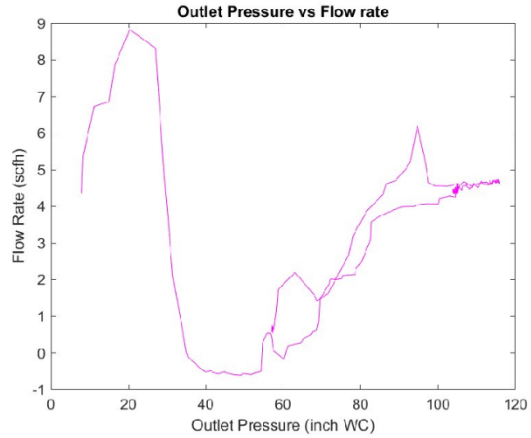
GTI ENERGY

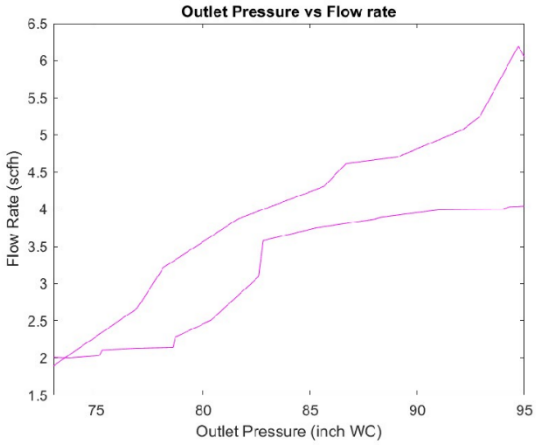
- 222489-017_DT1
  The volume of total emissions in 194.45 seconds is 0.0585 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 4.21 scfh.





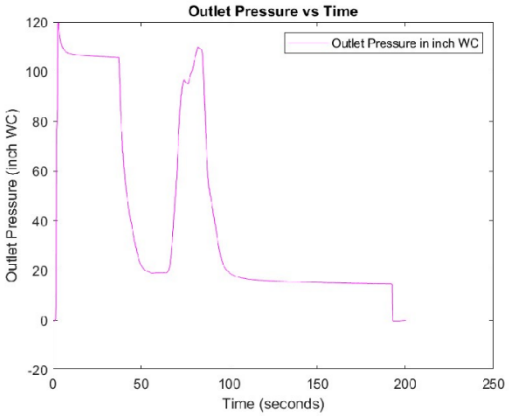
GTI ENERGY

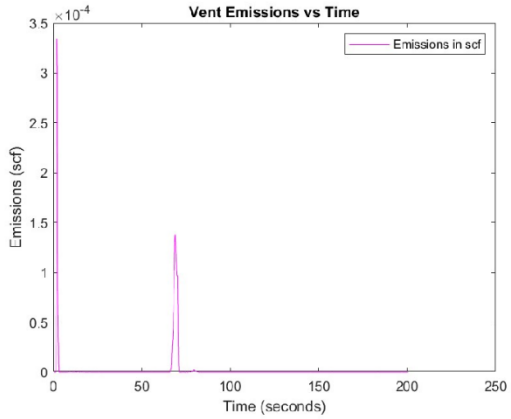

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
9
8
7
6
5
4
3
2
1
0
-1
0
20
40
60
80
100
120


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
6.5
6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
75
80
85
90
95

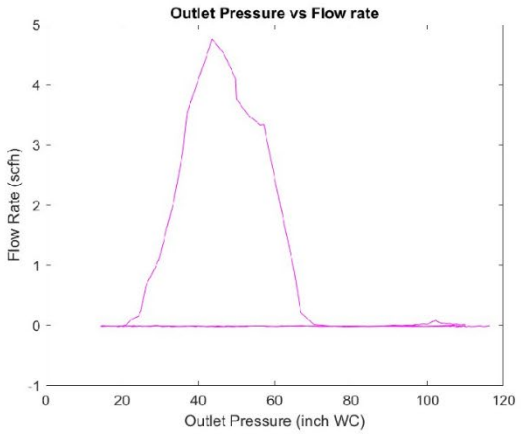
GTI ENERGY

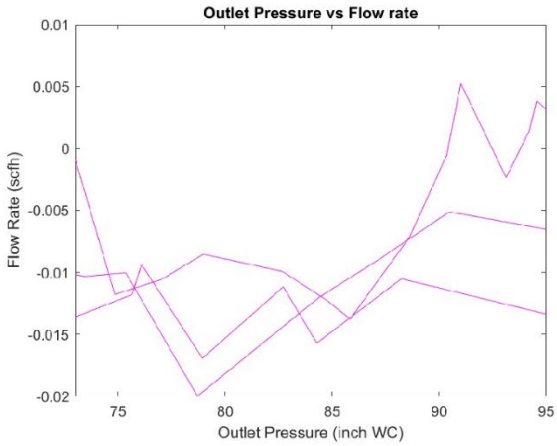
- 222489-017_LD
  The volume of total emissions in 200.43 seconds is 0.0055 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is -0.00 scfh.





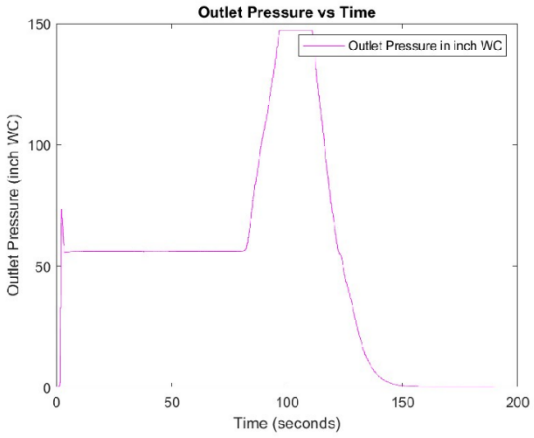
GTI ENERGY

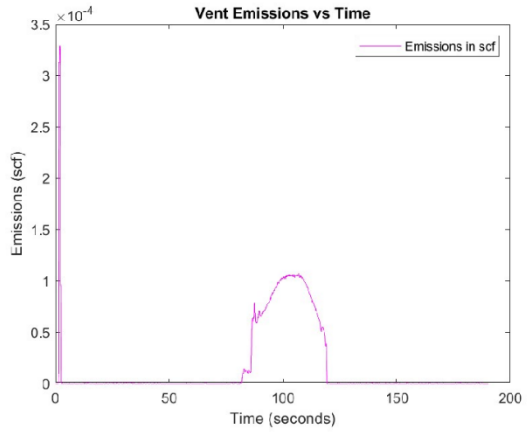

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
5
4
3
2
1
0
-1
0
20
40
60
80
100
120


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0.01
0.005
0
-0.005
-0.01
-0.015
-0.02
75
80
85
90
95

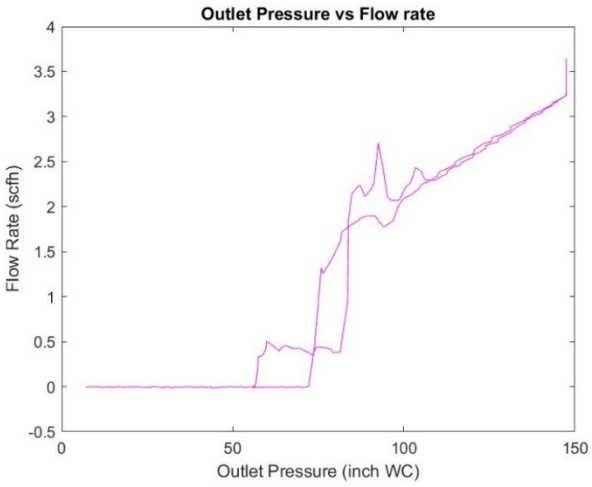
GTI ENERGY

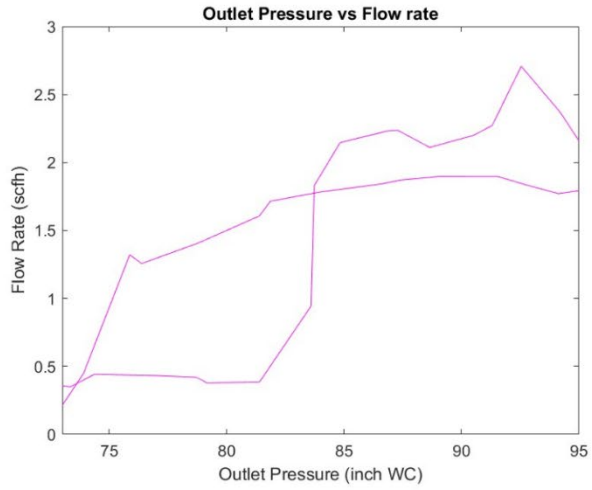
- 222489-018
  The volume of total emissions in 190.24 seconds is 0.0294 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 2.08 scfh.





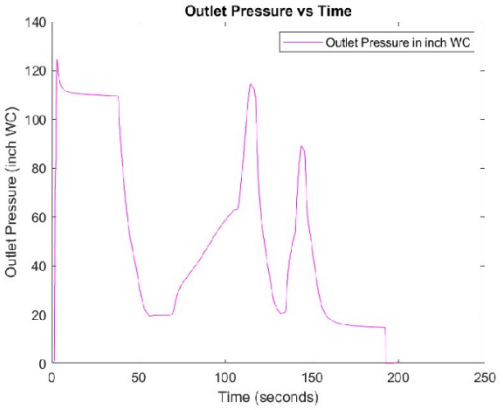
GTI ENERGY

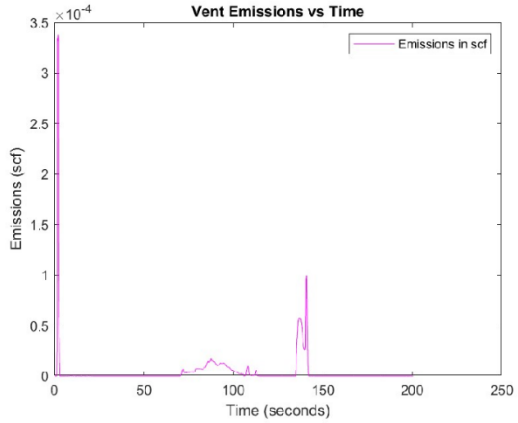

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
4
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
3
2.5
2
1.5
1
0.5
0
75
80
85
90
95

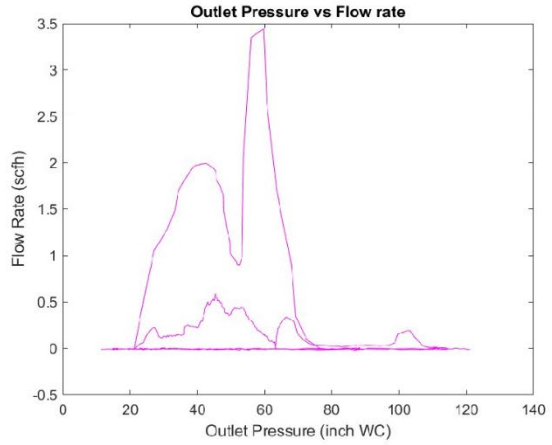
GTI ENERGY

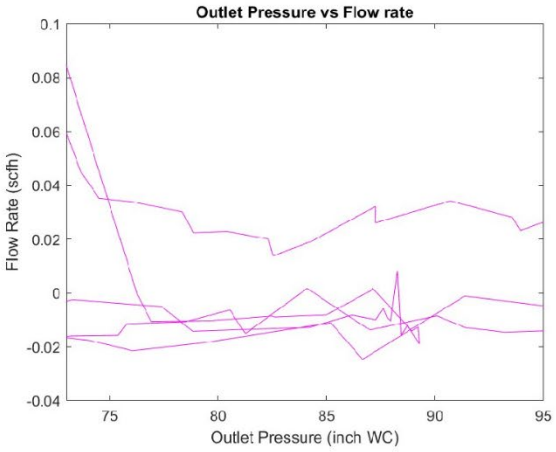
- 222489-018_LD
  The volume of total emissions in 200.41 seconds is 0.0082 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is -0.00 scfh.





GTI ENERGY

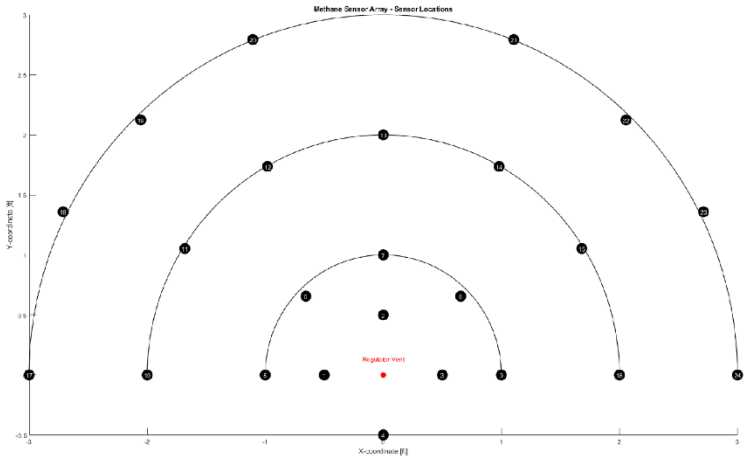

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
0
20
40
60
80
100
120
140


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0.1
0.08
0.06
0.04
0.02
0
-0.02
-0.04
75
80
85
90
95

GTI ENERGY

Methane Concentration Maps

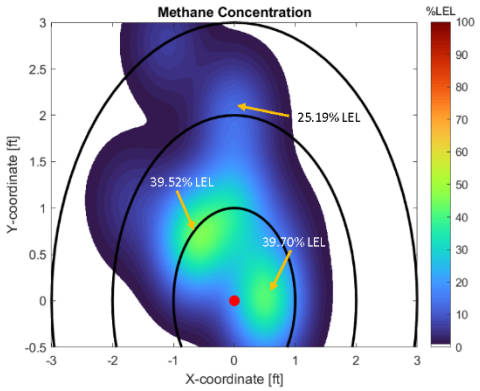
Sensor Locations



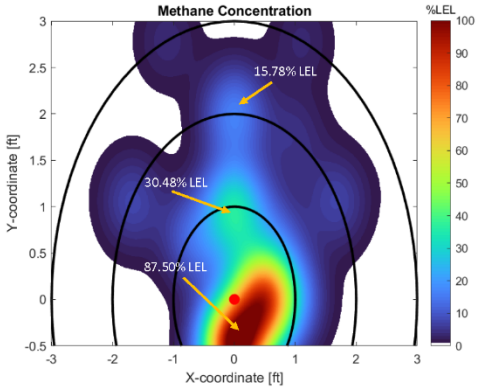
GTI ENERGY

2-psig

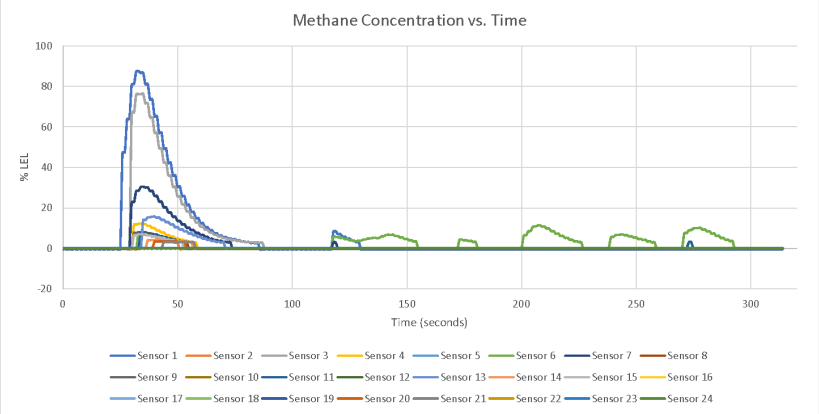
	2 PSI	222489-017_DT1	Sigma = .4
VL1	Primary Diaphragm Tear	Standard Array Configuration	6 in from vent



	2 PSI	222489-017_DT2_trial1	Sigma = .35
VL1	Primary and Secondary Diaphragm Tear	Standard Array Configuration	6 in from vent

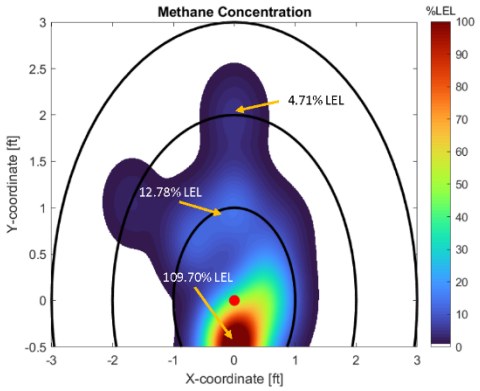


GTI ENERGY

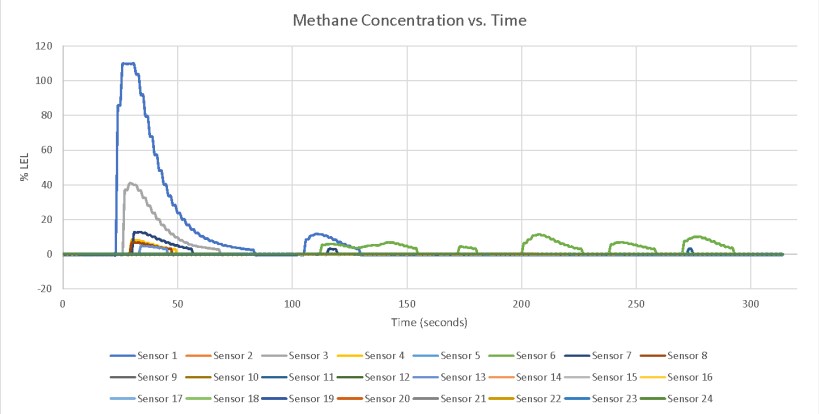

Methane Concentration vs. Time
% LEL
100
80
60
40
20
0
-20
0
50
100
150
200
250
300
Time (seconds)
Sensor 1
Sensor 2
Sensor 3
Sensor 4
Sensor 5
Sensor 6
Sensor 7
Sensor 8
Sensor 9
Sensor 10
Sensor 11
Sensor 12
Sensor 13
Sensor 14
Sensor 15
Sensor 16
Sensor 17
Sensor 18
Sensor 19
Sensor 20
Sensor 21
Sensor 22
Sensor 23
Sensor 24

GTI ENERGY

	2 PSI	222489-017_DT2_trial2	Sigma = .32
VL1	Primary and Secondary Diaphragm Tear	Standard Array Configuration	6 in from vent

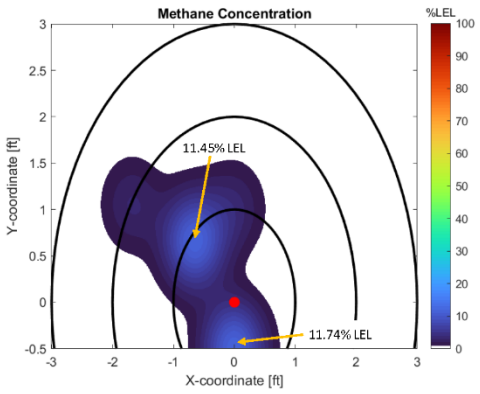


GTI ENERGY


Methane Concentration vs. Time
% LEL
120
100
80
60
40
20
0
-20
0
50
100
150
200
250
300
Time (seconds)
Sensor 1
Sensor 2
Sensor 3
Sensor 4
Sensor 5
Sensor 6
Sensor 7
Sensor 8
Sensor 9
Sensor 10
Sensor 11
Sensor 12
Sensor 13
Sensor 14
Sensor 15
Sensor 16
Sensor 17
Sensor 18
Sensor 19
Sensor 20
Sensor 21
Sensor 22
Sensor 23
Sensor 24

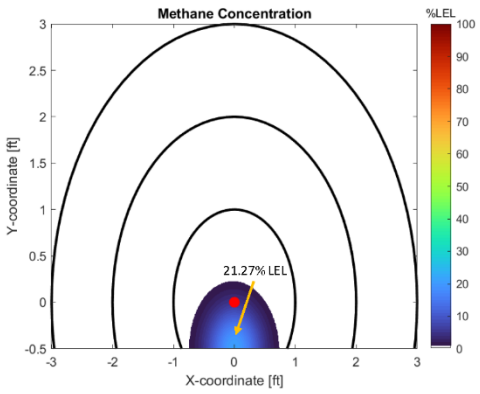
GTI ENERGY

	2 PSI	222489-017_LD	Sigma = .34
VL1	Lever Disconnect	Standard Array Configuration	6 in from vent



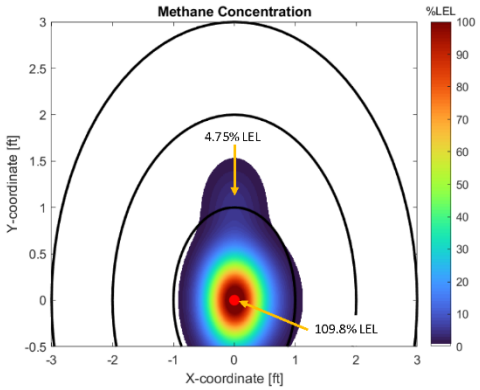
GTI ENERGY

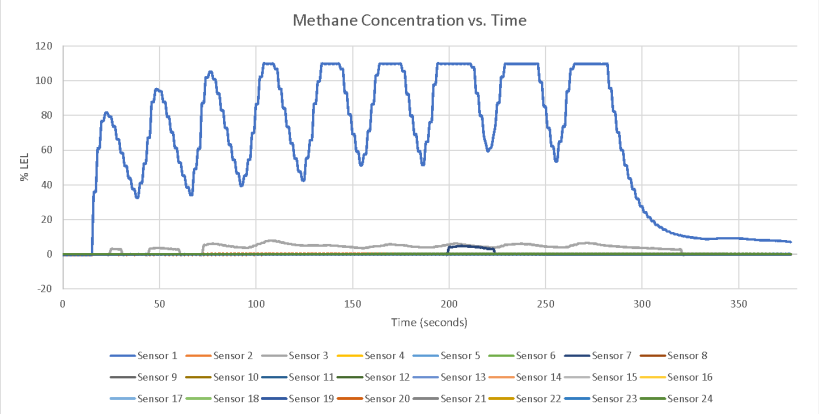
	2 PSI	222489-018_multi lockup_sensor1 6in	Sigma = .3
VL1	Normal Condition – Multi Lockup	Standard Array Configuration	6 in from vent



GTI ENERGY

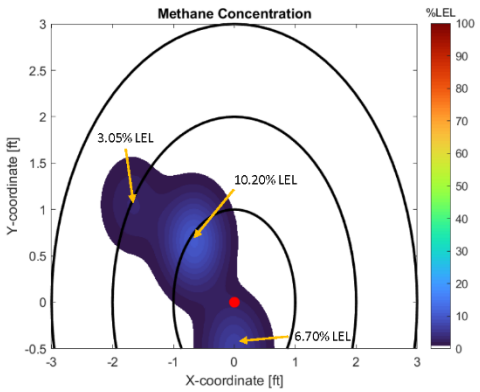
	2 PSI	222489-018_multi lockup_sensor1 next to vent	Sigma = .3
VL1	Normal Condition – Multi Lockup	Standard Array Configuration	1 in from vent




Methane Concentration vs. Time
% LEL
120
100
80
60
40
20
0
-20
0
50
100
150
200
250
300
350
Time (seconds)
Sensor 1
Sensor 2
Sensor 3
Sensor 4
Sensor 5
Sensor 6
Sensor 7
Sensor 8
Sensor 9
Sensor 10
Sensor 11
Sensor 12
Sensor 13
Sensor 14
Sensor 15
Sensor 16
Sensor 17
Sensor 18
Sensor 19
Sensor 20
Sensor 21
Sensor 22
Sensor 23
Sensor 24

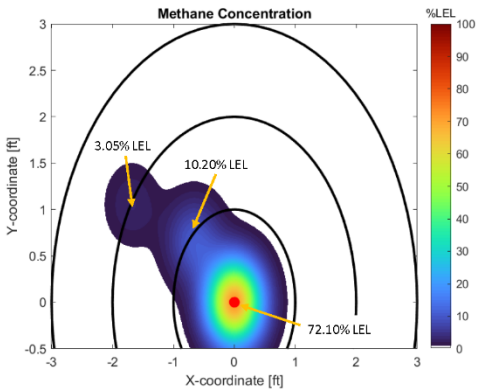
GTI ENERGY

	2 PSI	222489-018_single lockup_sensor1 6in	Sigma = .34
VL1	Normal Condition – Single Lockup	Standard Array Configuration	6 in from vent

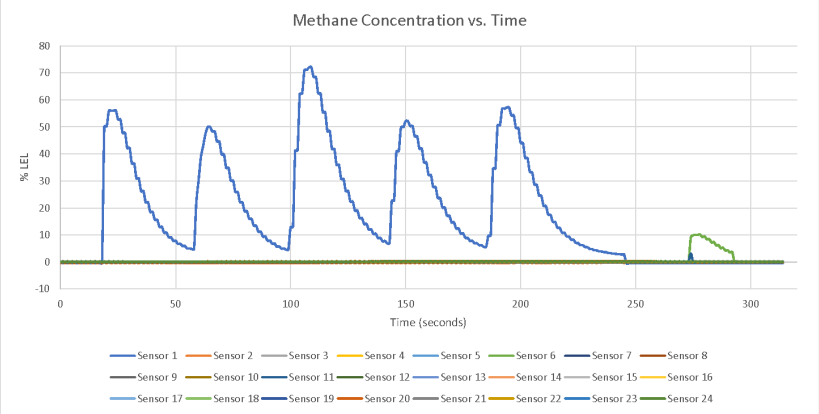


GTI ENERGY

	2 PSI	222489-018_single_sensor1 next to vent	Sigma = .3
VL1	Normal Condition – Single Lockup	Standard Array Configuration	1 in from vent

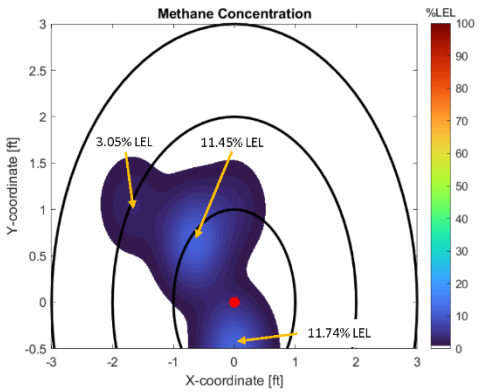


GTI ENERGY


Methane Concentration vs. Time
% LEL
80
70
60
50
40
30
20
10
0
-10
0
50
100
150
200
250
300
Time (seconds)
Sensor 1
Sensor 2
Sensor 3
Sensor 4
Sensor 5
Sensor 6
Sensor 7
Sensor 8
Sensor 9
Sensor 10
Sensor 11
Sensor 12
Sensor 13
Sensor 14
Sensor 15
Sensor 16
Sensor 17
Sensor 18
Sensor 19
Sensor 20
Sensor 21
Sensor 22
Sensor 23
Sensor 24

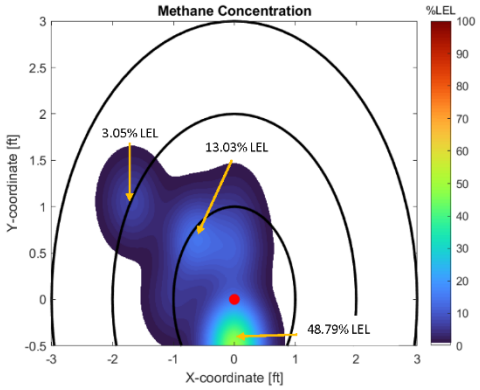
7" WC

	7 In-WC	222489-013_DT1	Sigma = .34
VL1	Primary Diaphragm Tear	Standard Array Configuration	6 in from vent

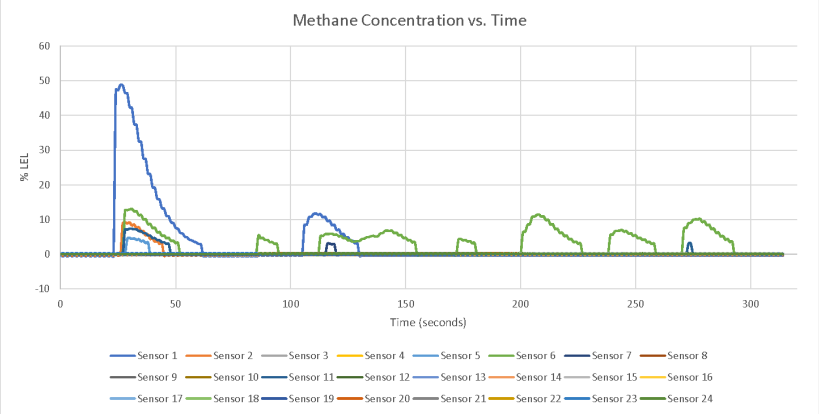


GTI ENERGY

	7 In-WC	222489-013_DT2_trial1	Sigma = .3
VL1	Primary and Secondary Diaphragm Tear	Standard Array Configuration	6 in from vent

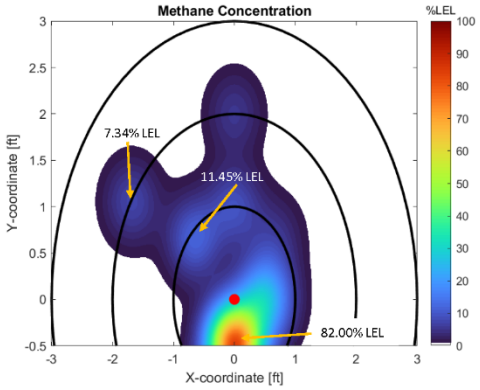


GTI ENERGY

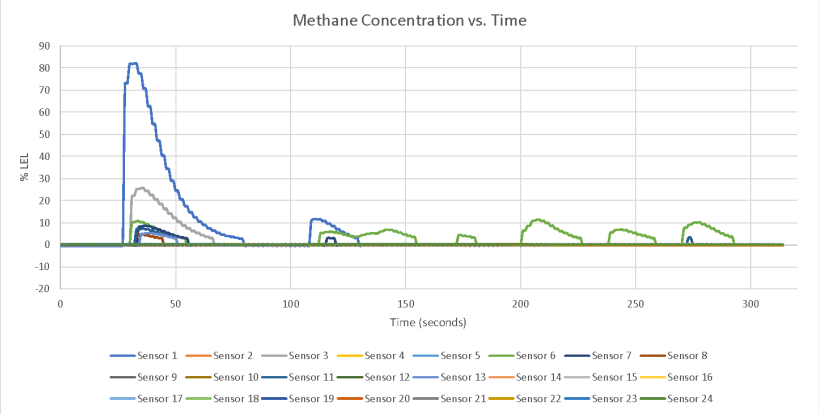

Methane Concentration vs. Time
% LEL
60
50
40
30
20
10
0
-10
0
50
100
150
200
250
300
Time (seconds)
Sensor 1
Sensor 2
Sensor 3
Sensor 4
Sensor 5
Sensor 6
Sensor 7
Sensor 8
Sensor 9
Sensor 10
Sensor 11
Sensor 12
Sensor 13
Sensor 14
Sensor 15
Sensor 16
Sensor 17
Sensor 18
Sensor 19
Sensor 20
Sensor 21
Sensor 22
Sensor 23
Sensor 24

GTI ENERGY

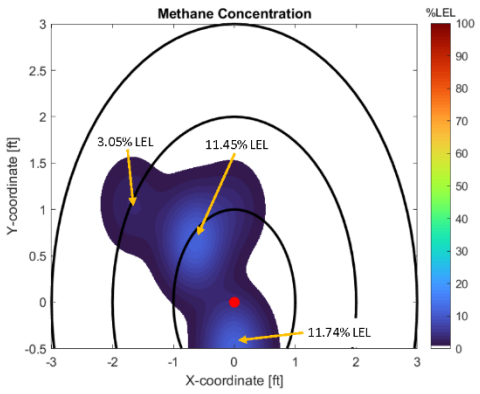
	7 In-WC	222489-013_DT2_trial2	Sigma = .3
VL1	Primary and Secondary Diaphragm Tear	Standard Array Configuration	6 in from vent



GTI ENERGY

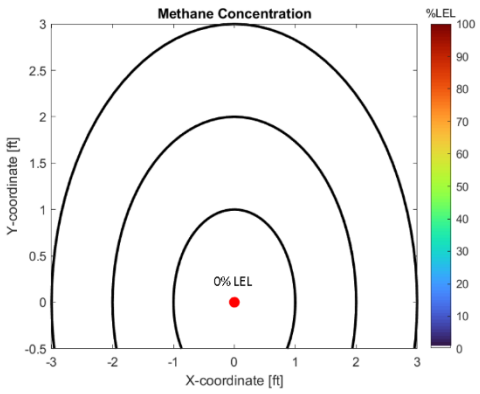

Methane Concentration vs. Time
% LEL
90
80
70
60
50
40
30
20
10
0
-10
-20
0
50
100
150
200
250
300
Time (seconds)
Sensor 1
Sensor 2
Sensor 3
Sensor 4
Sensor 5
Sensor 6
Sensor 7
Sensor 8
Sensor 9
Sensor 10
Sensor 11
Sensor 12
Sensor 13
Sensor 14
Sensor 15
Sensor 16
Sensor 17
Sensor 18
Sensor 19
Sensor 20
Sensor 21
Sensor 22
Sensor 23
Sensor 24

	7 In-WC	222489-014_LD	Sigma = .34
VL1	Lever Disconnect	Standard Array Configuration	6 in from vent



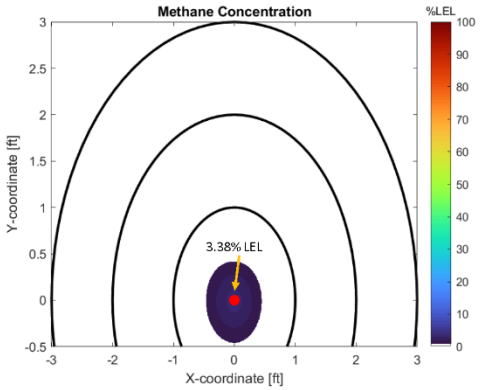
GTI ENERGY

	7 In-WC	222489-015_multi lockup_sensor1 6in	Sigma = .3
VL1	Normal Condition – Multi Lockup	Standard Array Configuration	6 in from vent



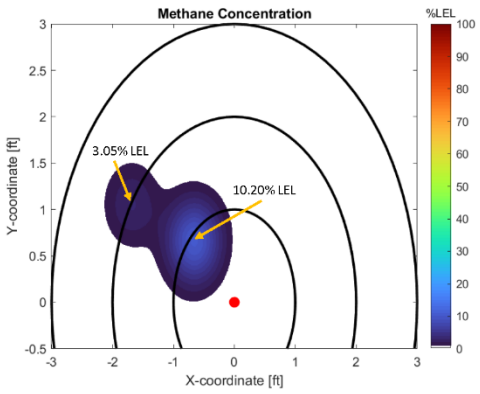
GTI ENERGY

	7 In-WC	222489-015_multi lockup_sensor1 next to vent	Sigma = .3
VL1	Normal Condition – Multi Lockup	Standard Array Configuration	1 in from vent

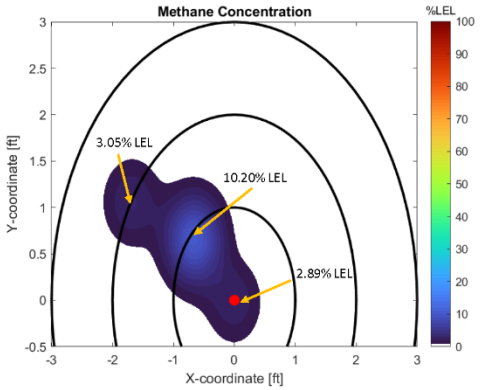


GTI ENERGY

	7 In-WC	222489-015_single lockup_sensor1 6in	Sigma = .3
VL1	Normal Condition – Single Lockup	Standard Array Configuration	6 in from vent



	7 In-WC	222489-015_single lockup_sensor1 next to vent	Sigma = .31
VL1	Normal Condition – Single Lockup	Standard Array Configuration	1 in from vent



GTI ENERGY

VL2

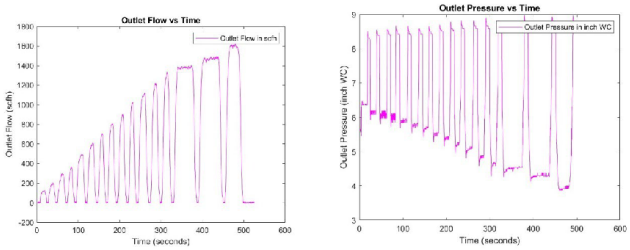
Modified Lockup Tests

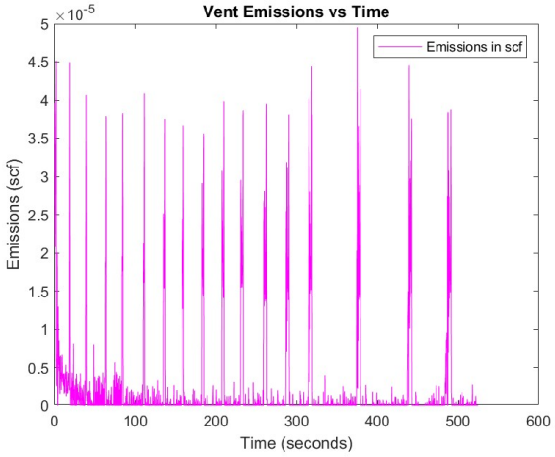
7" WC Outlet, 10-psig Inlet

- 222489-039

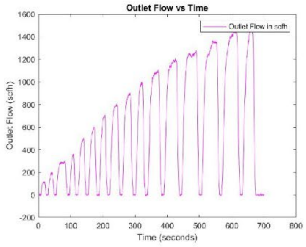
The volume of total emissions in 525.15 seconds is 0.0120 scf.

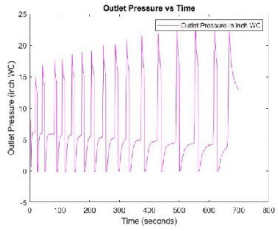
The flow rate of emissions is 0.0825 scfh.

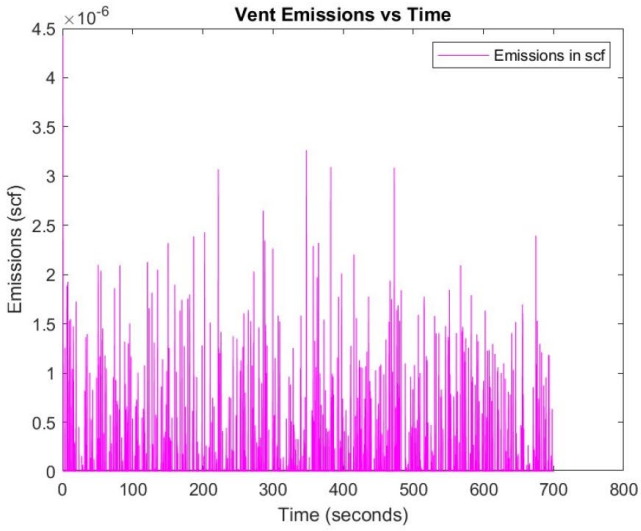




- 222489-039 (Blocked Vent)
  The volume of total emissions in 701.00 seconds is 0.0008 scf.
  The flow rate of emissions is 0.0042 scfh.

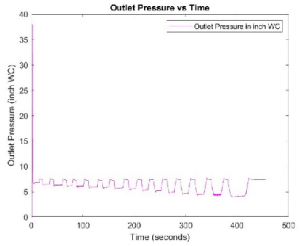


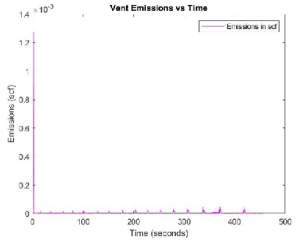


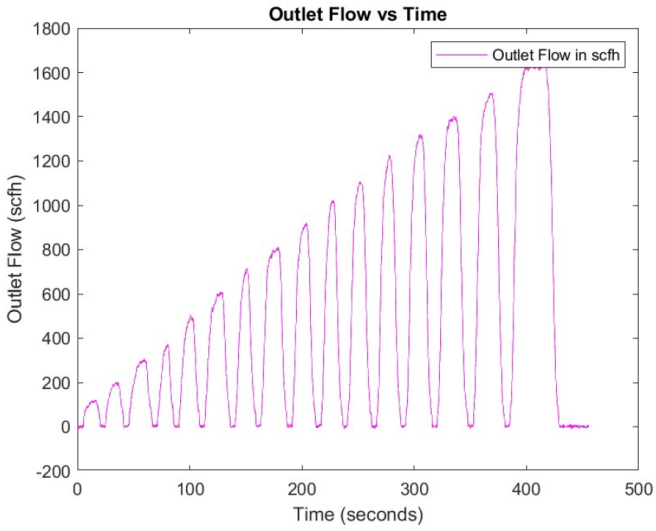


GTI ENERGY

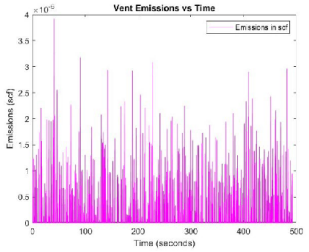
- 222489-040
  The volume of total emissions in 455.63 seconds is 0.0159 scf.
  The flow rate of emissions is 0.1260 scfh.

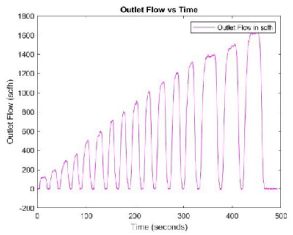


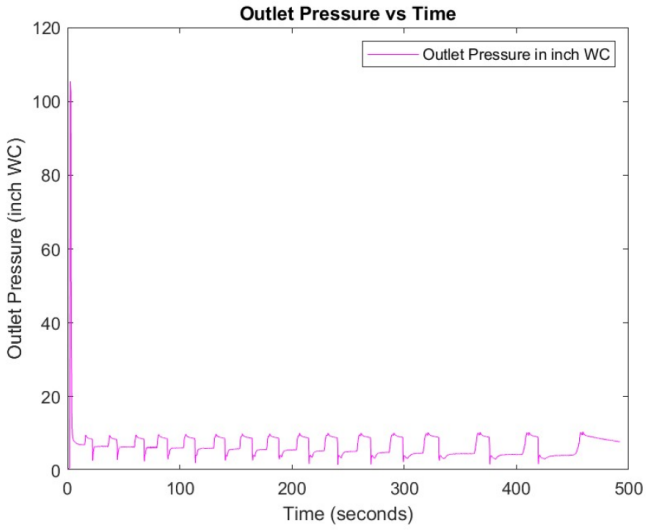




- 222489-040 (Blocked Vent)
  The volume of total emissions in 492.14 seconds is 0.0009 scf.
  The flow rate of emissions is 0.0069 scfh.

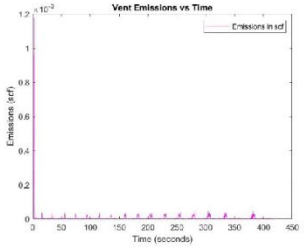


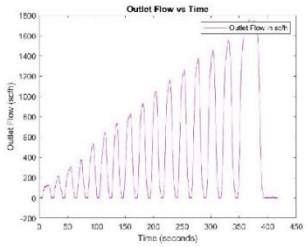


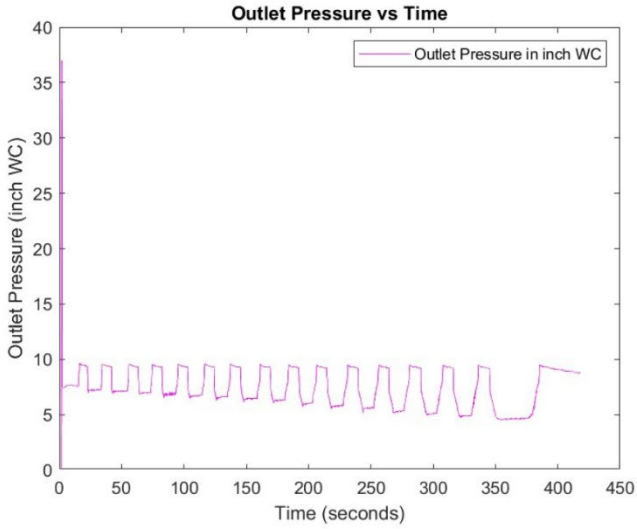


GTI ENERGY

- 222489-041
  The volume of total emissions in 418.46 seconds is 0.0169 scf.
  The flow rate of emissions is 0.1454 scfh.

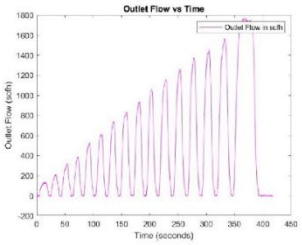


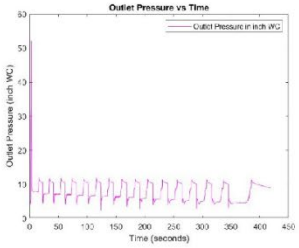


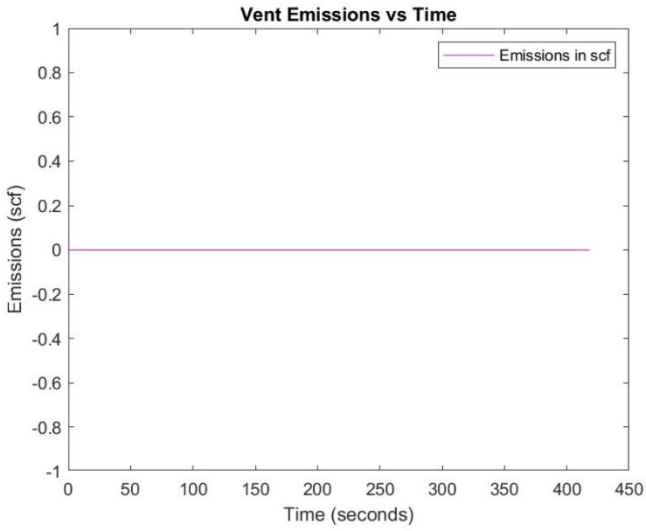


GTI ENERGY

- 222489-041 (Blocked Vent)
  The volume of total emissions in 418.50 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.







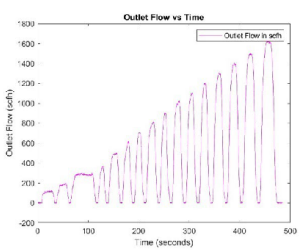
GTI ENERGY

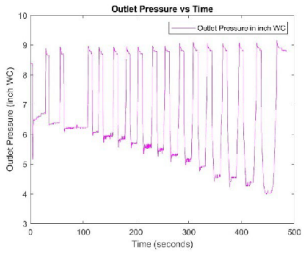
7" WC Outlet, 60-psig Inlet

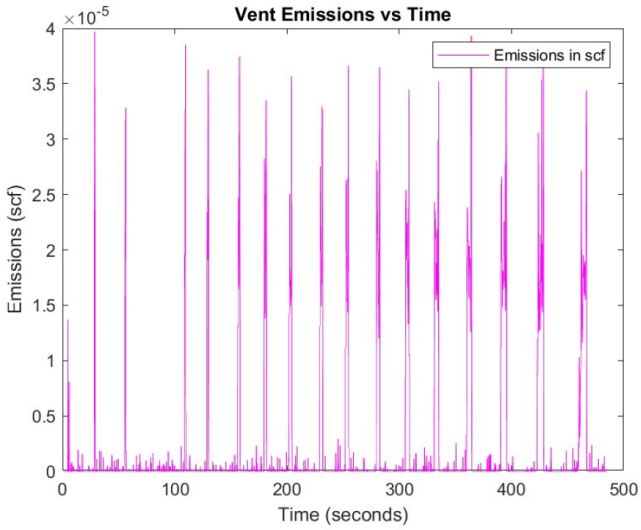
- 222489-039

The volume of total emissions in 485.17 seconds is 0.0101 scf.

The flow rate of emissions is 0.0747 scfh.

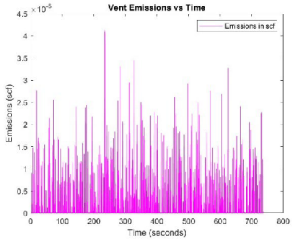


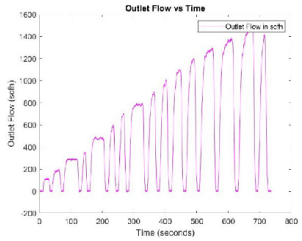


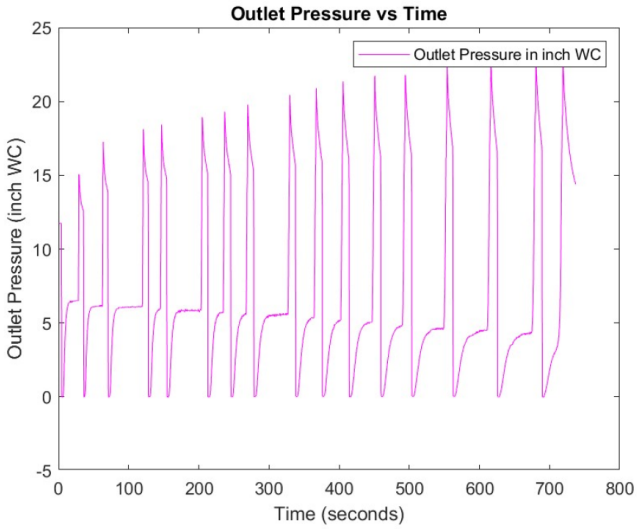


GTI ENERGY

- 222489-039 (Blocked Vent)
  The volume of total emissions in 737.19 seconds is 0.0011 scf.
  The flow rate of emissions is 0.0052 scfh.





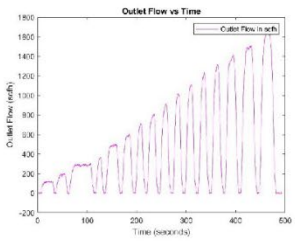


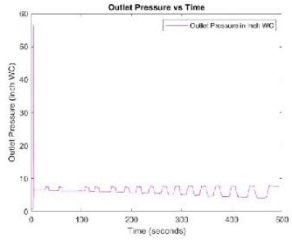
GTI ENERGY

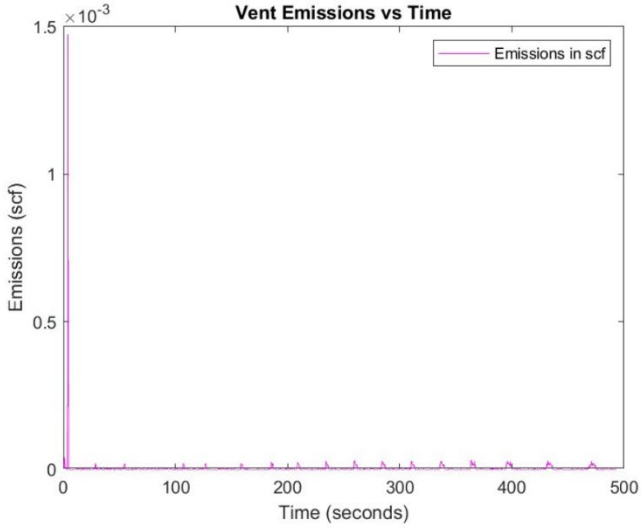
- 222489-040

The volume of total emissions in 493.02 seconds is 0.0155 scf.

The flow rate of emissions is 0.1131 scfh.

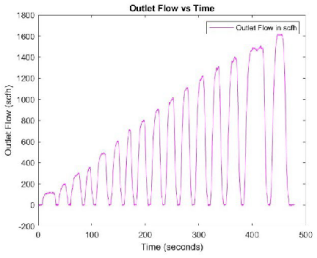


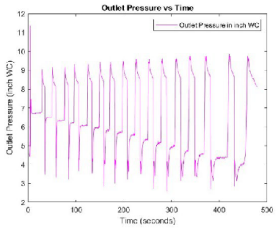


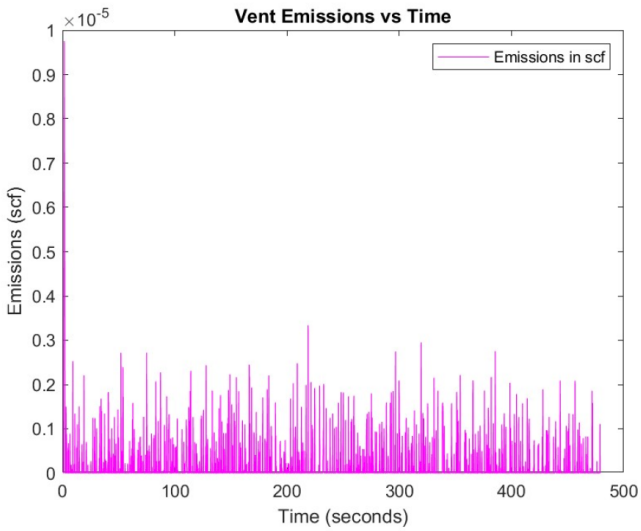


GTI ENERGY

- 222489-040 (Blocked Vent)
  The volume of total emissions in 479.17 seconds is 0.0009 scf.
  The flow rate of emissions is 0.0067 scfh.

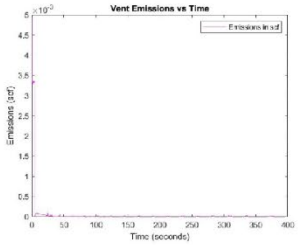


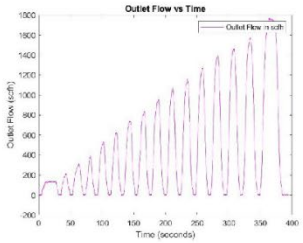


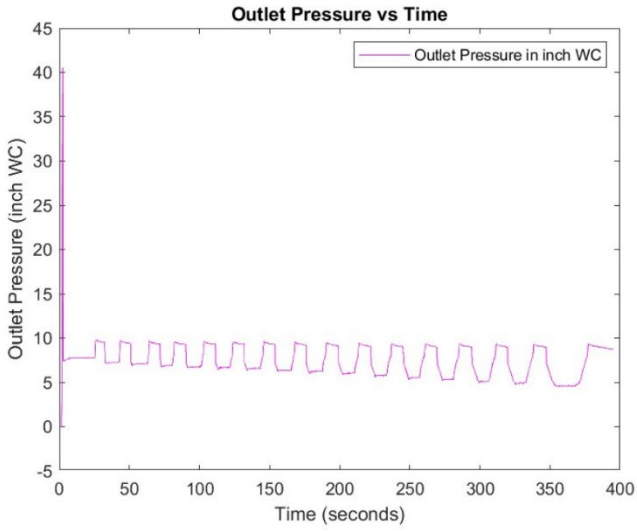


GTI ENERGY

- 222489-041
  The volume of total emissions in 395.46 seconds is 0.1480 scf.
  The flow rate of emissions is 1.3477 scfh.

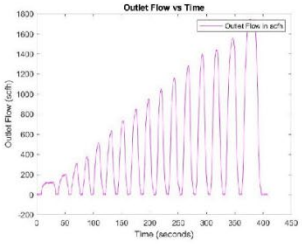


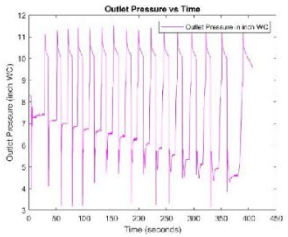


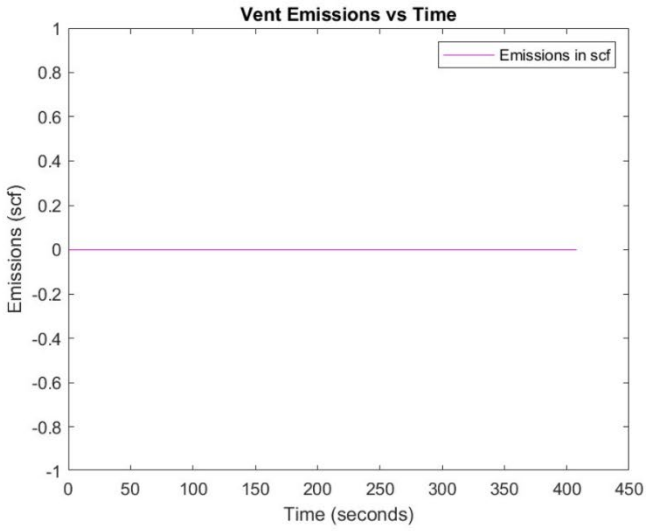


GTI ENERGY

- 222489-041 (Blocked Vent)
  The volume of total emissions in 407.96 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.





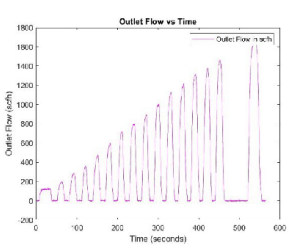


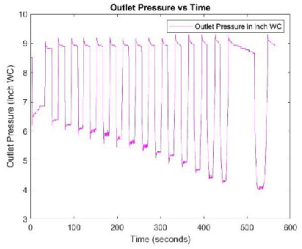
GTI ENERGY

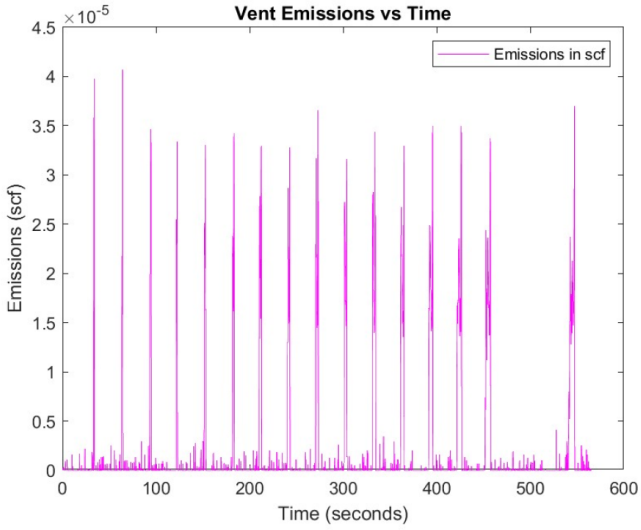
7" WC Outlet, 100-psig Inlet

- 222489-039

  The volume of total emissions in 565.72 seconds is 0.0102 scf.
  The flow rate of emissions is 0.0651 scfh.

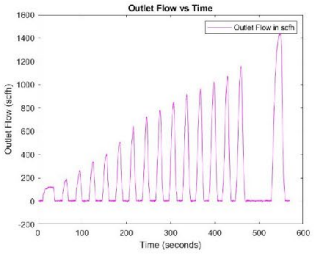


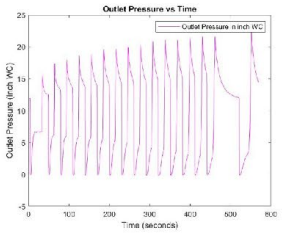


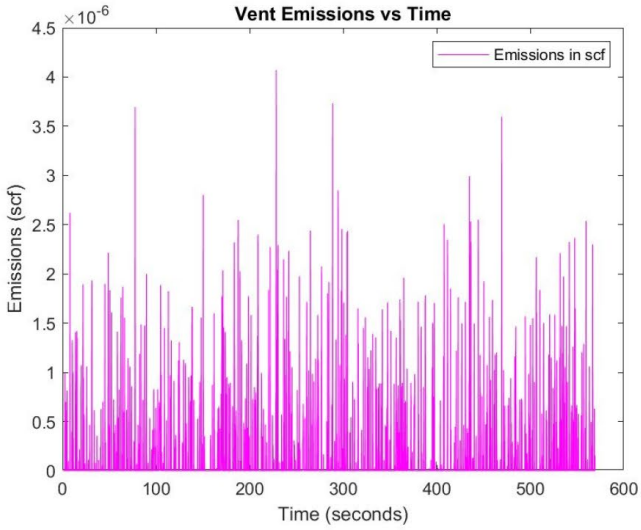


GTI ENERGY

- 222489-039 (Blocked Vent)
  The volume of total emissions in 569.48 seconds is 0.0010 scf.
  The flow rate of emissions is 0.0061 scfh.

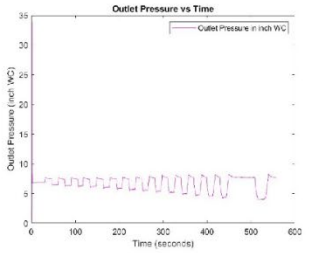


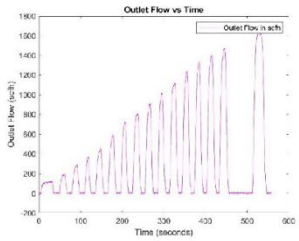


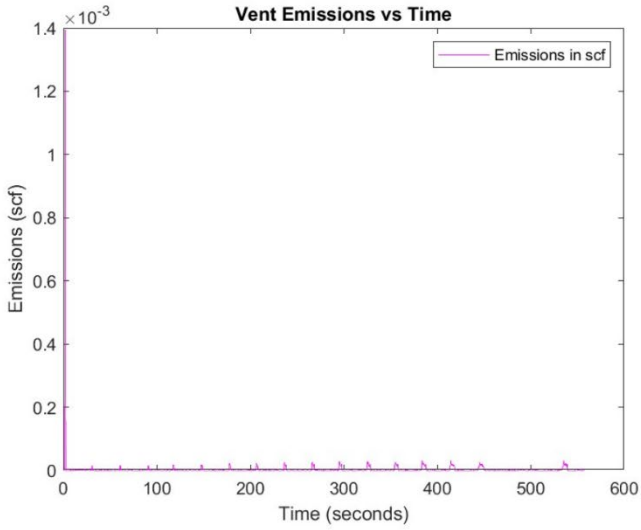


GTI ENERGY

- 222489-040
  The volume of total emissions in 557.64 seconds is 0.0154 scf.
  The flow rate of emissions is 0.0993 scfh.

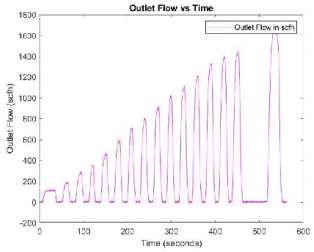


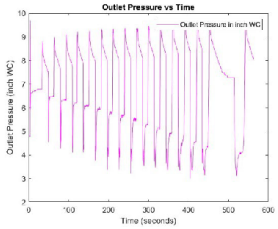


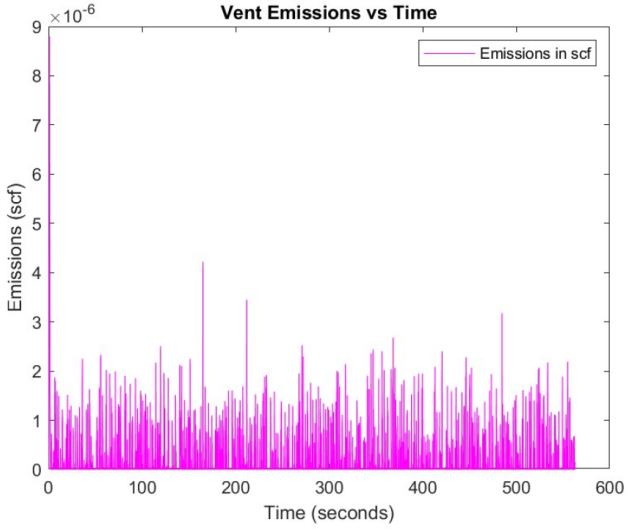


GTI ENERGY

- 222489-040 (Blocked Vent)
  The volume of total emissions in 563.03 seconds is 0.0012 scf.
  The flow rate of emissions is 0.0078 scfh.

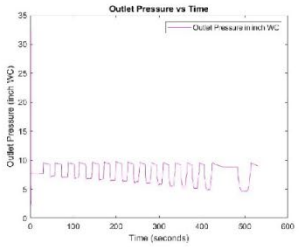


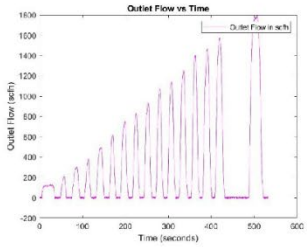


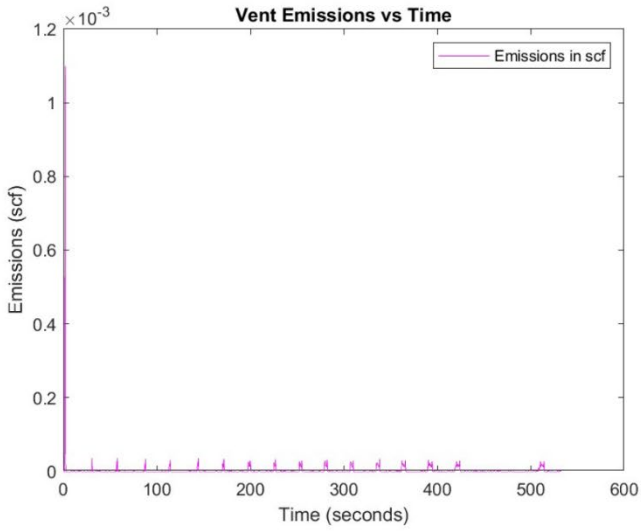


GTI ENERGY

- 222489-041
  The volume of total emissions in 532.69 seconds is 0.0149 scf.
  The flow rate of emissions is 0.1005 scfh.

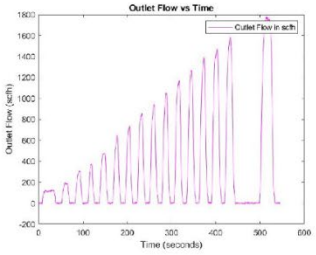


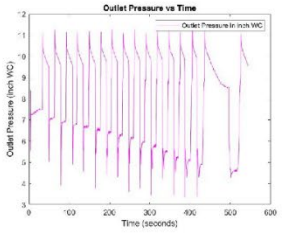


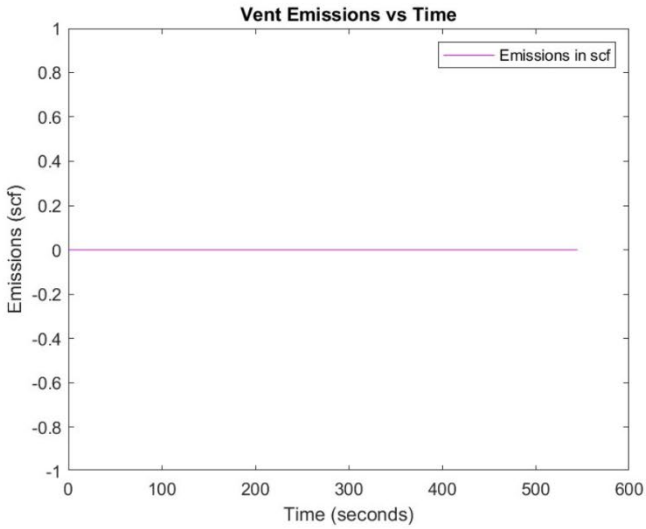


GTI ENERGY

- 222489-041 (Blocked Vent)
  The volume of total emissions in 544.94 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.







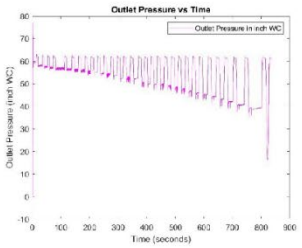
GTI ENERGY

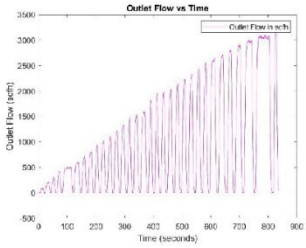
2-psig Outlet, 10-psig Inlet

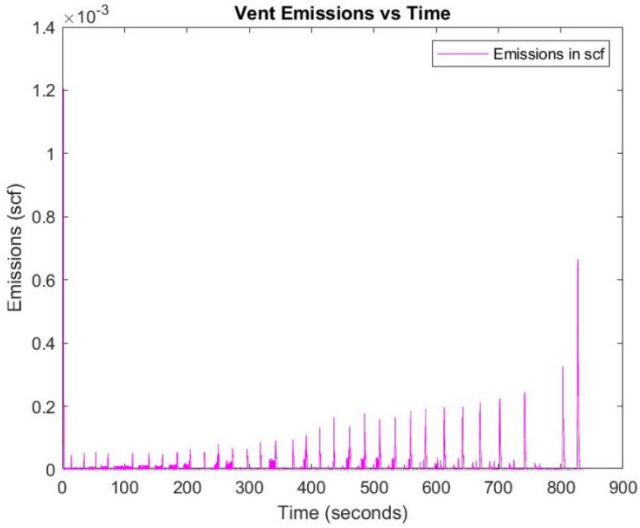
- 222489-042

  The volume of total emissions in 836.93 seconds is 0.0738 scf.

  The flow rate of emissions is 0.3176 scfh.

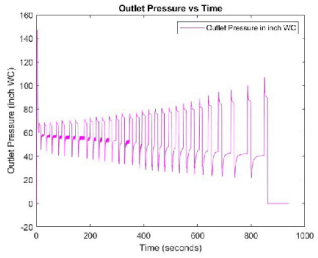


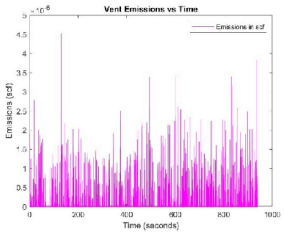


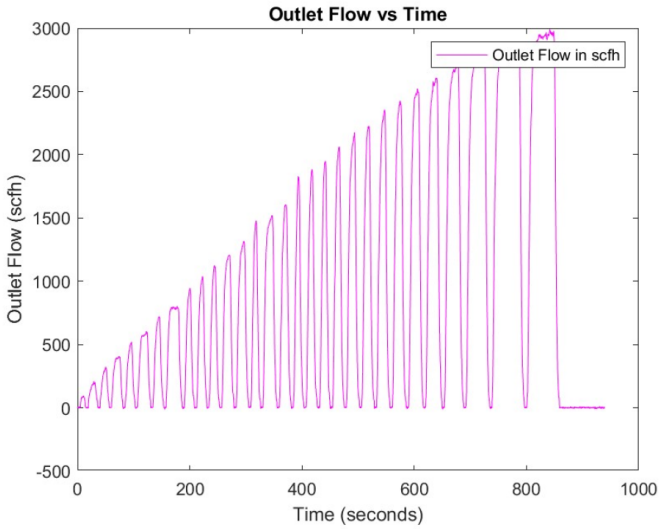


GTI ENERGY

- 222489-042_BV
  The volume of total emissions in 938.97 seconds is 0.0011 scf.
  The flow rate of emissions is 0.0040 scfh.

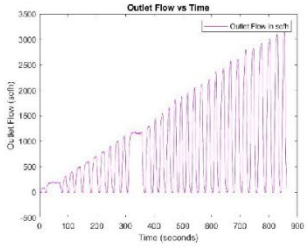


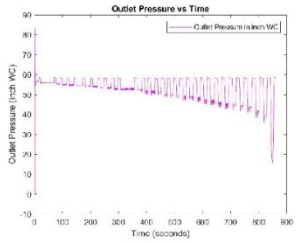


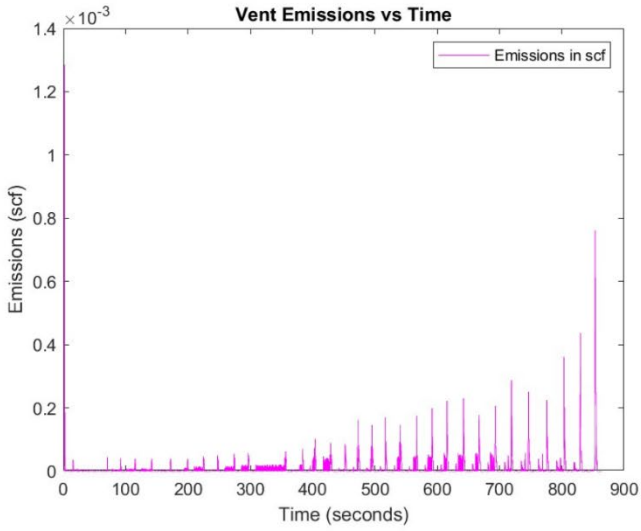


GTI ENERGY

- 222489-043
  The volume of total emissions in 863.51 seconds is 0.0781 scf.
  The flow rate of emissions is 0.3254 scfh.

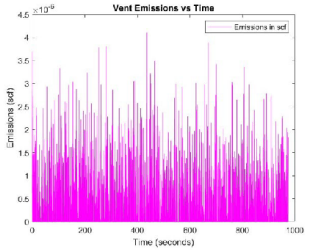


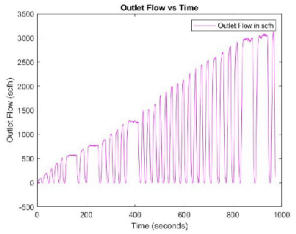


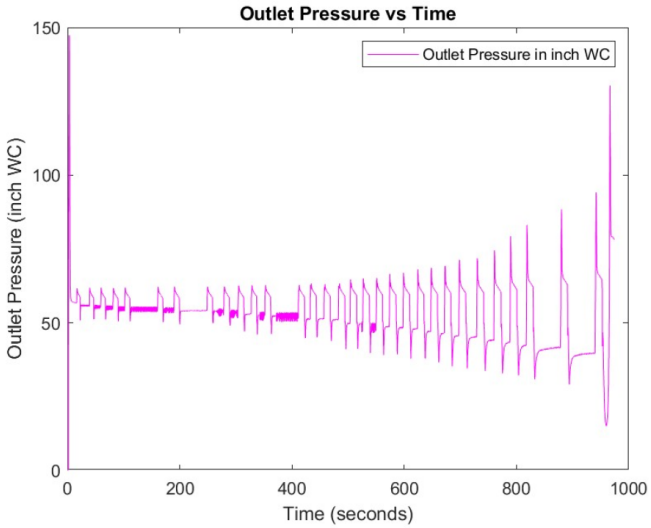


GTI ENERGY

- 222489-043_BV
  The volume of total emissions in 974.31 seconds is 0.0026 scf.
  The flow rate of emissions is 0.0095 scfh.

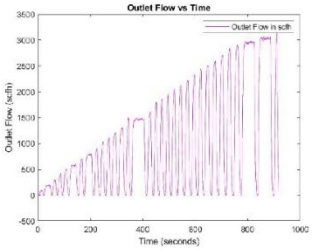


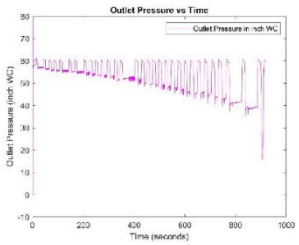


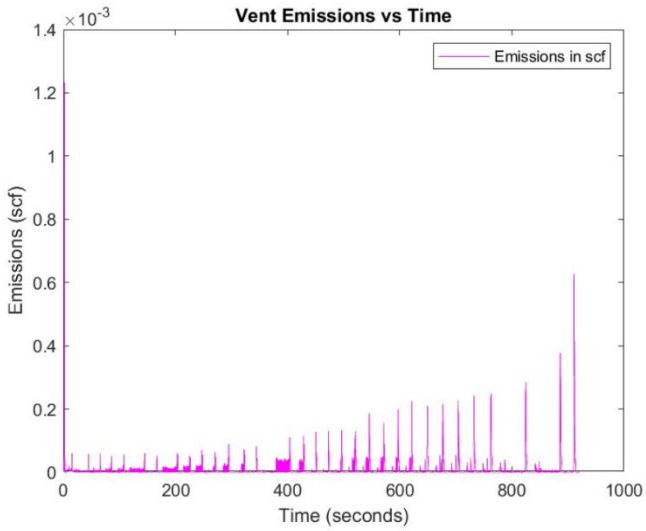


GTI ENERGY

- 222489-044
  The volume of total emissions in 920.20 seconds is 0.0852 scf.
  The flow rate of emissions is 0.3333 scfh.

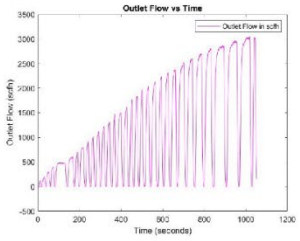


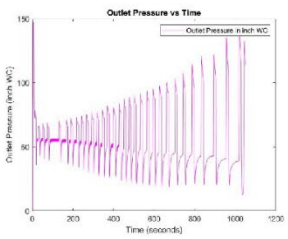


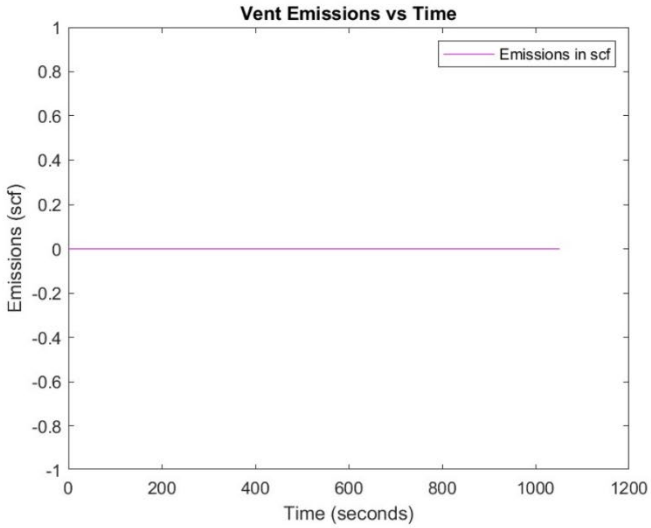


GTI ENERGY

- 222489-044_BV
  The volume of total emissions in 1051.51 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.







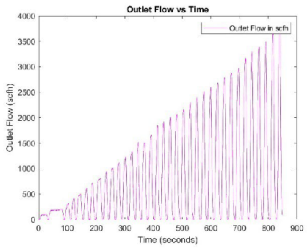
GTI ENERGY

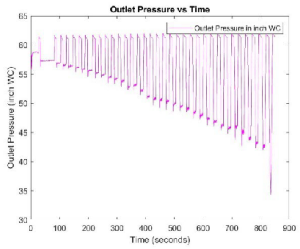
2-psig Outlet, 60-psig Inlet

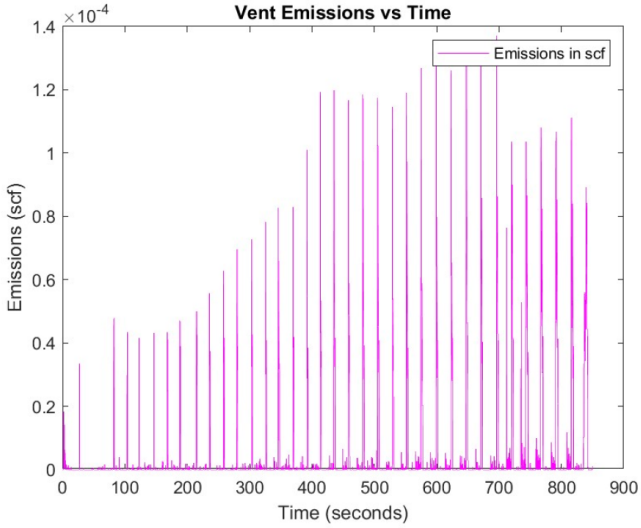
- 222489-042

  The volume of total emissions in 849.67 seconds is 0.0433 scf.

  The flow rate of emissions is 0.1835 scfh.

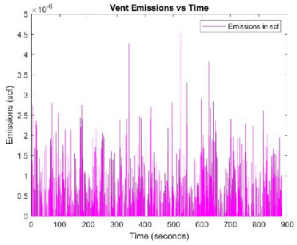


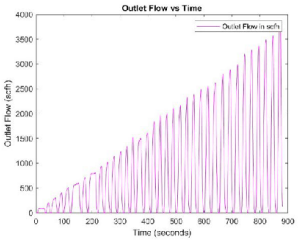


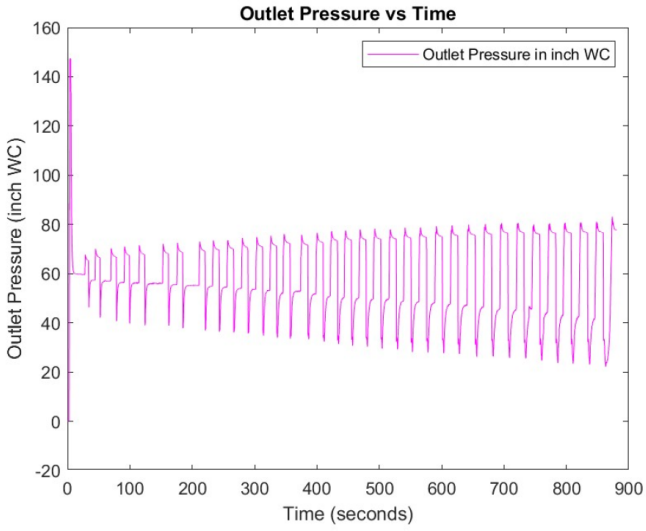


GTI ENERGY

- 222489-042_BV
  The volume of total emissions in 880.87 seconds is 0.0011 scf.
  The flow rate of emissions is 0.0047 scfh.

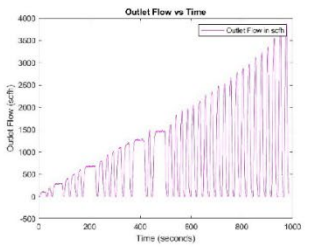


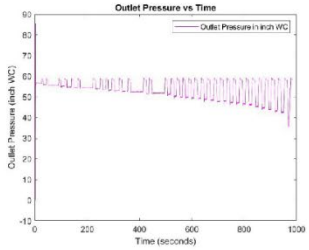


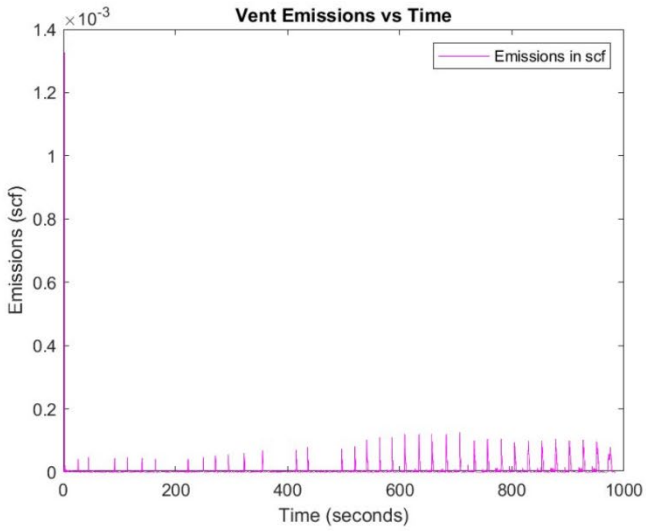


GTI ENERGY

- 222489-043
  The volume of total emissions in 984.83 seconds is 0.0509 scf.
  The flow rate of emissions is 0.1860 scfh.

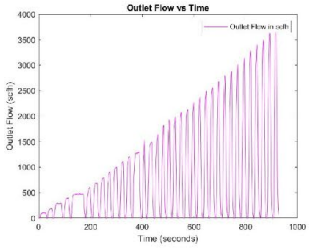


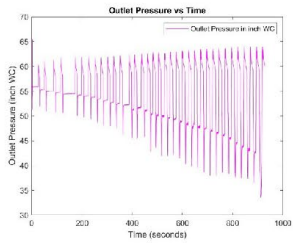


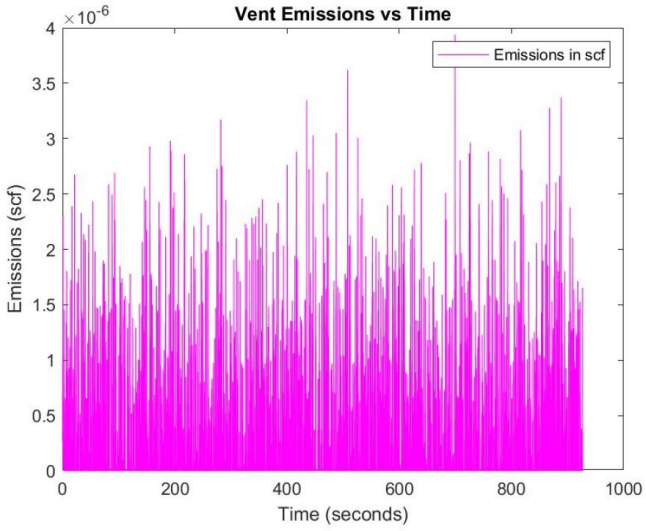


GTI ENERGY

- 222489-043_BV
  The volume of total emissions in 926.88 seconds is 0.0026 scf.
  The flow rate of emissions is 0.0102 scfh.

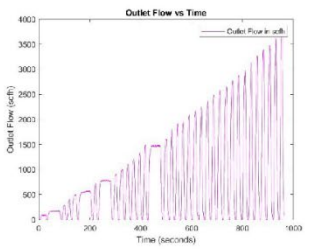


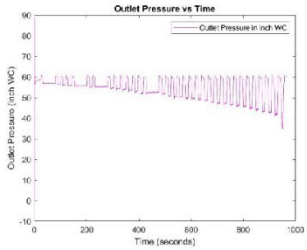


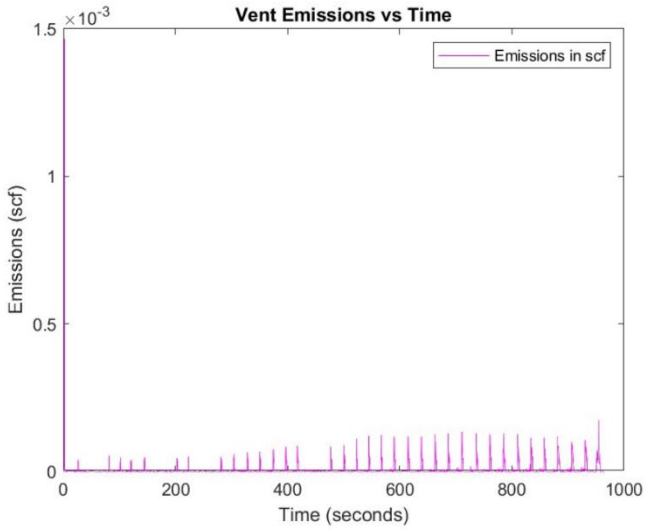


GTI ENERGY

- 222489-044
  The volume of total emissions in 964.46 seconds is 0.0547 scf.
  The flow rate of emissions is 0.2042 scfh.

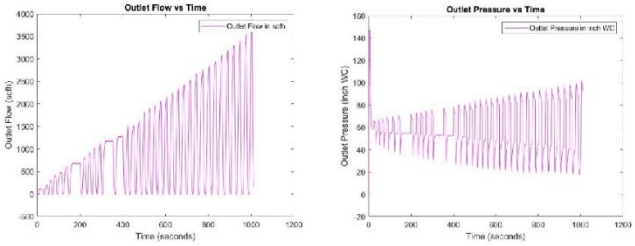


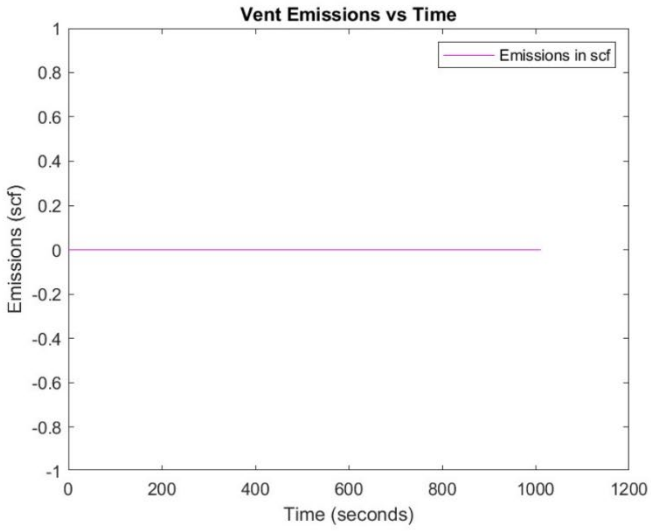




GTI ENERGY

- 222489-044_BV
  The volume of total emissions in 1011.73 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.





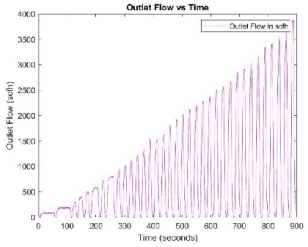
GTI ENERGY

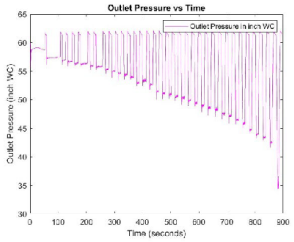
2-psig Outlet, 100-psig Inlet

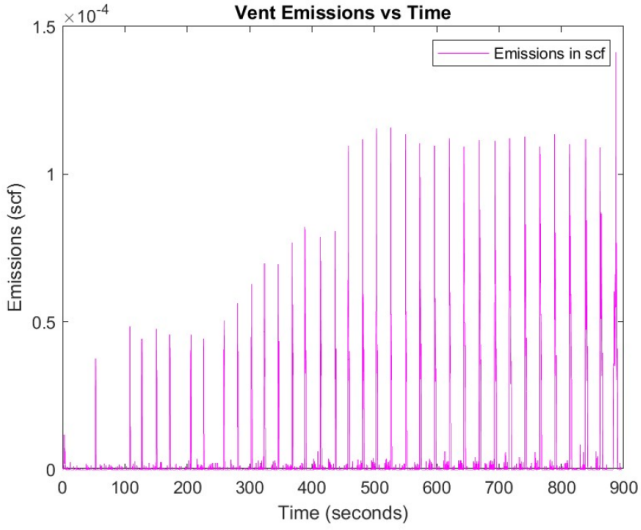
- 222489-042

  The volume of total emissions in 896.86 seconds is 0.0419 scf.

  The flow rate of emissions is 0.1681 scfh.

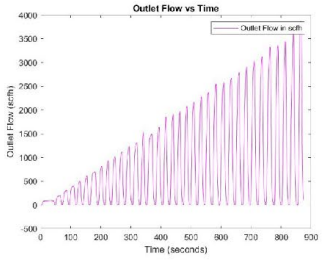


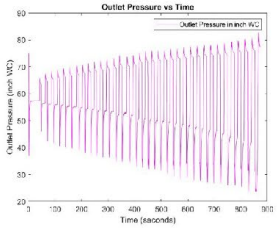


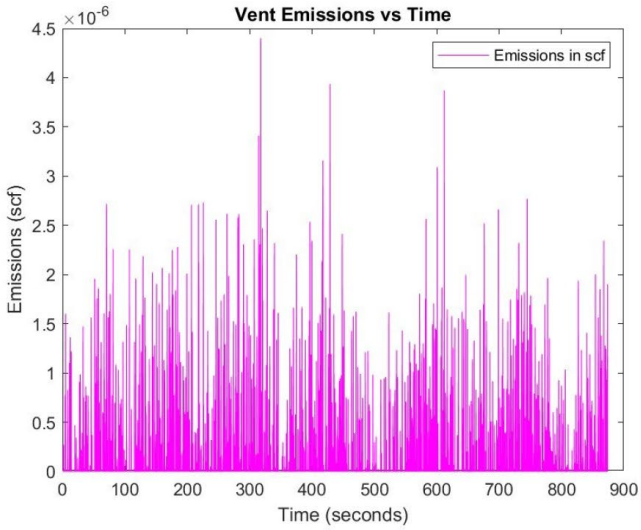


GTI ENERGY

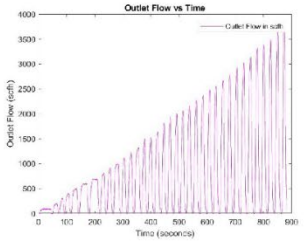
- 222489-042_BV
  The volume of total emissions in 874.51 seconds is 0.0013 scf.
  The flow rate of emissions is 0.0054 scfh.

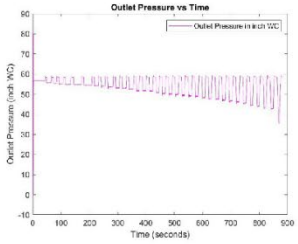


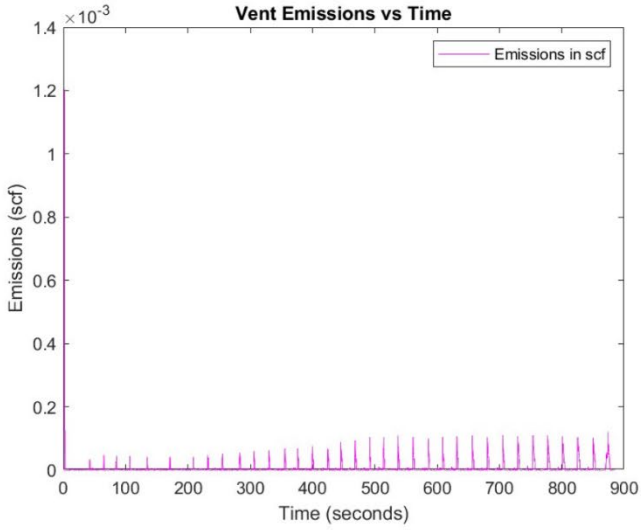




- 222489-043
  The volume of total emissions in 884.35 seconds is 0.0487 scf.
  The flow rate of emissions is 0.1983 scfh.

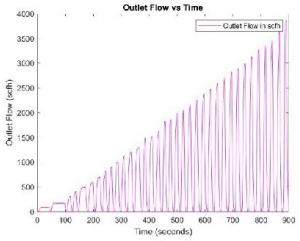


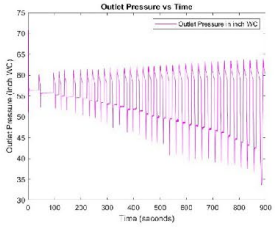


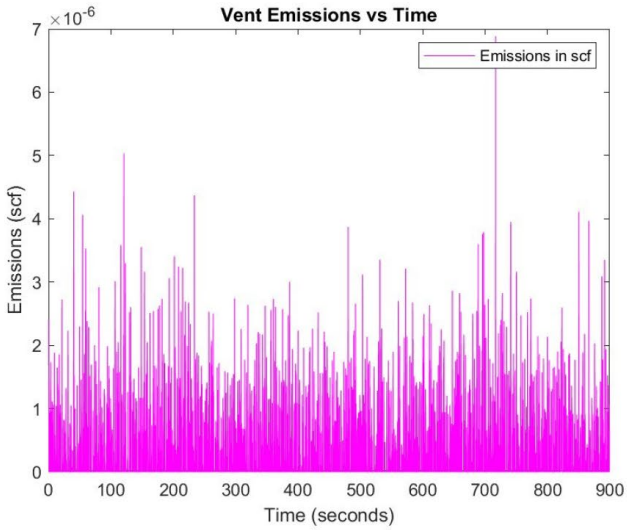


GTI ENERGY

- 222489-043_BV
  The volume of total emissions in 899.55 seconds is 0.0027 scf.
  The flow rate of emissions is 0.0107 scfh.

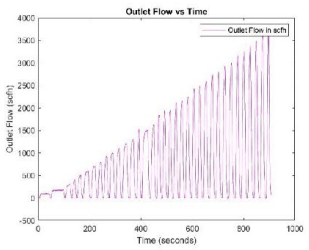


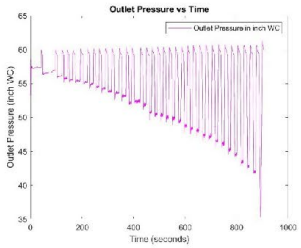


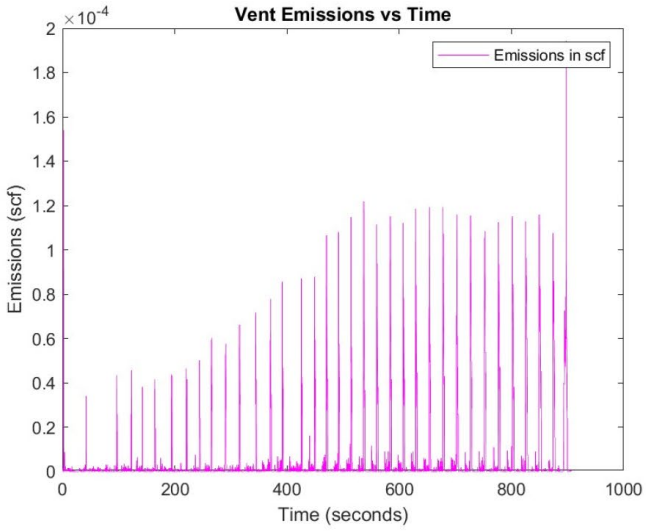


GTI ENERGY

- 222489-044

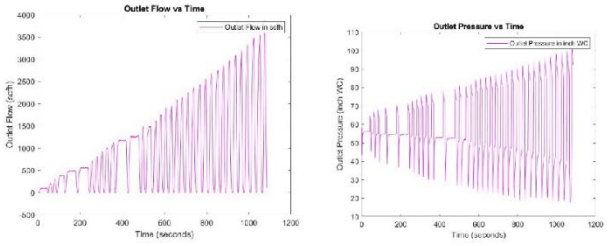


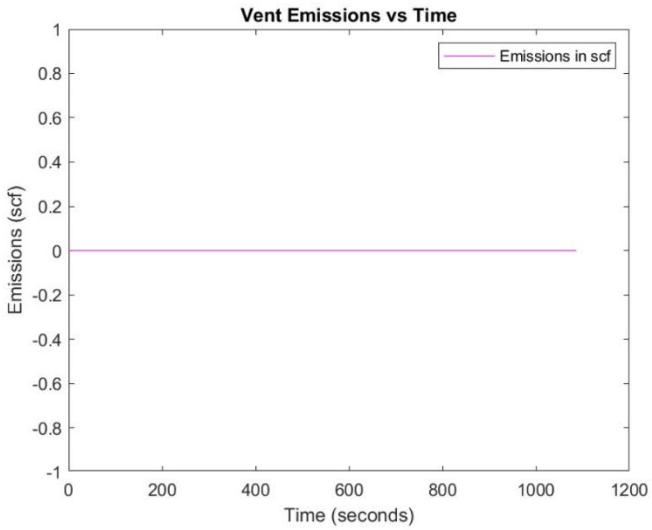




GTI ENERGY

- 222489-044_BV
  The volume of total emissions in 1086.12 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.





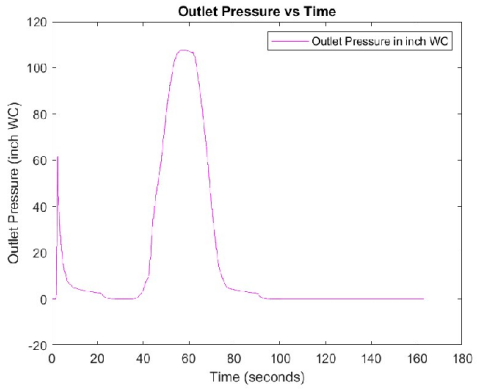
GTI ENERGY

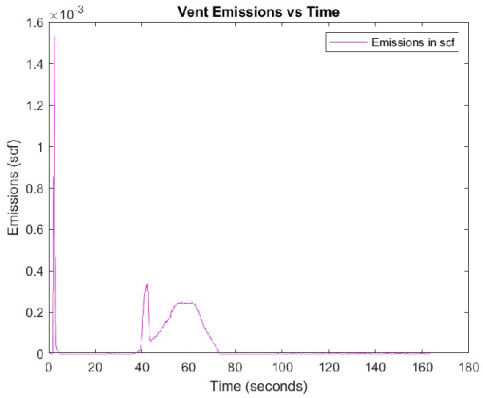
Relief Tests

7" WC Outlet, 10-psig Inlet

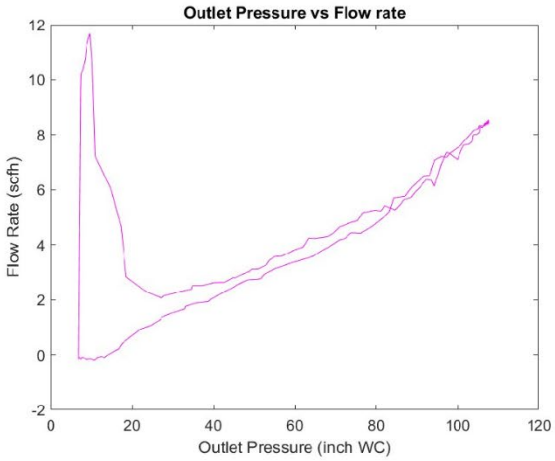
- 222489-039

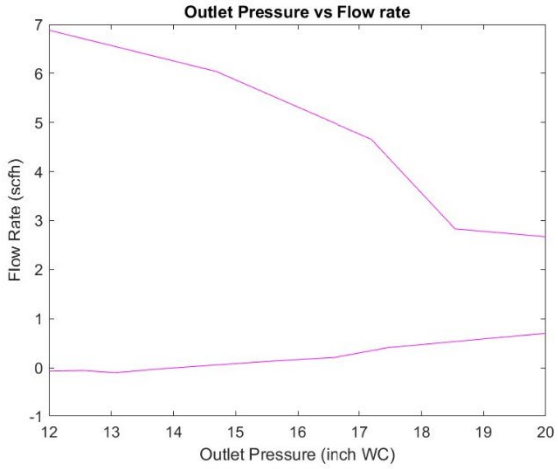
  The volume of total emissions in 163.42 seconds is 0.0627 scf.
  The average flow rate of emissions at 18 inches WC is 2.00 scfh.



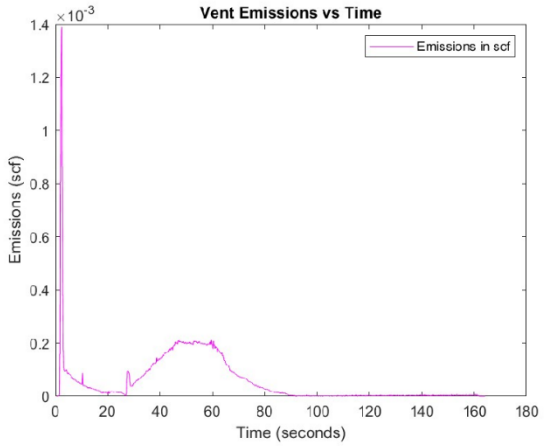


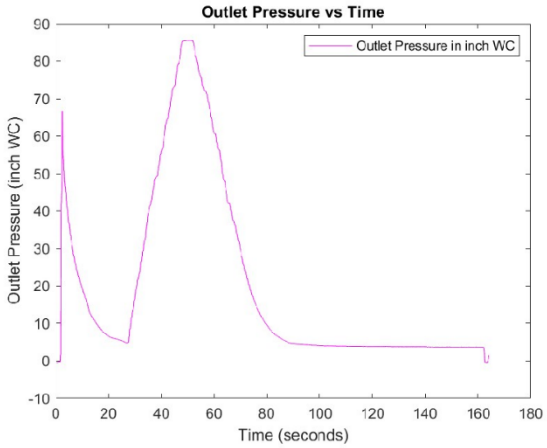
GTI ENERGY


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
12
10
8
6
4
2
0
-2
0
20
40
60
80
100
120

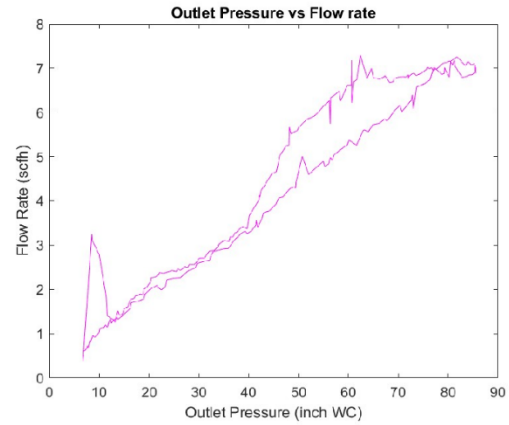

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
7
6
5
4
3
2
1
0
-1
12
13
14
15
16
17
18
19
20

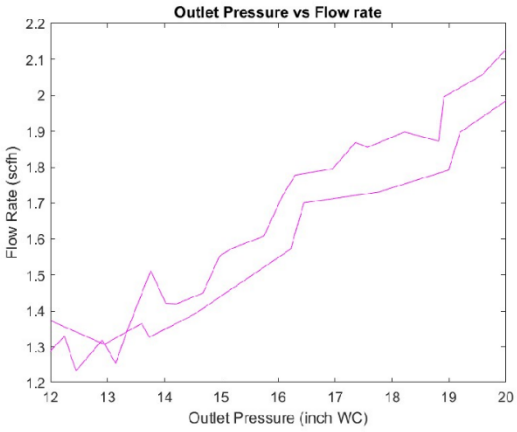
- 222489-039_DT1
  The volume of total emissions in 164.31 seconds is 0.0865 scf.
  The average flow rate of emissions at 18 inches WC is 1.73 scfh.





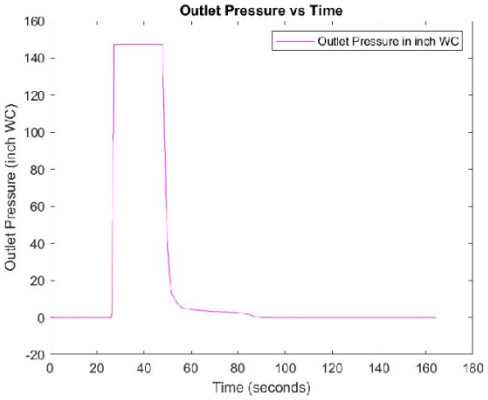
GTI ENERGY

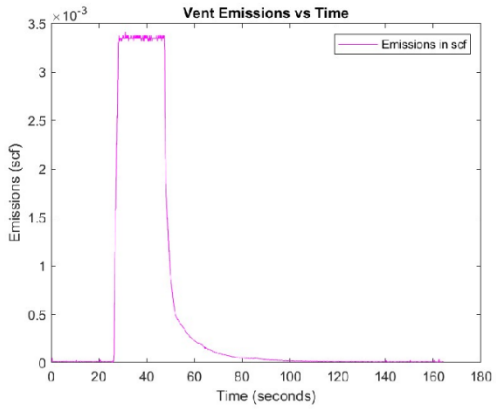

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
1
2
3
4
5
6
7
8
0
10
20
30
40
50
60
70
80
90


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2
2.1
2.2
12
13
14
15
16
17
18
19
20

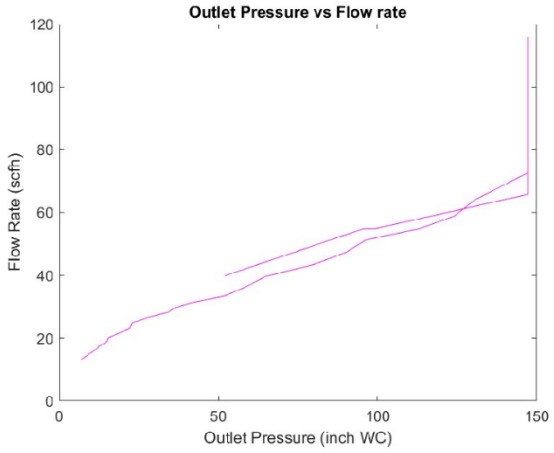
GTI ENERGY

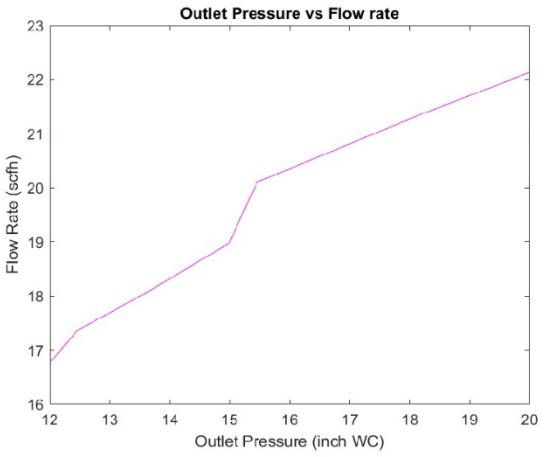
- 222489-039_DT2
  The volume of total emissions in 164.30 seconds is 0.7772 scf.
  The average flow rate of emissions at 18 inches WC is 21.34 scfh.





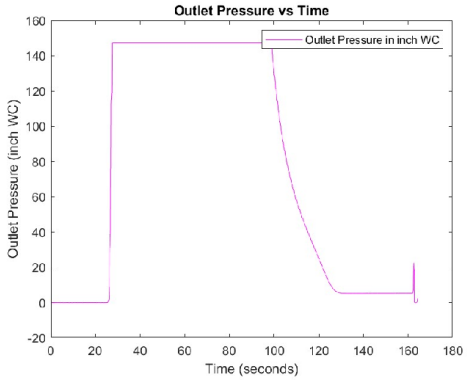
GTI ENERGY

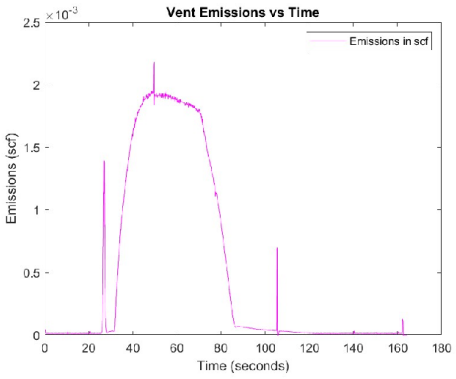

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
20
40
60
80
100
120
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
16
17
18
19
20
21
22
23
12
13
14
15
16
17
18
19
20

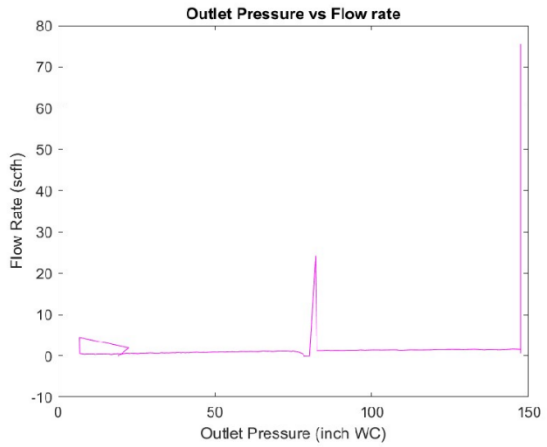
GTI ENERGY

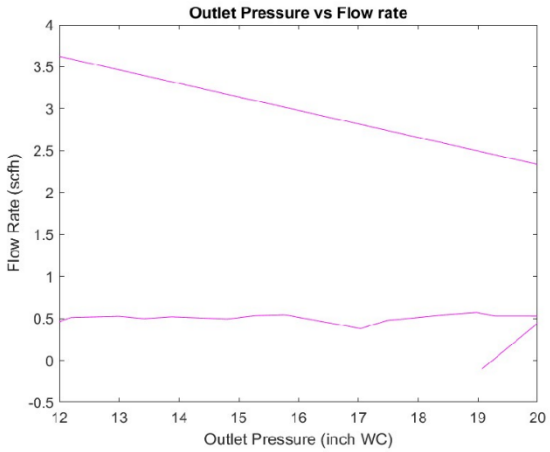
- 222489-039_LD
  The volume of total emissions in 164.32 seconds is 0.8147 scf.
  The average flow rate of emissions at 18 inches WC is 0.49 scfh.





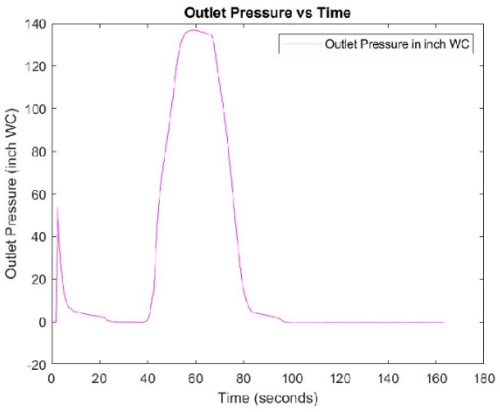
GTI ENERGY

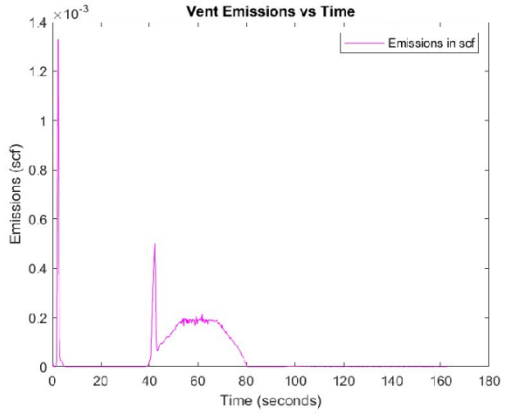

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
80
70
60
50
40
30
20
10
0
-10
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
4
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
12
13
14
15
16
17
18
19
20

GTI ENERGY

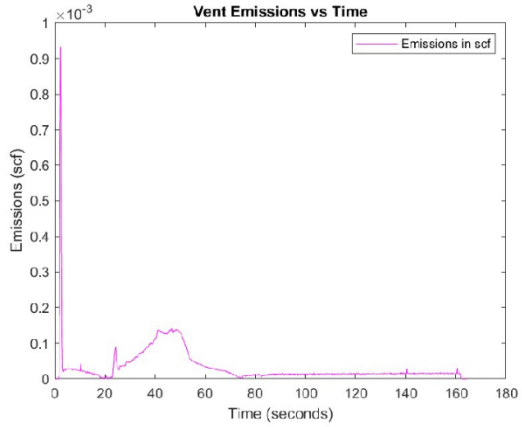
- 222489-040
  The volume of total emissions in 163.26 seconds is 0.0674 scf.
  The average flow rate of emissions at 18 inches WC is 0.27 scfh.

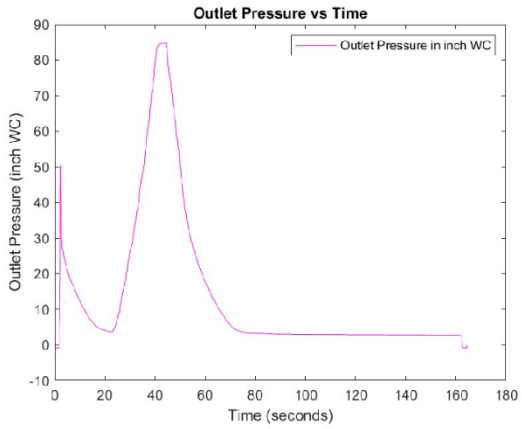




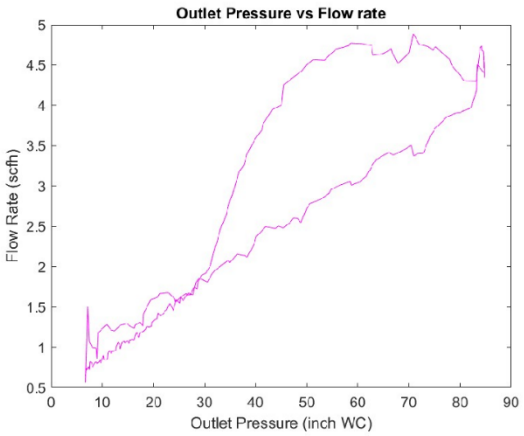
GTI ENERGY

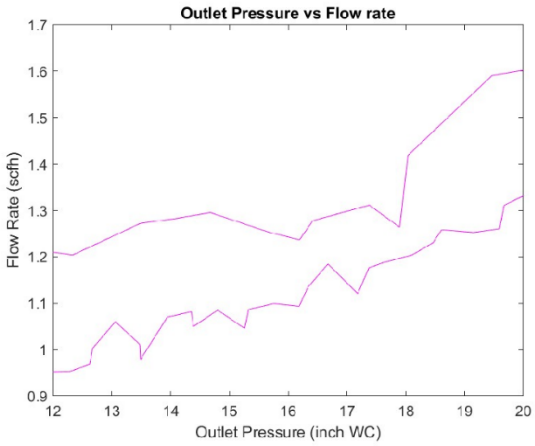
- 222489-040_DT1
  The volume of total emissions in 164.26 seconds is 0.0526 scf.
  The average flow rate of emissions at 18 inches WC is 2.72 scfh.





GTI ENERGY

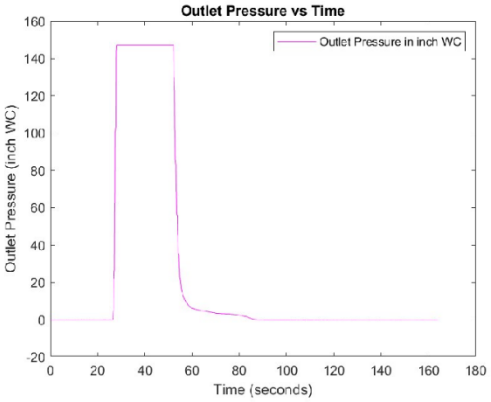

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
10
20
30
40
50
60
70
80
90

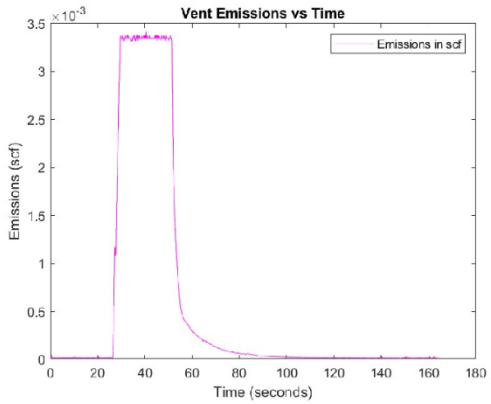

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
12
13
14
15
16
17
18
19
20

- 222489-040_DT2

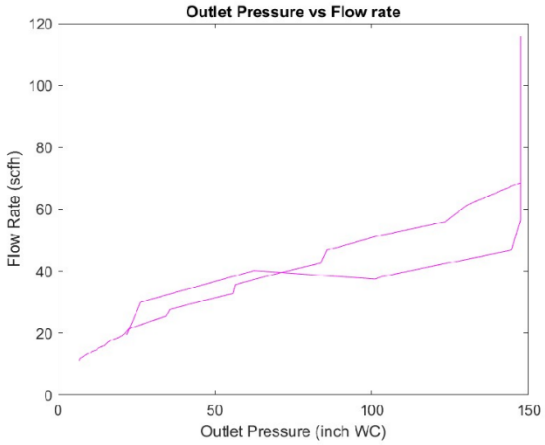
Commented [JW1]: Avg calculation outside of range

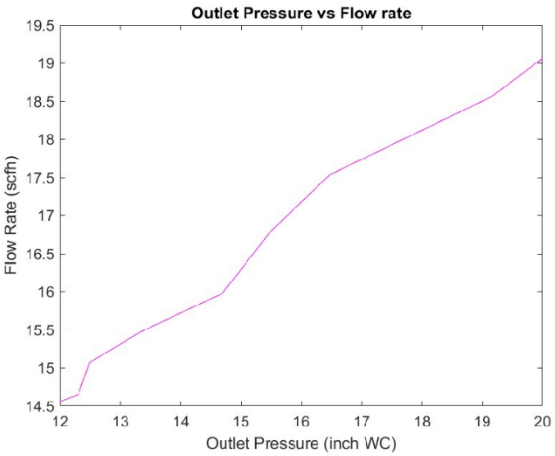
The volume of total emissions in 164.24 seconds is 0.8689 scf.





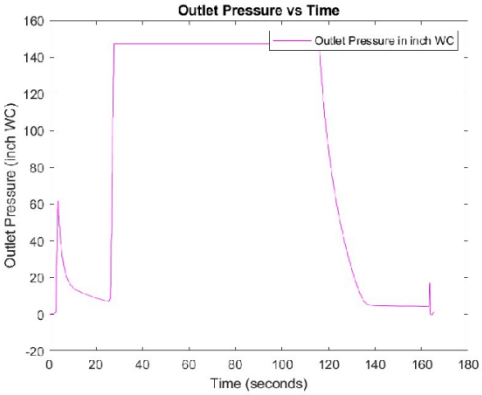
GTI ENERGY

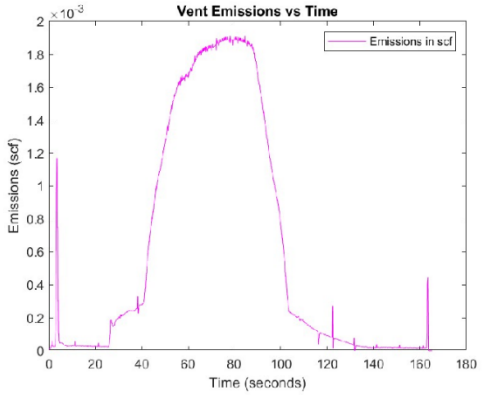

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
20
40
60
80
100
120
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
14.5
15
15.5
16
16.5
17
17.5
18
18.5
19
19.5
12
13
14
15
16
17
18
19
20

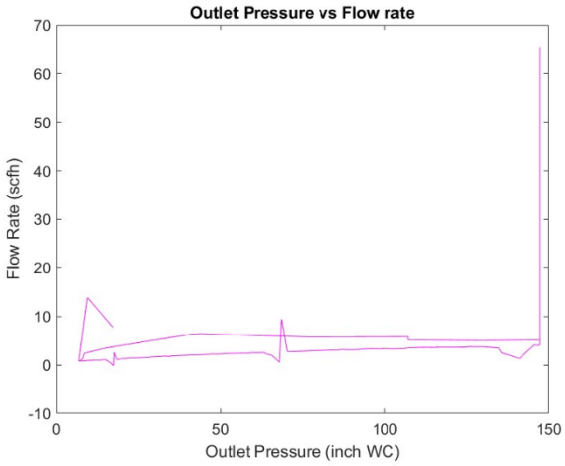
GTI ENERGY

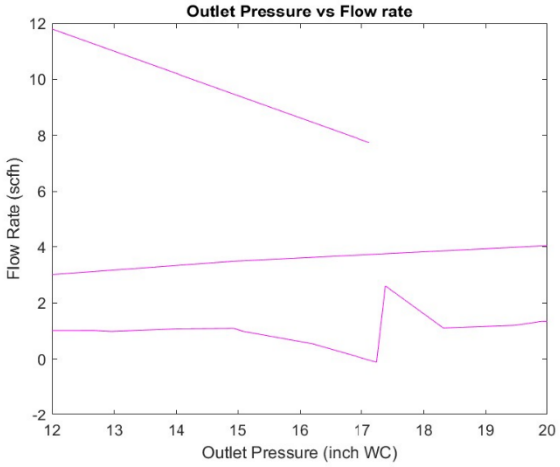
- 222489-040_LD
  The volume of total emissions in 165.26 seconds is 0.9737 scf.
  The average flow rate of emissions at 18 inches WC is 1.91 scfh.





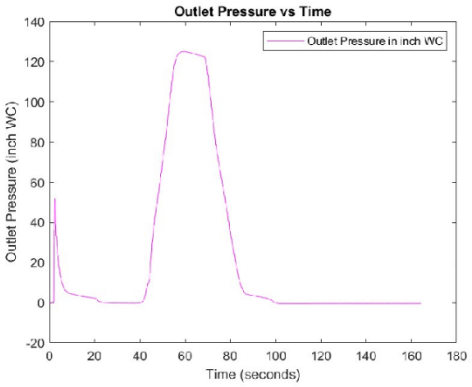
GTI ENERGY

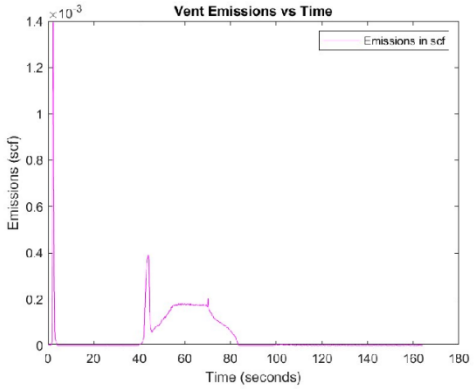

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
70
60
50
40
30
20
10
0
-10
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
12
10
8
6
4
2
0
-2
12
13
14
15
16
17
18
19
20

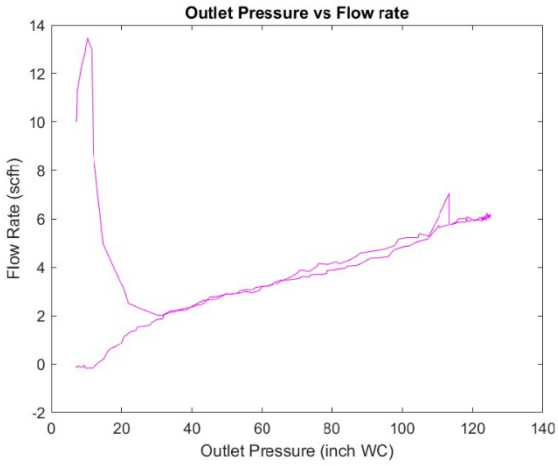
GTI ENERGY

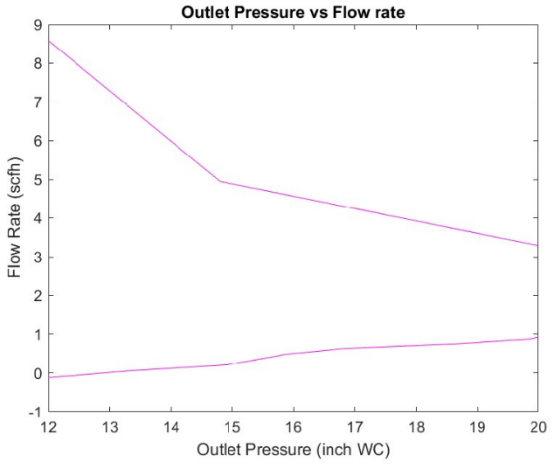
- 222489-041
  The volume of total emissions in 164.24 seconds is 0.0629 scf.
  The average flow rate of emissions at 18 inches WC is 0.23 scfh.





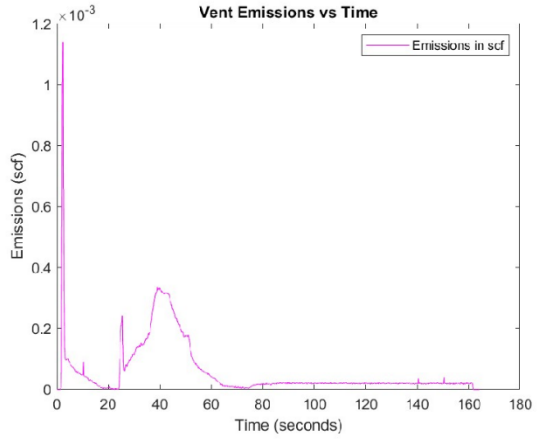
GTI ENERGY

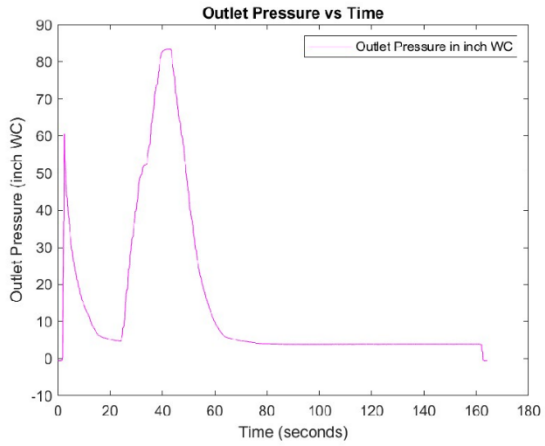

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
14
12
10
8
6
4
2
0
-2
0
20
40
60
80
100
120
140


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
9
8
7
6
5
4
3
2
1
0
-1
12
13
14
15
16
17
18
19
20

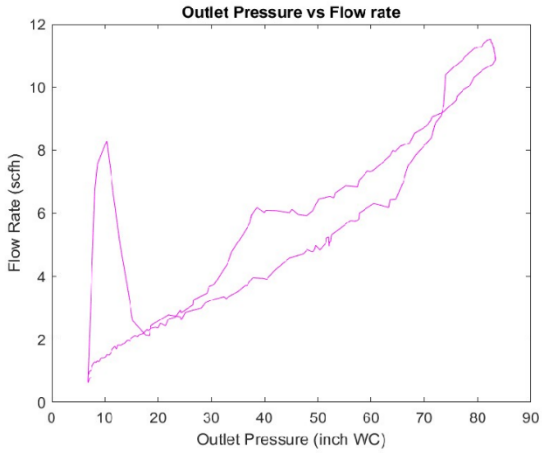
GTI ENERGY

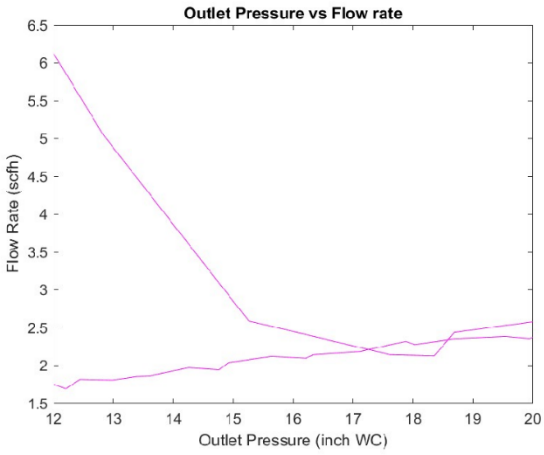
- 222489-041_DT1
  The volume of total emissions in 164.26 seconds is 0.0915 scf.
  The average flow rate of emissions at 18 inches WC is 2.13 scfh.





GTI ENERGY


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
2
4
6
8
10
12
0
10
20
30
40
50
60
70
80
90

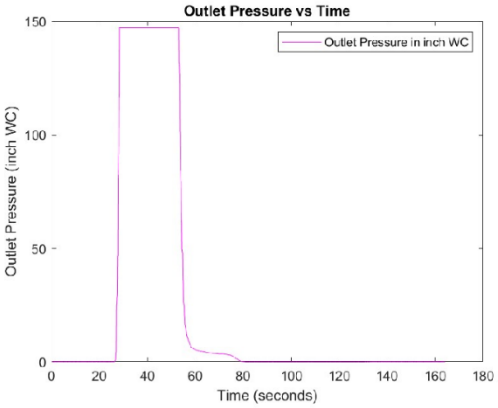

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
6.5
12
13
14
15
16
17
18
19
20

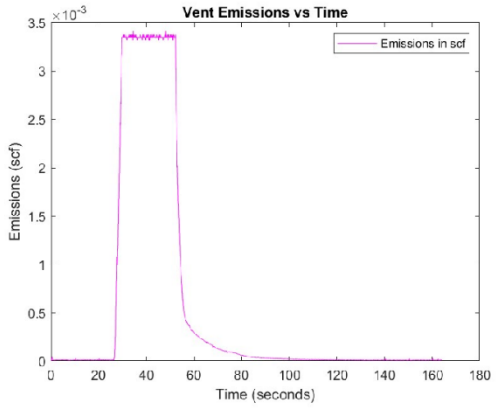
GTI ENERGY

- 222489-041_DT2

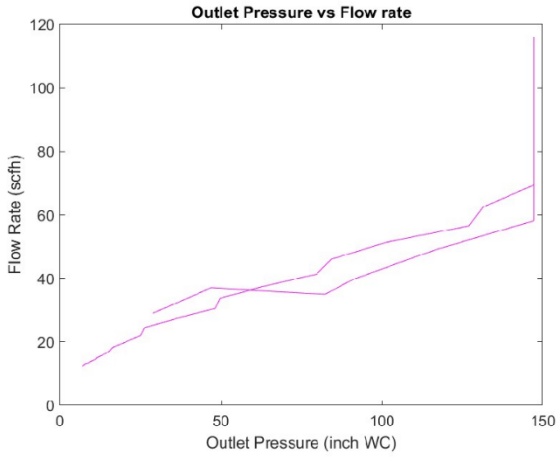
  The volume of total emissions in 164.29 seconds is 0.8836 scf.

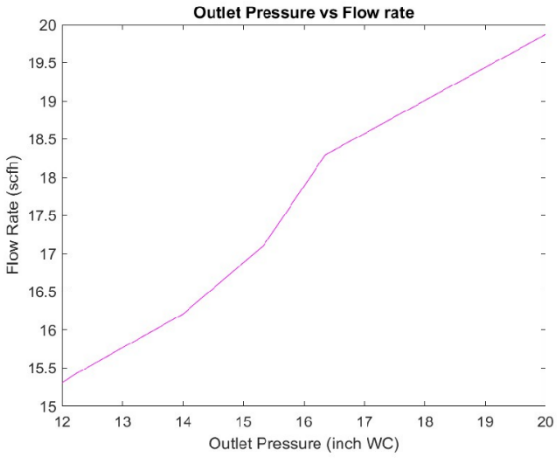
Commented [JW2]: Avg calculation out of range





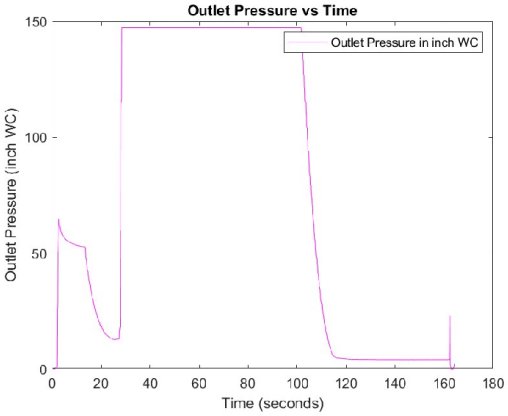
GTI ENERGY

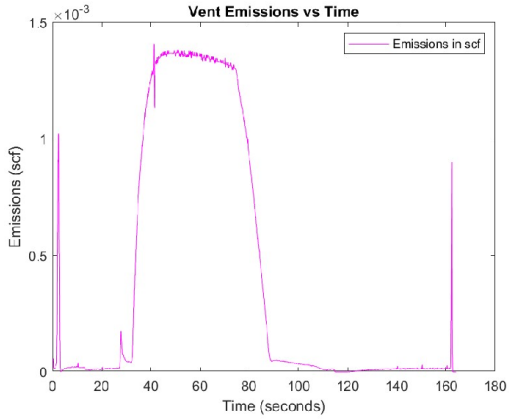

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
20
40
60
80
100
120
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
15
15.5
16
16.5
17
17.5
18
18.5
19
19.5
20
12
13
14
15
16
17
18
19
20

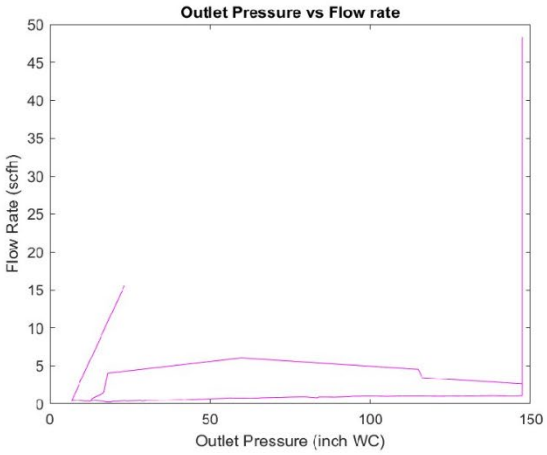
GTI ENERGY

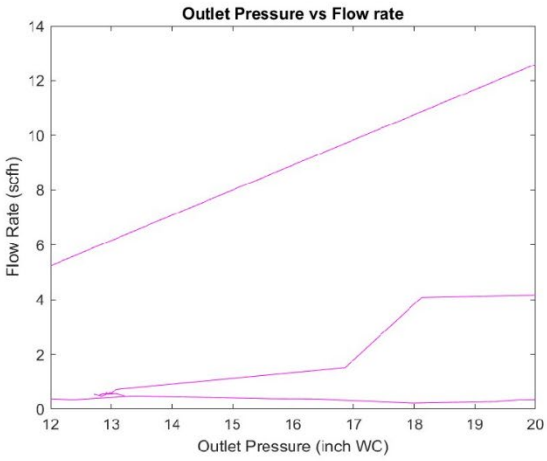
- 222489-041_LD
  The volume of total emissions in 164.25 seconds is 0.6349 scf.
  The average flow rate of emissions at 18 inches WC is 0.95 scfh.





GTI ENERGY

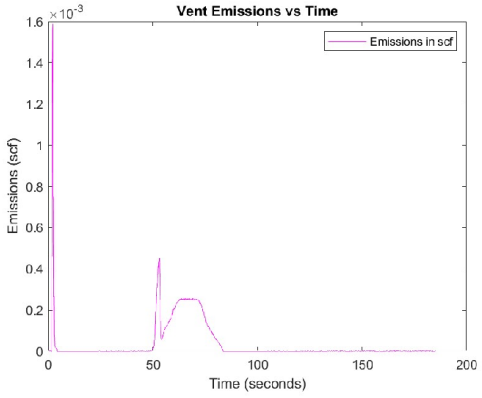

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
5
10
15
20
25
30
35
40
45
50
0
50
100
150

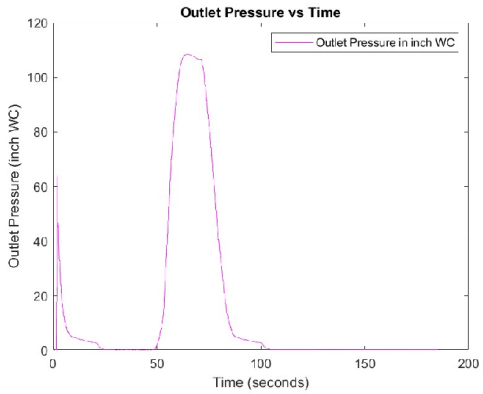

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
2
4
6
8
10
12
14
12
13
14
15
16
17
18
19
20

GTI ENERGY

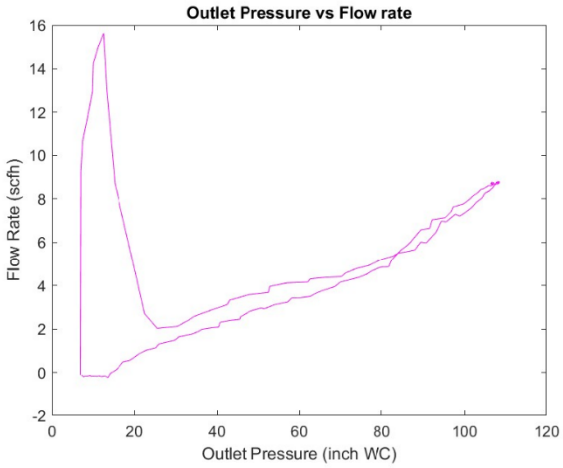
7" WC Outlet, 60-psig Inlet

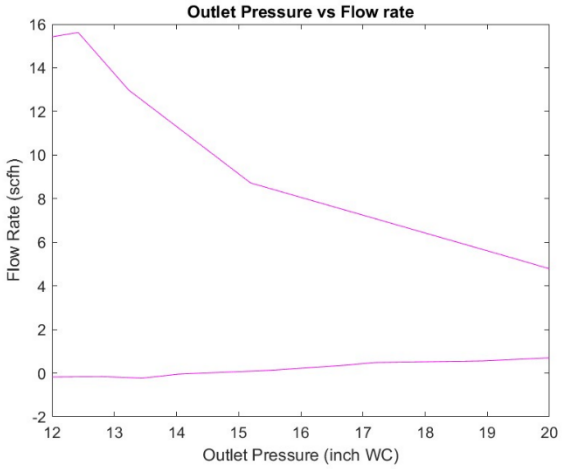
- 222489-039
  The volume of total emissions in 185.37 seconds is 0.0662 scf.
  The average flow rate of emissions at 18 inches WC is 3.40 scfh.



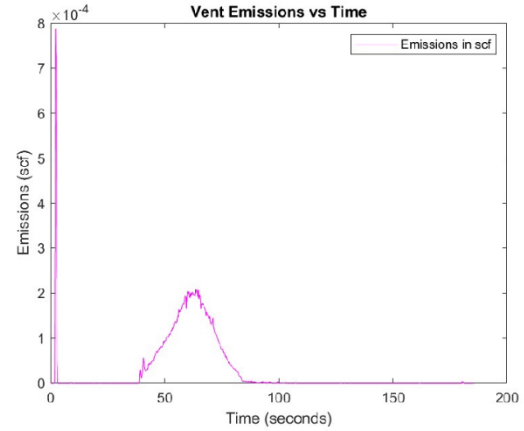


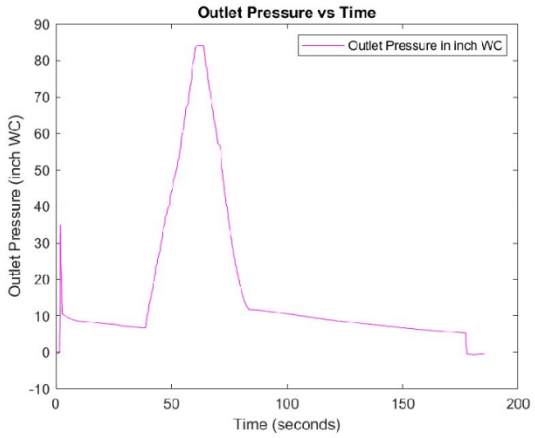
GTI ENERGY


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
16
14
12
10
8
6
4
2
0
-2
0
20
40
60
80
100
120

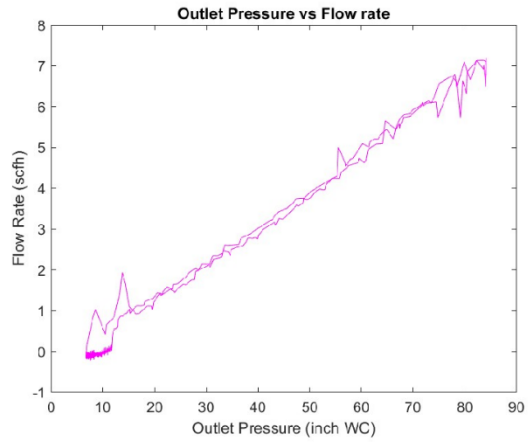

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
16
14
12
10
8
6
4
2
0
-2
12
13
14
15
16
17
18
19
20

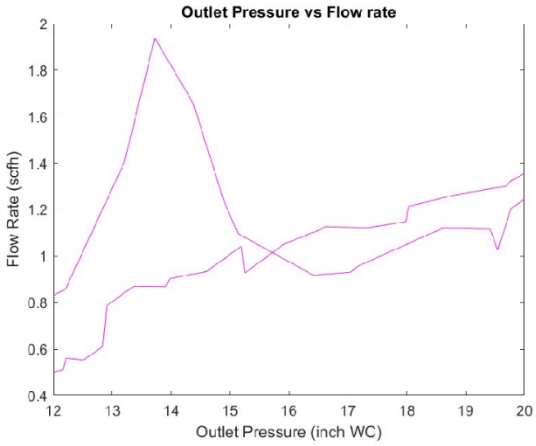
- 222489-039_DT1
  The volume of total emissions in 185.49 seconds is 0.0507 scf.
  The average flow rate of emissions at 18 inches WC is 1.11 scfh.





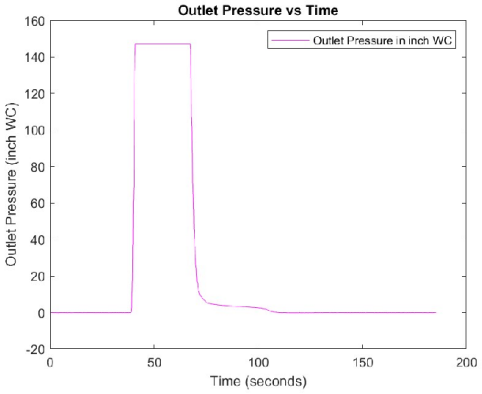
GTI ENERGY

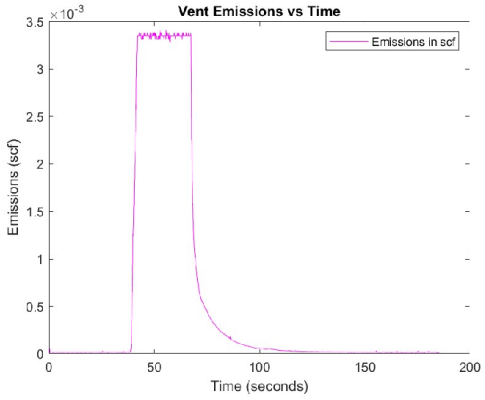

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
8
7
6
5
4
3
2
1
0
-1
0
10
20
30
40
50
60
70
80
90


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
12
13
14
15
16
17
18
19
20

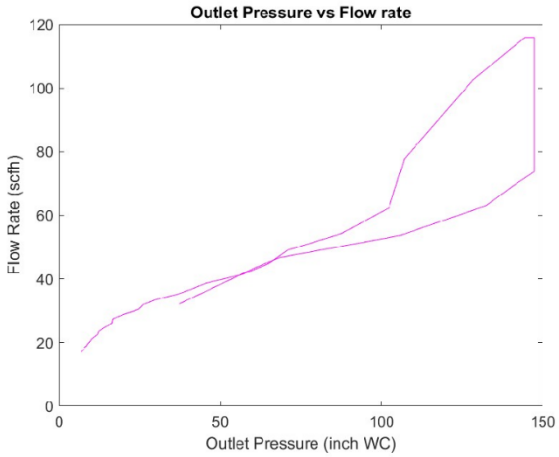
GTI ENERGY

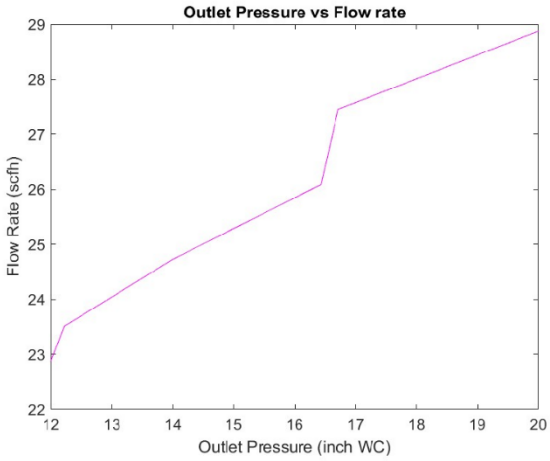
- 222489-039_DT2
  The volume of total emissions in 185.45 seconds is 0.9993 scf.
  The average flow rate of emissions at 18 inches WC is 22.43 scfh.





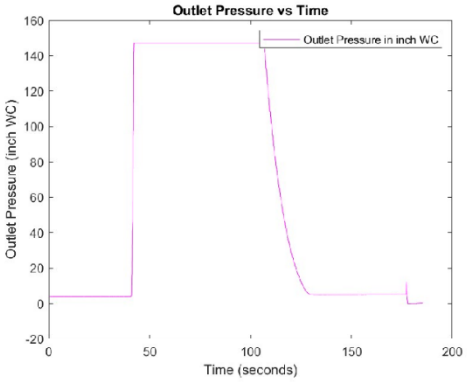
GTI ENERGY

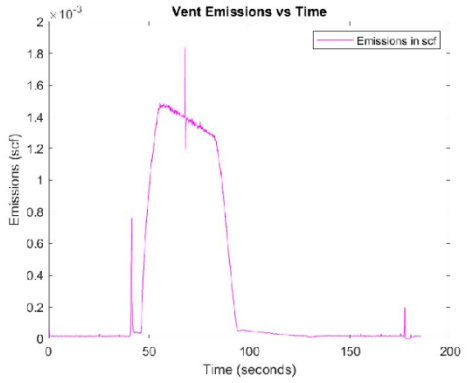

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
20
40
60
80
100
120
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
22
23
24
25
26
27
28
29
12
13
14
15
16
17
18
19
20

GTI ENERGY

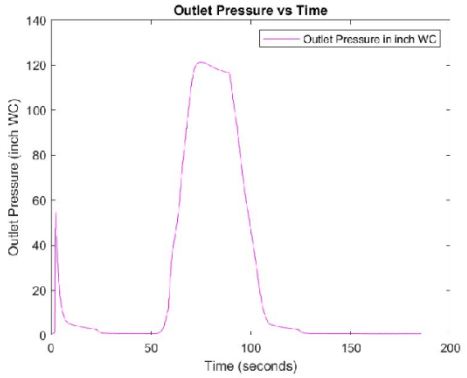
- 222489-039_LD
  The volume of total emissions in 185.37 seconds is 0.5555 scf.
  The average flow rate of emissions at 18 inches WC is 0.59 scfh.

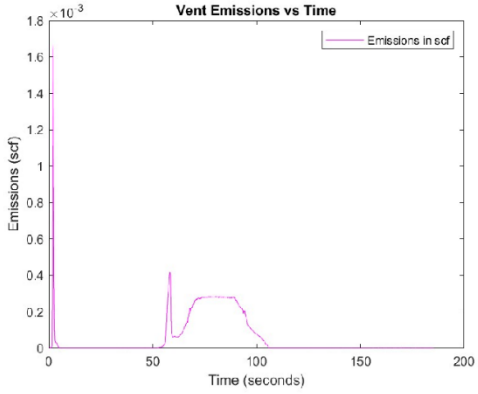




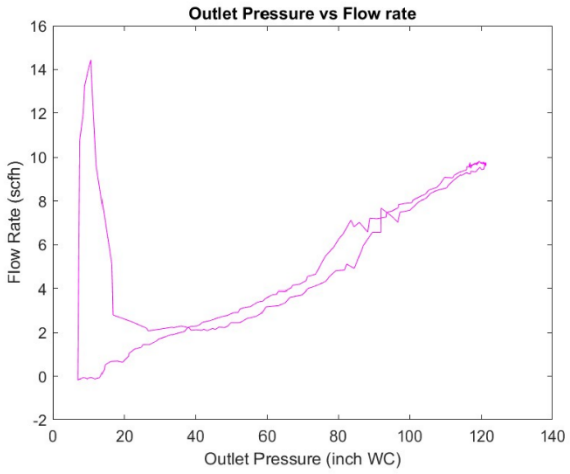
GTI ENERGY

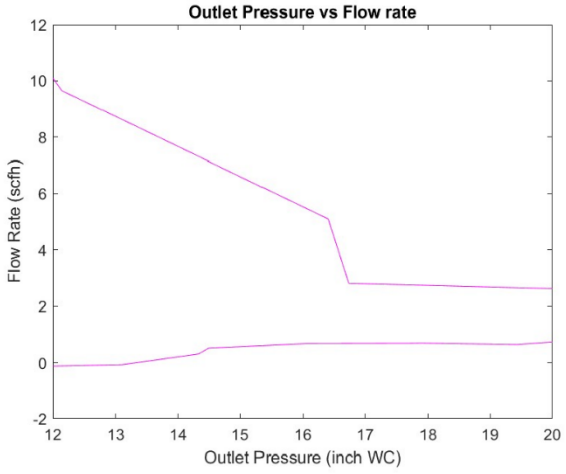
- 222489-040
  The volume of total emissions in 185.41 seconds is 0.1014 scf.
  The average flow rate of emissions at 18 inches WC is 0.62 scfh.



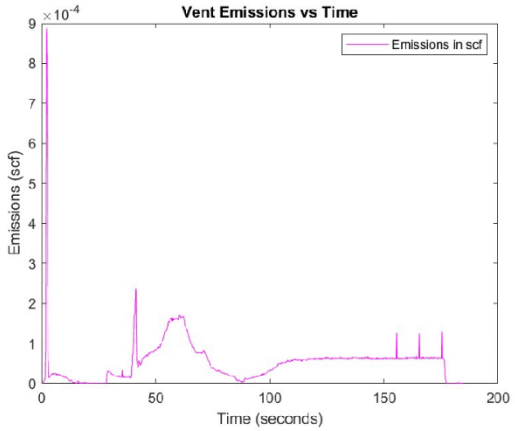


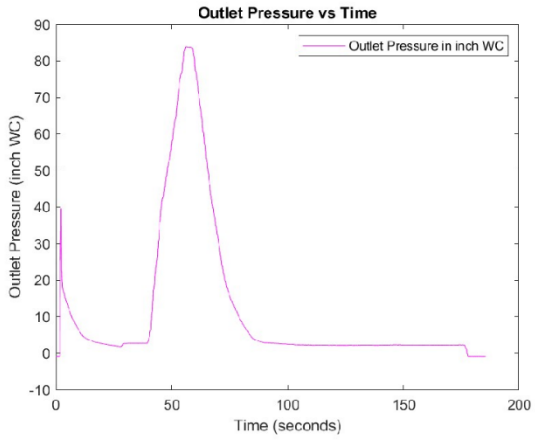
GTI ENERGY


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
16
14
12
10
8
6
4
2
0
-2
0
20
40
60
80
100
120
140

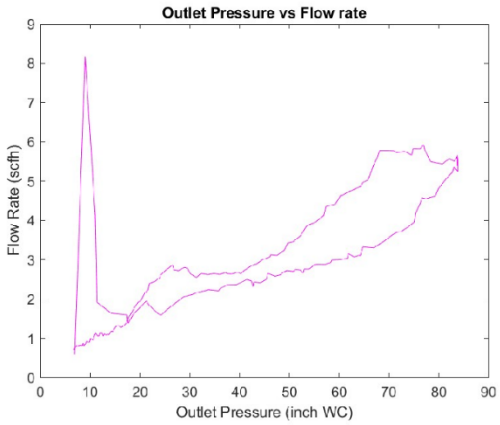

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
12
10
8
6
4
2
0
-2
12
13
14
15
16
17
18
19
20

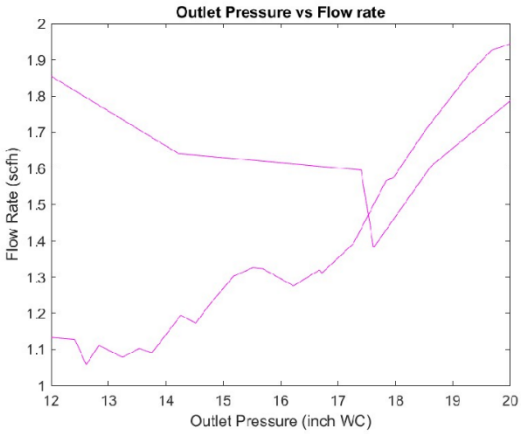
- 222489-040_DT1
  The volume of total emissions in 185.41 seconds is 0.0947 scf.
  The average flow rate of emissions at 18 inches WC is 1.48 scfh.





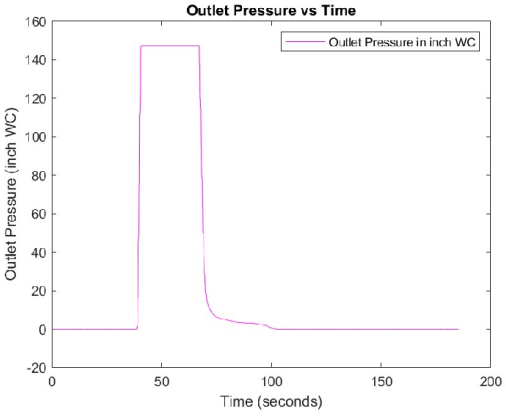
GTI ENERGY

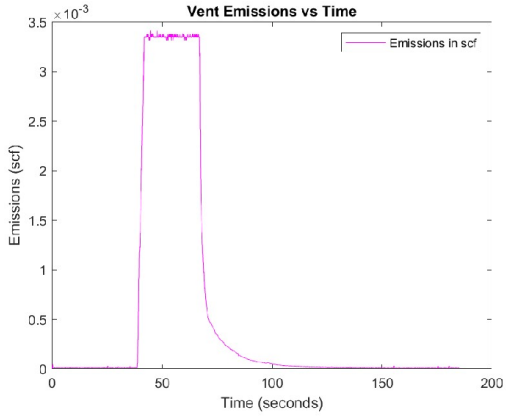

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
1
2
3
4
5
6
7
8
9
0
10
20
30
40
50
60
70
80
90


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
1
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2
12
13
14
15
16
17
18
19
20

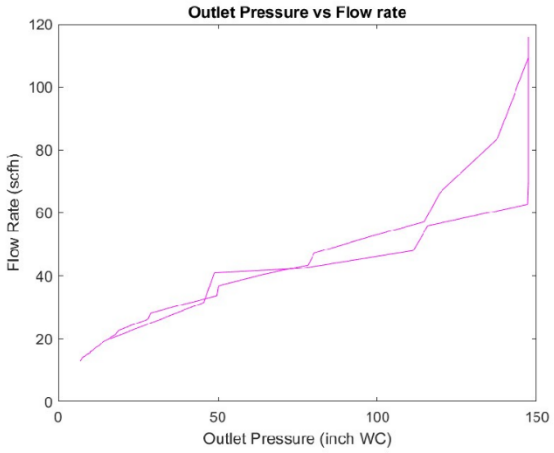
GTI ENERGY

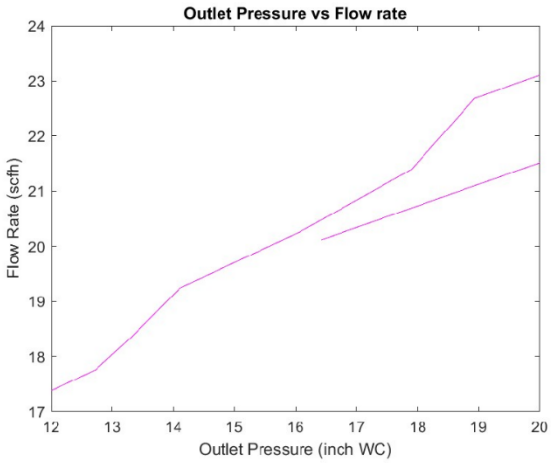
- 222489-040_DT2
  The volume of total emissions in 185.36 seconds is 0.9780 scf.
  The average flow rate of emissions at 18 inches WC is 22.04 scfh.





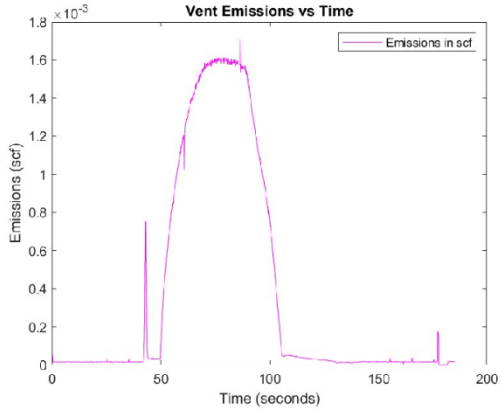
GTI ENERGY

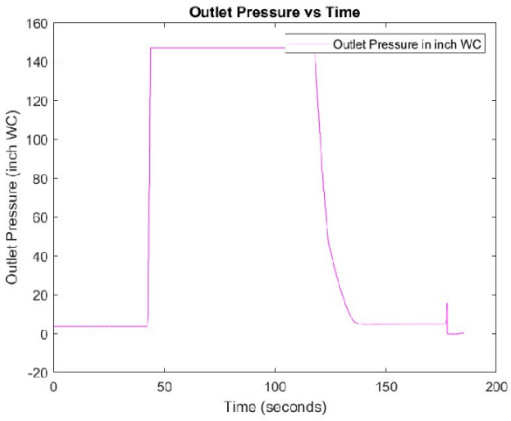

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
20
40
60
80
100
120
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
17
18
19
20
21
22
23
24
12
13
14
15
16
17
18
19
20

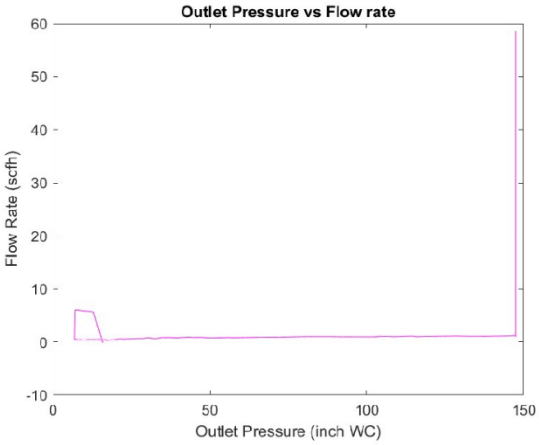
GTI ENERGY

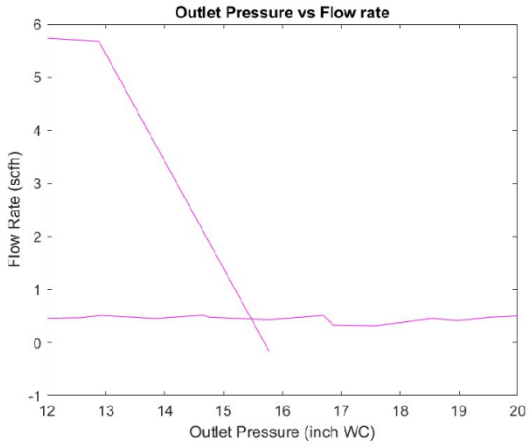
- 222489-040_LD
  The volume of total emissions in 185.40 seconds is 0.6717 scf.
  The average flow rate of emissions at 18 inches WC is 0.40 scfh.





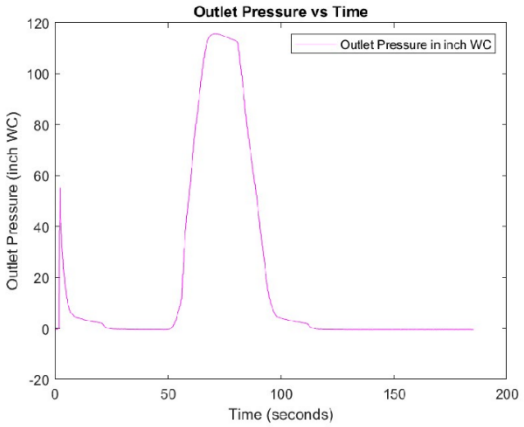
GTI ENERGY

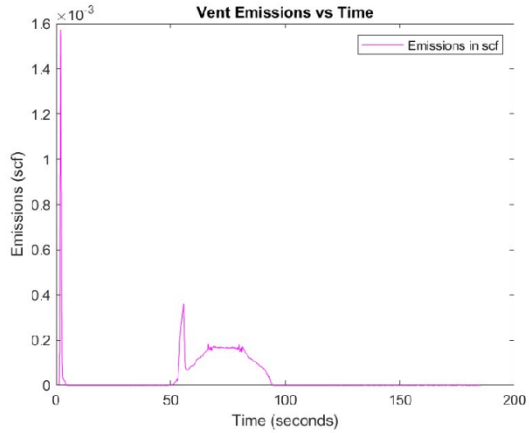

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
60
50
40
30
20
10
0
-10
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
6
5
4
3
2
1
0
-1
12
13
14
15
16
17
18
19
20

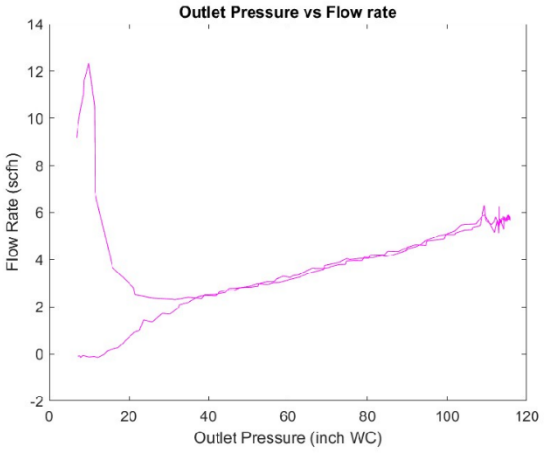
GTI ENERGY

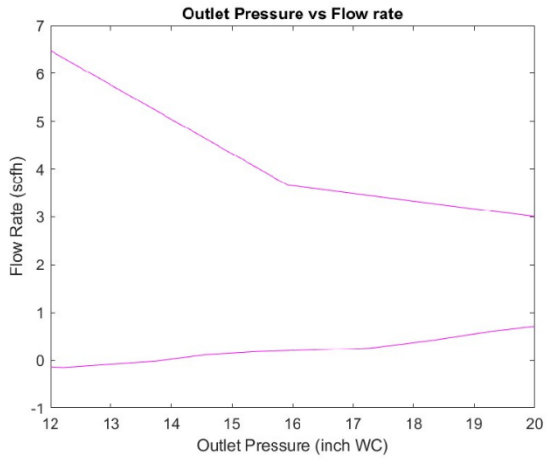
- 222489-041
  The volume of total emissions in 185.30 seconds is 0.0610 scf.
  The average flow rate of emissions at 18 inches WC is 0.25 scfh.





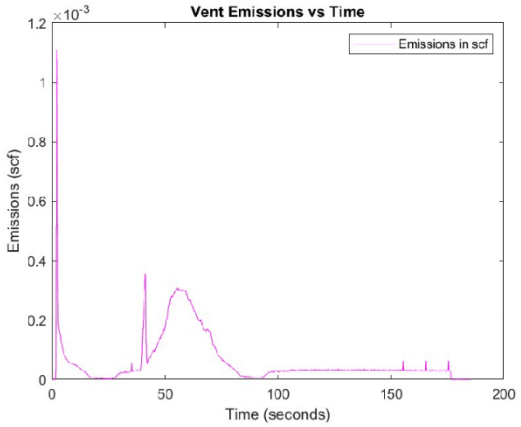
GTI ENERGY

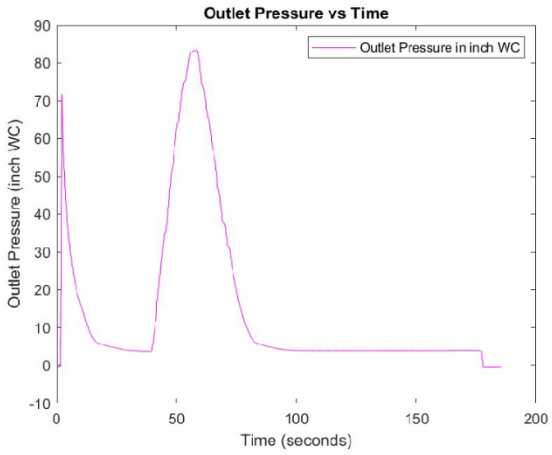

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
14
12
10
8
6
4
2
0
-2
0
20
40
60
80
100
120


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
7
6
5
4
3
2
1
0
-1
12
13
14
15
16
17
18
19
20

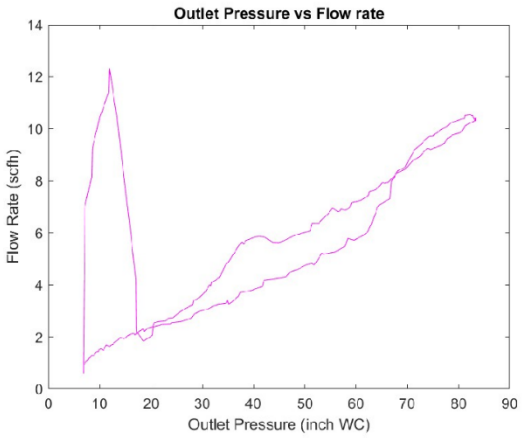
GTI ENERGY

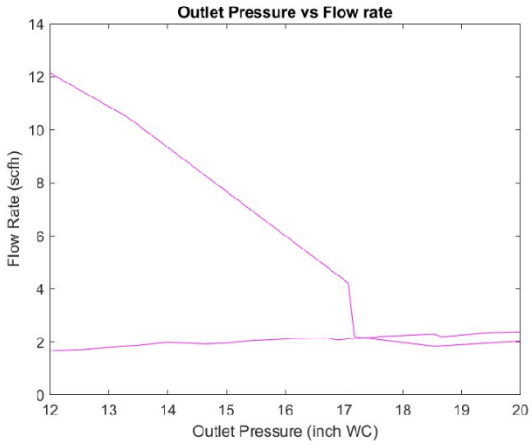
- 222489-041_DT1
  The volume of total emissions in 185.37 seconds is 0.1121 scf.
  The average flow rate of emissions at 18 inches WC is 3.48 scfh.





GTI ENERGY


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
2
4
6
8
10
12
14
0
10
20
30
40
50
60
70
80
90

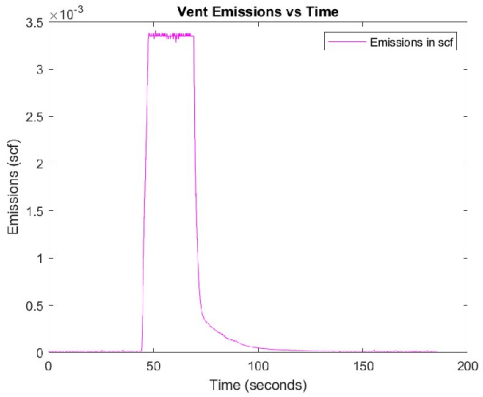

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
2
4
6
8
10
12
14
12
13
14
15
16
17
18
19
20

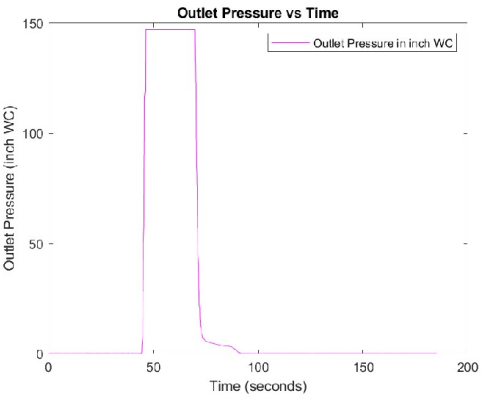
GTI ENERGY

- 222489-041_DT2

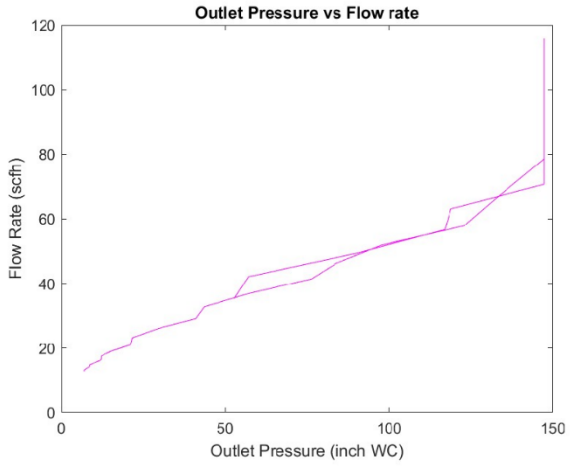
Commented [JW3]: Avg calculation out of range

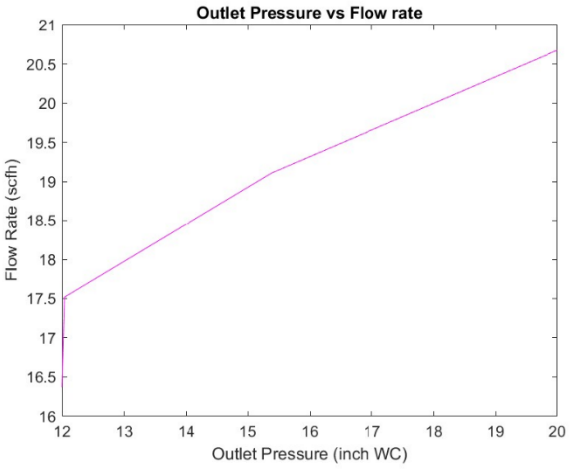
The volume of total emissions in 185.38 seconds is 0.8624 scf.





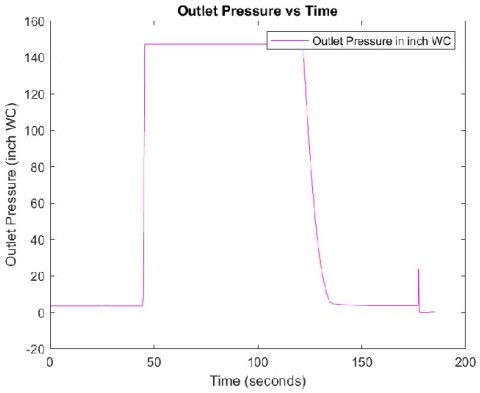
GTI ENERGY

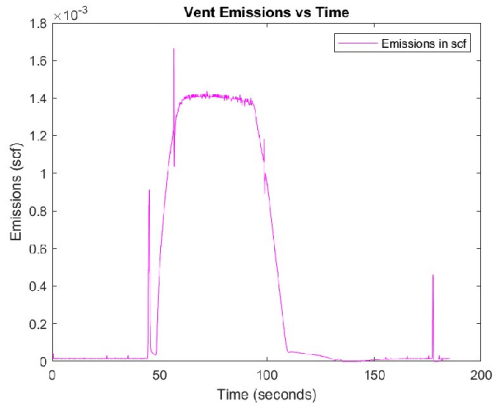

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
20
40
60
80
100
120
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
16
16.5
17
17.5
18
18.5
19
19.5
20
20.5
21
12
13
14
15
16
17
18
19
20

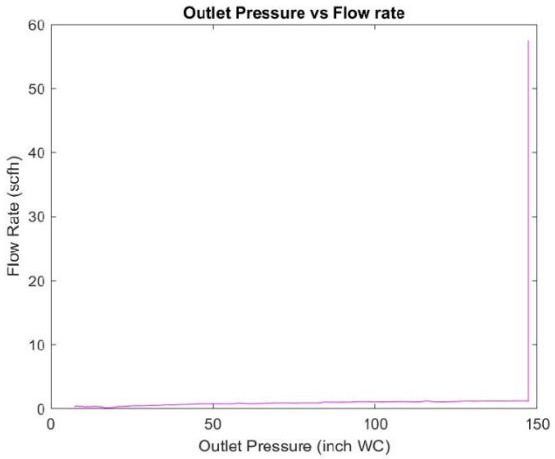
GTI ENERGY

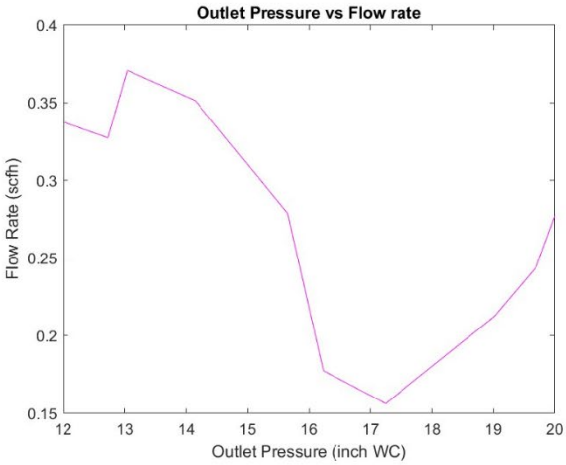
- 222489-041_LD
  The volume of total emissions in 185.34 seconds is 0.7022 scf.
  The average flow rate of emissions at 18 inches WC is 0.16 scfh.





GTI ENERGY


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
10
20
30
40
50
60
0
50
100
150

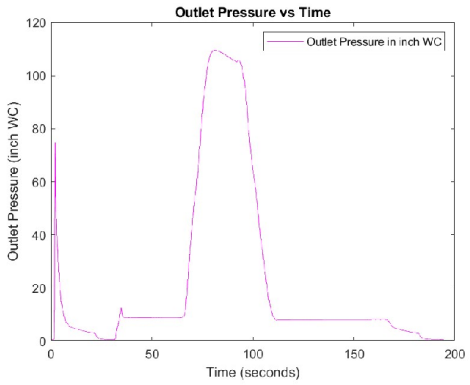

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0.15
0.2
0.25
0.3
0.35
0.4
12
13
14
15
16
17
18
19
20

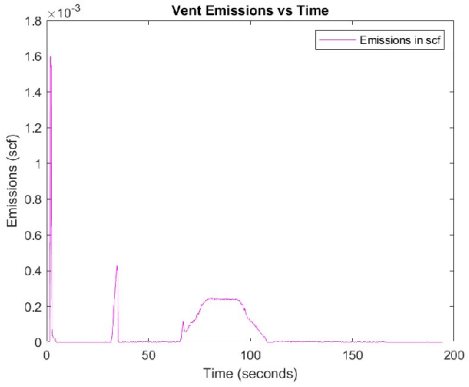
GTI ENERGY

7" WC Outlet, 100-psig Inlet

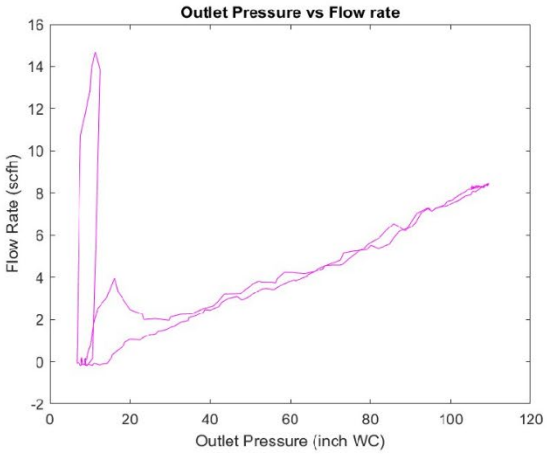
- 222489-039

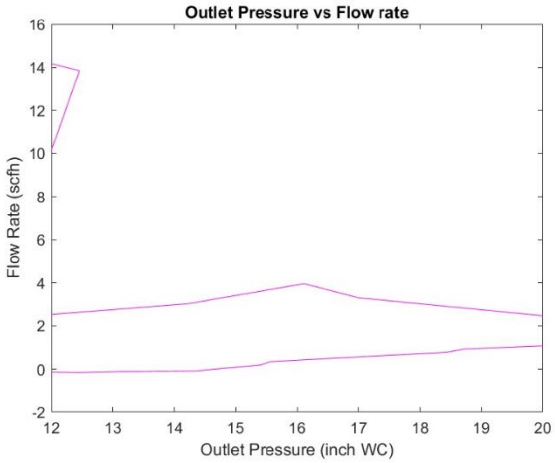
  The volume of total emissions in 194.40 seconds is 0.0852 scf.
  The average flow rate of emissions at 18 inches WC is 1.28 scfh.





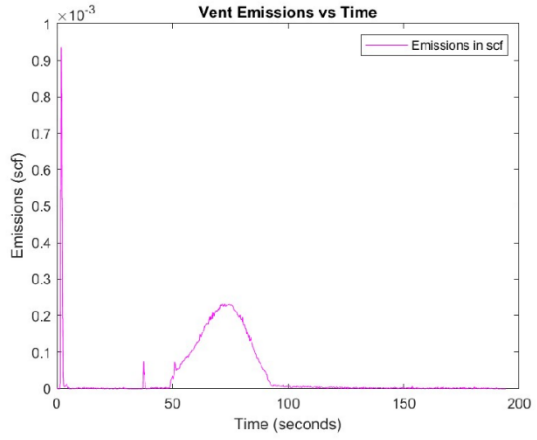
GTI ENERGY

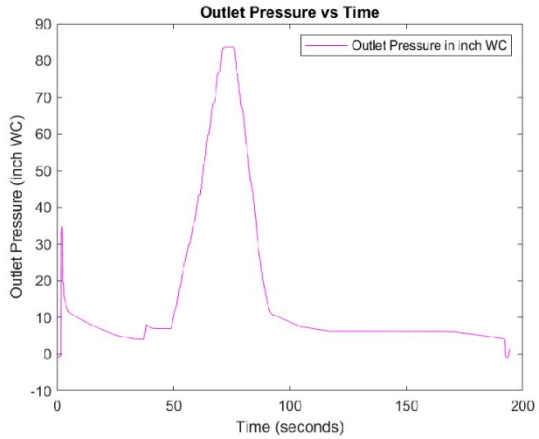

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
16
14
12
10
8
6
4
2
0
-2
0
20
40
60
80
100
120


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
16
14
12
10
8
6
4
2
0
-2
12
13
14
15
16
17
18
19
20

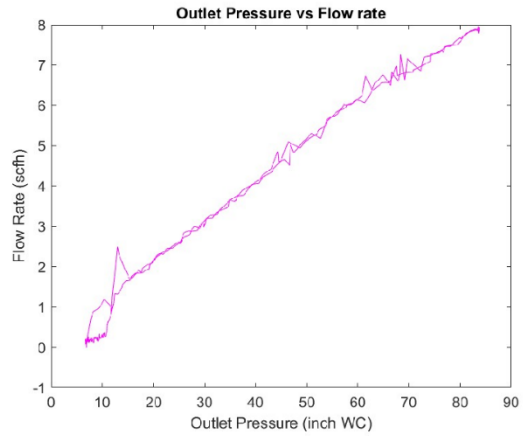
GTI ENERGY

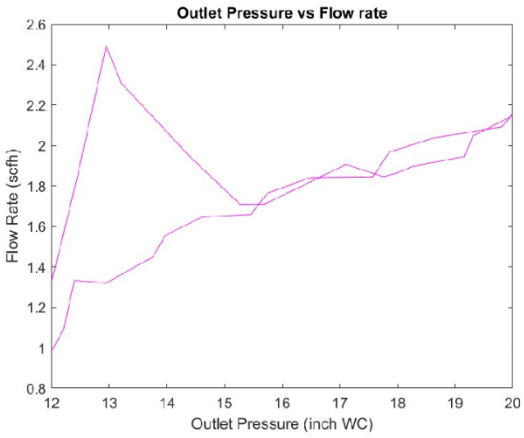
- 222489-039_DT1
  The volume of total emissions in 194.39 seconds is 0.0668 scf.
  The average flow rate of emissions at 18 inches WC is 2.50 scfh.





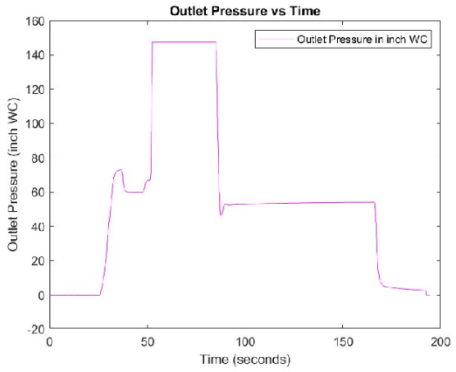
GTI ENERGY

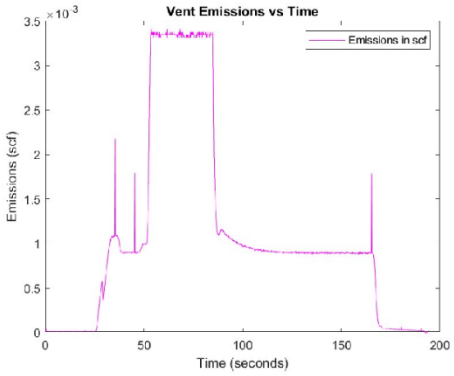

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
8
7
6
5
4
3
2
1
0
-1
0
10
20
30
40
50
60
70
80
90


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
12
13
14
15
16
17
18
19
20

GTI ENERGY

- 222489-039_DT2
  The volume of total emissions in 194.47 seconds is 2.0314 scf.
  The average flow rate of emissions at 18 inches WC is 16.39 scfh.



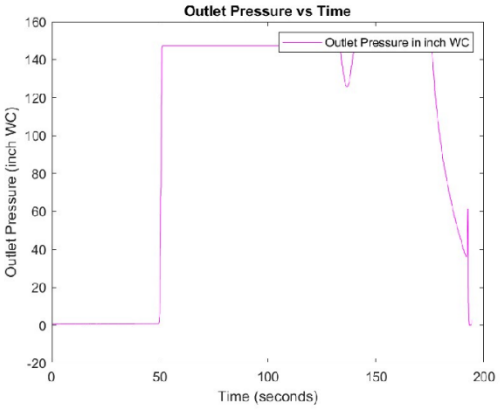


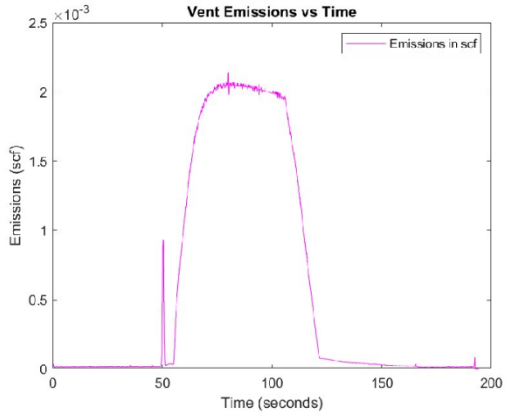
GTI ENERGY

- 222489-039_LD

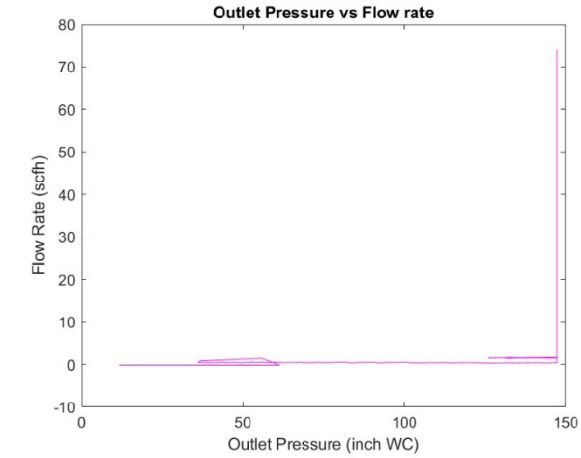
Commented [JW4]: Avg calculation out of range

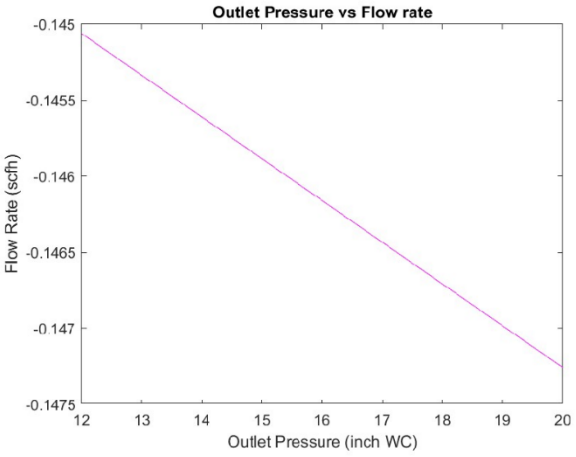
The volume of total emissions in 194.40 seconds is 1.0763 scf.





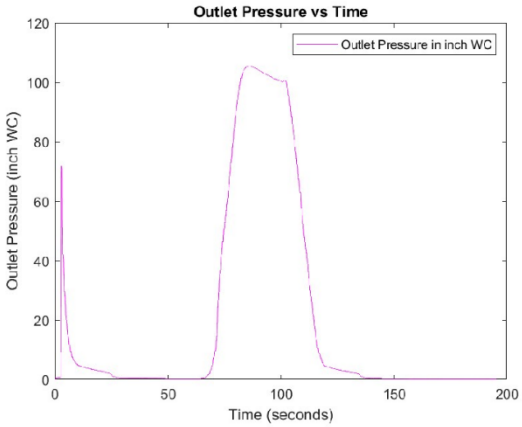
GTI ENERGY

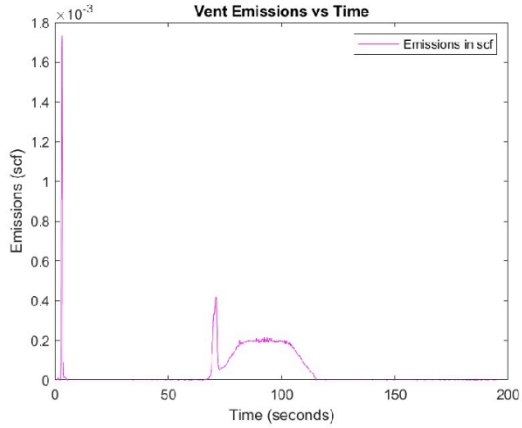

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
80
70
60
50
40
30
20
10
0
-10
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
-0.145
-0.1455
-0.146
-0.1465
-0.147
-0.1475
12
13
14
15
16
17
18
19
20

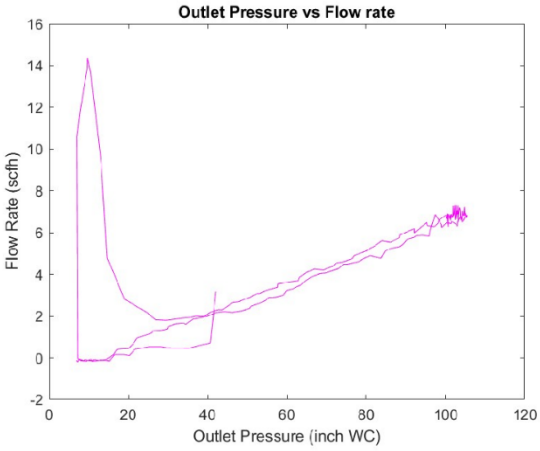
GTI ENERGY

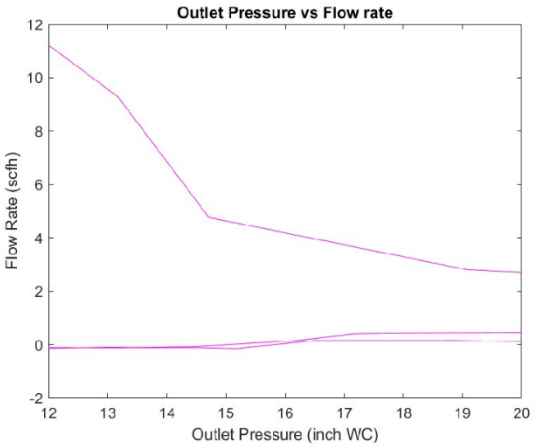
- 222489-040
  The volume of total emissions in 195.40 seconds is 0.0787 scf.
  The average flow rate of emissions at 18 inches WC is 0.33 scfh.



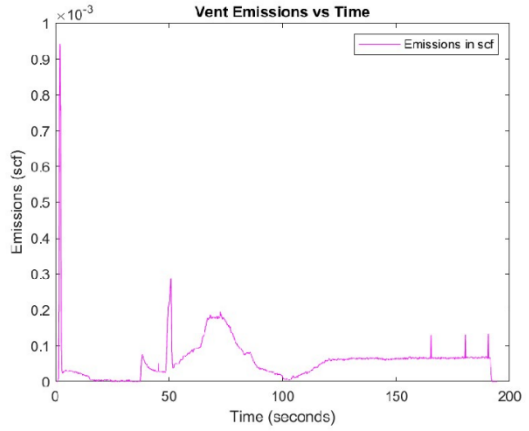


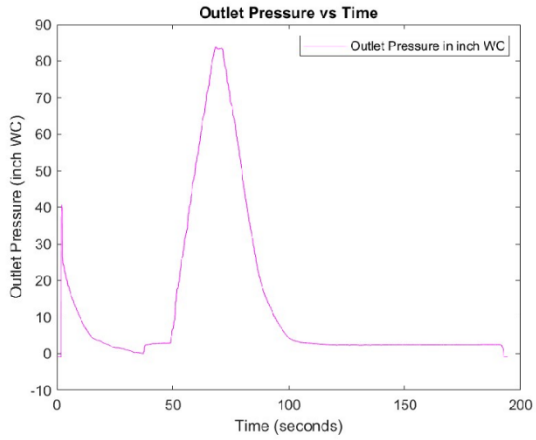
GTI ENERGY


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
16
14
12
10
8
6
4
2
0
-2
0
20
40
60
80
100
120

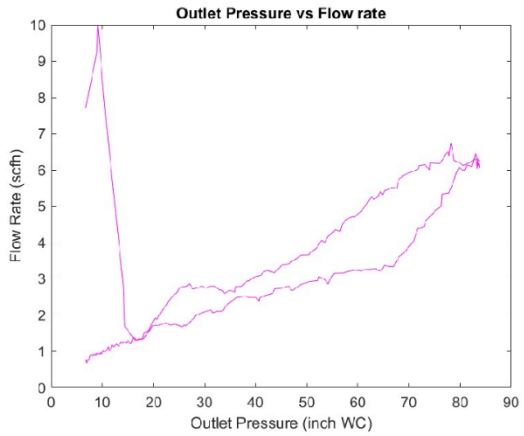

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
12
10
8
6
4
2
0
-2
12
13
14
15
16
17
18
19
20

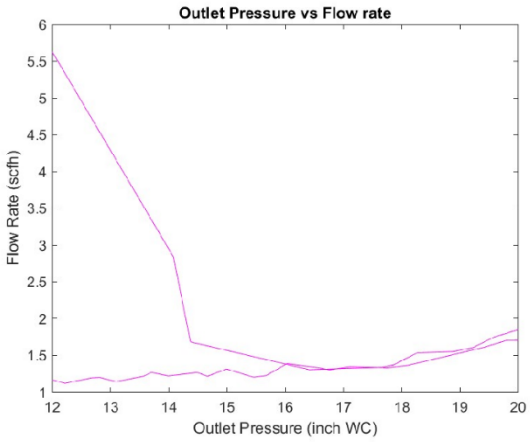
- 222489-040_DT1
  The volume of total emissions in 194.41 seconds is 0.1104 scf.
  The average flow rate of emissions at 18 inches WC is 1.28 scfh.



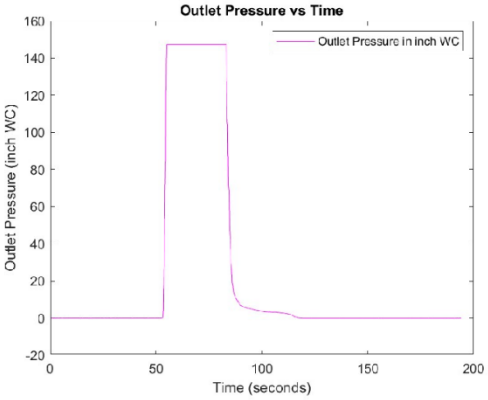


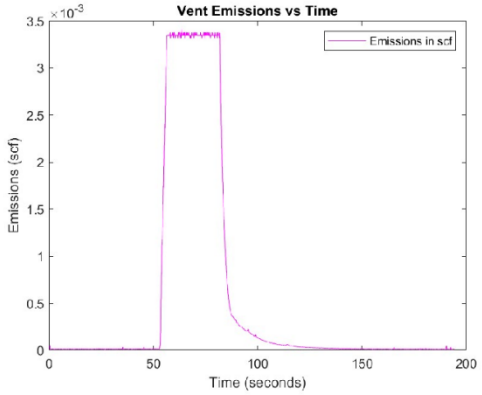
GTI ENERGY


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
1
2
3
4
5
6
7
8
9
10
0
10
20
30
40
50
60
70
80
90

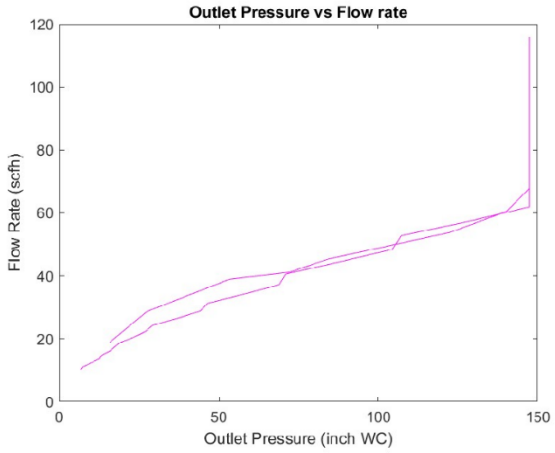

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
12
13
14
15
16
17
18
19
20

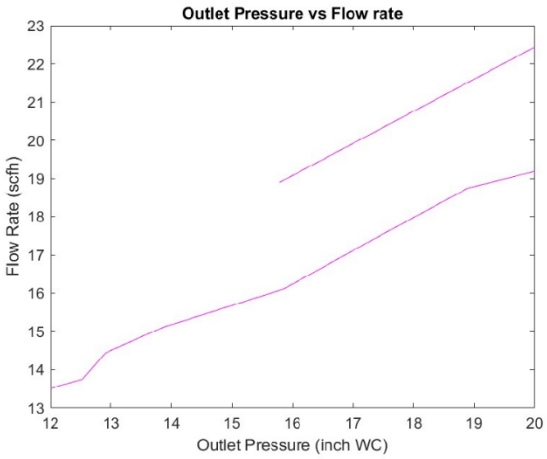
- 222489-040_DT2
  The volume of total emissions in 194.33 seconds is 1.0015 scf.
  The average flow rate of emissions at 18 inches WC is 18.06 scfh.



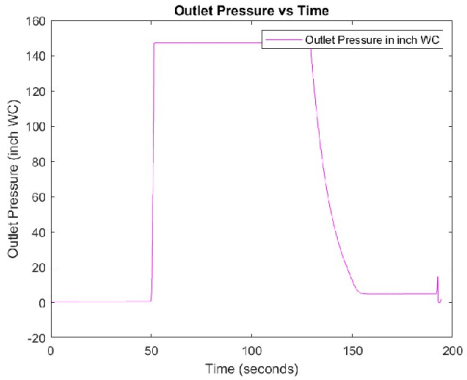


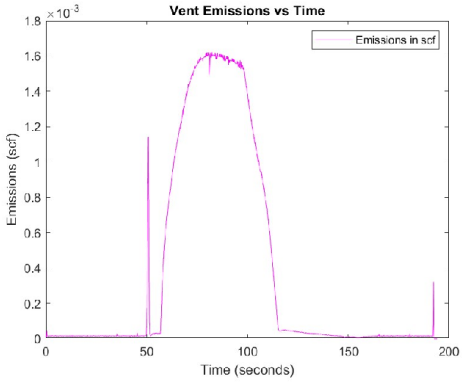
GTI ENERGY


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
20
40
60
80
100
120
0
50
100
150

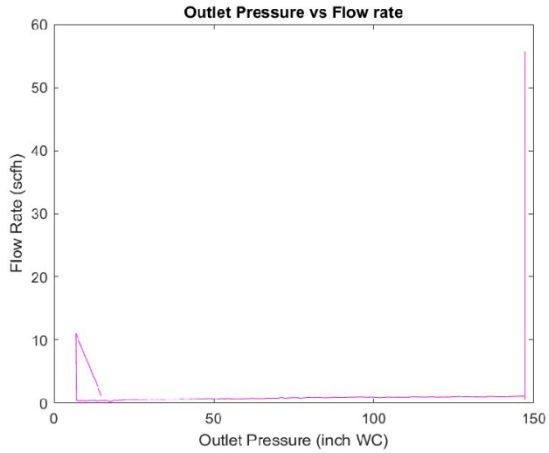

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
13
14
15
16
17
18
19
20
21
22
23
12
13
14
15
16
17
18
19
20

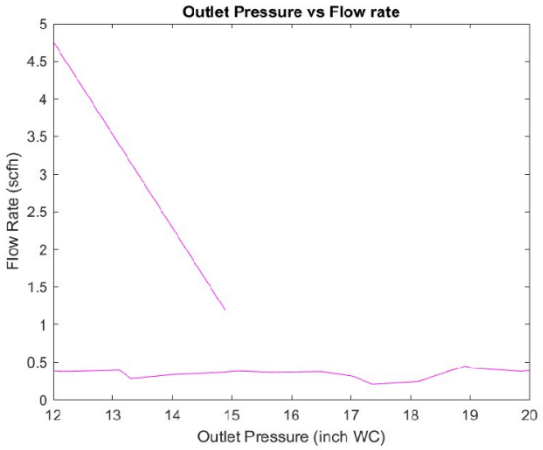
- 222489-040_LD
  The volume of total emissions in 194.32 seconds is 0.7180 scf.
  The average flow rate of emissions at 18 inches WC is 0.31 scfh.





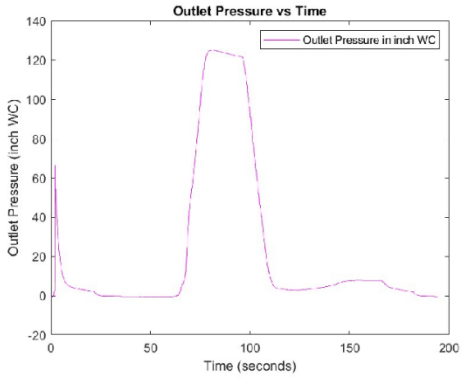
GTI ENERGY

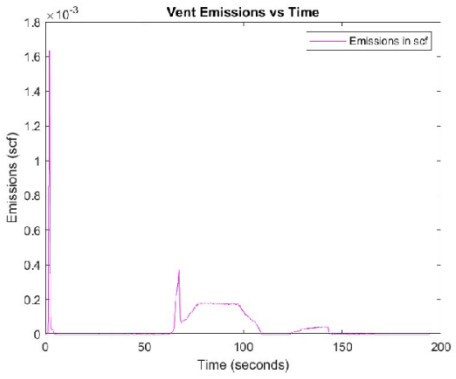

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
10
20
30
40
50
60
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
12
13
14
15
16
17
18
19
20

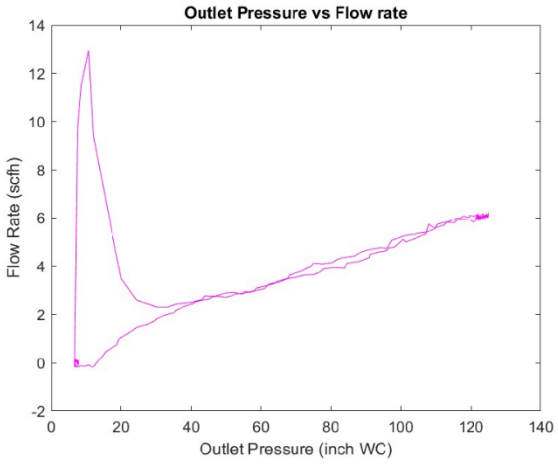
GTI ENERGY

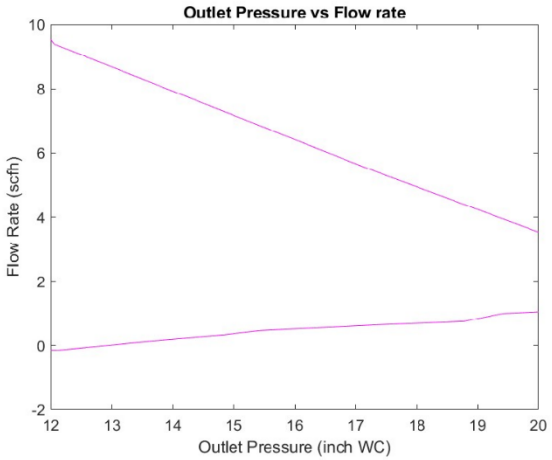
- 222489-041
  The volume of total emissions in 194.43 seconds is 0.0760 scf.
  The average flow rate of emissions at 18 inches WC is 1.75 scfh.



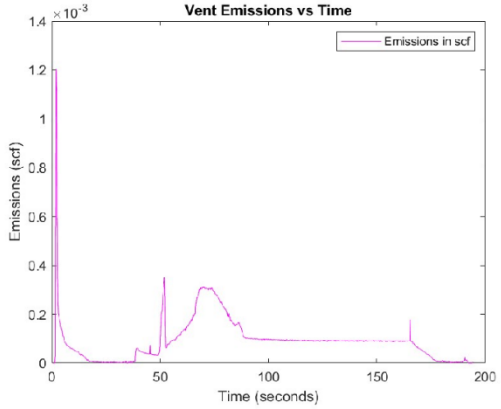


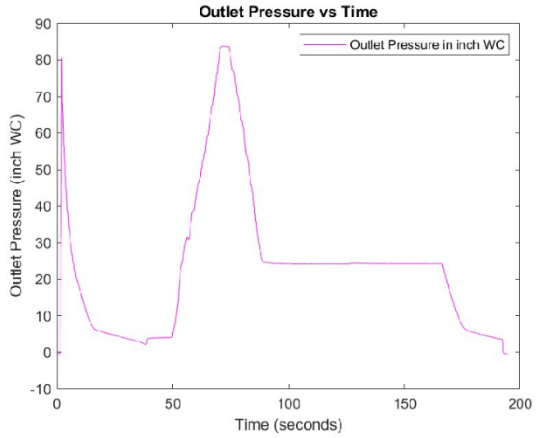
GTI ENERGY


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
14
12
10
8
6
4
2
0
-2
0
20
40
60
80
100
120
140

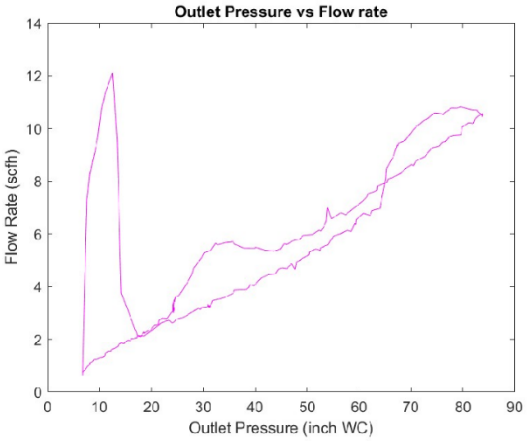

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
10
8
6
4
2
0
-2
12
13
14
15
16
17
18
19
20

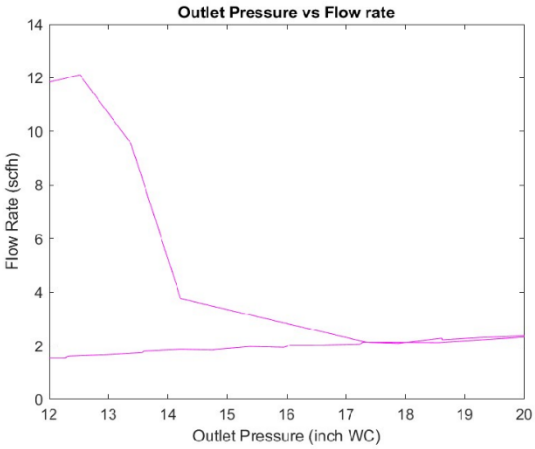
- 222489-041_DT1
  The volume of total emissions in 194.43 seconds is 0.1705 scf.
  The average flow rate of emissions at 18 inches WC is 2.08 scfh.





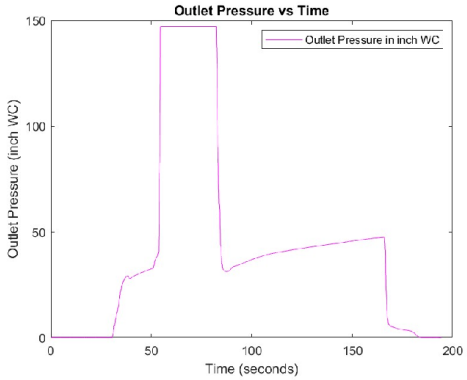
GTI ENERGY

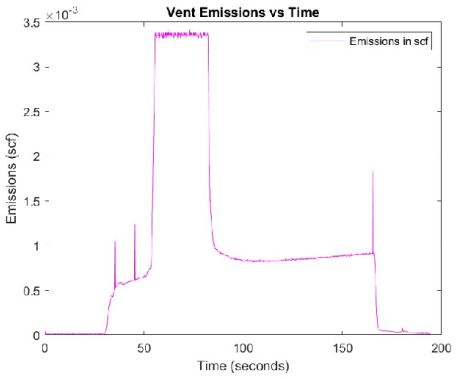

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
2
4
6
8
10
12
14
0
10
20
30
40
50
60
70
80
90


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
2
4
6
8
10
12
14
12
13
14
15
16
17
18
19
20

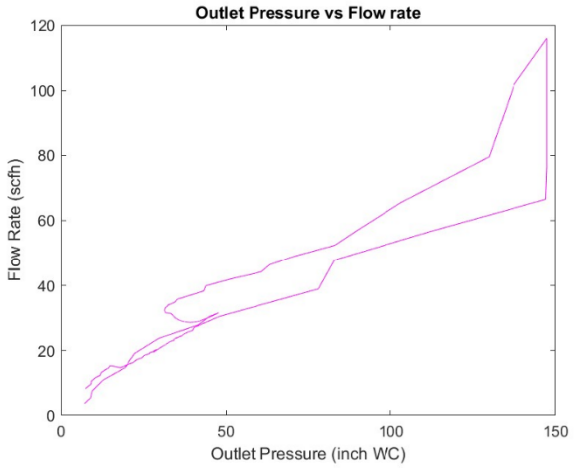
GTI ENERGY

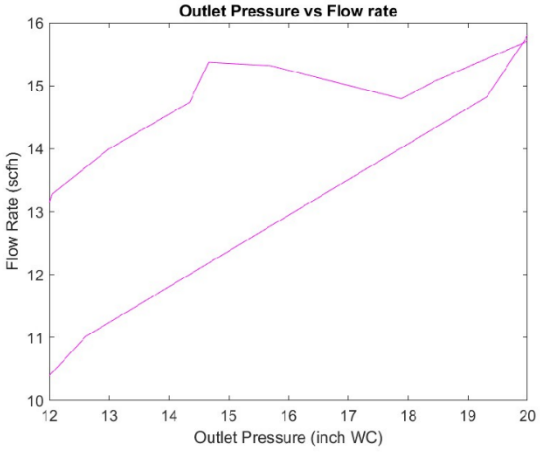
- 222489-041_DT2
  The volume of total emissions in 194.39 seconds is 1.7622 scf.
  The average flow rate of emissions at 18 inches WC is 14.94 scfh.





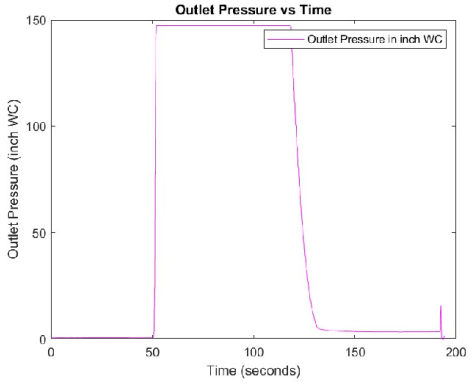
GTI ENERGY

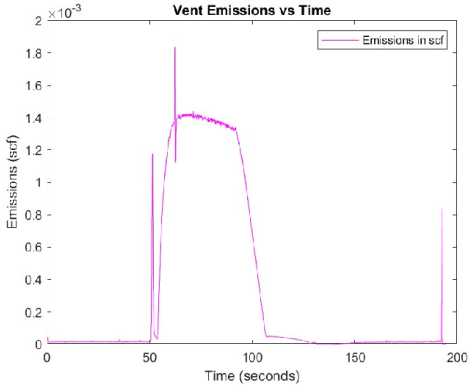

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
20
40
60
80
100
120
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
10
11
12
13
14
15
16
12
13
14
15
16
17
18
19
20

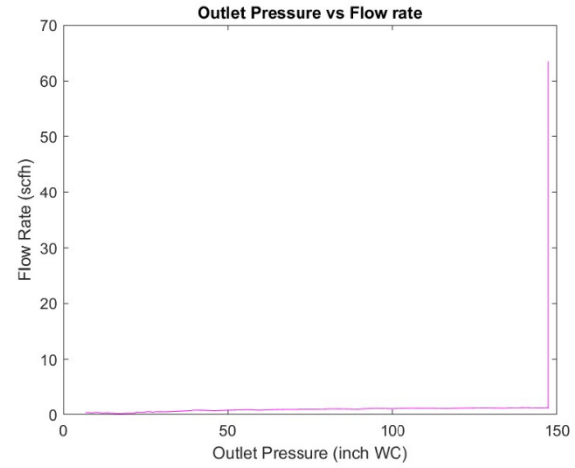
GTI ENERGY

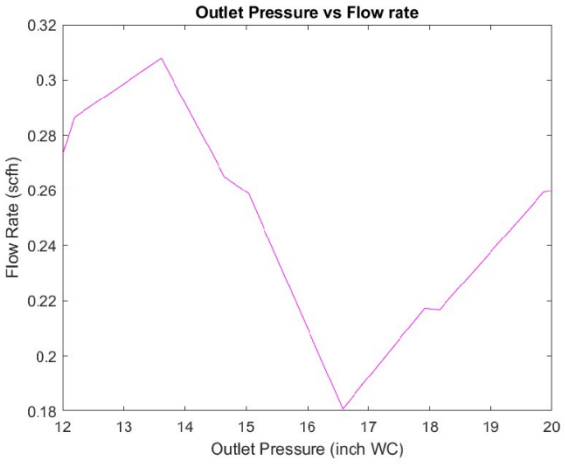
- 222489-041_LD
  The volume of total emissions in 194.46 seconds is 0.6101 scf.
  The average flow rate of emissions at 18 inches WC is 0.22 scfh.





GTI ENERGY


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
10
20
30
40
50
60
70
0
50
100
150

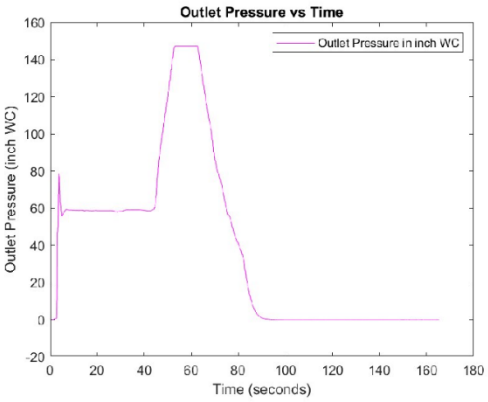

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0.18
0.2
0.22
0.24
0.26
0.28
0.3
0.32
12
13
14
15
16
17
18
19
20

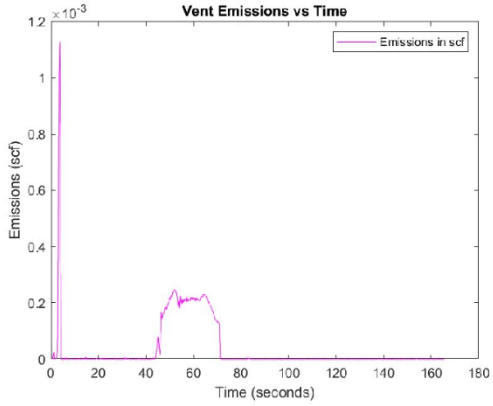
GTI ENERGY

2-psig Outlet, 10-psig Inlet

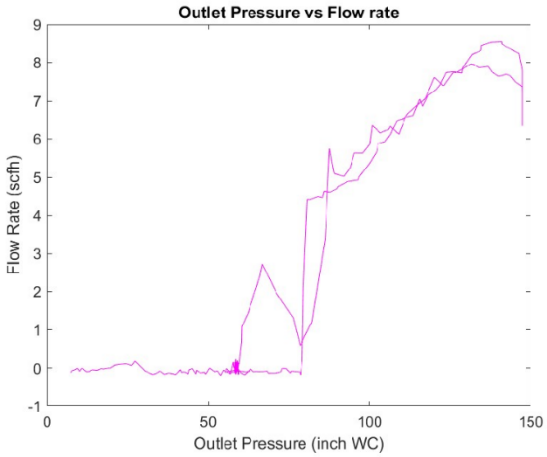
- 222489-042

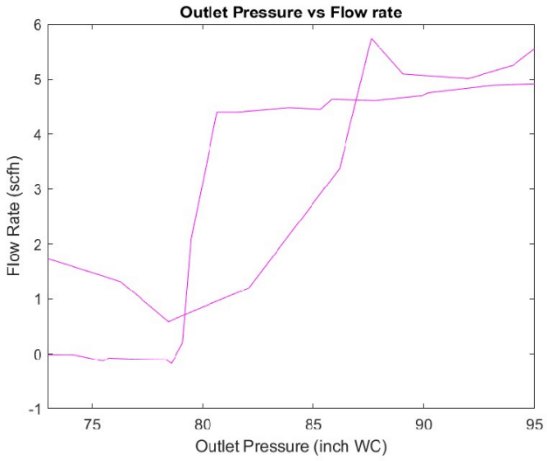
  The volume of total emissions in 165.37 seconds is 0.0584 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 4.71 scfh.





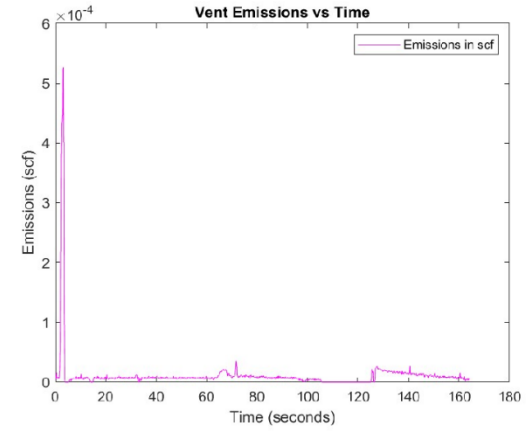
GTI ENERGY

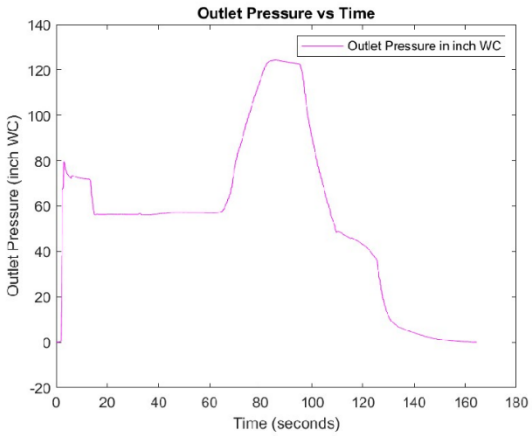

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
9
8
7
6
5
4
3
2
1
0
-1
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
6
5
4
3
2
1
0
-1
75
80
85
90
95

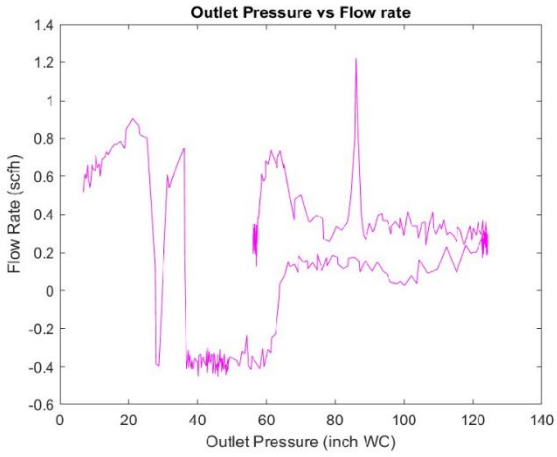
GTI ENERGY

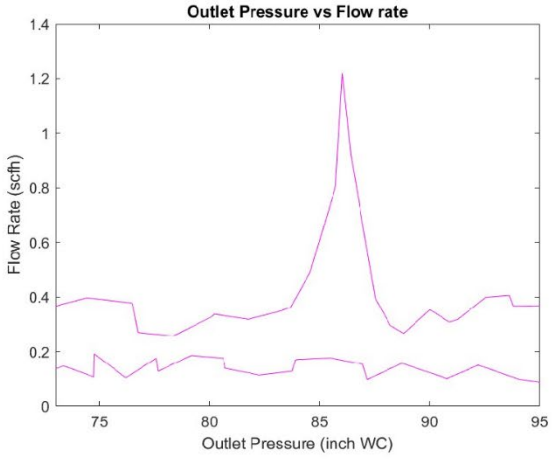
- 222489-042_DT1
  The volume of total emissions in 164.35 seconds is 0.0172 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 0.36 scfh.





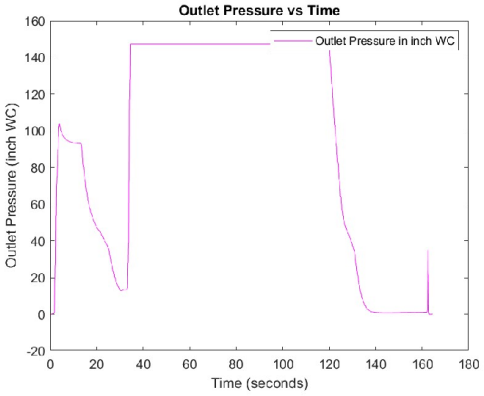
GTI ENERGY

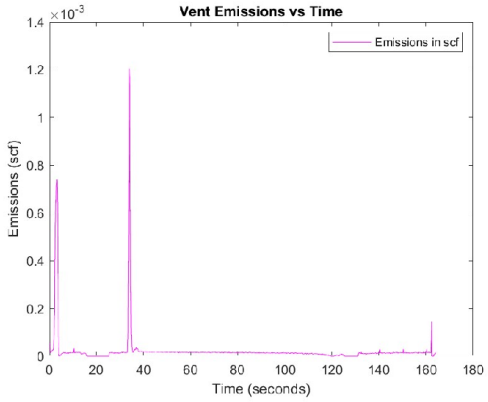

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
0
20
40
60
80
100
120
140


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
75
80
85
90
95

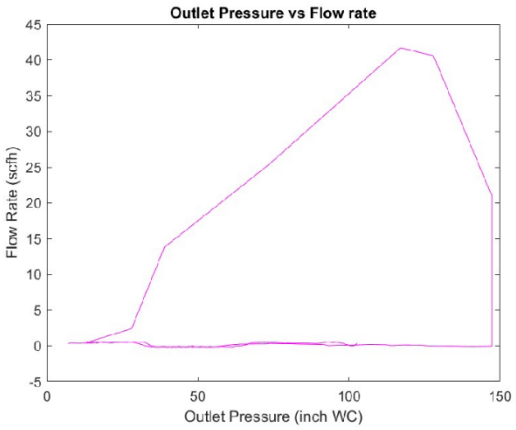
GTI ENERGY

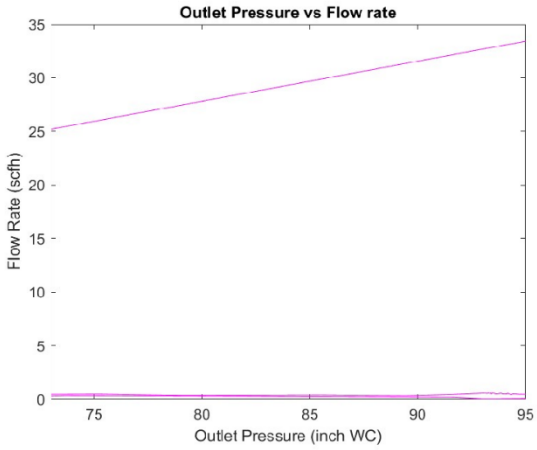
- 222489-042_LD
  The volume of total emissions in 164.30 seconds is 0.0380 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 8.72 scfh.





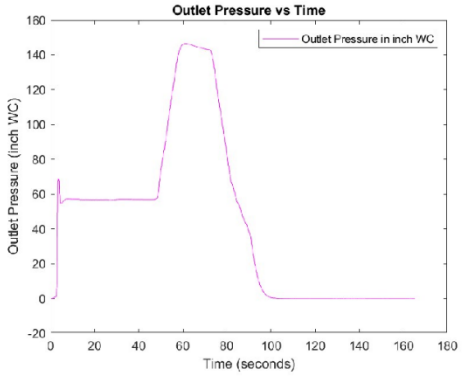
GTI ENERGY

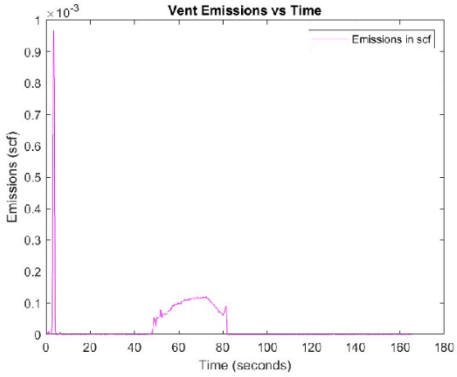

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
45
40
35
30
25
20
15
10
5
0
-5
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
35
30
25
20
15
10
5
0
75
80
85
90
95

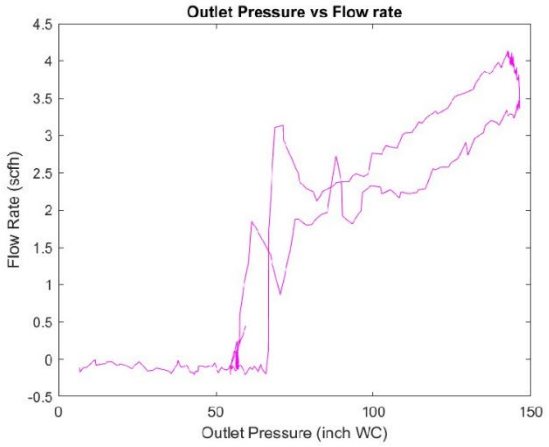
GTI ENERGY

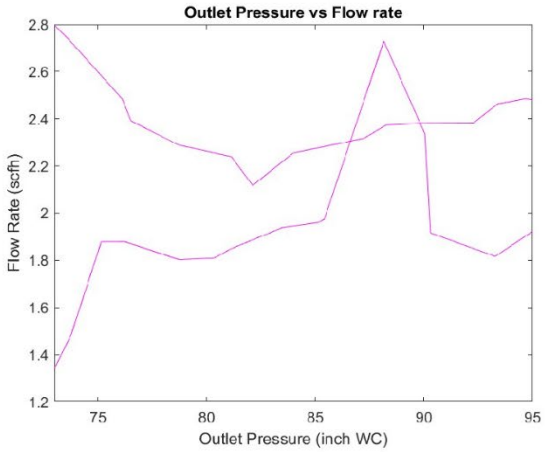
- 222489-043
  The volume of total emissions in 165.32 seconds is 0.0373 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 2.34 scfh.





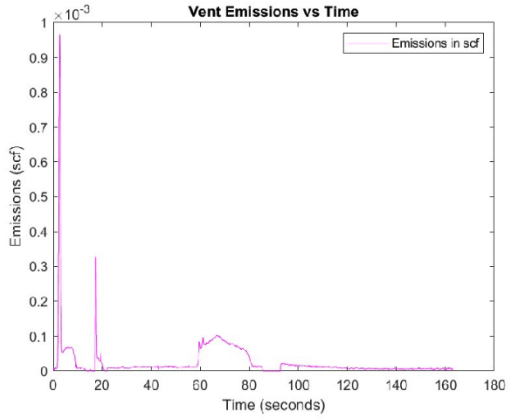
GTI ENERGY

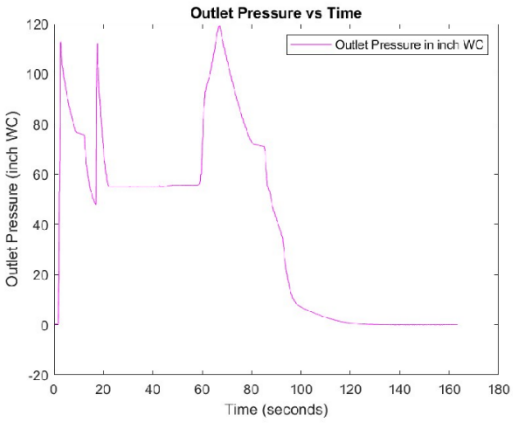

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
75
80
85
90
95

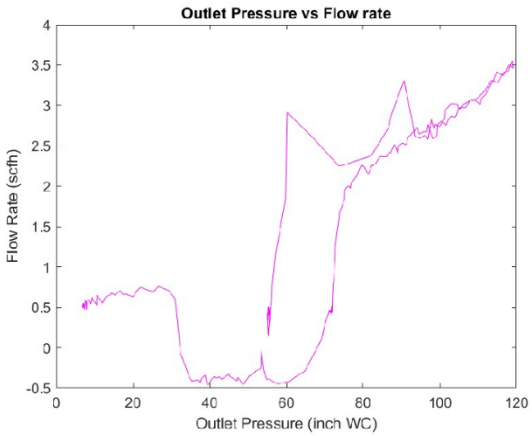
GTI ENERGY

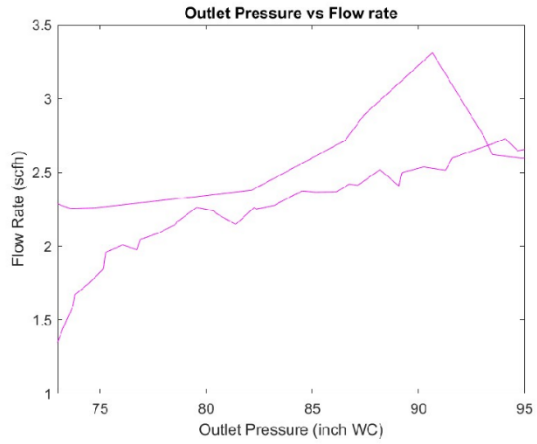
- 222489-043_DT1
  The volume of total emissions in 163.32 seconds is 0.0397 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 2.35 scfh.





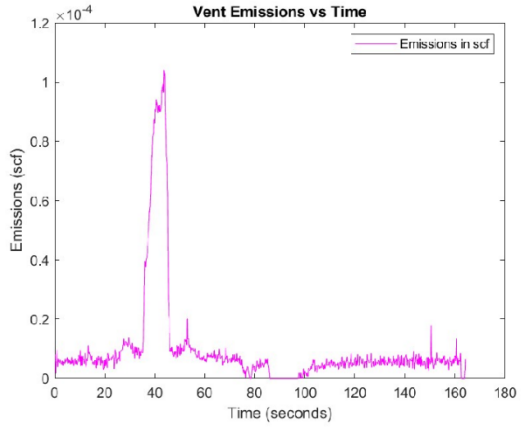
GTI ENERGY

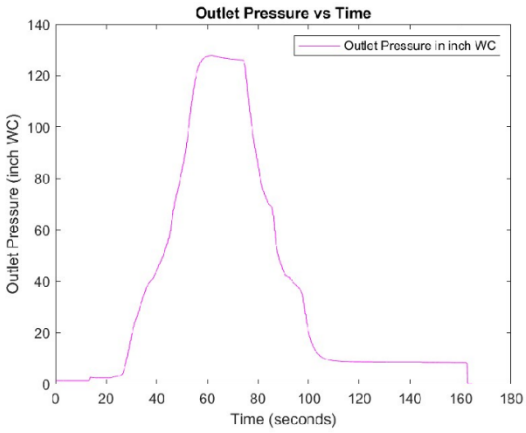

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
4
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
0
20
40
60
80
100
120


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
3.5
3
2.5
2
1.5
1
75
80
85
90
95

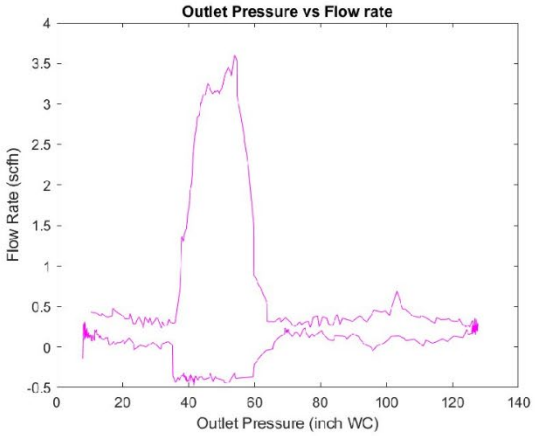
GTI ENERGY

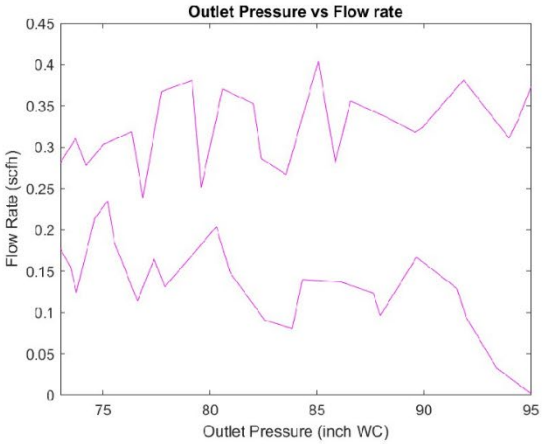
- 222489-043_LD
  The volume of total emissions in 164.39 seconds is 0.0153 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 0.23 scfh.





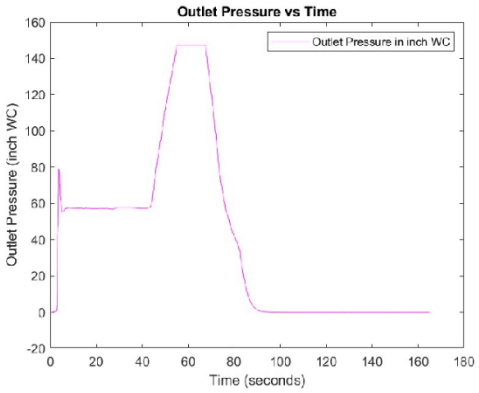
GTI ENERGY

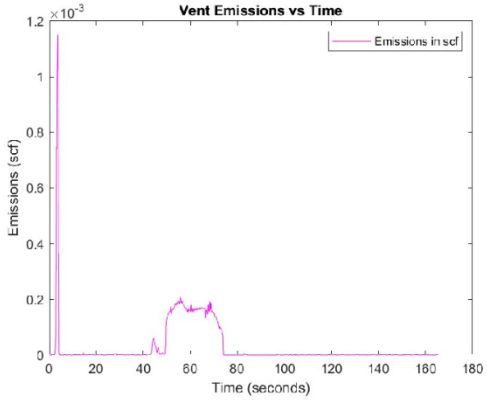

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
4
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
0
20
40
60
80
100
120
140


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
75
80
85
90
95

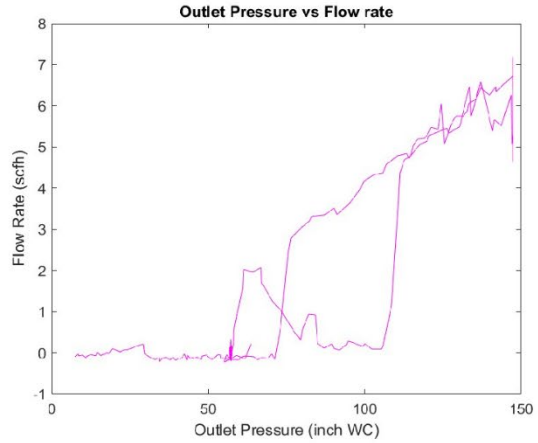
GTI ENERGY

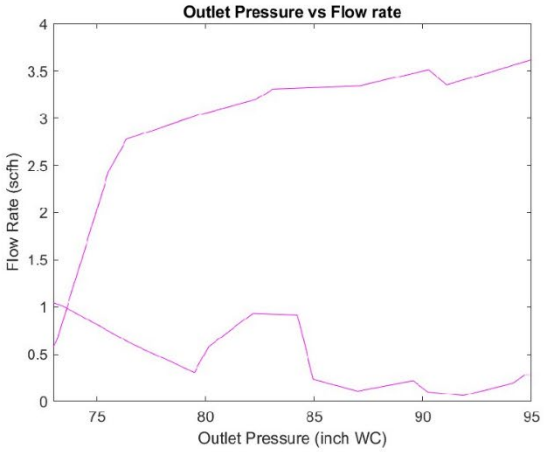
- 222489-044
  The volume of total emissions in 165.22 seconds is 0.0481 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 1.77 scfh.





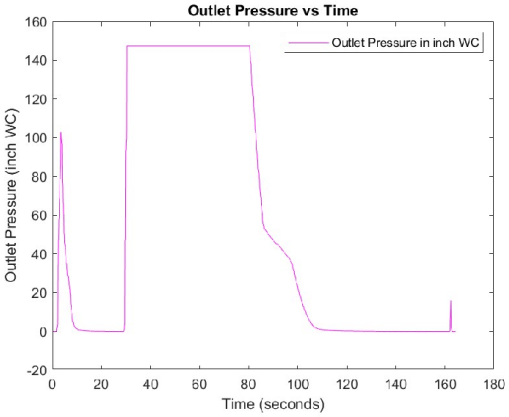
GTI ENERGY

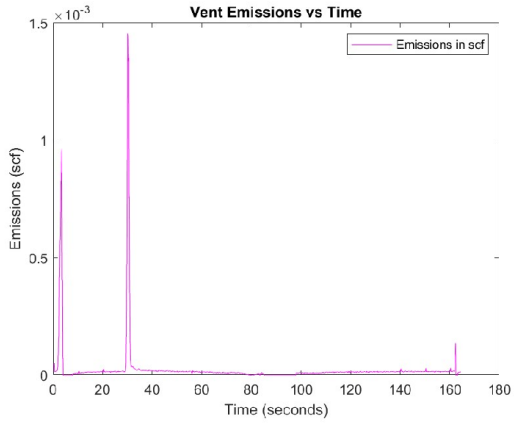

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
8
7
6
5
4
3
2
1
0
-1
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
4
3.5
3
2.5
2
1.5
1
0.5
0
75
80
85
90
95

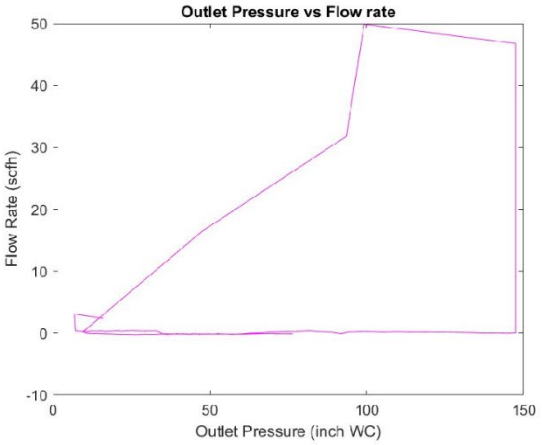
GTI ENERGY

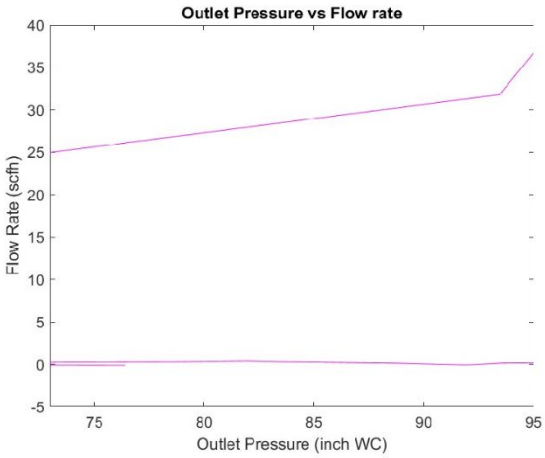
- 222489-044_LD
  The volume of total emissions in 164.33 seconds is 0.0408 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 0.15 scfh.





GTI ENERGY


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
50
40
30
20
10
0
-10
0
50
100
150

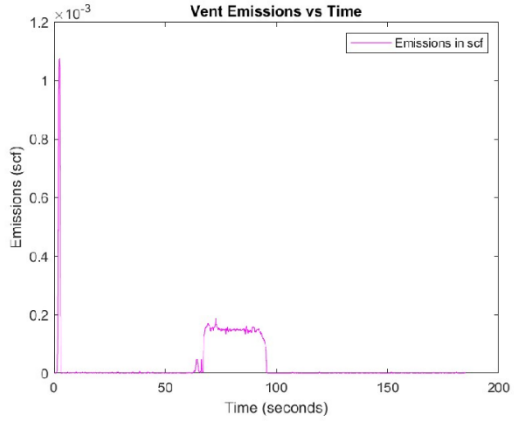

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
40
35
30
25
20
15
10
5
0
-5
75
80
85
90
95

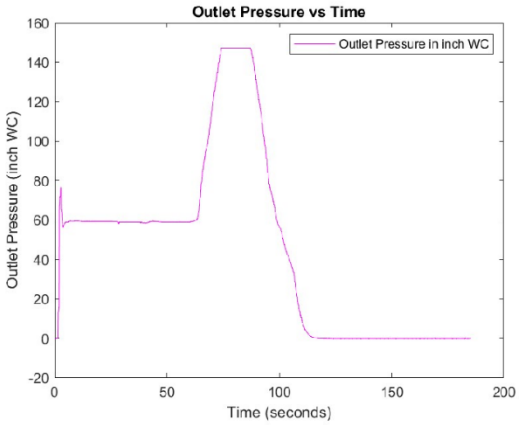
GTI ENERGY

2-psig Outlet, 60-psig Inlet

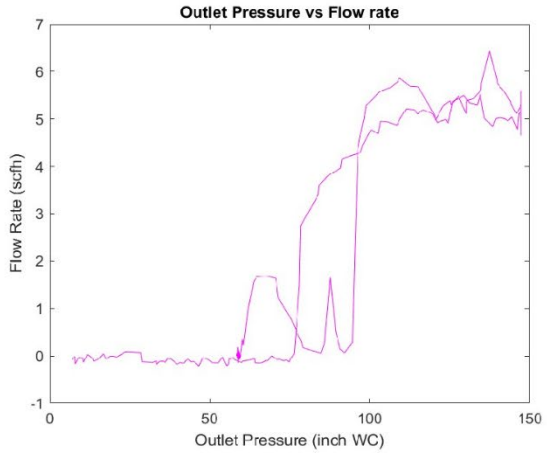
- 222489-042

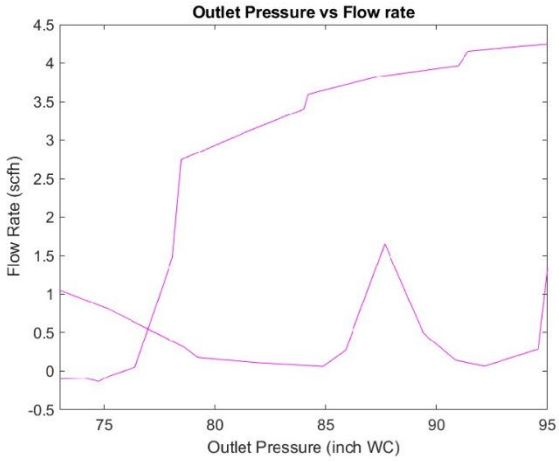
  The volume of total emissions in 185.26 seconds is 0.0504 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 2.37 scfh.





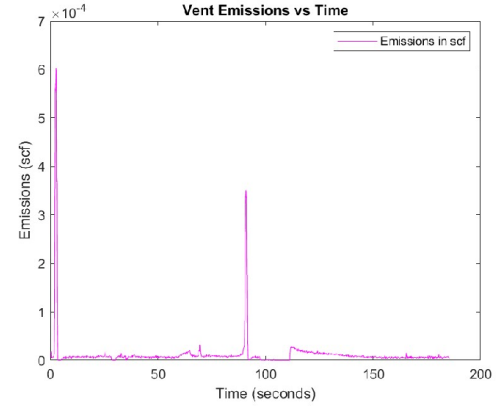
GTI ENERGY

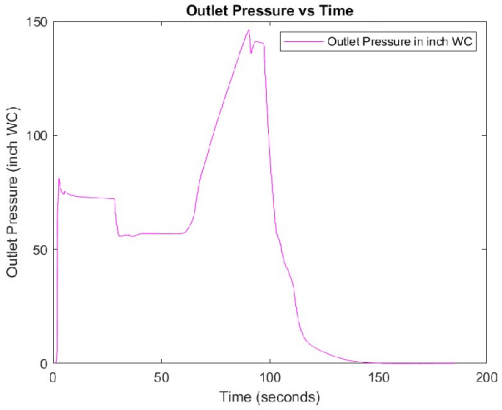

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
7
6
5
4
3
2
1
0
-1
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
75
80
85
90
95

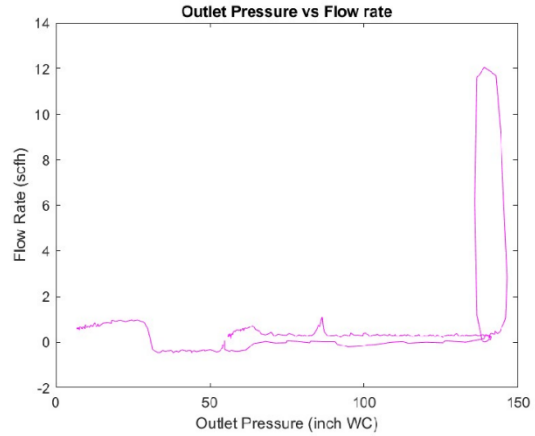
GTI ENERGY

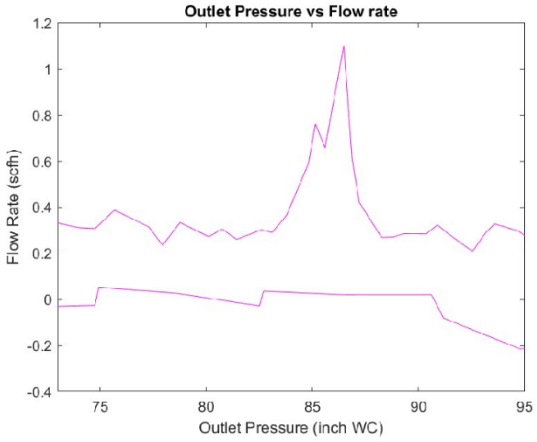
- 222489-042_DT1
  The volume of total emissions in 185.37 seconds is 0.0226 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 0.32 scfh.





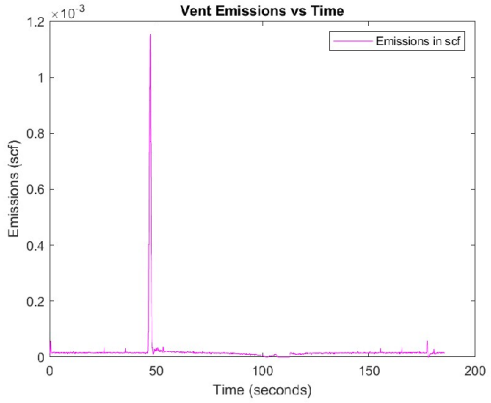
GTI ENERGY

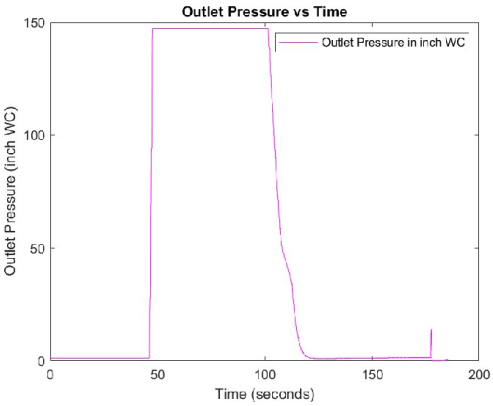

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
14
12
10
8
6
4
2
0
-2
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
75
80
85
90
95

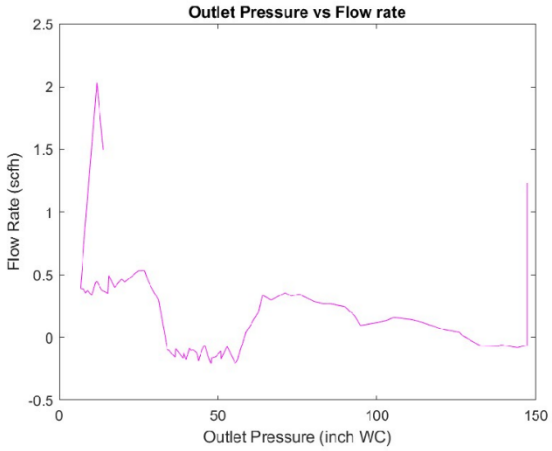
GTI ENERGY

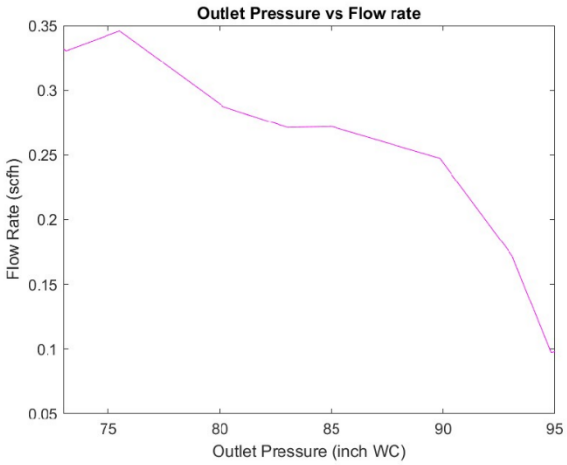
- 222489-042_LD
  The volume of total emissions in 185.54 seconds is 0.0346 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 0.25 scfh.





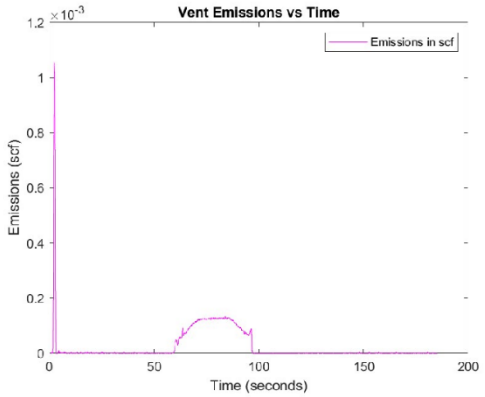
GTI ENERGY

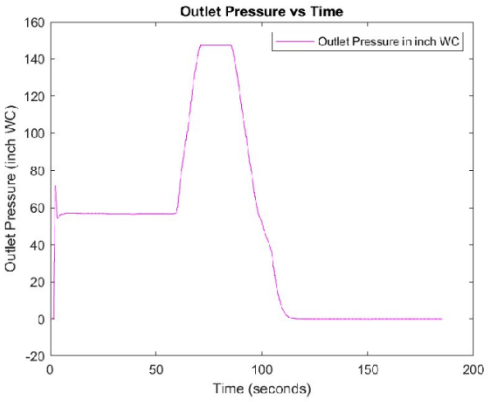

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
2.5
2
1.5
1
0.5
0
-0.5
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0.35
0.3
0.25
0.2
0.15
0.1
0.05
75
80
85
90
95

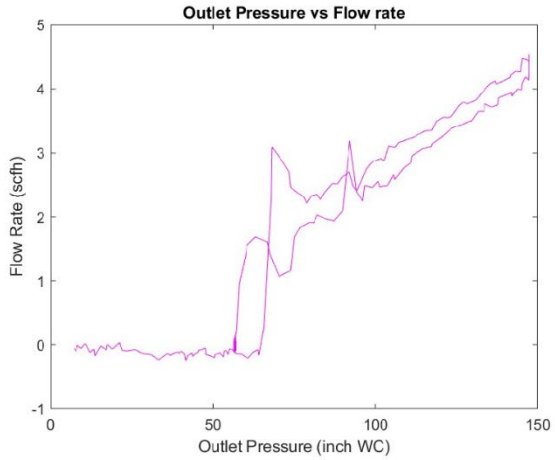
GTI ENERGY

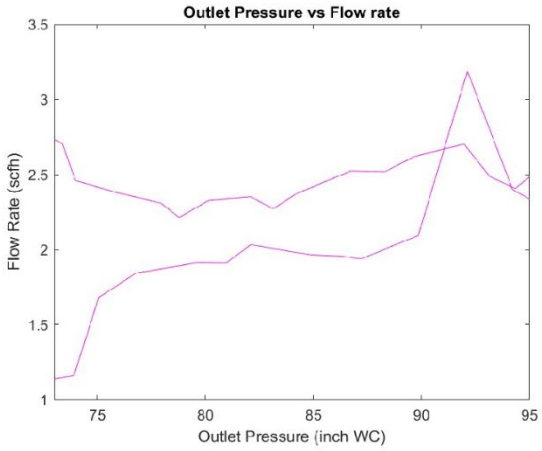
- 222489-043
  The volume of total emissions in 185.37 seconds is 0.0448 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 2.28 scfh.





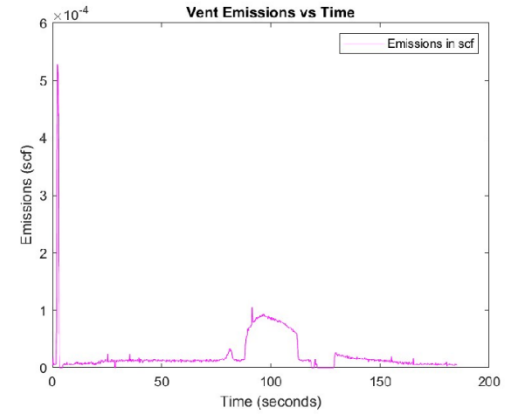
GTI ENERGY

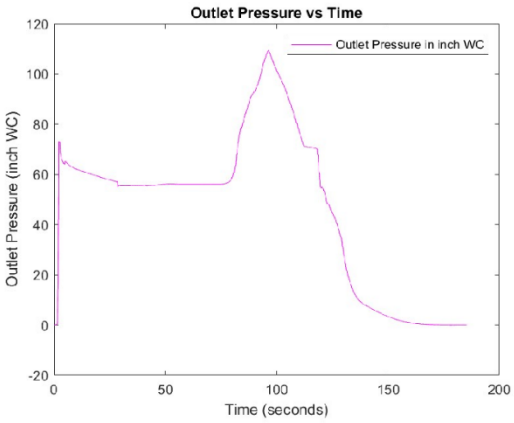

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
5
4
3
2
1
0
-1
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
3.5
3
2.5
2
1.5
1
75
80
85
90
95

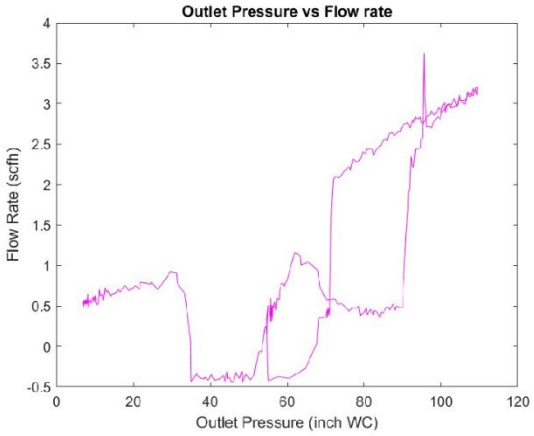
GTI ENERGY

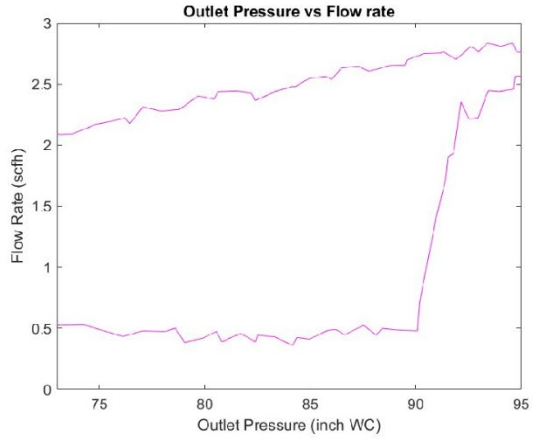
- 222489-043_DT1
  The volume of total emissions in 185.36 seconds is 0.0385 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 1.74 scfh.





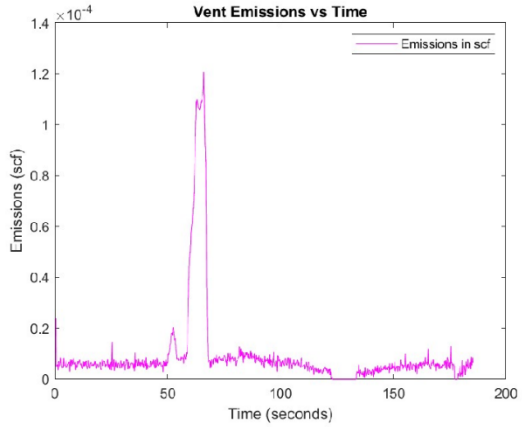
GTI ENERGY

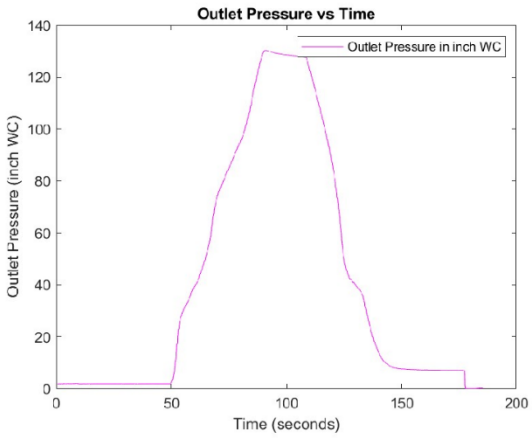

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
4
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
0
20
40
60
80
100
120


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
3
2.5
2
1.5
1
0.5
0
75
80
85
90
95

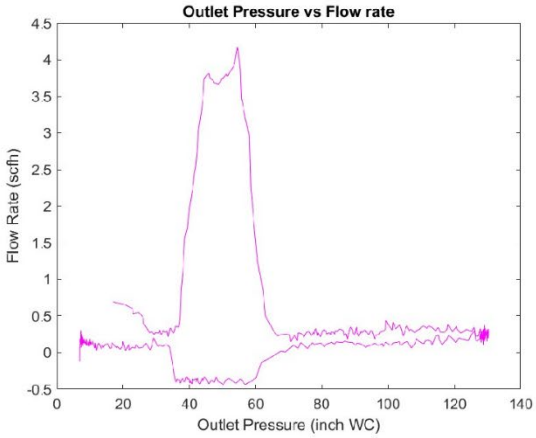
GTI ENERGY

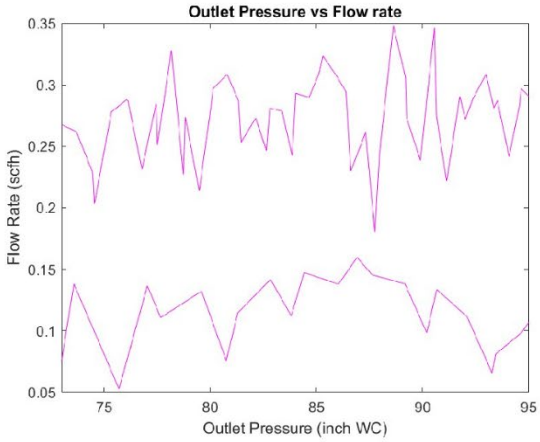
- 222489-043_LD
  The volume of total emissions in 185.41 seconds is 0.0165 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 0.23 scfh.





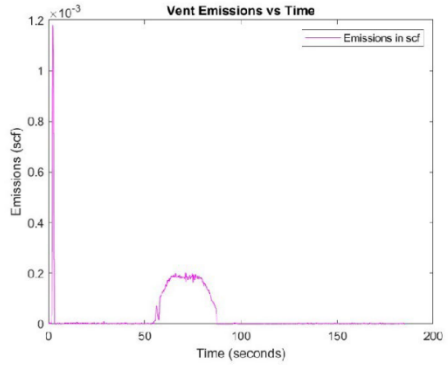
GTI ENERGY

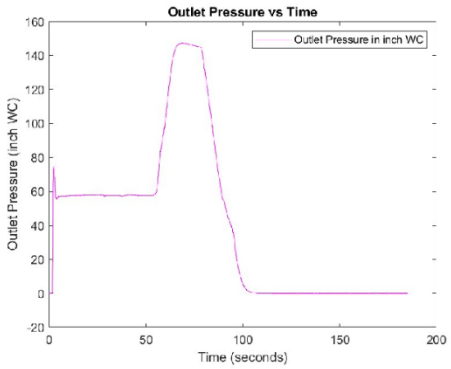

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
0
20
40
60
80
100
120
140


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0.35
0.3
0.25
0.2
0.15
0.1
0.05
75
80
85
90
95

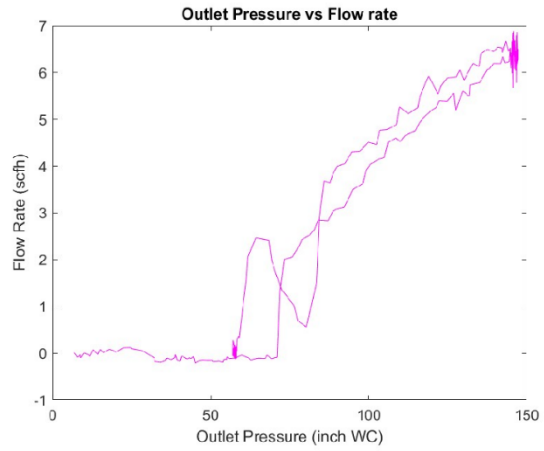
GTI ENERGY

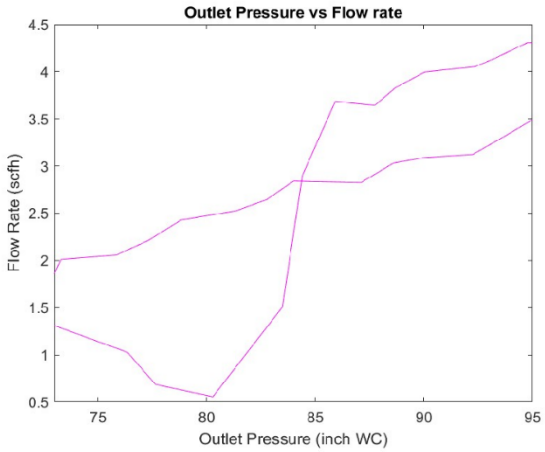
- 222489-044
  The volume of total emissions in 185.29 seconds is 0.0566 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 3.44 scfh.



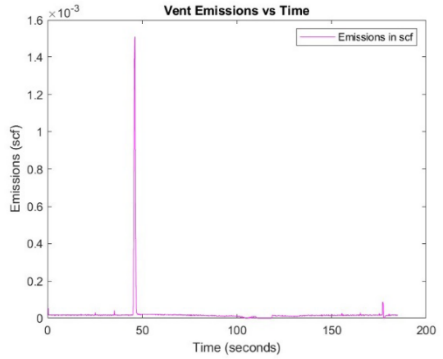


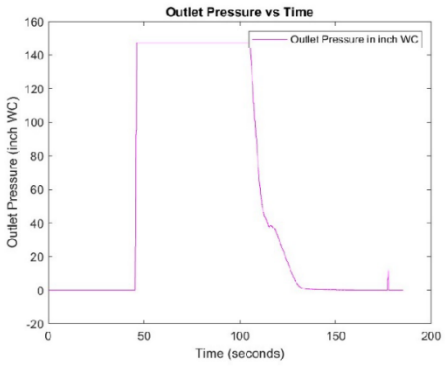
GTI ENERGY


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
7
6
5
4
3
2
1
0
-1
0
50
100
150

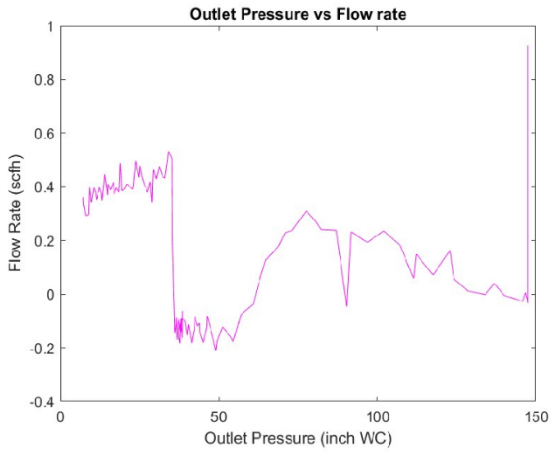

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
75
80
85
90
95

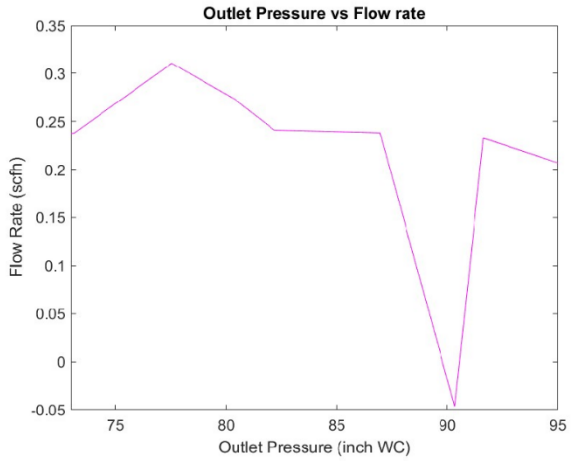
- 222489-044_LD
  The volume of total emissions in 185.35 seconds is 0.0360 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 0.10 scfh.





GTI ENERGY


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
0
50
100
150

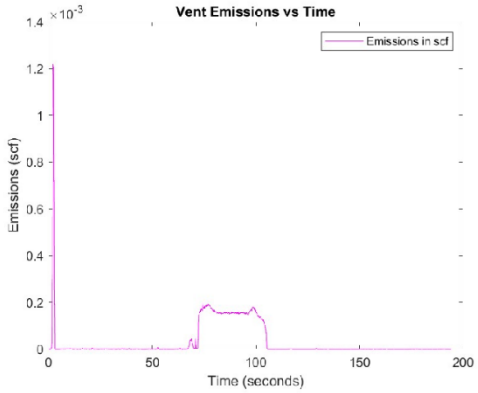

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
75
80
85
90
95

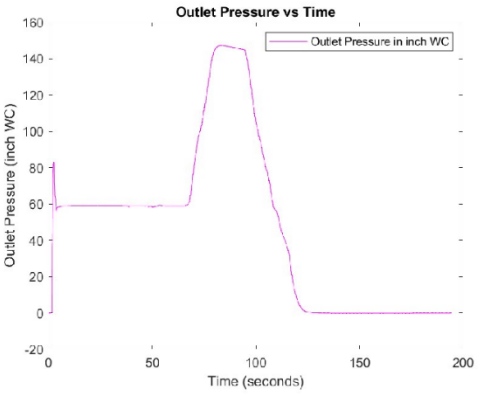
GTI ENERGY

2-psig Outlet, 100-psig Inlet

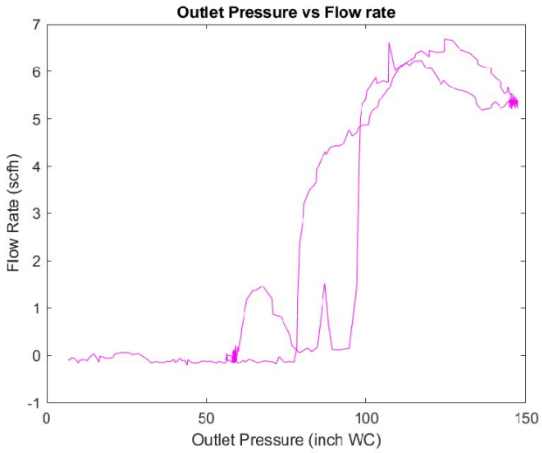
- 222489-042

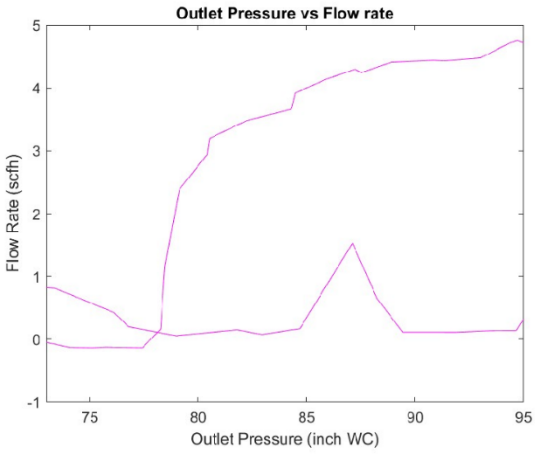
  The volume of total emissions in 194.38 seconds is 0.0600 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 3.14 scfh.





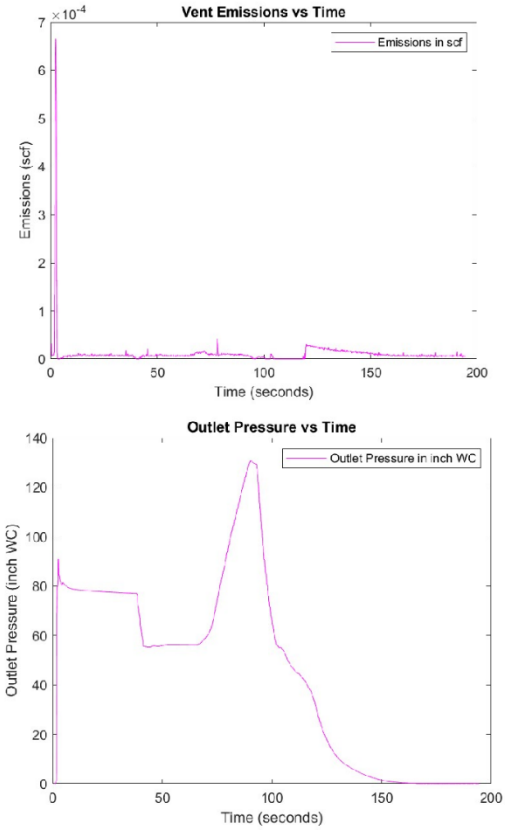
GTI ENERGY


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
7
6
5
4
3
2
1
0
-1
0
50
100
150

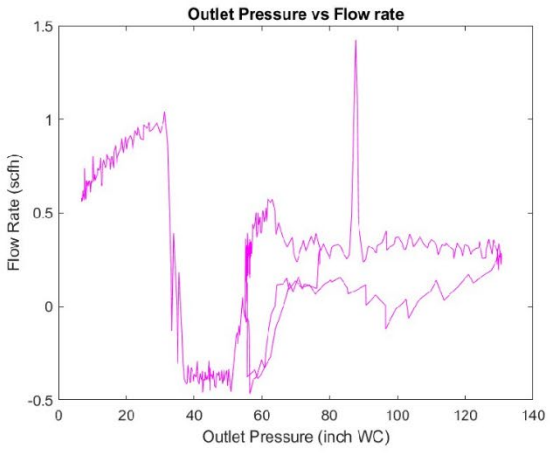

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
5
4
3
2
1
0
-1
75
80
85
90
95

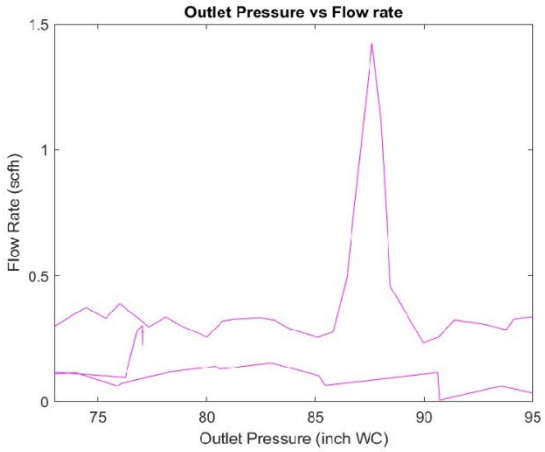
GTI ENERGY

- 222489-042_DT1
  The volume of total emissions in 194.49 seconds is 0.0208 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 2.10 scfh.



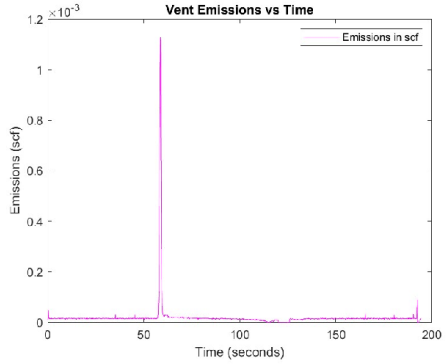
GTI ENERGY

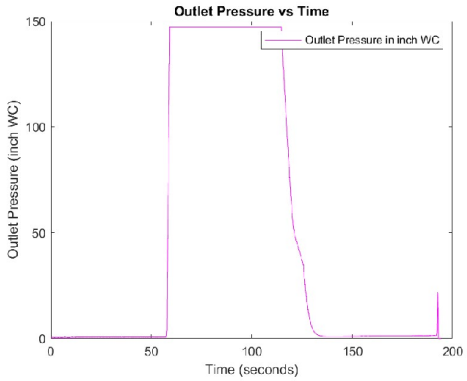

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
1.5
1
0.5
0
-0.5
0
20
40
60
80
100
120
140


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
1.5
1
0.5
0
75
80
85
90
95

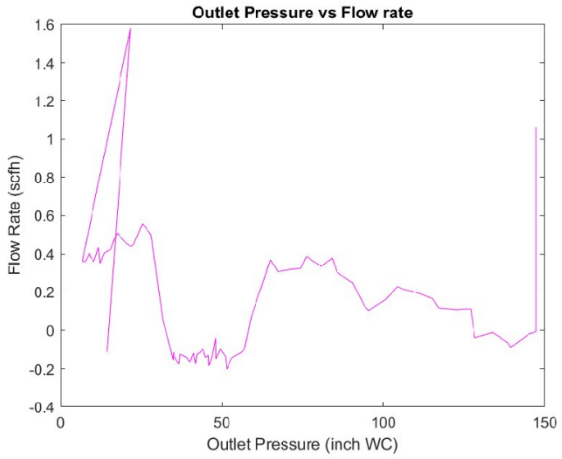
GTI ENERGY

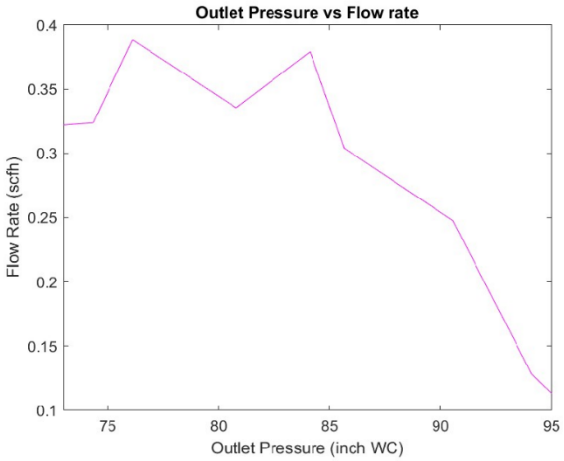
- 222489-042_LD
  The volume of total emissions in 194.35 seconds is 0.0362 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 0.25 scfh.





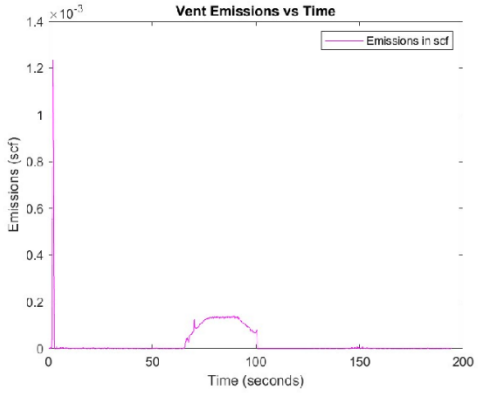
GTI ENERGY

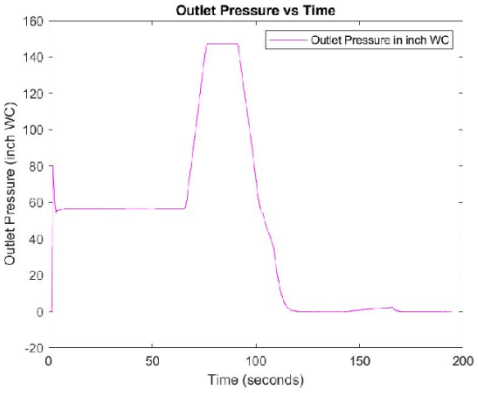

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0.4
0.35
0.3
0.25
0.2
0.15
0.1
75
80
85
90
95

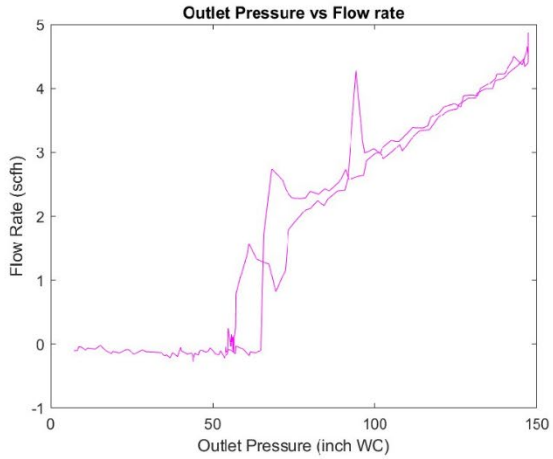
GTI ENERGY

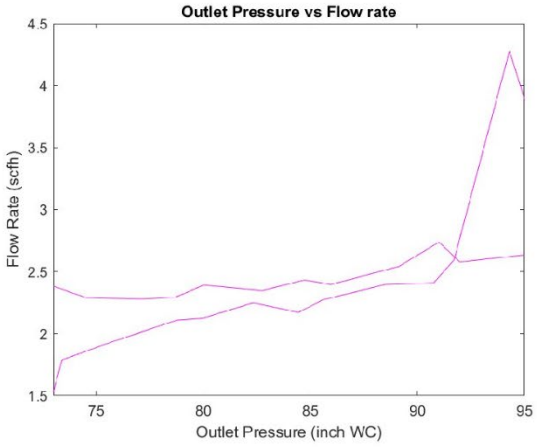
- 222489-043
  The volume of total emissions in 194.34 seconds is 0.0449 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 2.50 scfh.





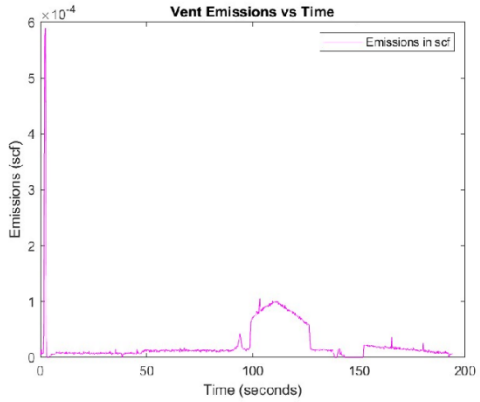
GTI ENERGY

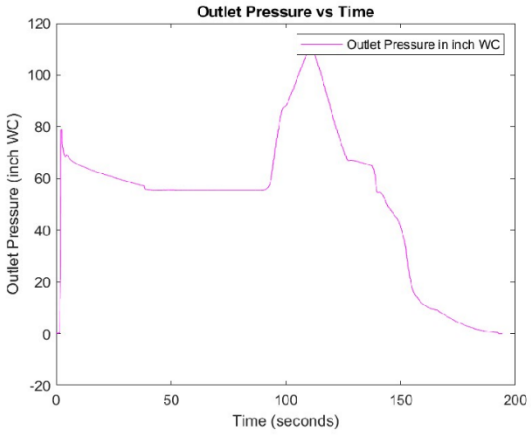

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
5
4
3
2
1
0
-1
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
4.5
4
3.5
3
2.5
2
1.5
75
80
85
90
95

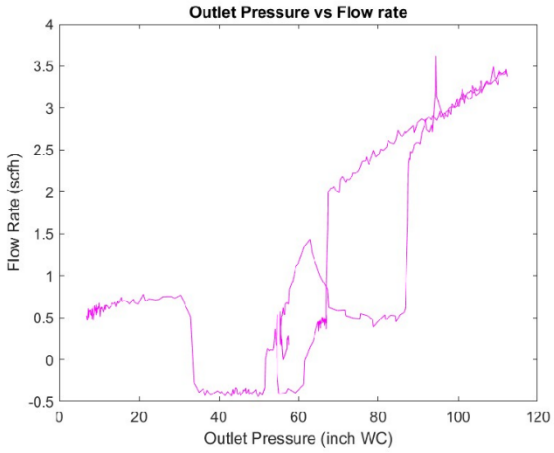
GTI ENERGY

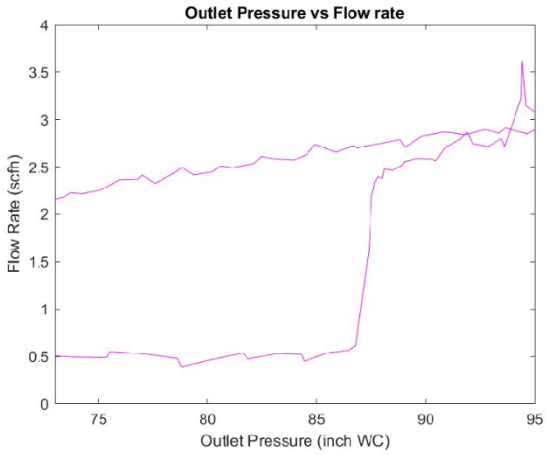
- 222489-043_DT1
  The volume of total emissions in 194.42 seconds is 0.0432 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 2.38 scfh.





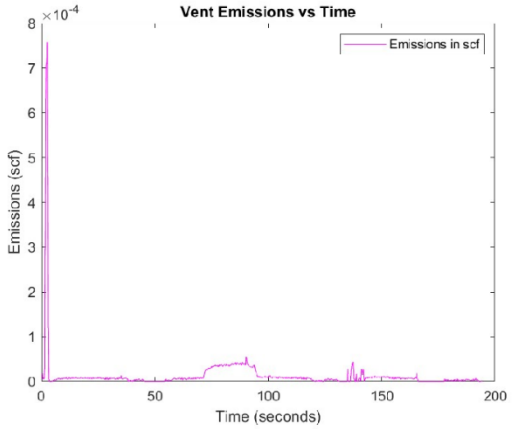
GTI ENERGY

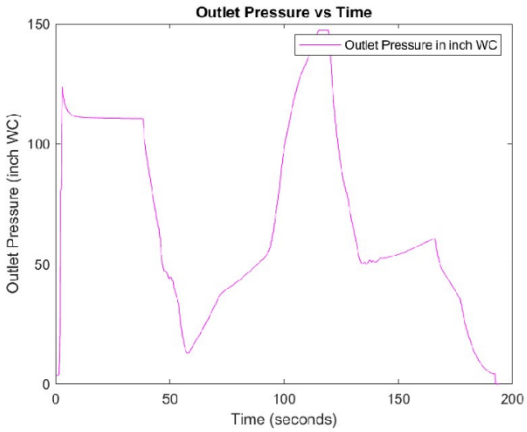

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
4
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
0
20
40
60
80
100
120


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
4
3.5
3
2.5
2
1.5
1
0.5
0
75
80
85
90
95

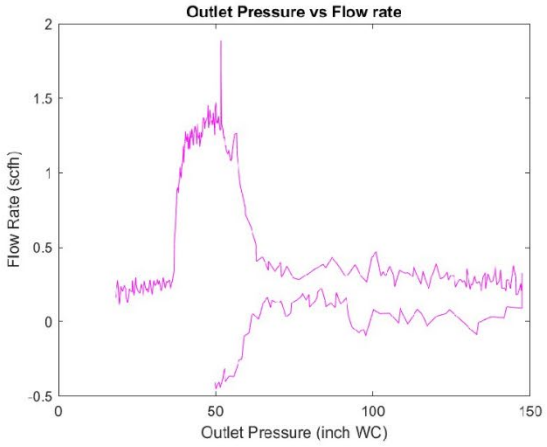
GTI ENERGY

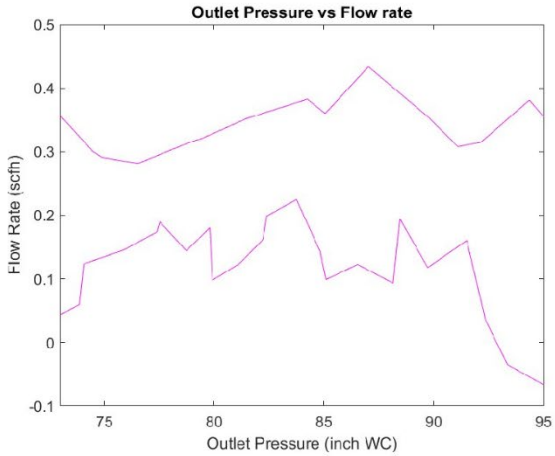
- 222489-043_LD
  The volume of total emissions in 194.41 seconds is 0.0241 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 0.18 scfh.





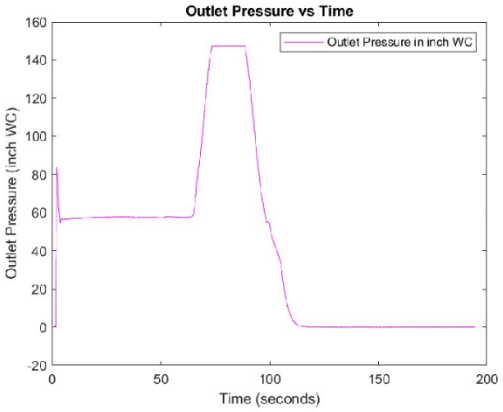
GTI ENERGY

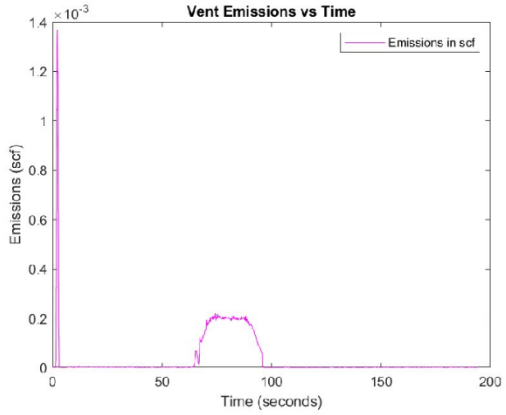

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
2
1.5
1
0.5
0
-0.5
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0.5
0.4
0.3
0.2
0.1
0
-0.1
75
80
85
90
95

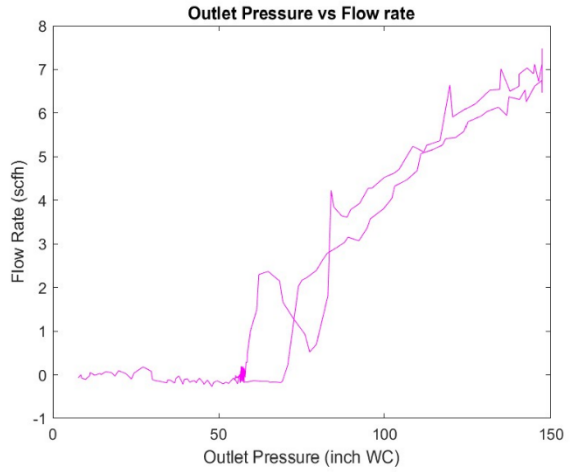
GTI ENERGY

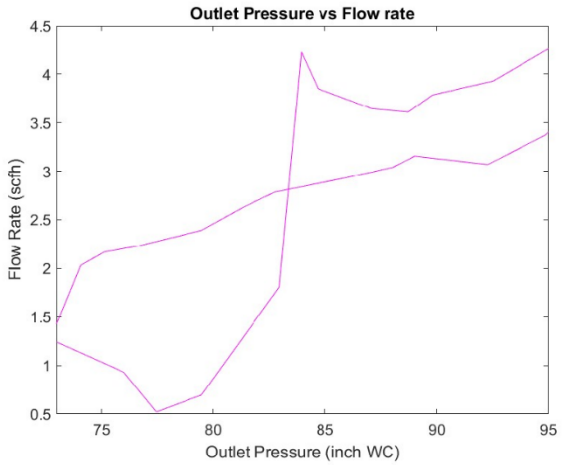
- 222489-044
  The volume of total emissions in 194.38 seconds is 0.0597 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 3.45 scfh.





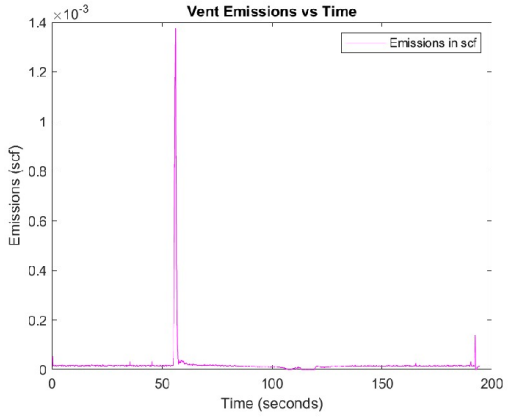
GTI ENERGY

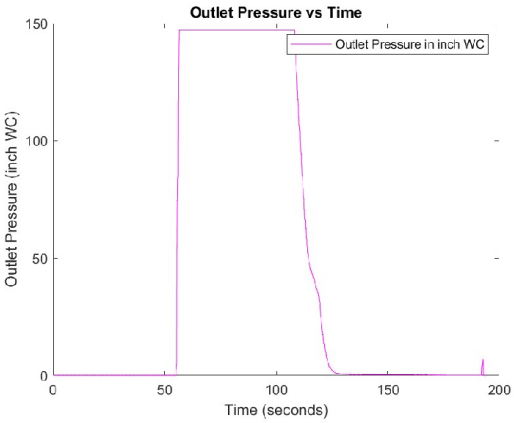

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
8
7
6
5
4
3
2
1
0
-1
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
75
80
85
90
95

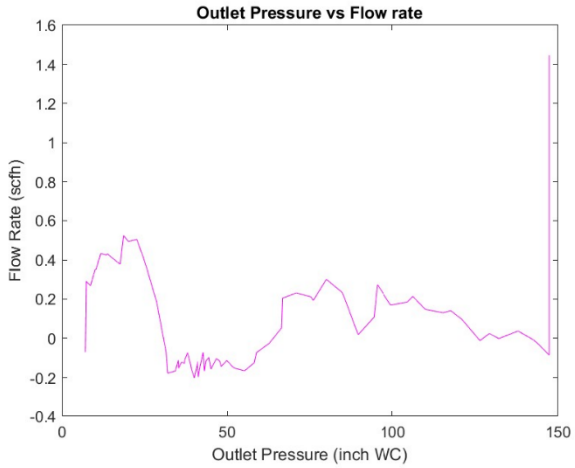
GTI ENERGY

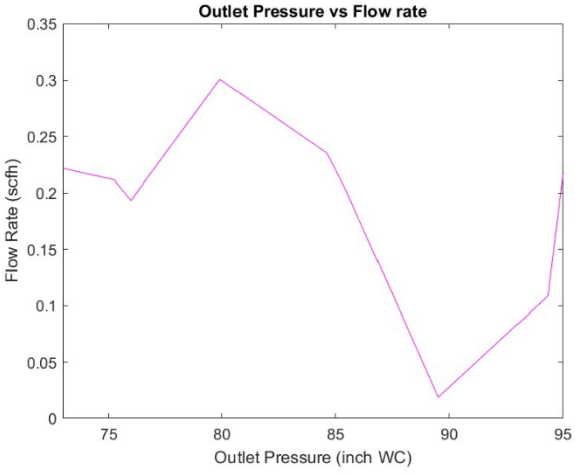
- 222489-044_LD
  The volume of total emissions in 194.38 seconds is 0.0378 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 0.02 scfh.





GTI ENERGY

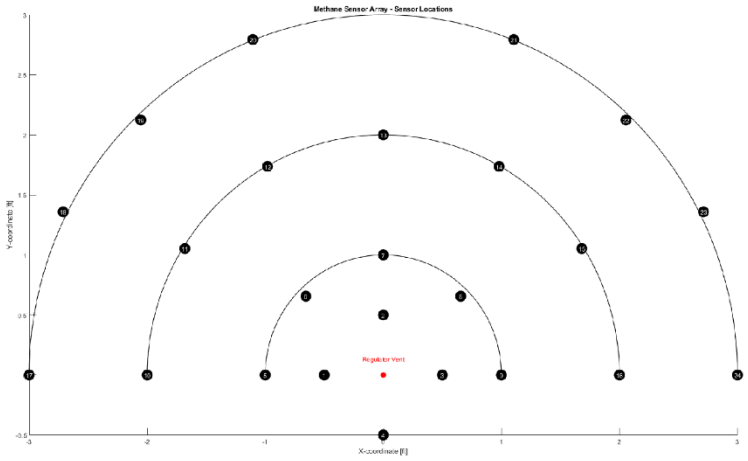

Outlet Pressure vs Flow rate
Flow Rate (scfh)
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
0
50
100
150
Outlet Pressure (inch WC)


Outlet Pressure vs Flow rate
Flow Rate (scfh)
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
75
80
85
90
95
Outlet Pressure (inch WC)

GTI ENERGY

Methane Concentration Maps

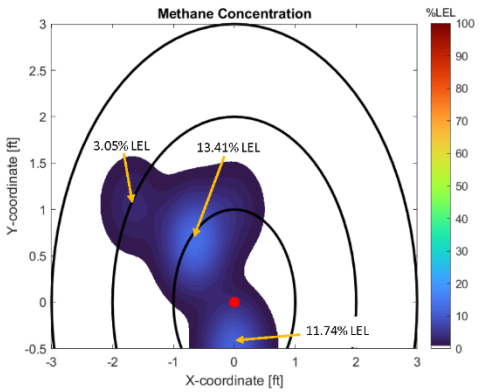
Sensor Locations



GTI ENERGY

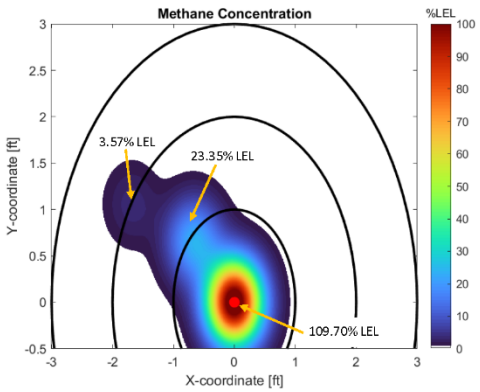
7" WC

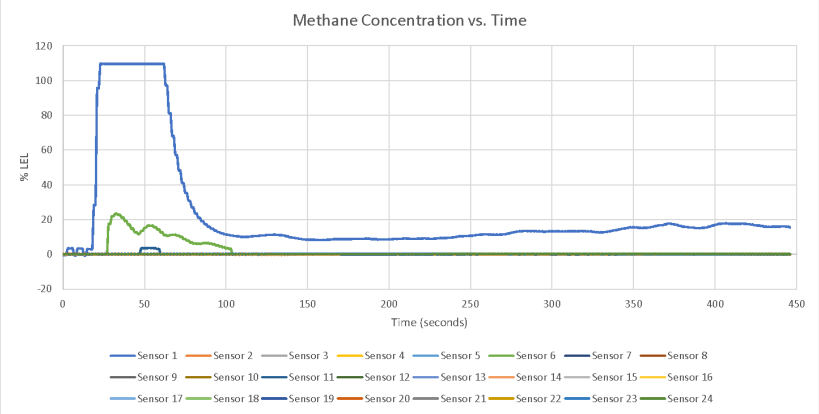
	7 In-WC	222489-041_DT1_sensor1 6in	Sigma = .33
VL2	Primary Diaphragm Tear	Standard Array Configuration	6 in from vent



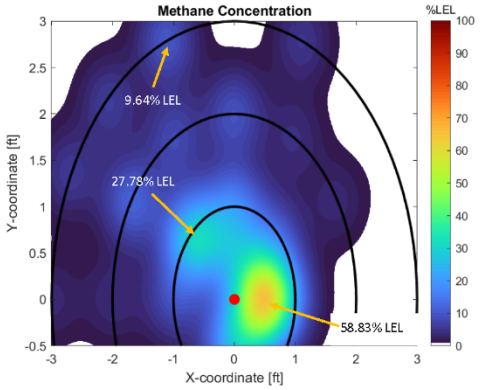
GTI ENERGY

	7 In-WC	222489-041_DT1_sensor1 next to vent	Sigma = .3
VL2	Primary Diaphragm Tear	Standard Array Configuration	1 in from vent



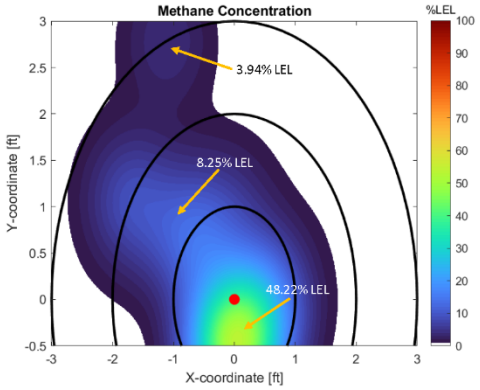

Methane Concentration vs. Time
% LEL
120
100
80
60
40
20
0
-20
0
50
100
150
200
250
300
350
400
450
Time (seconds)
Sensor 1
Sensor 2
Sensor 3
Sensor 4
Sensor 5
Sensor 6
Sensor 7
Sensor 8
Sensor 9
Sensor 10
Sensor 11
Sensor 12
Sensor 13
Sensor 14
Sensor 15
Sensor 16
Sensor 17
Sensor 18
Sensor 19
Sensor 20
Sensor 21
Sensor 22
Sensor 23
Sensor 24

	7 In-WC	222489-041_DT2_trial1	Sigma = .34
VL2	Primary and Secondary Diaphragm Tear	Standard Array Configuration	6 in from vent



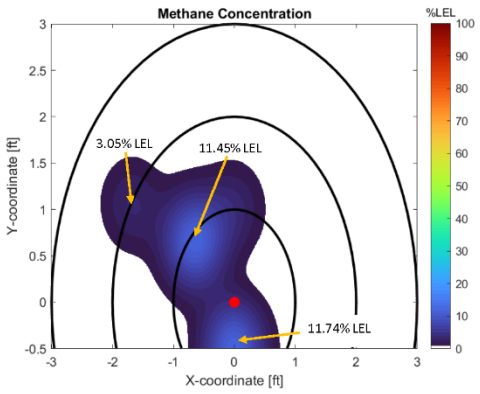
GTI ENERGY

	7 In-WC	222489-041_DT2_trial2	Sigma = .5
VL2	Primary and Secondary Diaphragm Tear	Standard Array Configuration	6 in from vent



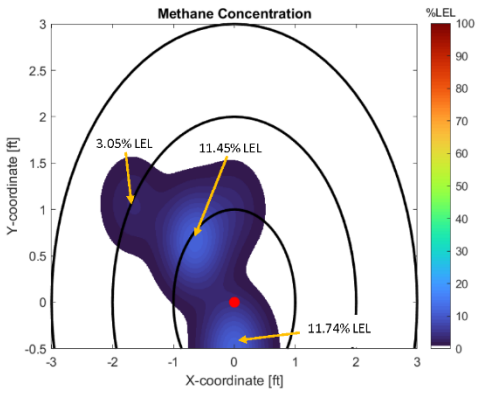
GTI ENERGY

	7 In-WC	222489-040_LD	Sigma = .34
VL2	Lever Disconnect	Standard Array Configuration	6 in from vent



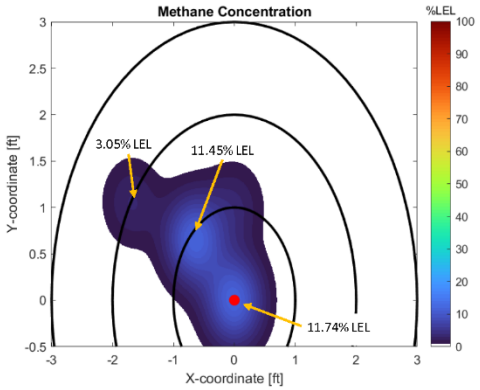
GTI ENERGY

	7 In-WC	222489-040_LD_trial2	Sigma = .34
VL2	Lever Disconnect	Standard Array Configuration	6 in from vent



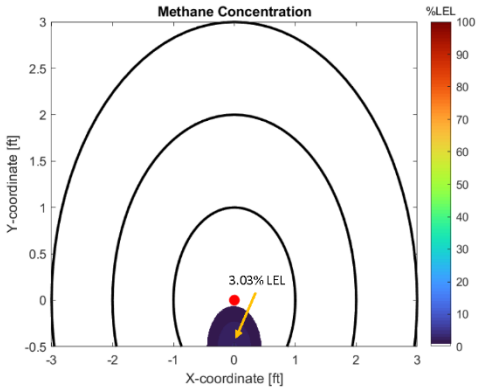
GTI ENERGY

	7 In-WC	222489-040_LD_trial3_sensor1 next to vent	Sigma = .32
VL2	Lever Disconnect	Standard Array Configuration	1 in from vent



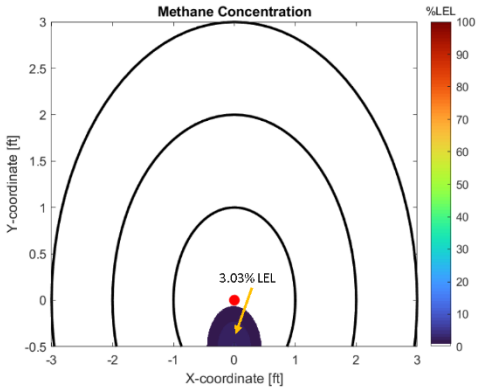
GTI ENERGY

	7 In-WC	222489-039_multi lockup_sensor1 6in_trial1	Sigma = .3
VL2	Normal Condition – Multi Lockup	Standard Array Configuration	6 in from vent

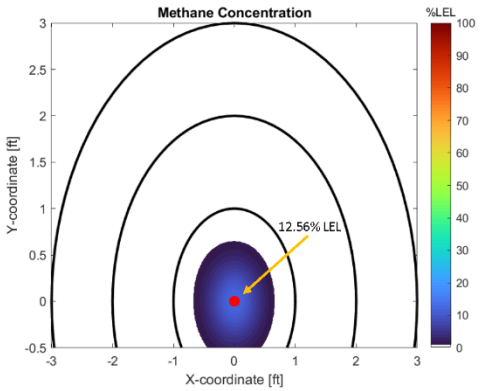


GTI ENERGY

	7 In-WC	222489-039_multi lockup_sensor1 6in_trial2	Sigma = .3
VL2	Normal Condition – Multi Lockup	Standard Array Configuration	6 in from vent

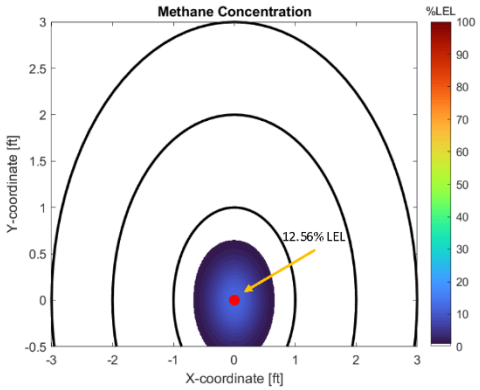


	7 In-WC	222489-039_multi lockup_sensor1 next to vent_trial1	Sigma = .3
VL2	Normal Condition – Multi Lockup	Standard Array Configuration	1 in from vent



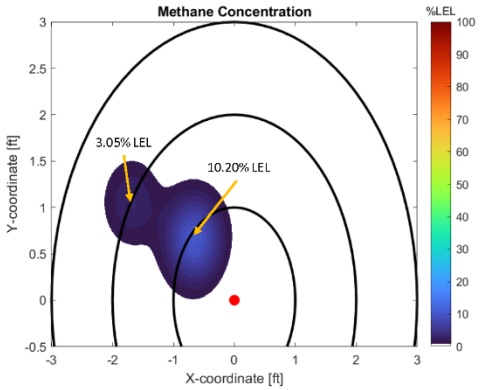
GTI ENERGY

	7 In-WC	222489-039_multi lockup_sensor1 next to vent_trial2	Sigma = .3
VL2	Normal Condition – Multi Lockup	Standard Array Configuration	1 in from vent

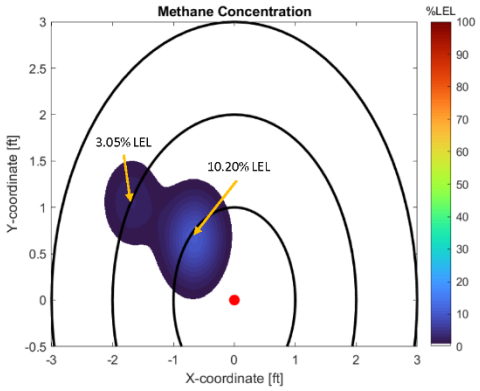


GTI ENERGY

	7 In-WC	222489-039_single lockup_sensor1 next to vent_trial1	Sigma = .3
VL2	Normal Condition – Single Lockup	Standard Array Configuration	1 in from vent

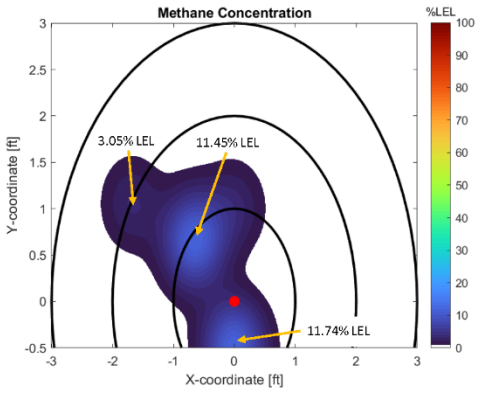


	7 In-WC	222489-039_single lockup_sensor1 next to vent_trial2	Sigma = .3
VL2	Normal Condition – Single Lockup	Standard Array Configuration	1 in from vent



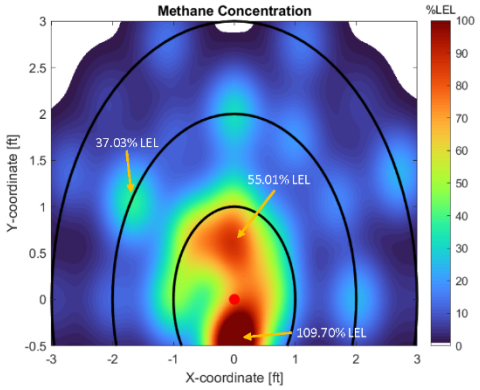
2-psig

	2 PSI	222489-042_DT1	Sigma = .34
VL2	Primary Diaphragm Tear	Standard Array Configuration	6 in from vent

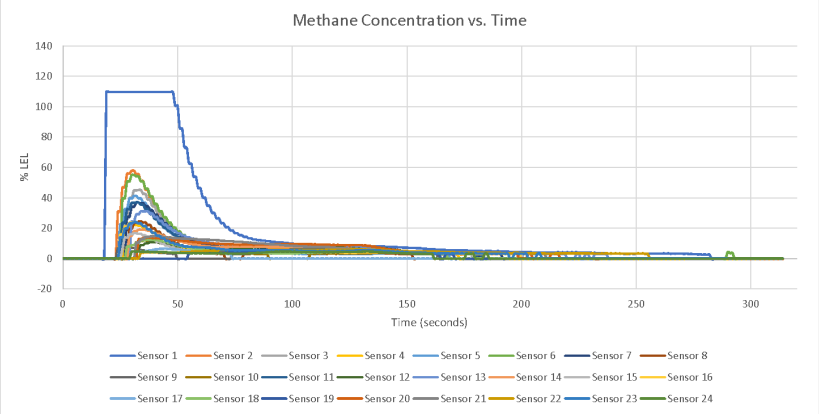


GTI ENERGY

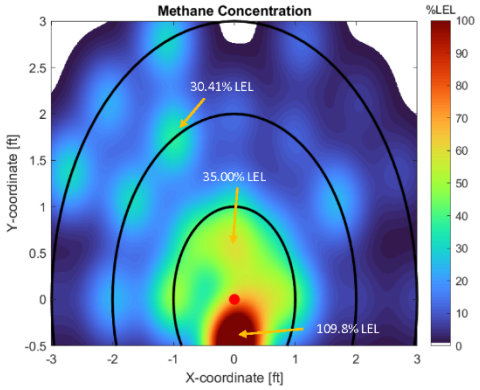
	2 PSI	222489-042_DT2_trial1	Sigma = .33
VL2	Primary and Secondary Diaphragm Tear	Standard Array Configuration	6 in from vent



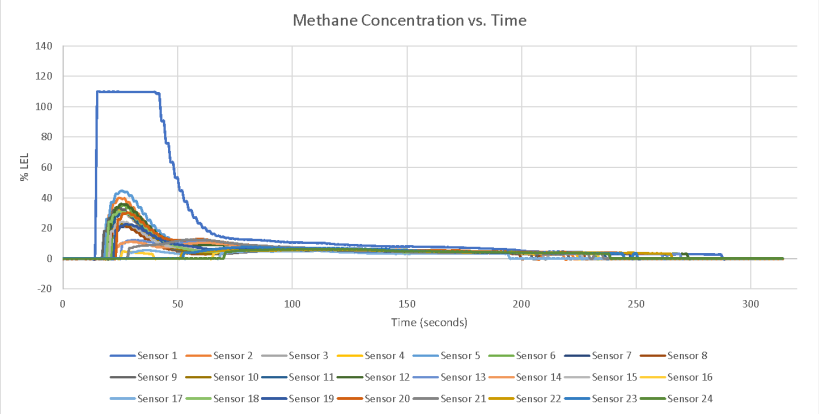
GTI ENERGY


Methane Concentration vs. Time
% LEL
140
120
100
80
60
40
20
0
-20
0
50
100
150
200
250
300
Time (seconds)
Sensor 1
Sensor 2
Sensor 3
Sensor 4
Sensor 5
Sensor 6
Sensor 7
Sensor 8
Sensor 9
Sensor 10
Sensor 11
Sensor 12
Sensor 13
Sensor 14
Sensor 15
Sensor 16
Sensor 17
Sensor 18
Sensor 19
Sensor 20
Sensor 21
Sensor 22
Sensor 23
Sensor 24

	2 PSI	222489-042_DT2_trial2	Sigma = .33
VL2	Primary and Secondary Diaphragm Tear	Standard Array Configuration	6 in from vent

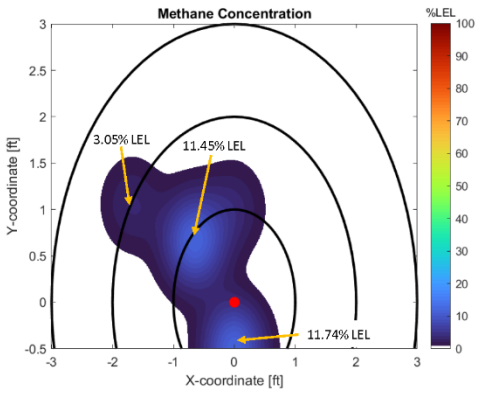


GTI ENERGY


Methane Concentration vs. Time
% LEL
140
120
100
80
60
40
20
0
-20
0
50
100
150
200
250
300
Time (seconds)
Sensor 1
Sensor 2
Sensor 3
Sensor 4
Sensor 5
Sensor 6
Sensor 7
Sensor 8
Sensor 9
Sensor 10
Sensor 11
Sensor 12
Sensor 13
Sensor 14
Sensor 15
Sensor 16
Sensor 17
Sensor 18
Sensor 19
Sensor 20
Sensor 21
Sensor 22
Sensor 23
Sensor 24

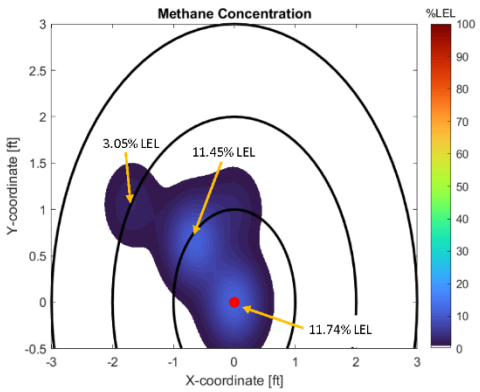
GTI ENERGY

	2 PSI	222489-044_LD	Sigma = .34
VL2	Lever Disconnect	Standard Array Configuration	6 in from vent



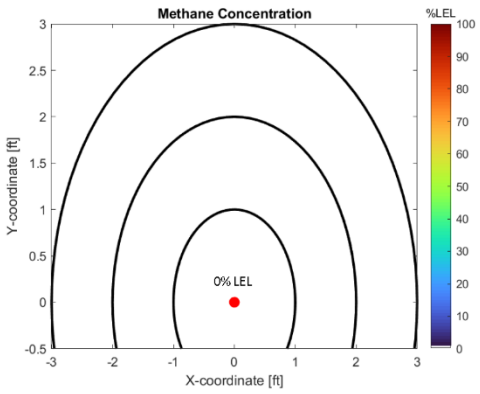
GTI ENERGY

	2 PSI	222489-044_LD_sensor1 next to vent	Sigma = .3
VL2	Lever Disconnect	Standard Array Configuration	1 in from vent



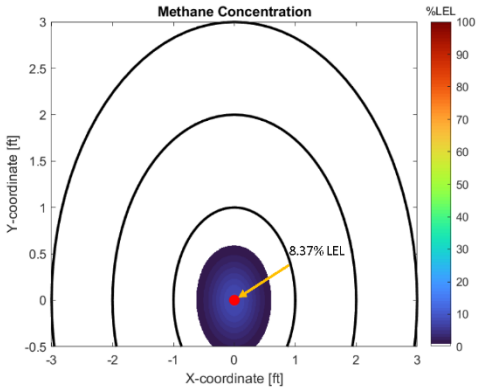
GTI ENERGY

	2 PSI	222489-043_multi lockup_sensor1 6in	Sigma = .3
VL2	Normal Condition – Multi Lockup	Standard Array Configuration	6 in from vent

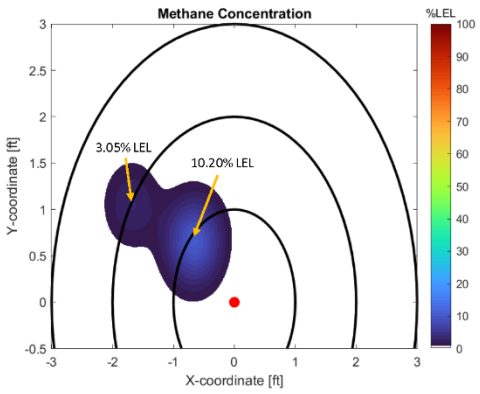


GTI ENERGY

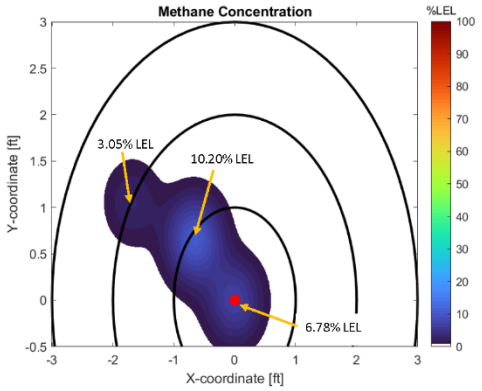
	2 PSI	222489-043_multi lockup_sensor1 next to vent	Sigma = .3
VL2	Normal Condition – Multi Lockup	Standard Array Configuration	1 in from vent



	2 PSI	222489-043_single lockup_sensor1 6in	Sigma = .3
VL2	Normal Condition – Single Lockup	Standard Array Configuration	6 in from vent



	2 PSI	222489-043_single lockup_sensor1 next to vent	Sigma = .31
VL2	Normal Condition – Single Lockup	Standard Array Configuration	1 in from vent



GTI ENERGY

Appendix C – VL3 & IRV3 Manufacturer Test Data

GTI ENERGY
solutions that transform

REPORT
GTI ENERGY PROJECT NUMBER 23059

Comparison of Compact Service Regulators – Results of Testing

VL3 & IRV3 Summary

GTI Energy Technical Contact:
Joe Carlstrom
Joseph Irwin, PE
Tom Bates
Jake Witecha

1700 S. Mount Prospect Rd.
Des Plaines, Illinois 60018
www.gti.energy

Introduction

This report was created to review data obtained during PHMSA project 693JK32110001 and OTD project 5.22.j - Design and Placement of Compact Service Regulators with subject matter experts from the manufacturer. The following Part 1 and Part 2 matrix outlines the test methodology used to obtain data for analysis purposes for safe clearance distances.

Part 1 Test methodology

All testing was performed on the rig with air and software formula coefficients for natural gas.

Test	Standard/Procedure reference	Conditions	Test Criteria	Parameters
Modified Lock-Up Test	ANSI B109.4 -[5.3.5]	Temperature: Ambient; Inlet pressure: 10, 60, 100 psig; Flow: 100, 200, 300, until maximum manufacturer specifications [SCFH Air]	Outlet pressure Max 9"±0.5 iwc 2.15±0.15 psig (2psig reg.)	Lock up [iwc]
			Flow rate at vent 2.5 SCFH (vent limited) 100 SCFH (IRV)	Vent flow rate [SCFH]
Modified Relief Point Test	ANSI B109.4 -[5.3.8]	Temperature: Ambient; Inlet pressure: 10, 60, 100 psig; Outlet pressure: slowly increase until slam shut closes or maximum allowable pressure reached	Outlet pressure MAX 17"±0.5 iwc; 3.3±0.15iwc psig (2psig reg.)	Relief point [iwc]
			Flow rate at vent 2.5 SCFH (vent limited) 100 SCFH (IRV)	Vent flow rate [SCFH]

GTI ENERGY

Part 2 Test Methodology

Testing was performed in an enclosed and controlled environment with natural gas. Safety rules were implemented to monitor and limit the amounts of natural gas. When an accumulation of natural gas greater than 100% LEL was detected by multiple sensors the natural gas source was terminated and the test concluded.

Single Lock-Up Test	ANSI B109.4 - [5.3.5]	**Temperature**: Ambient; **Inlet pressure**: 60 psig; **Flow Rate**: 390 SCFH (7 iwc reg.) 1260 SCFH (2 psig reg.) **Lockup condition**: One lock up induced, wait 30 seconds for gas concentration dissipate to 0% LEL, repeat 10 times.	Outlet pressure Max 9"±0.5 iwc (7 iwc reg.) 2.15±0.15 psig (2psig reg.)	Lock up pressure [iwc]
			Methane concentration at vent 0%LEL (vent limited) 3%LEL (IRV)	Methane Concentration [% LEL]
Multi Lock-Up Test	ANSI B109.4 - [5.3.5]	**Temperature**: Ambient; **Inlet pressure**: 60 psig; **Flow Rate**: 390 SCFH (7 iwc reg.) 1260 SCFH (2 psig reg.) **Lockup condition**: Two lock ups induced in quick succession, wait 30 seconds for gas concentration dissipate to 0%LEL, repeat 3 times, after 3 repetitions increase the number of lockups by 1 to a maximum of 4.	Outlet pressure Max 9"±0.5 iwc (7 inW/C reg.) 2.15±0.15 psig (2psig reg.)	Lock up pressure [inW/C]
			Methane concentration at vent 0%LEL (vent limited) 3%LEL (IRV)	Methane Concentration [% LEL]

Summary

Modified Lockup Tests

Average Emission Rate [SCFH], Normal Conditions, 7" WC

Type	Model	10-psig inlet	60-psig inlet	100-psig inlet
IRV	IRV3	0.5484	0.4789	0.4556
Vent-Limited	VL3	1.0197	0.5850	0.5552

*Under abnormal conditions, IRV3 flow rate exceeded flow meter range
**Under abnormal conditions, VL3 OPSO was triggered

Average Emission Rate [SCFH], Normal Conditions, 2-psig

Type	Model	10-psig inlet	60-psig inlet	100-psig inlet
IRV	IRV3	1.2586	0.6212	0.6398
Vent-Limited	VL3	N/A**	N/A**	N/A**

*Under abnormal conditions, IRV3 flow rate exceeded flow meter range
**No 2-psig VL3 samples tested

Relief Tests

Average Emission Rate [SCFH], Normal Conditions, 7" WC

Type	Model	10-psig inlet	60-psig inlet	100-psig inlet
IRV	IRV3	3.0000	3.4567	3.5333
Vent-Limited	VL3	3.3300	3.9150	4.9400

Average Emission Rate [SCFH], Diaphragm Tear, 7" WC

Type	Model	10-psig inlet	60-psig inlet	100-psig inlet
IRV	IRV3	N/A*	N/A*	N/A*
Vent-Limited	VL3	22.7350	24.8900	25.1050

*Flow rate exceeded flow meter range

GTI ENERGY

Average Emission Rate [SCFH], Lever Disconnect, 7" WC

Type	Model	10-psig inlet	60-psig inlet	100-psig inlet
IRV	IRV3	N/A*	N/A*	N/A*
Vent-Limited	VL3	9.7950	11.9200	12.1450

*Flow rate exceeded flow meter range

Average Emission Rate [SCFH], Normal Conditions, 2-psig

Type	Model	10-psig inlet	60-psig inlet	100-psig inlet
IRV	IRV3	10.2567	9.5700	9.9167
Vent-Limited	VL3	N/A**	N/A**	N/A**

*Under abnormal conditions, IRV3 flow rate exceeded flow meter range
**No 2-psig VL3 samples tested

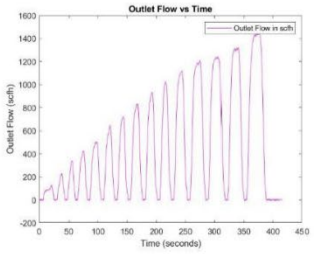
IRV3

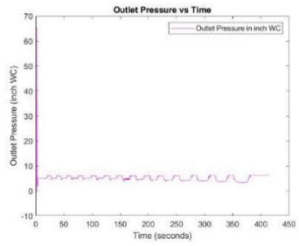
Modified Lockup Tests

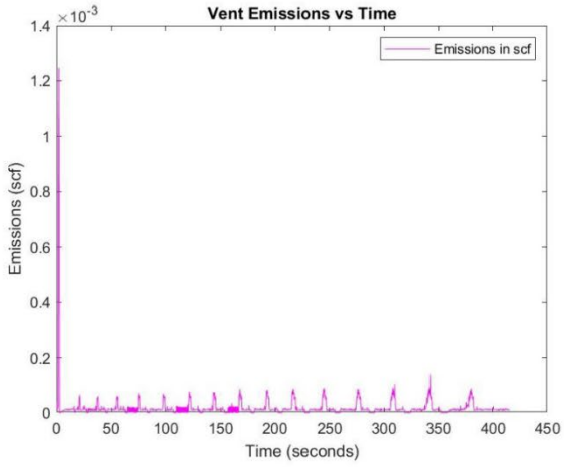
7" WC Outlet, 10-psig Inlet
222489-004

The volume of total emissions in 415.24 seconds is 0.0695 scf.

The flow rate of emissions is 0.6022 scfh.





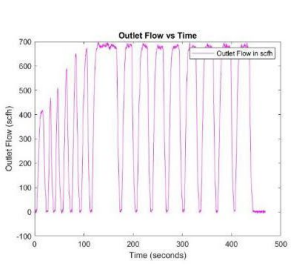


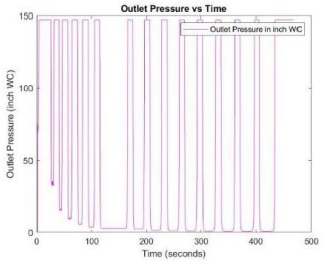
GTI ENERGY

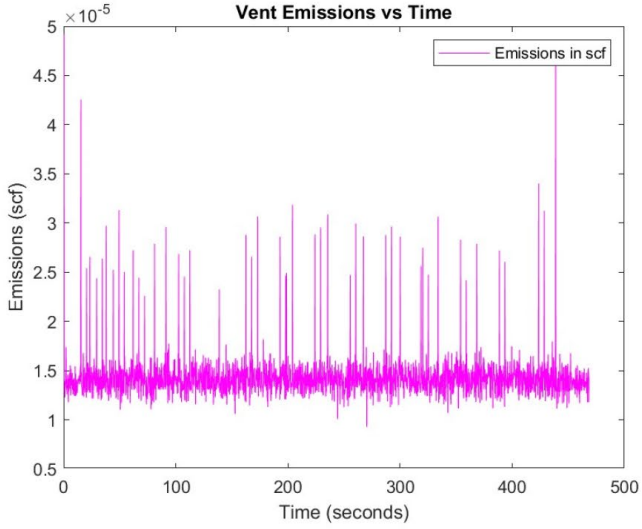
222489-004_BV

The volume of total emissions in 468.50 seconds is 0.0633 scf.

The flow rate of emissions is 0.4863 scfh.





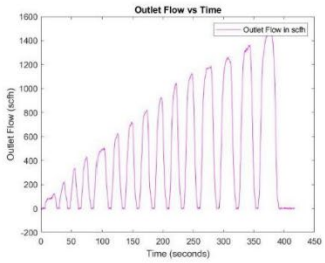


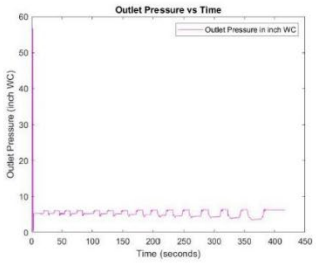
GTI ENERGY

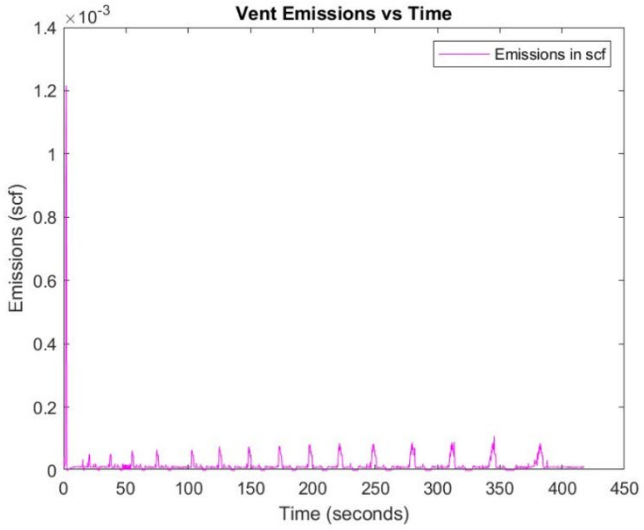
222489-005

The volume of total emissions in 417.07 seconds is 0.0632 scf.

The flow rate of emissions is 0.5458 scfh.





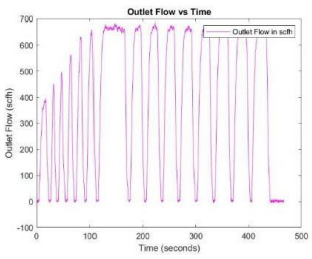


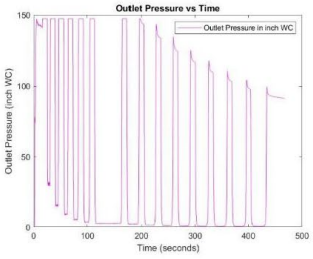
GTI ENERGY

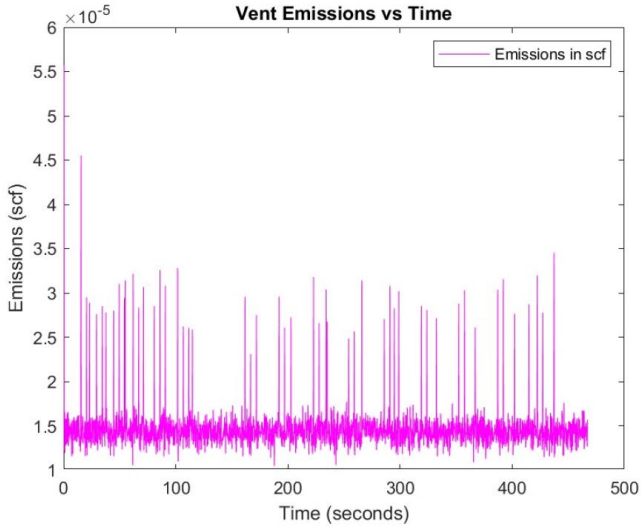
222489-005_BV

The volume of total emissions in 467.09 seconds is 0.0642 scf.

The flow rate of emissions is 0.4950 scfh.





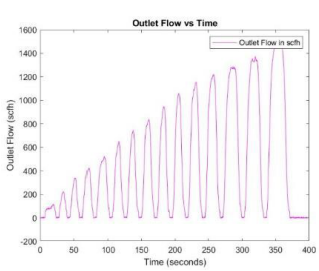


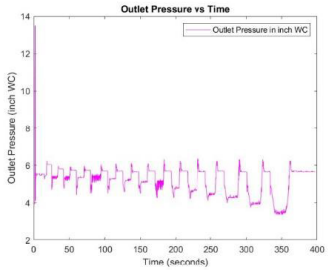
GTI ENERGY

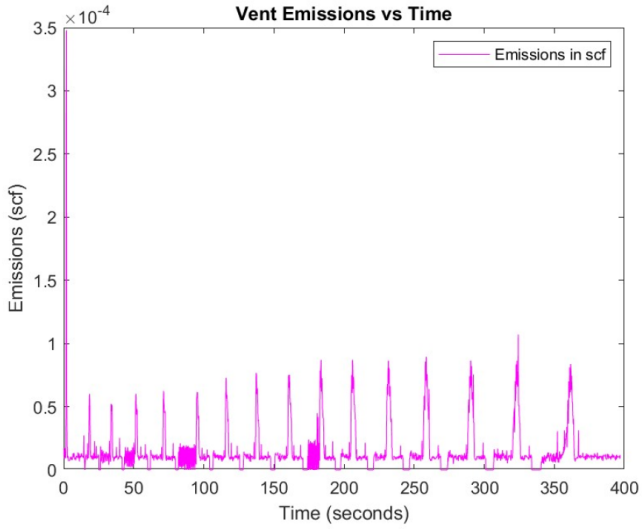
222489-006

The volume of total emissions in 397.07 seconds is 0.0549 scf.

The flow rate of emissions is 0.4973 scfh.





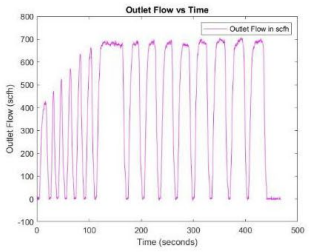


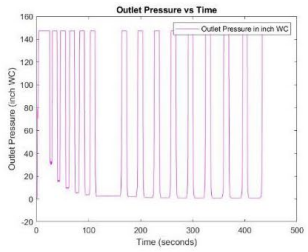
GTI ENERGY

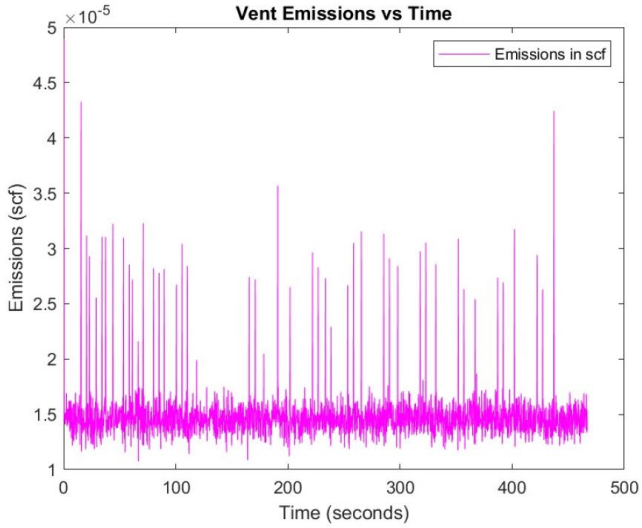
222489-006_BV

The volume of total emissions in 466.94 seconds is 0.0652 scf.

The flow rate of emissions is 0.5030 scfh.





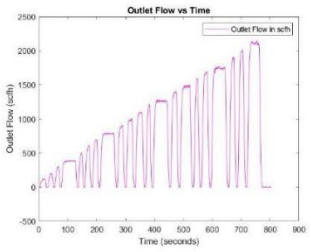


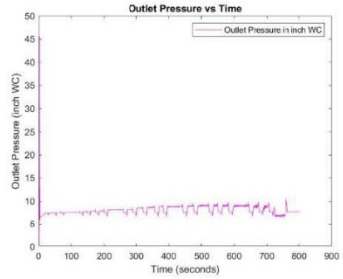
GTI ENERGY

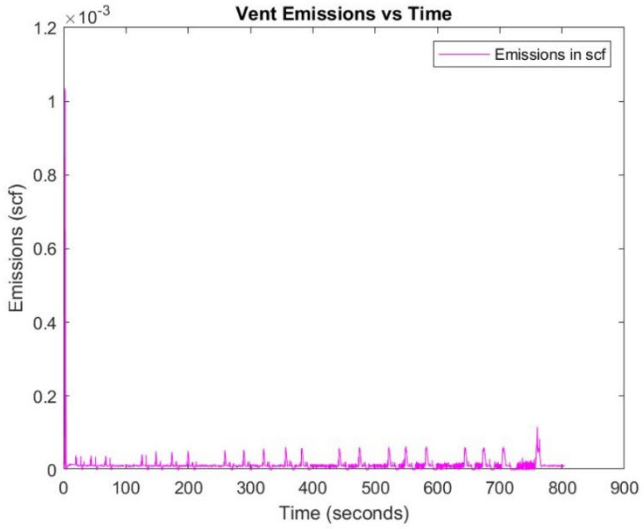
7" WC Outlet, 60-psig Inlet
222489-004

The volume of total emissions in 803.88 seconds is 0.1069 scf.

The flow rate of emissions is 0.4789 scfh.





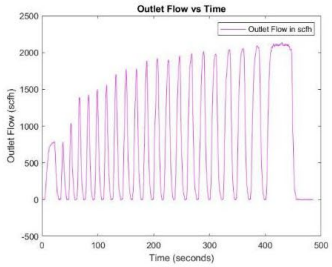


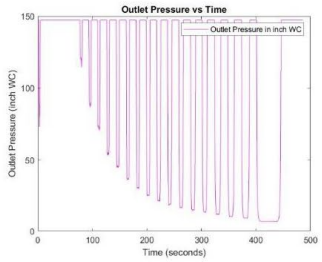
GTI ENERGY

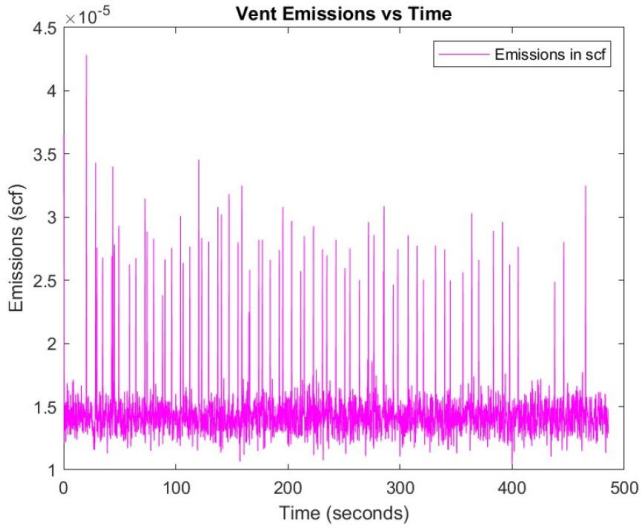
222489-004_BV

The volume of total emissions in 485.79 seconds is 0.0660 scf.

The flow rate of emissions is 0.4892 scfh.





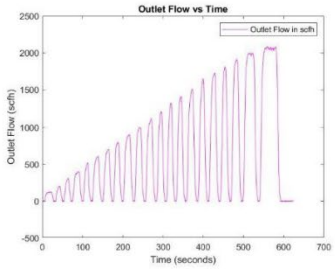


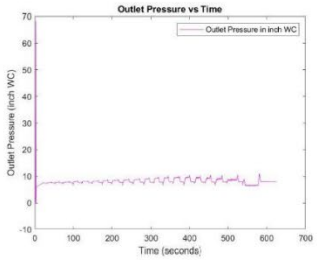
GTI ENERGY

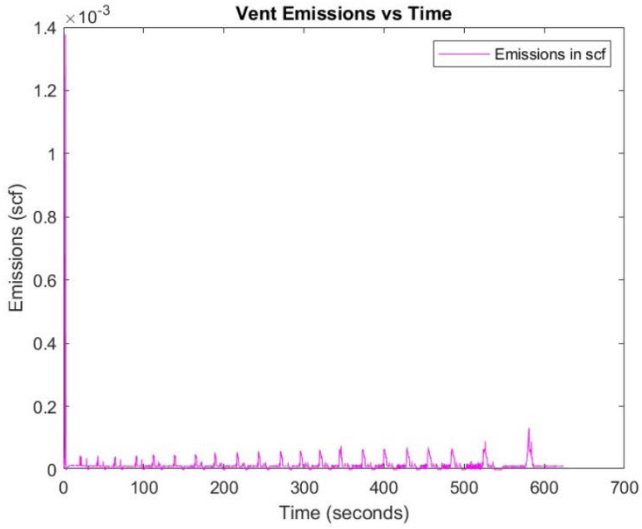
222489-005

The volume of total emissions in 623.96 seconds is 0.0888 scf.

The flow rate of emissions is 0.5124 scfh.





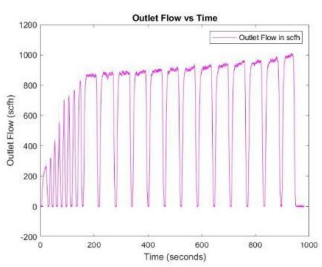


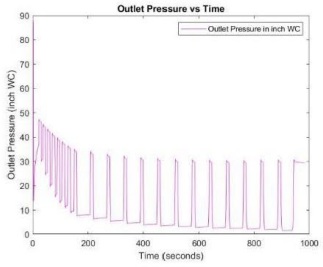
GTI ENERGY

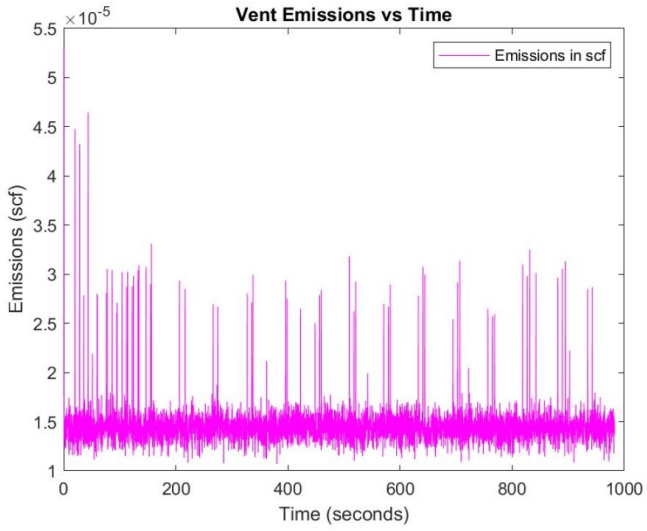
222489-005_BV

The volume of total emissions in 982.64 seconds is 0.1355 scf.

The flow rate of emissions is 0.4966 scfh.





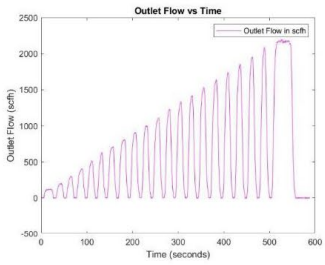


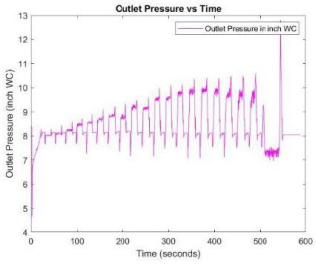
GTI ENERGY

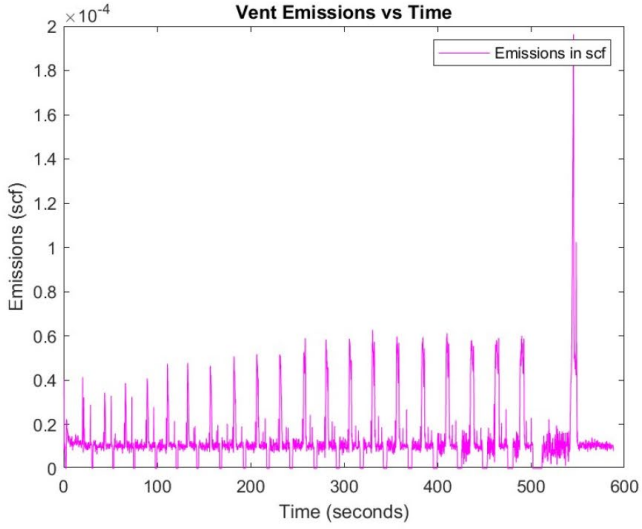
222489-006

The volume of total emissions in 588.37 seconds is 0.0728 scf.

The flow rate of emissions is 0.4455 scfh.





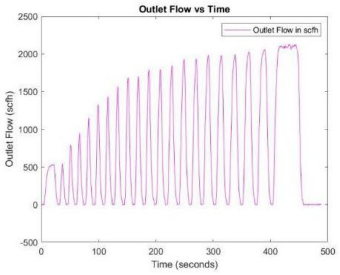


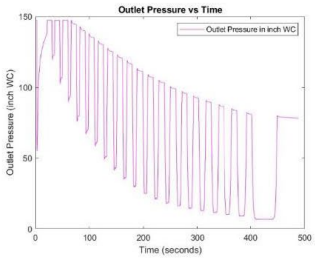
GTI ENERGY

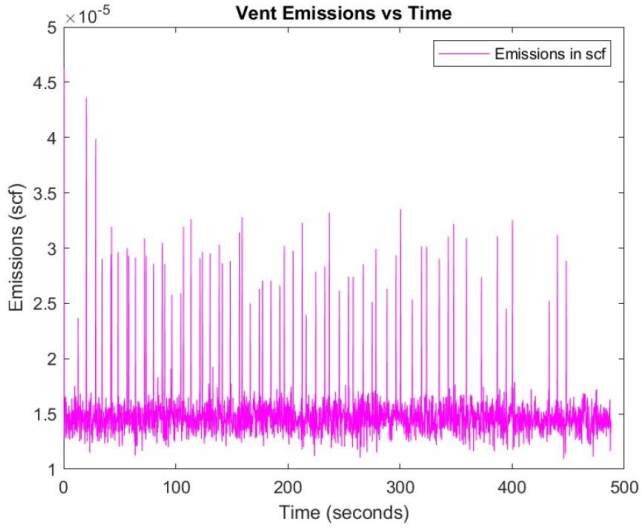
222489-006_BV

The volume of total emissions in 488.10 seconds is 0.0683 scf.

The flow rate of emissions is 0.5036 scfh.





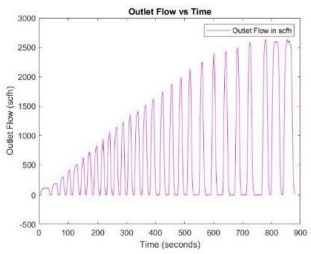


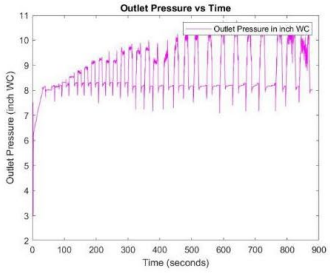
GTI ENERGY

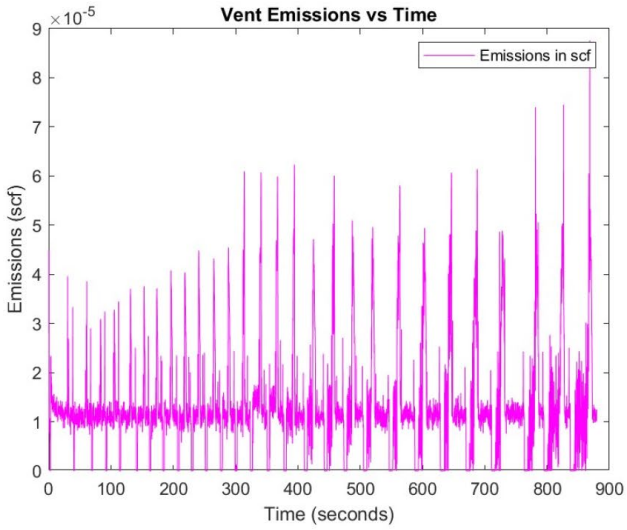
7" WC Outlet, 100-psig Inlet
222489-004

The volume of total emissions in 879.64 seconds is 0.1094 scf.

The flow rate of emissions is 0.4476 scfh.





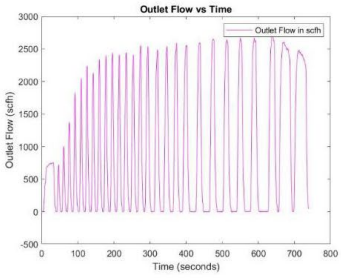


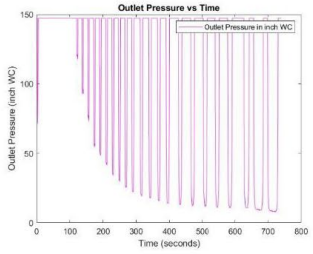
GTI ENERGY

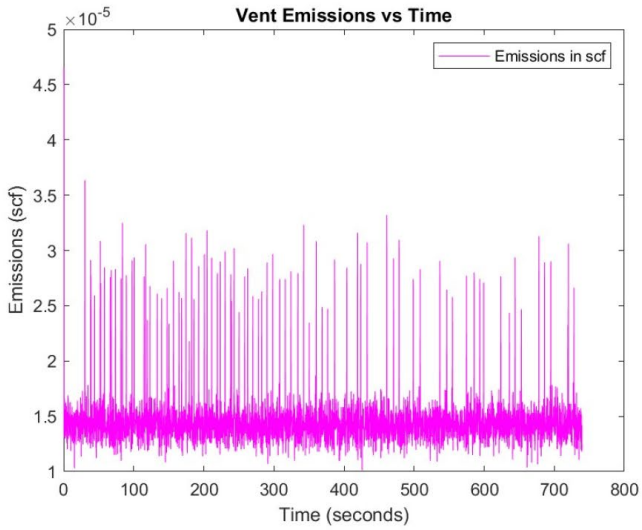
222489-004_BV

The volume of total emissions in 739.58 seconds is 0.1010 scf.

The flow rate of emissions is 0.4915 scfh.





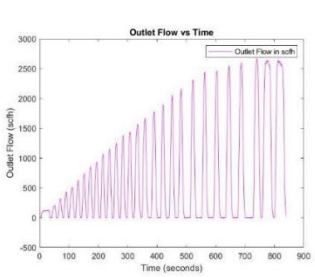


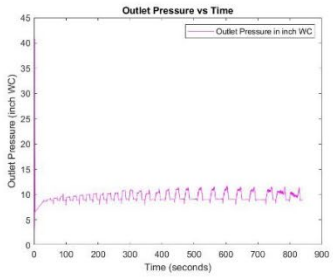
GTI ENERGY

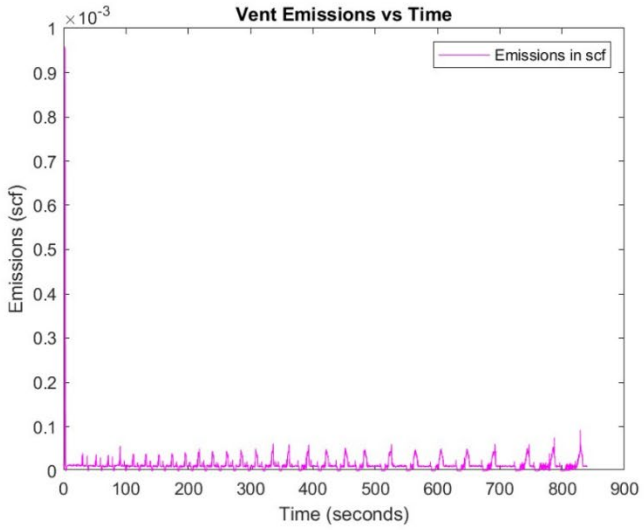
222489-005

The volume of total emissions in 840.27 seconds is 0.1088 scf.

The flow rate of emissions is 0.4661 scfh.





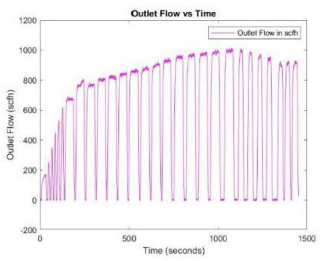


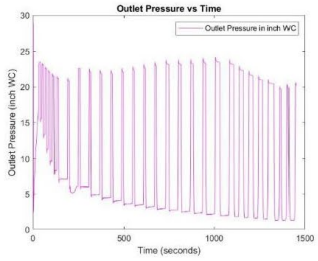
GTI ENERGY

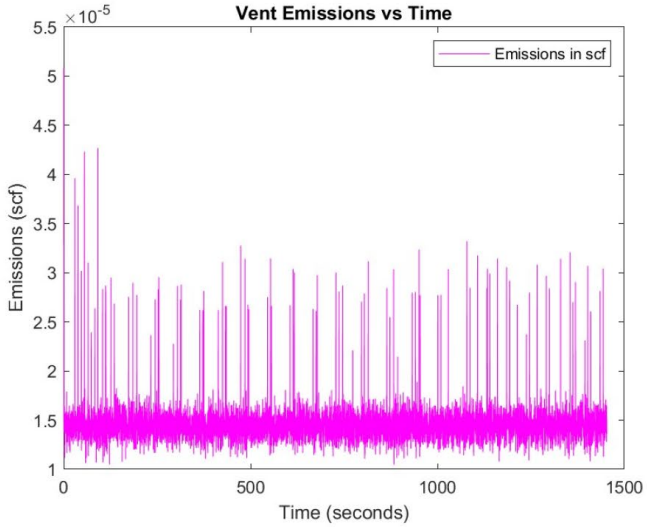
222489-005_BV

The volume of total emissions in 1453.15 seconds is 0.2012 scf.

The flow rate of emissions is 0.4986 scfh.





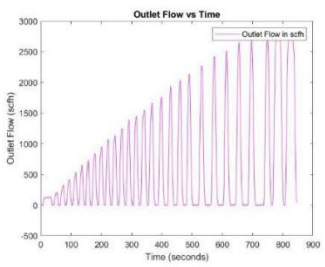


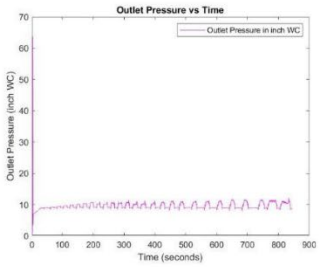
GTI ENERGY

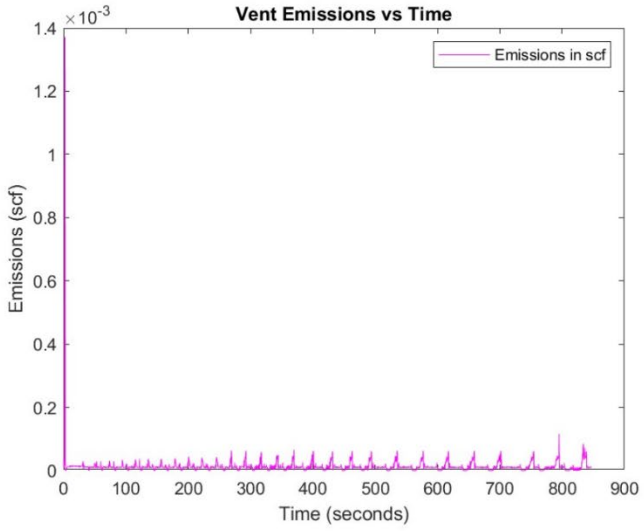
222489-006

The volume of total emissions in 847.06 seconds is 0.1066 scf.

The flow rate of emissions is 0.4532 scfh.





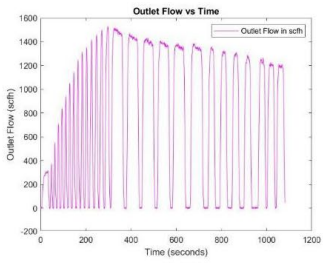


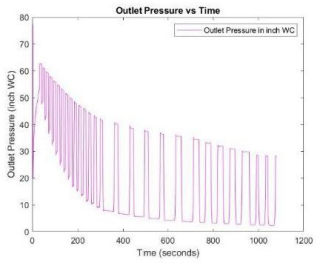
GTI ENERGY

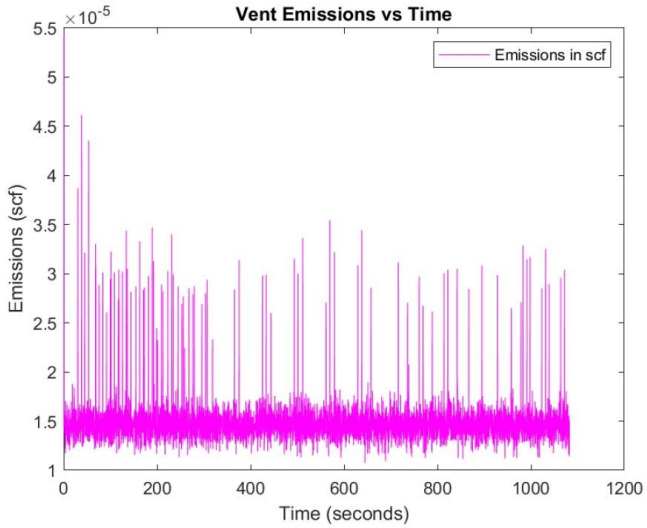
222489-006_BV

The volume of total emissions in 1082.38 seconds is 0.1522 scf.

The flow rate of emissions is 0.5061 scfh.





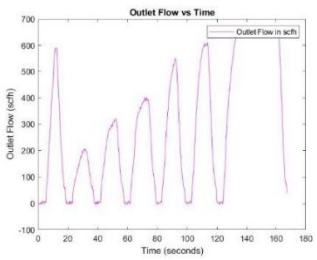


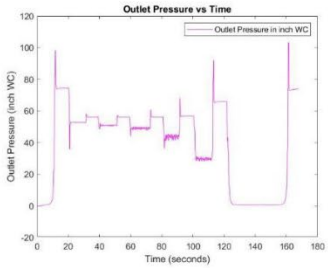
GTI ENERGY

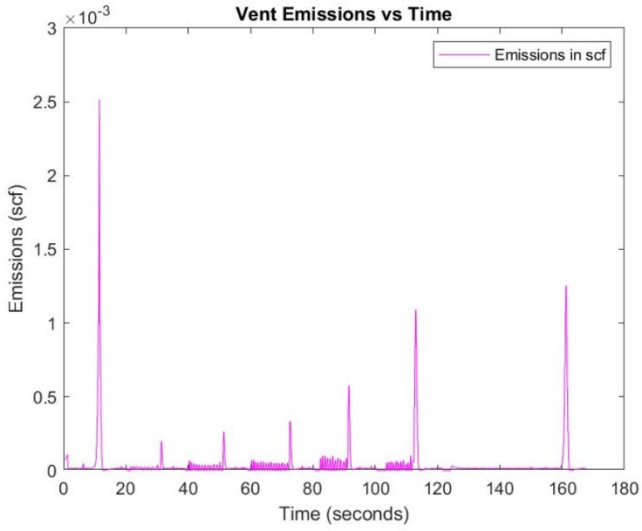
2-psig Outlet, 10-psig Inlet
222489-048

The volume of total emissions in 167.61 seconds is 0.0610 scf.

The flow rate of emissions is 1.3099 scfh.





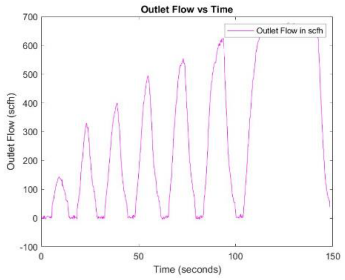


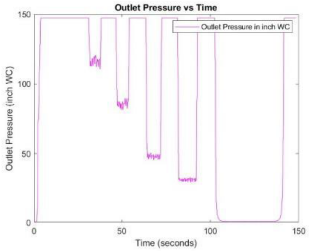
GTI ENERGY

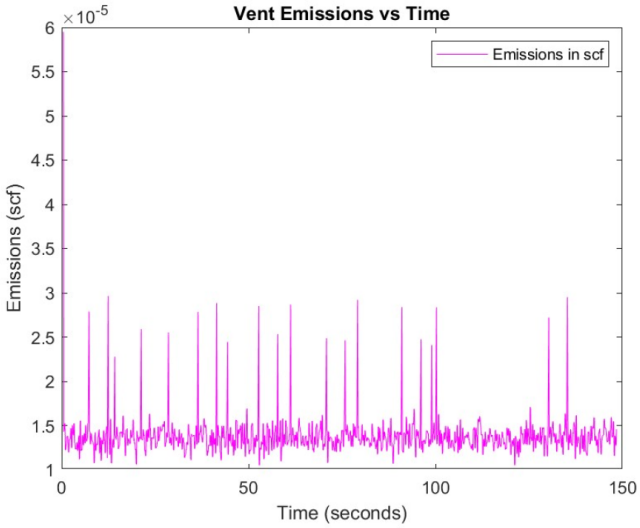
222489-048_BV

The volume of total emissions in 148.54 seconds is 0.0193 scf.

The flow rate of emissions is 0.4682 scfh.





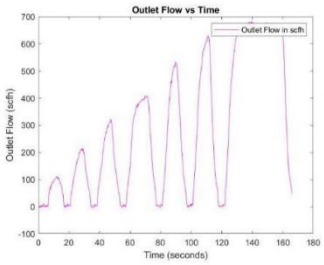


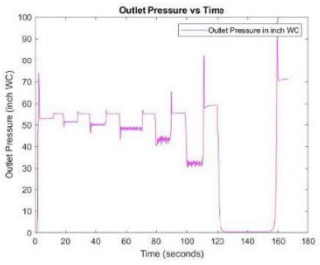
GTI ENERGY

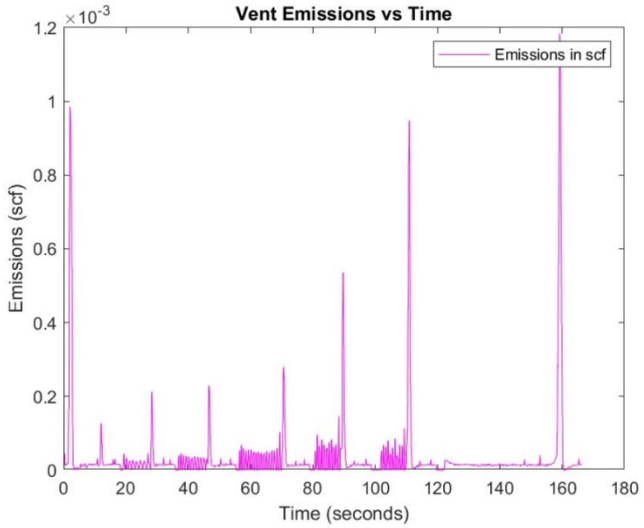
222489-049

The volume of total emissions in 166.30 seconds is 0.0573 scf.

The flow rate of emissions is 1.2402 scfh.





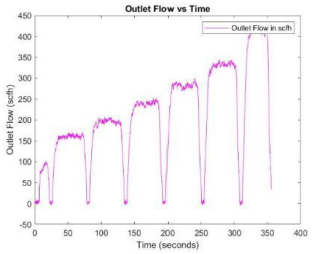


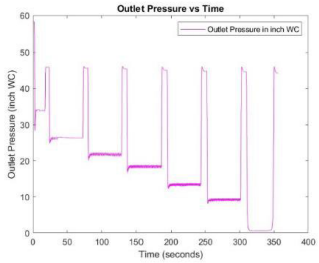
GTI ENERGY

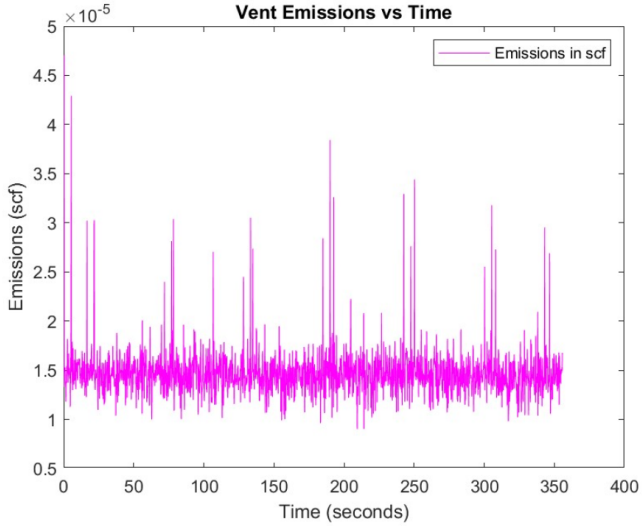
222489-049_BV

The volume of total emissions in 355.87 seconds is 0.0496 scf.

The flow rate of emissions is 0.5016 scfh.





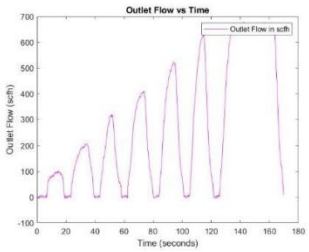


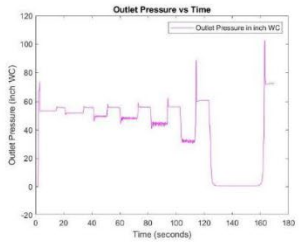
GTI ENERGY

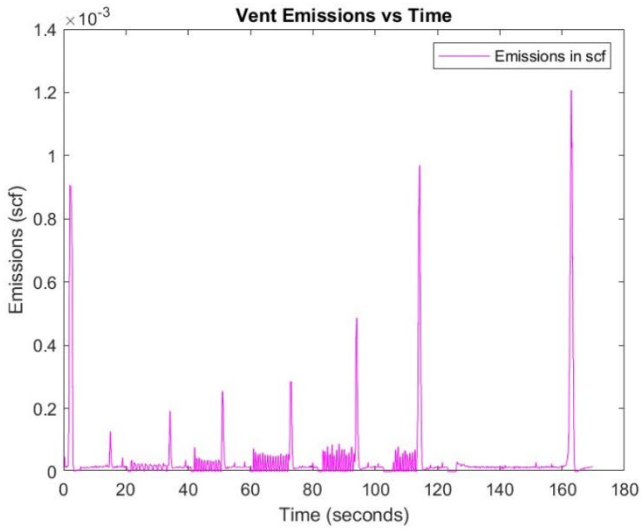
222489-050

The volume of total emissions in 169.79 seconds is 0.0578 scf.

The flow rate of emissions is 1.2258 scfh.





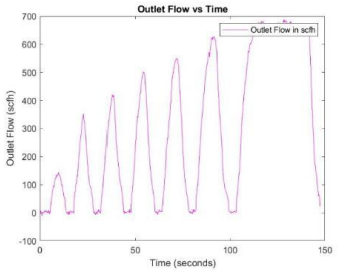


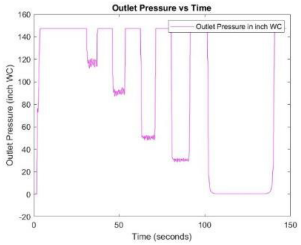
GTI ENERGY

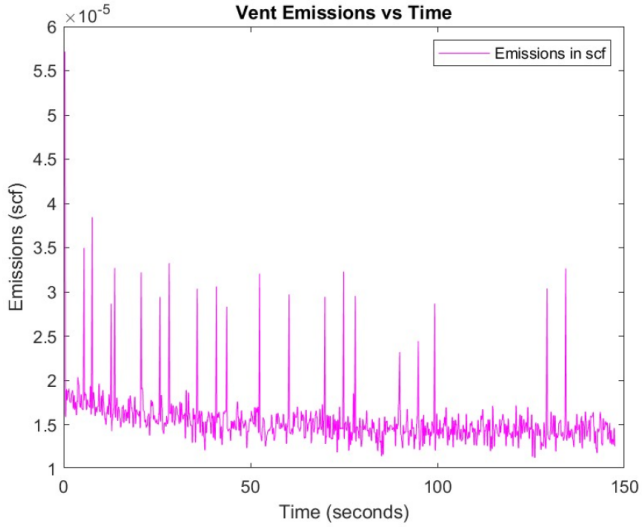
222489-050_BV

The volume of total emissions in 147.53 seconds is 0.0213 scf.

The flow rate of emissions is 0.5195 scfh.





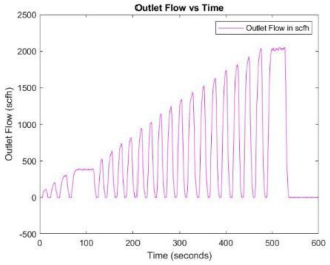


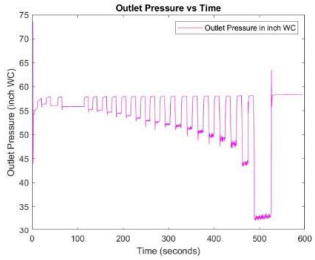
GTI ENERGY

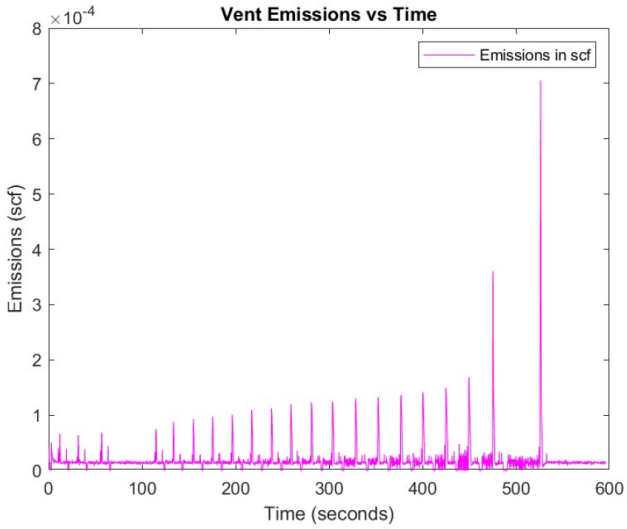
2-psig Outlet, 60-psig Inlet
222489-048

The volume of total emissions in 595.73 seconds is 0.1049 scf.

The flow rate of emissions is 0.6340 scfh.





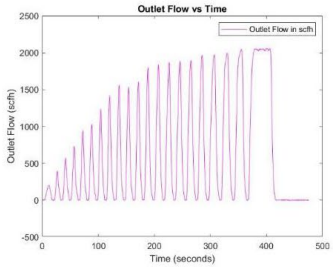


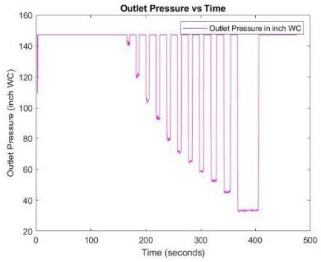
GTI ENERGY

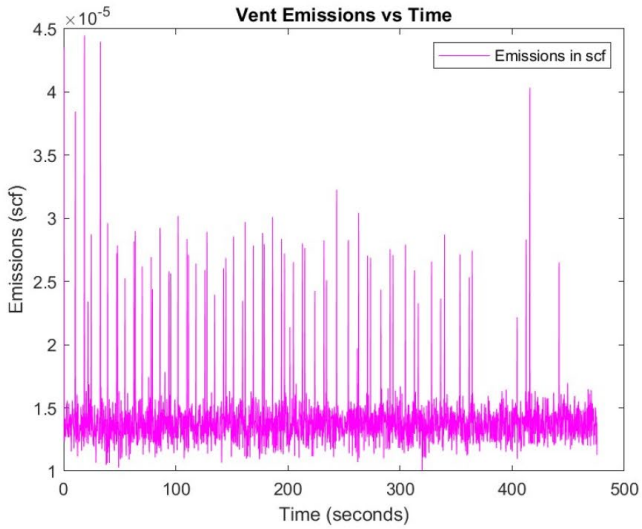
222489-048_BV

The volume of total emissions in 475.59 seconds is 0.0624 scf.

The flow rate of emissions is 0.4723 scfh.





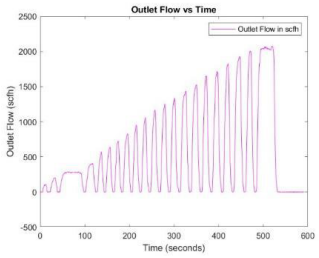


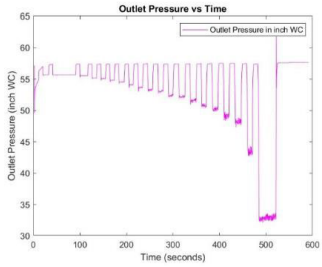
GTI ENERGY

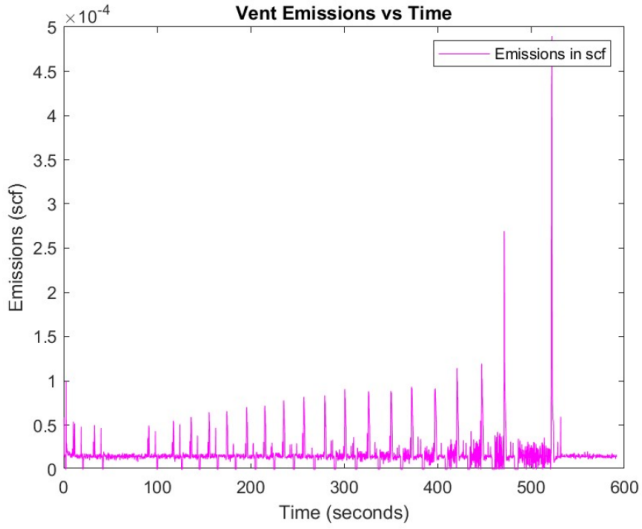
222489-049

The volume of total emissions in 591.77 seconds is 0.0971 scf.

The flow rate of emissions is 0.5907 scfh.





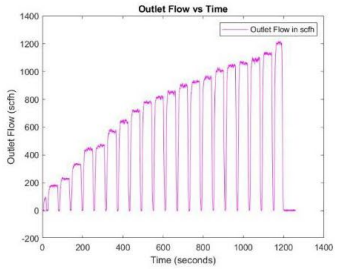


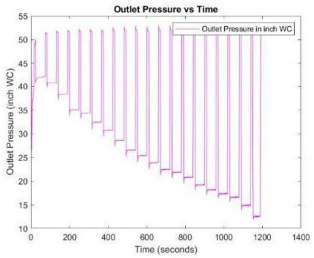
GTI ENERGY

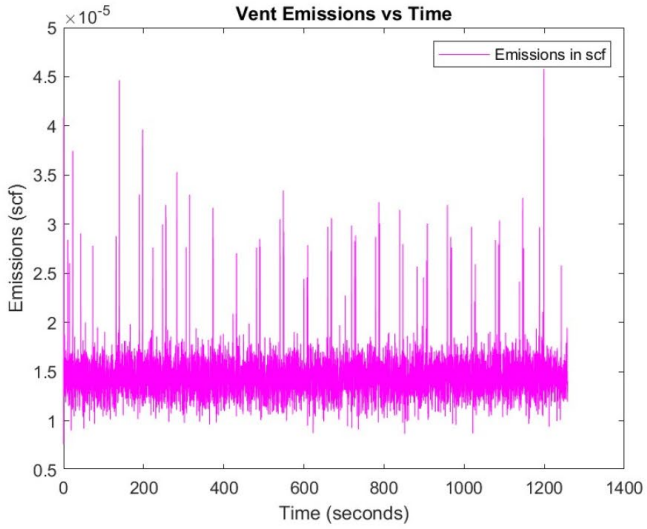
222489-049_BV

The volume of total emissions in 1259.02 seconds is 0.1737 scf.

The flow rate of emissions is 0.4967 scfh.





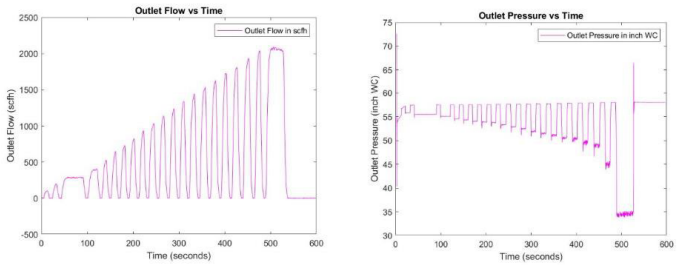


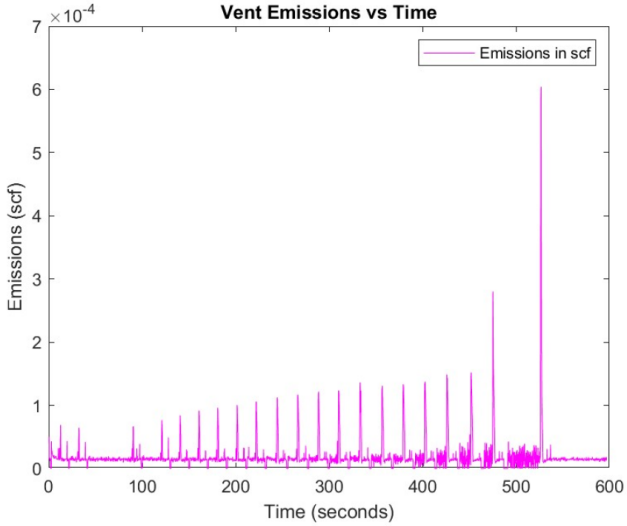
GTI ENERGY

222489-050

The volume of total emissions in 596.95 seconds is 0.1059 scf.

The flow rate of emissions is 0.6389 scfh.



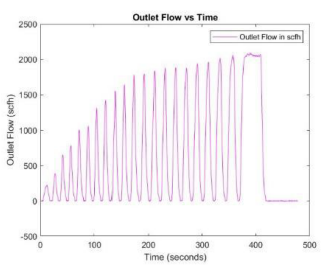


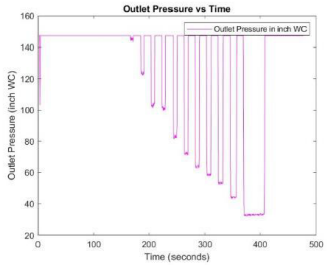
GTI ENERGY

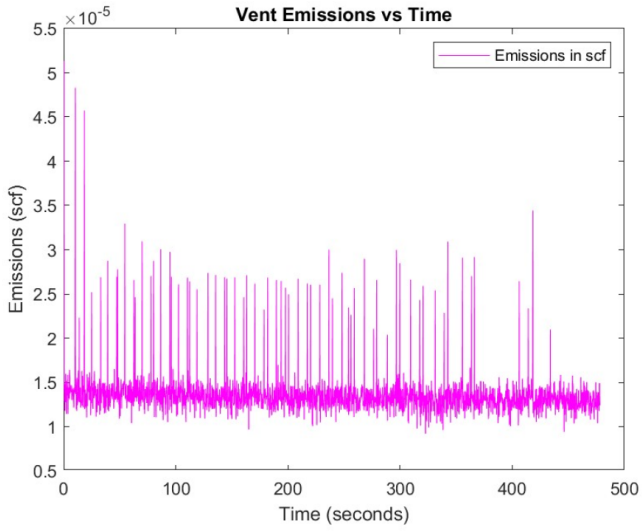
222489-050_BV

The volume of total emissions in 478.35 seconds is 0.0609 scf.

The flow rate of emissions is 0.4587 scfh.





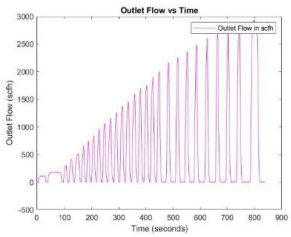


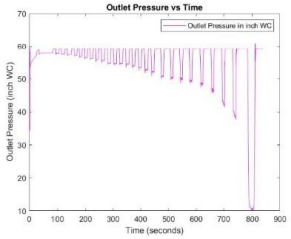
GTI ENERGY

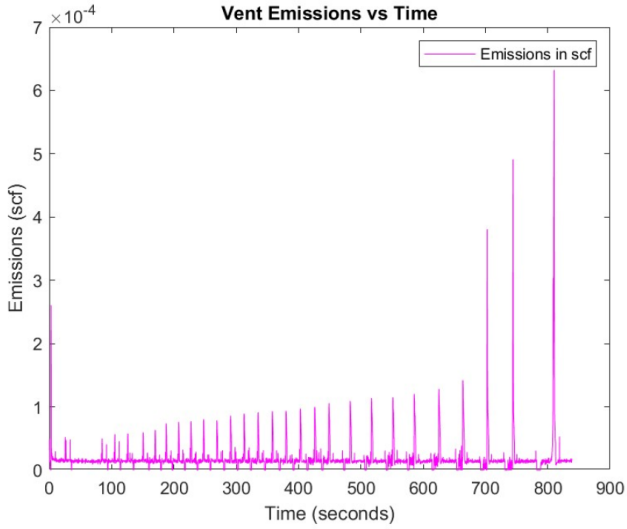
2-psig Outlet, 100-psig Inlet

- 222489-048

  The volume of total emissions in 838.86 seconds is 0.1475 scf.
  The flow rate of emissions is 0.6331 scfh.

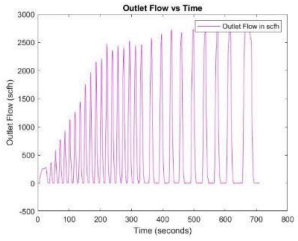


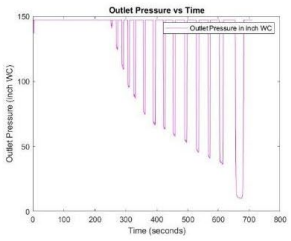


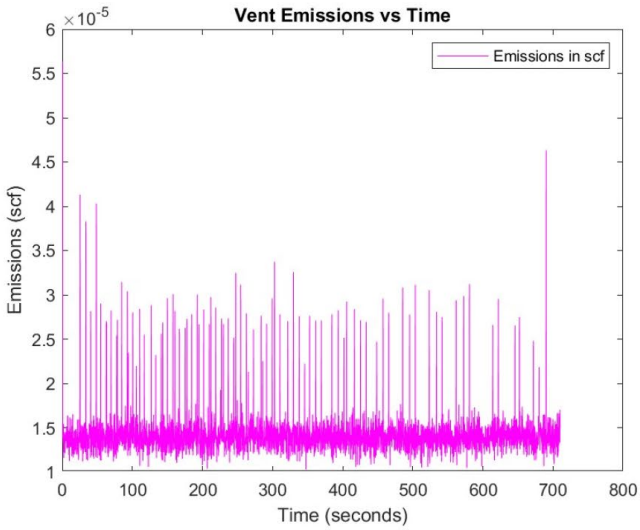


GTI ENERGY

- 222489-048_BV
  The volume of total emissions in 710.12 seconds is 0.0948 scf.
  The flow rate of emissions is 0.4805 scfh.

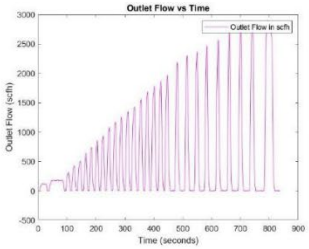


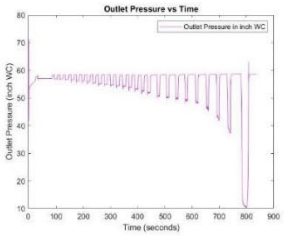


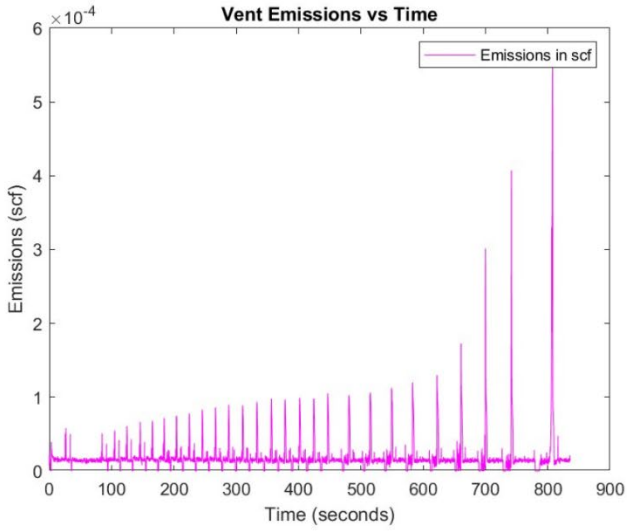


GTI ENERGY

- 222489-049
  The volume of total emissions in 836.26 seconds is 0.1502 scf.
  The flow rate of emissions is 0.6464 scfh.

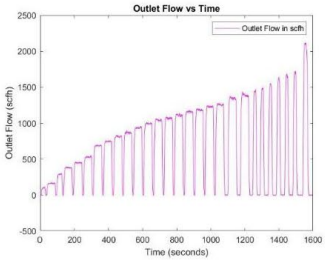


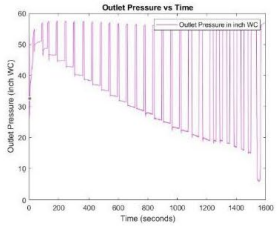


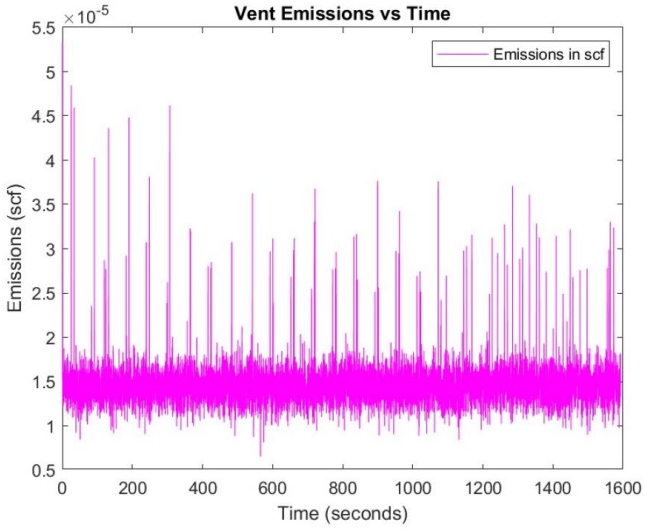


GTI ENERGY

- 222489-049_BV
  The volume of total emissions in 1593.37 seconds is 0.2214 scf.
  The flow rate of emissions is 0.5002 scfh.

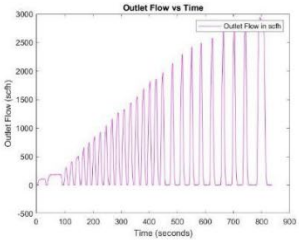


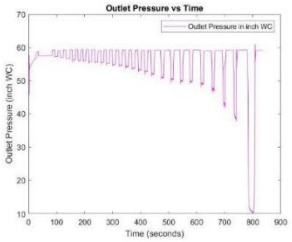


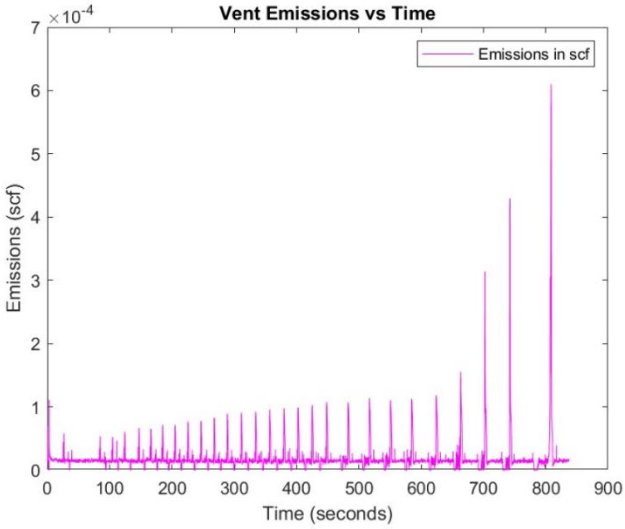


GTI ENERGY

- 222489-050
  The volume of total emissions in 837.18 seconds is 0.1488 scf.
  The flow rate of emissions is 0.6398 scfh.

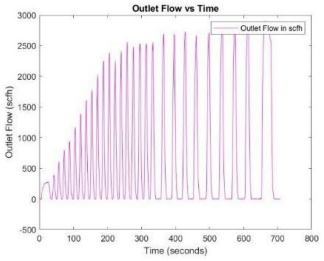


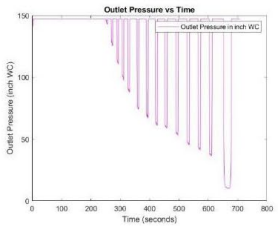


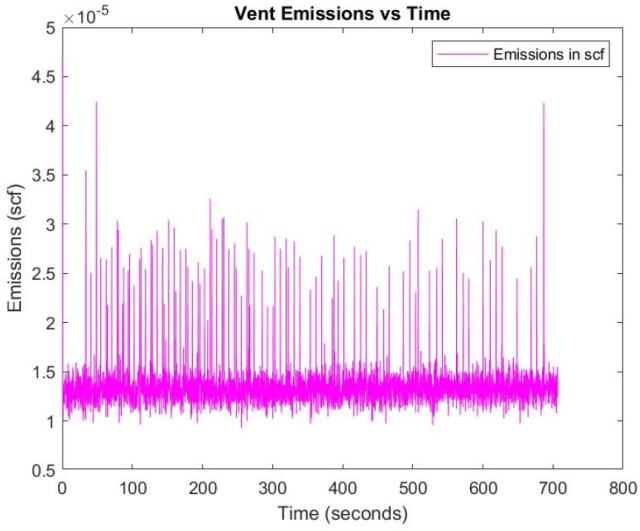


GTI ENERGY

- 222489-050_BV
  The volume of total emissions in 706.84 seconds is 0.0896 scf.
  The flow rate of emissions is 0.4562 scfh.





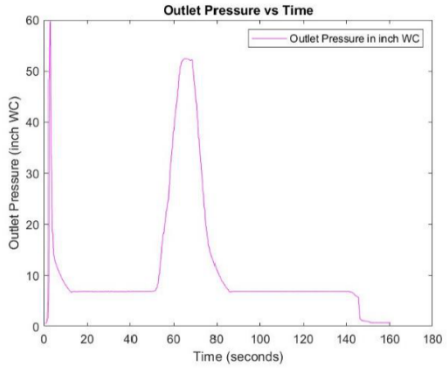


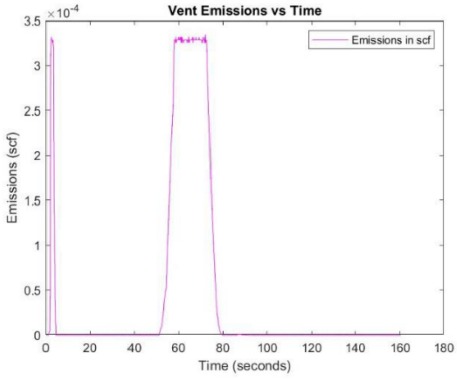
GTI ENERGY

Relief Tests

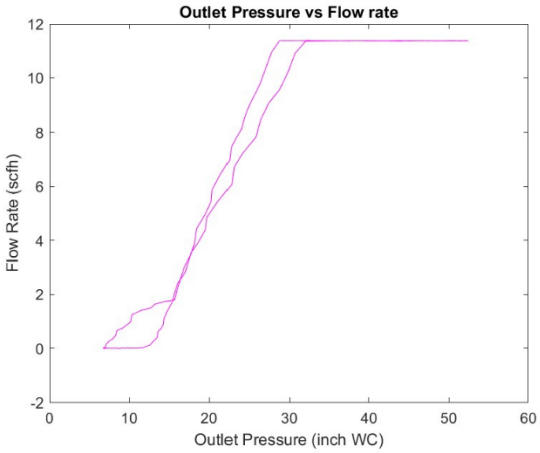
7" WC Outlet, 10-psig Inlet

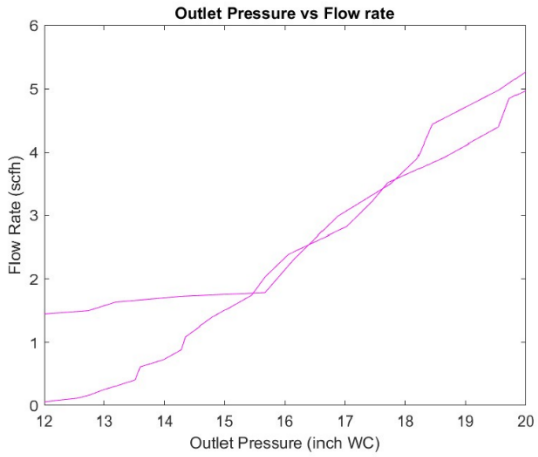
- 222489-004
  The volume of total emissions in 160.36 seconds is 0.0661 scf.
  The average flow rate of emissions at 18 inches WC is 3.65 scfh.





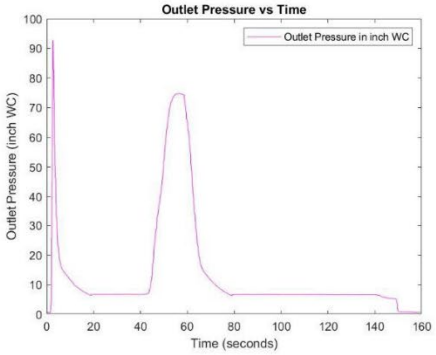
GTI ENERGY

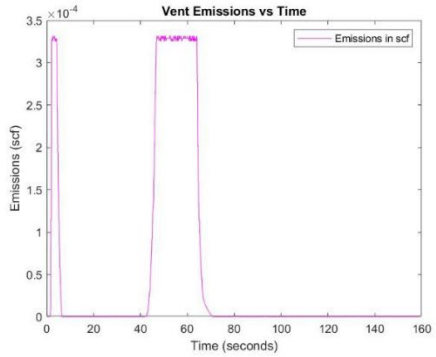

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
12
10
8
6
4
2
0
-2
0
10
20
30
40
50
60


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
6
5
4
3
2
1
0
12
13
14
15
16
17
18
19
20

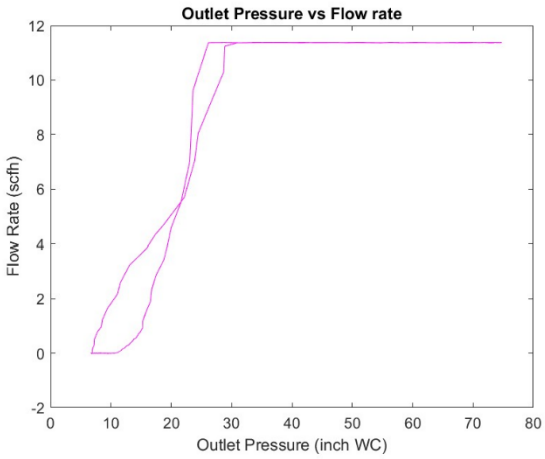
GTI ENERGY

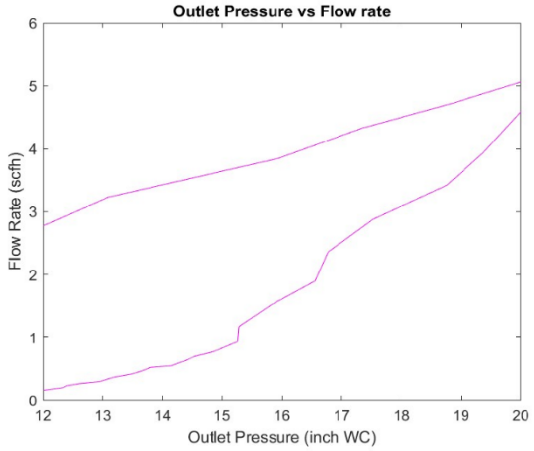
- 222489-005
  The volume of total emissions in 159.30 seconds is 0.0720 scf.
  The average flow rate of emissions at 18 inches WC is 3.09 scfh.





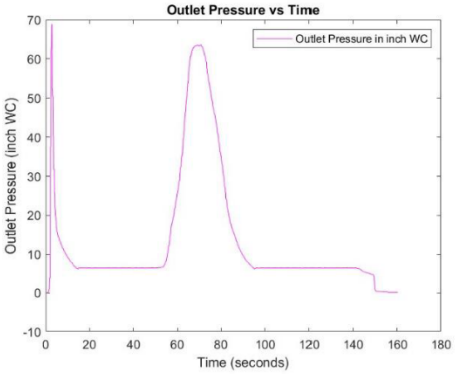
GTI ENERGY

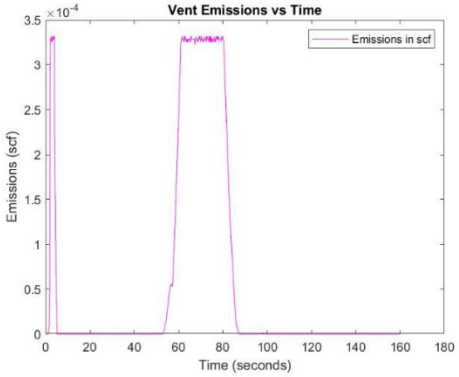

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
12
10
8
6
4
2
0
-2
0
10
20
30
40
50
60
70
80


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
6
5
4
3
2
1
0
12
13
14
15
16
17
18
19
20

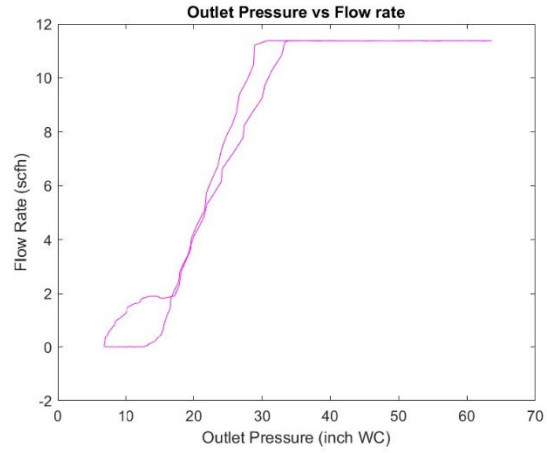
GTI ENERGY

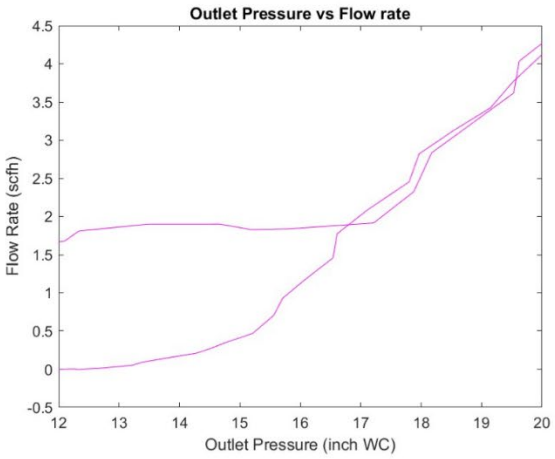
- 222489-006
  The volume of total emissions in 160.21 seconds is 0.0849 scf.
  The average flow rate of emissions at 18 inches WC is 2.56 scfh.





GTI ENERGY

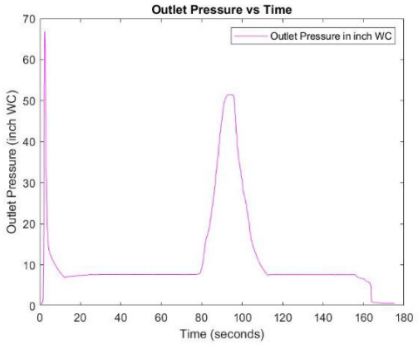

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
12
10
8
6
4
2
0
-2
0
10
20
30
40
50
60
70

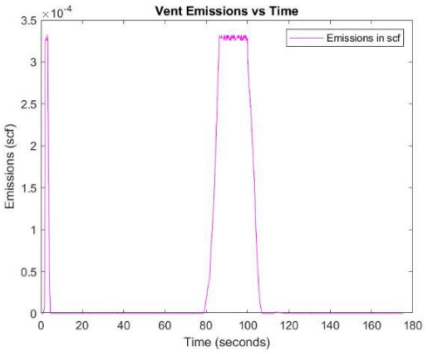

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
12
13
14
15
16
17
18
19
20

7" WC Outlet, 60-psig Inlet

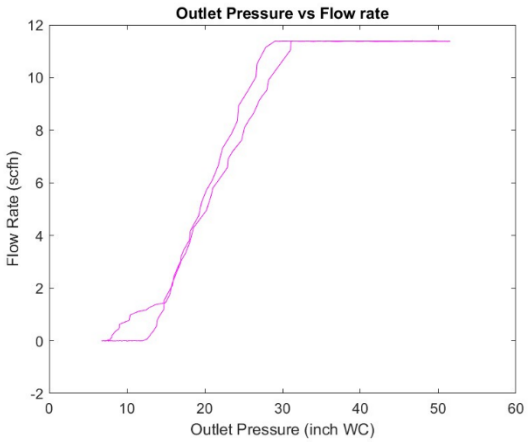
- 222489-004

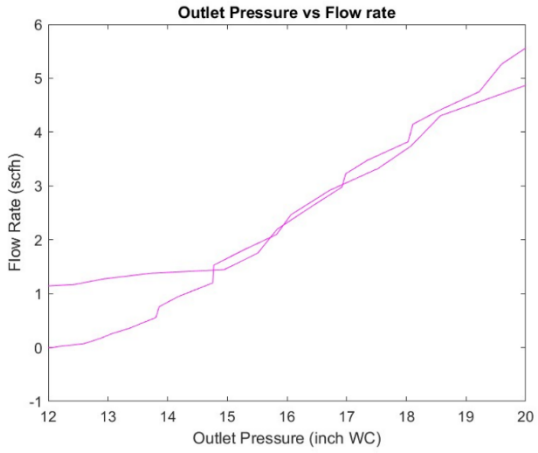
  The volume of total emissions in 175.32 seconds is 0.0669 scf.
  The average flow rate of emissions at 18 inches WC is 3.81 scfh.





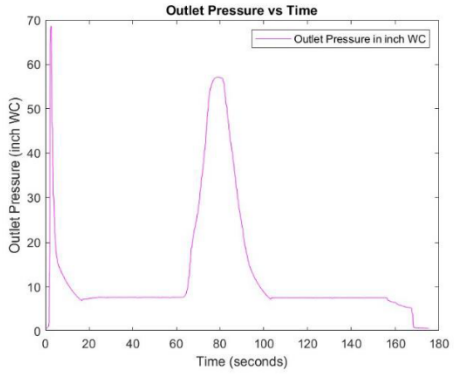
GTI ENERGY

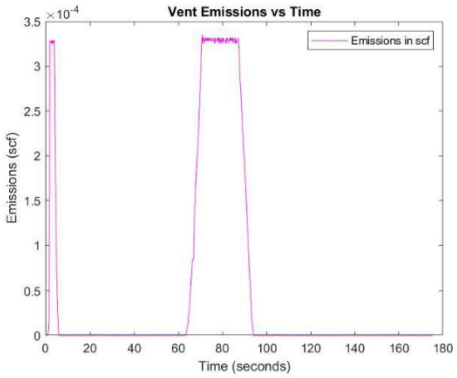

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
12
10
8
6
4
2
0
-2
0
10
20
30
40
50
60


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
6
5
4
3
2
1
0
-1
12
13
14
15
16
17
18
19
20

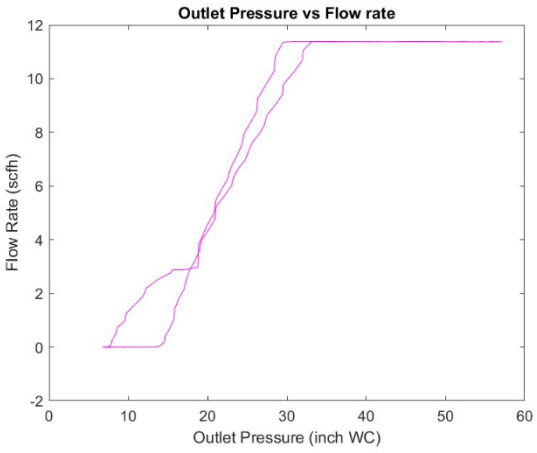
GTI ENERGY

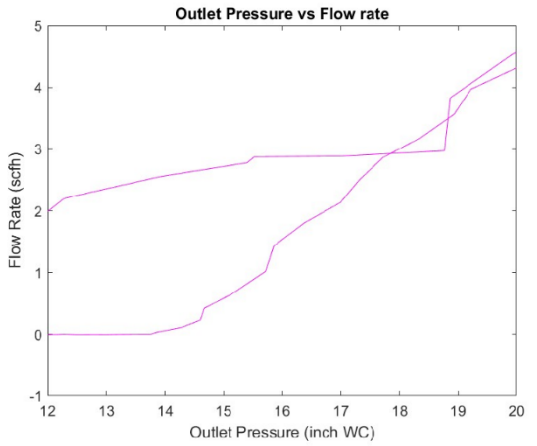
- 222489-005
  The volume of total emissions in 175.33 seconds is 0.0801 scf.
  The average flow rate of emissions at 18 inches WC is 3.93 scfh.





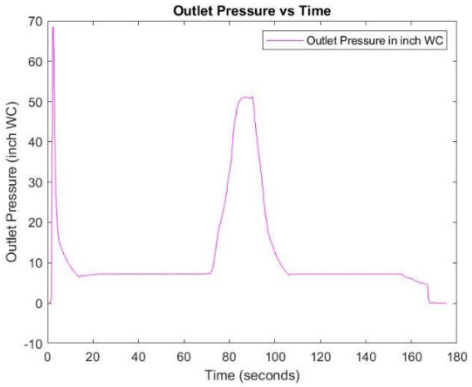
GTI ENERGY

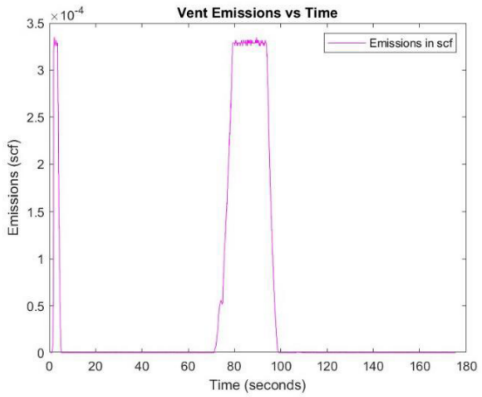

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
12
10
8
6
4
2
0
-2
0
10
20
30
40
50
60


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
5
4
3
2
1
0
-1
12
13
14
15
16
17
18
19
20

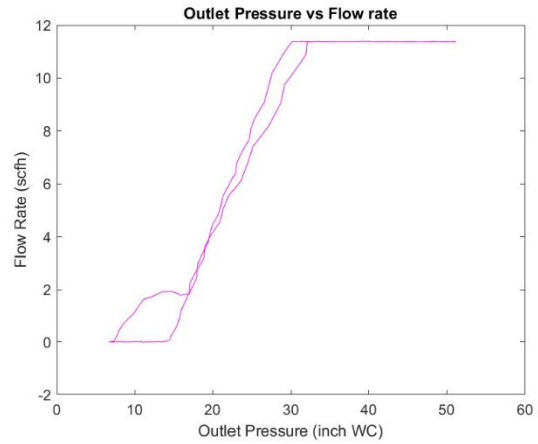
GTI ENERGY

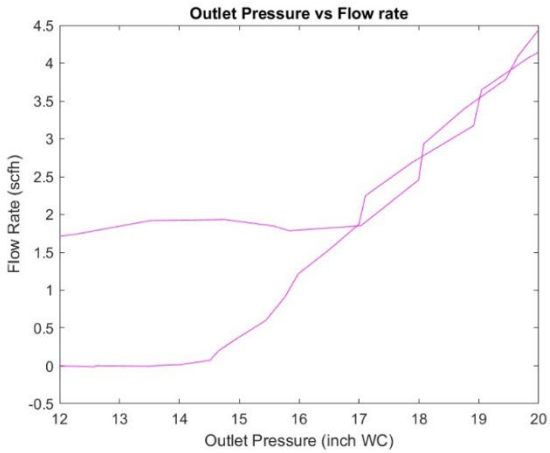
- 222489-006
  The volume of total emissions in 175.32 seconds is 0.0690 scf.
  The average flow rate of emissions at 18 inches WC is 2.63 scfh.





GTI ENERGY


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
12
10
8
6
4
2
0
-2
0
10
20
30
40
50
60

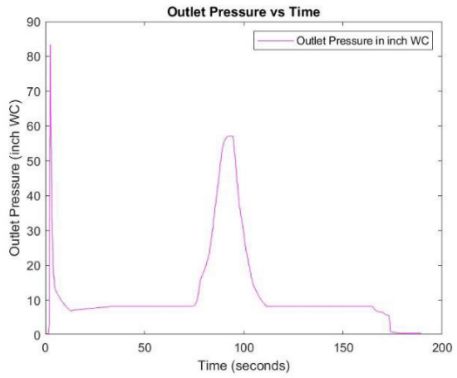

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
12
13
14
15
16
17
18
19
20

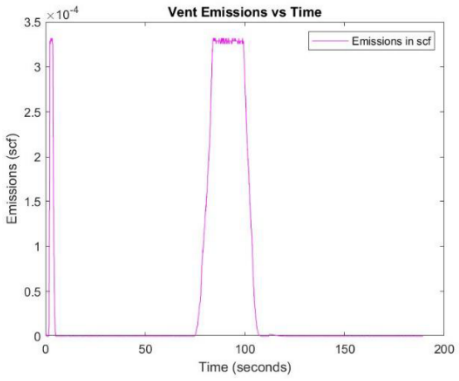
GTI ENERGY

7" WC Outlet 100-psig Inlet

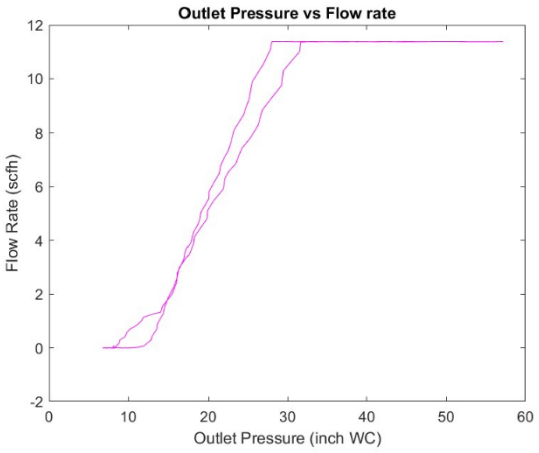
- 222489-004

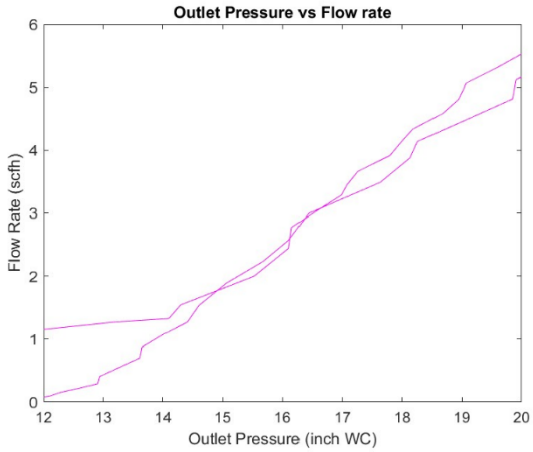
  The volume of total emissions in 189.35 seconds is 0.0755 scf.
  The average flow rate of emissions at 18 inches WC is 4.04 scfh.





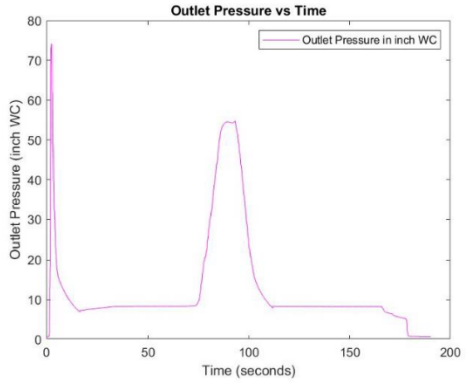
GTI ENERGY

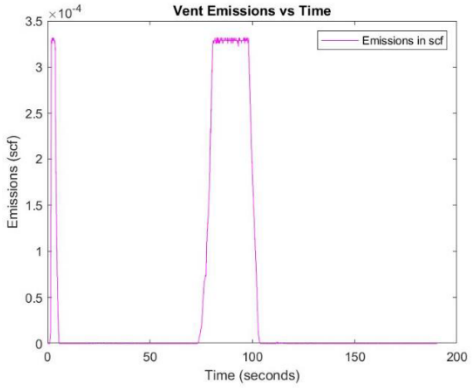

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
12
10
8
6
4
2
0
-2
0
10
20
30
40
50
60


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
6
5
4
3
2
1
0
12
13
14
15
16
17
18
19
20

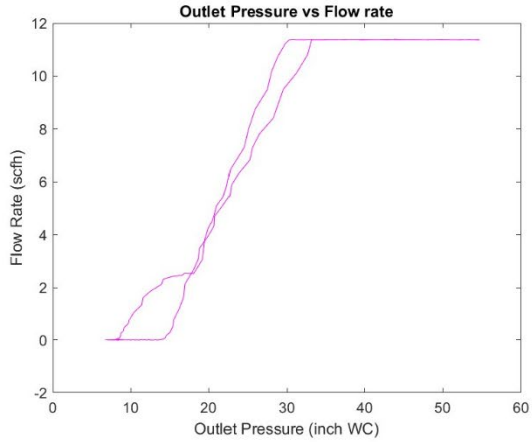
GTI ENERGY

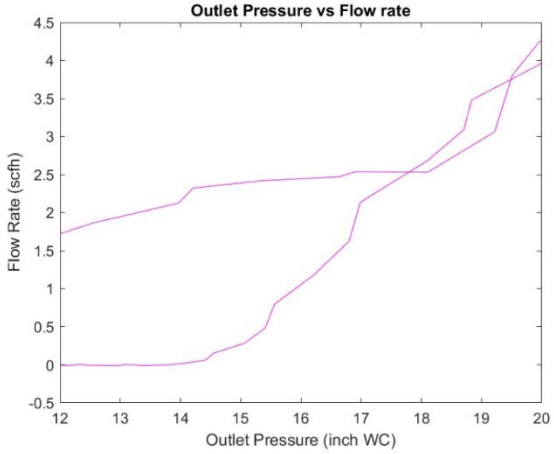
- 222489-005
  The volume of total emissions in 190.32 seconds is 0.0785 scf.
  The average flow rate of emissions at 18 inches WC is 3.90 scfh.





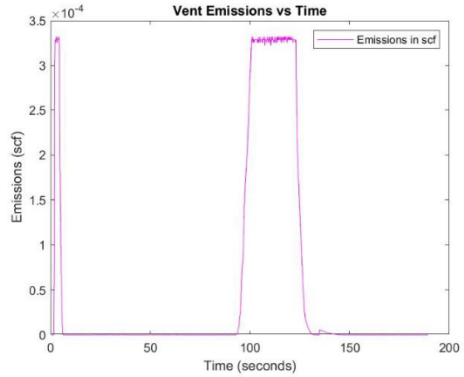
GTI ENERGY

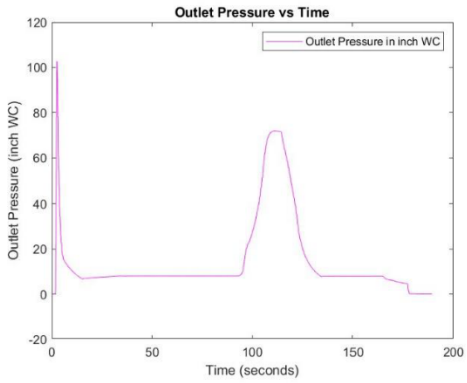

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
12
10
8
6
4
2
0
-2
0
10
20
30
40
50
60


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
12
13
14
15
16
17
18
19
20

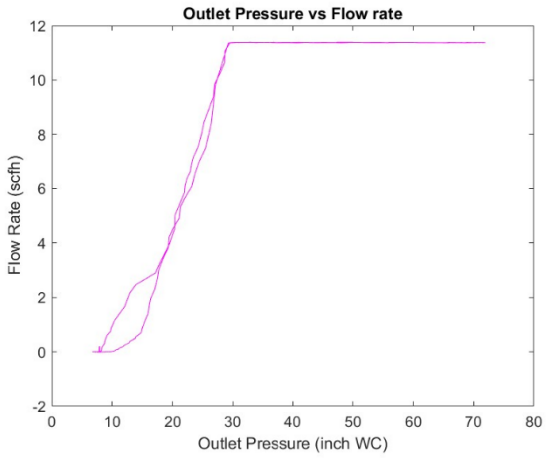
GTI ENERGY

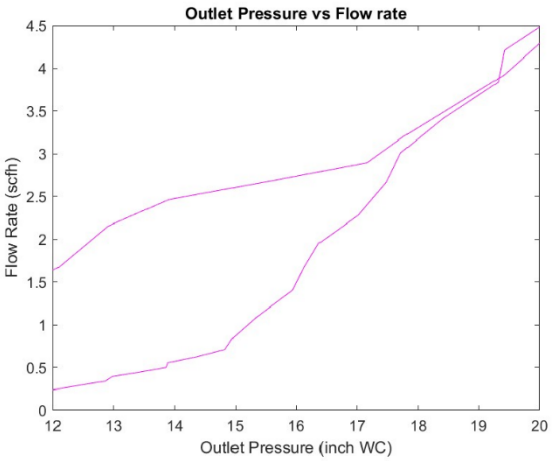
- 222489-006
  The volume of total emissions in 189.34 seconds is 0.0958 scf.
  The average flow rate of emissions at 18 inches WC is 2.66 scfh.





GTI ENERGY


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
12
10
8
6
4
2
0
-2
0
10
20
30
40
50
60
70
80

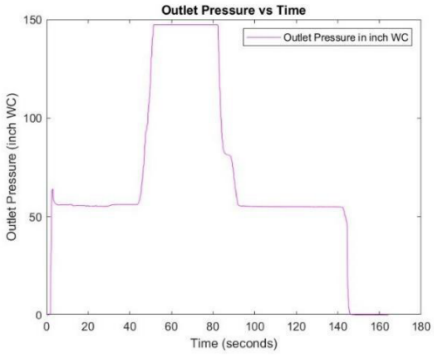

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
12
13
14
15
16
17
18
19
20

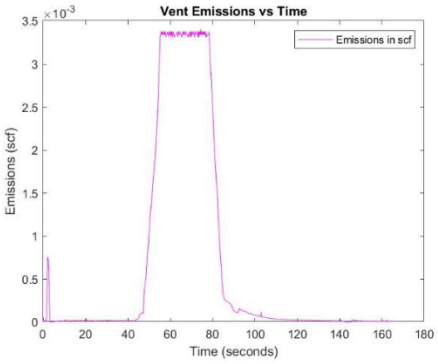
GTI ENERGY

2-psig Outlet, 10-psig Inlet

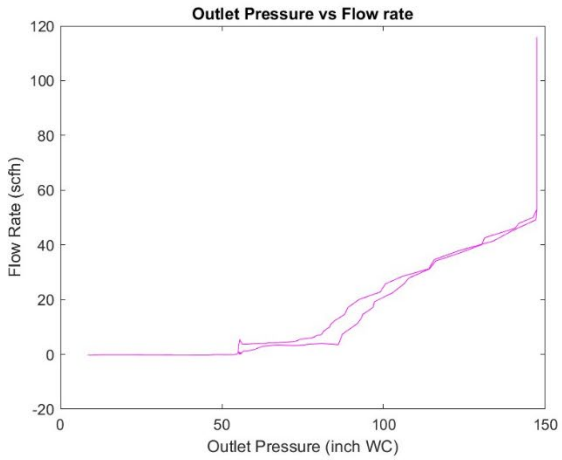
- 222489-048

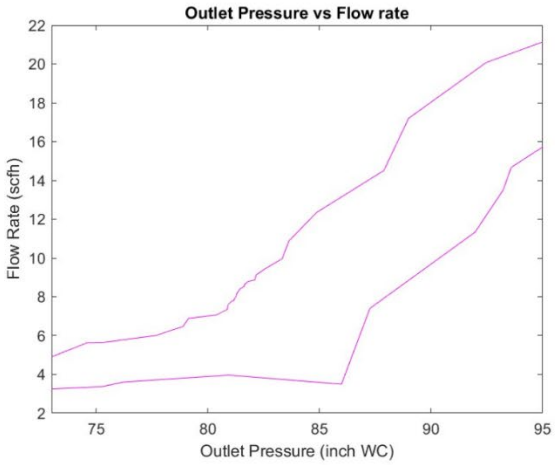
  The volume of total emissions in 164.29 seconds is 1.0205 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 10.65 scfh.





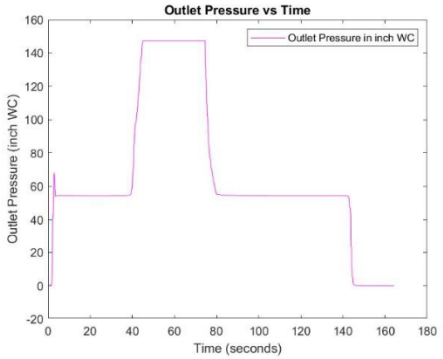
GTI ENERGY

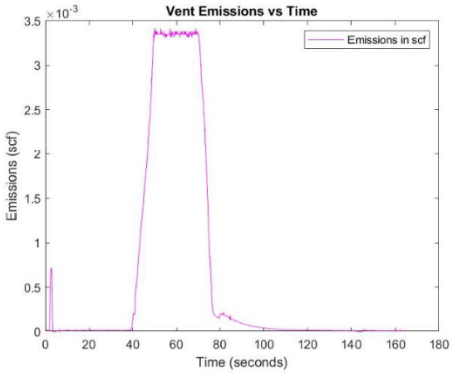

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
120
100
80
60
40
20
0
-20
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
22
20
18
16
14
12
10
8
6
4
2
75
80
85
90
95

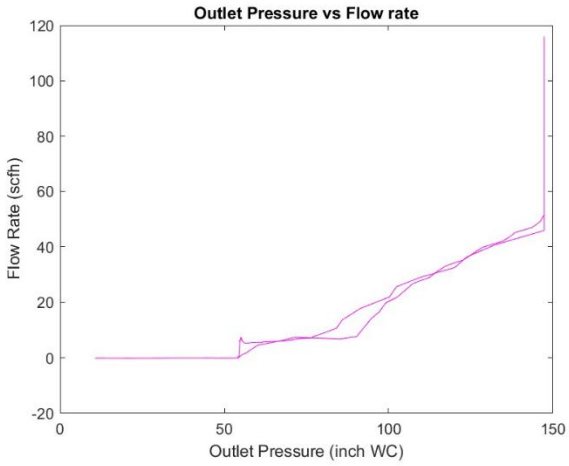
GTI ENERGY

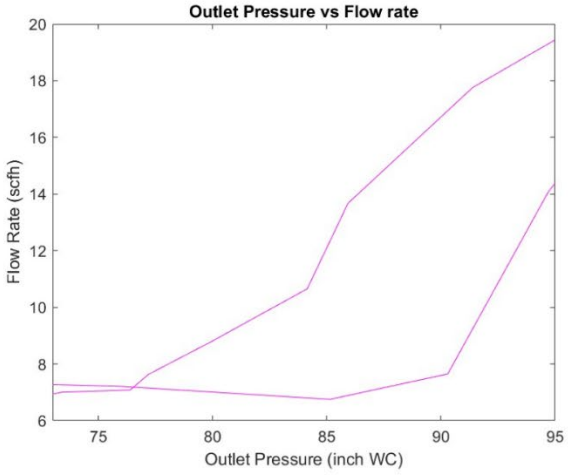
- 222489-049
  The volume of total emissions in 164.30 seconds is 0.9688 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 13.03 scfh.





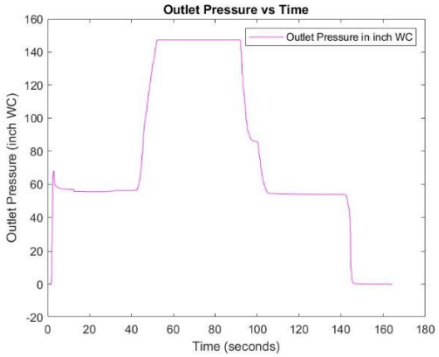
GTI ENERGY

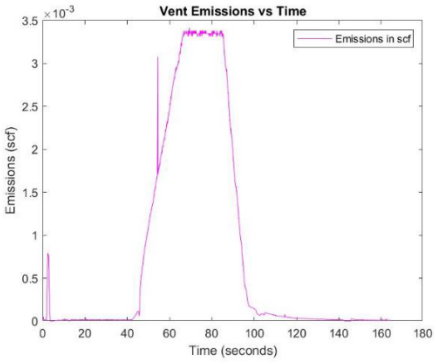

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
120
100
80
60
40
20
0
-20
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
20
18
16
14
12
10
8
6
75
80
85
90
95

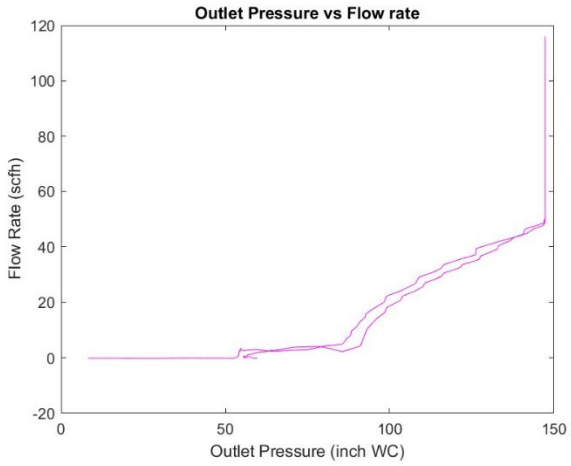
GTI ENERGY

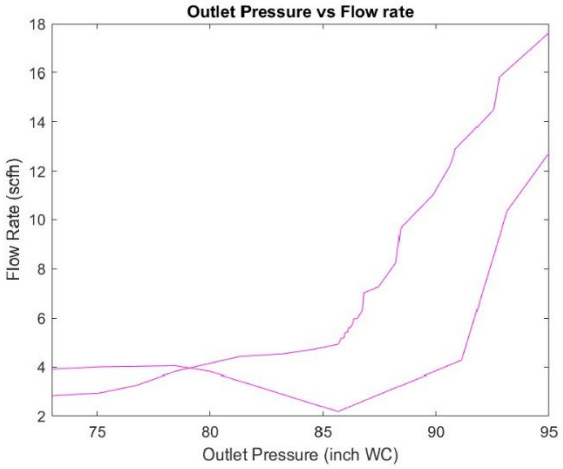
- 222489-050
  The volume of total emissions in 164.32 seconds is 1.2182 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 7.09 scfh.





GTI ENERGY


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
120
100
80
60
40
20
0
-20
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
18
16
14
12
10
8
6
4
2
75
80
85
90
95

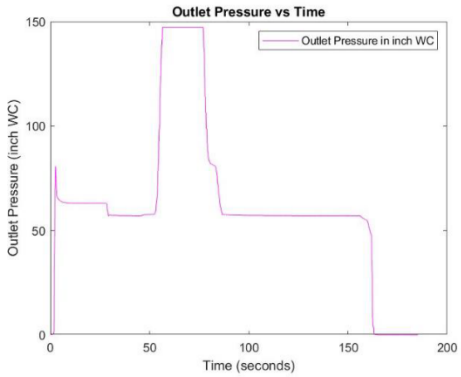
GTI ENERGY

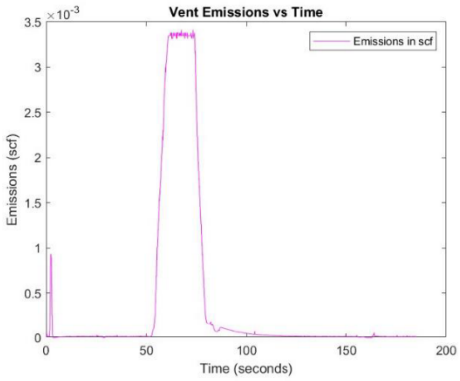
2-psig Outlet, 60-psig Inlet

- 222489-048

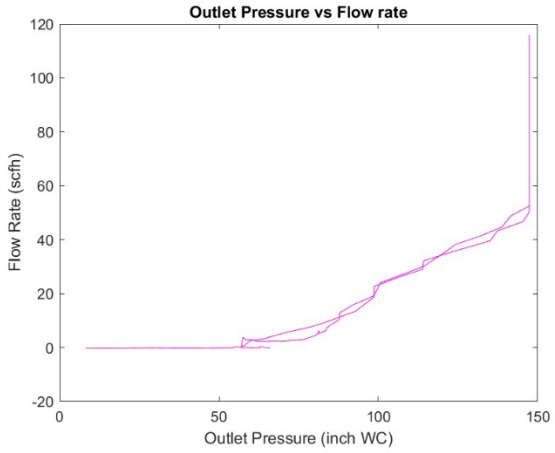
  The volume of total emissions in 185.33 seconds is 0.6793 scf.

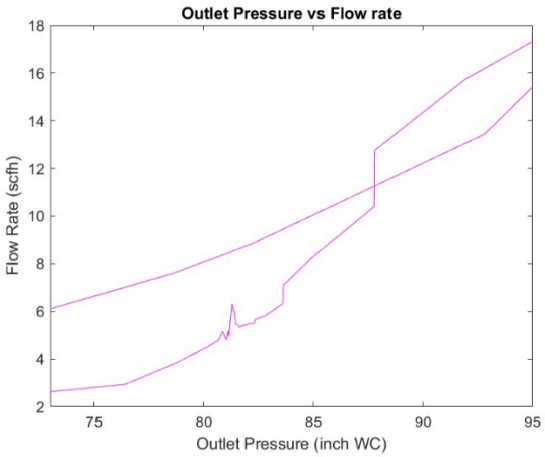
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 11.57 scfh.





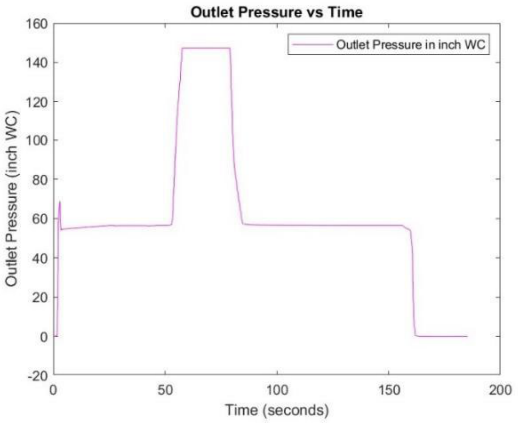
GTI ENERGY

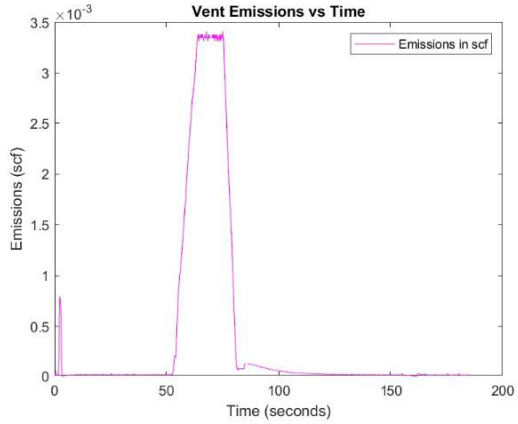

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
120
100
80
60
40
20
0
-20
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
18
16
14
12
10
8
6
4
2
75
80
85
90
95

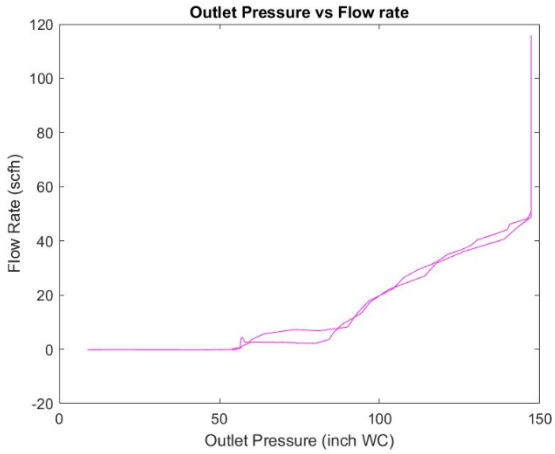
GTI ENERGY

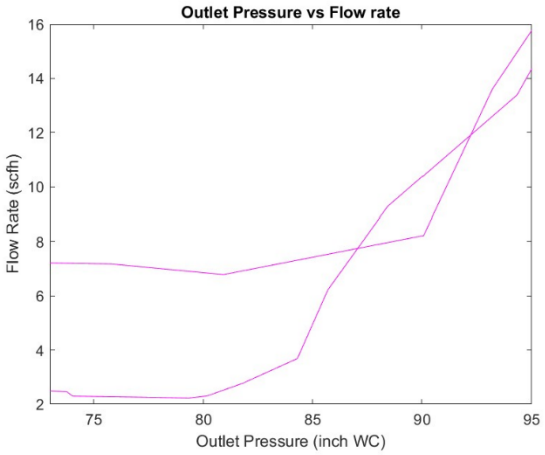
- 222489-049
  The volume of total emissions in 185.37 seconds is 0.6888 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 8.75 scfh.





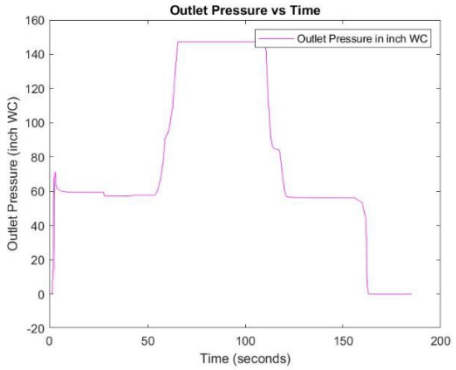
GTI ENERGY

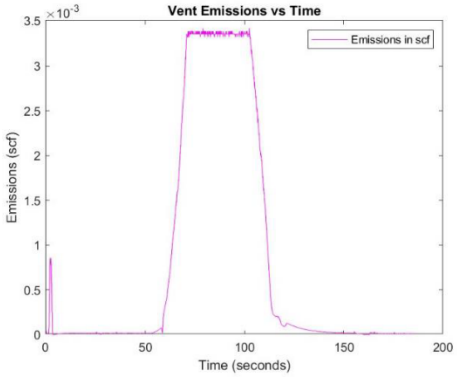

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
120
100
80
60
40
20
0
-20
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
16
14
12
10
8
6
4
2
75
80
85
90
95

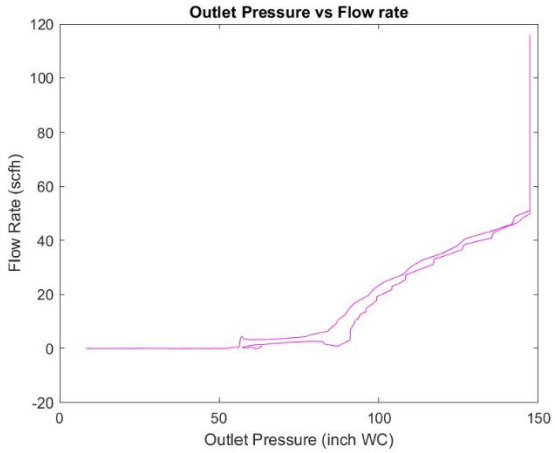
GTI ENERGY

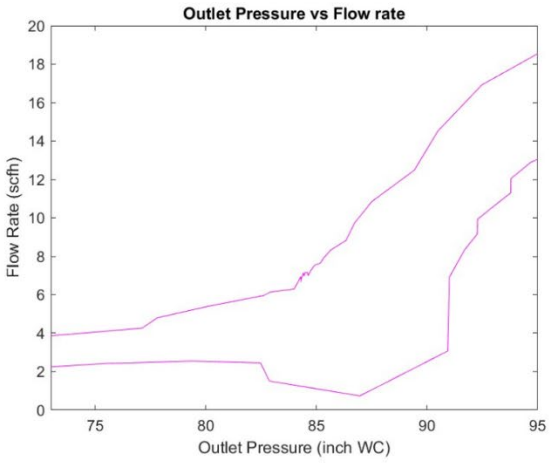
- 222489-050
  The volume of total emissions in 185.29 seconds is 1.4417 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 8.39 scfh.





GTI ENERGY


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
120
100
80
60
40
20
0
-20
0
50
100
150

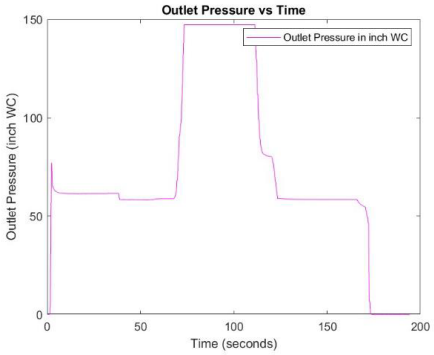

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
20
18
16
14
12
10
8
6
4
2
0
75
80
85
90
95

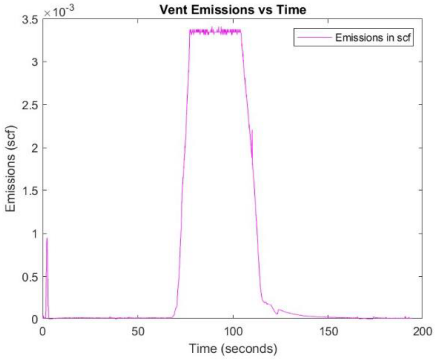
GTI ENERGY

2-psig Outlet, 100-psig Inlet

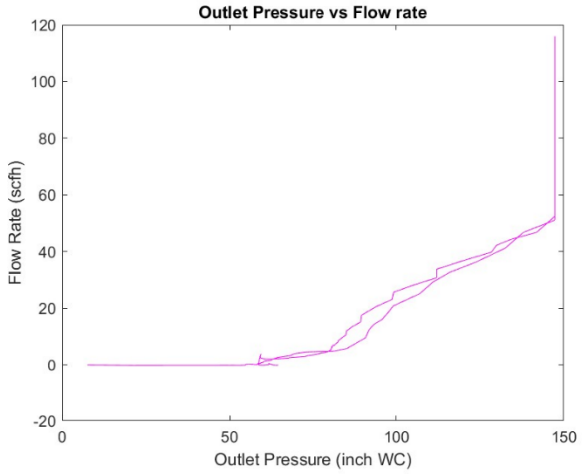
- 222489-048

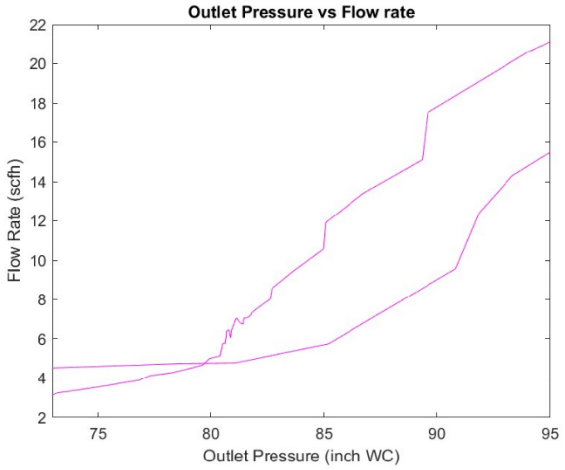
  The volume of total emissions in 194.27 seconds is 1.2162 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 13.90 scfh.





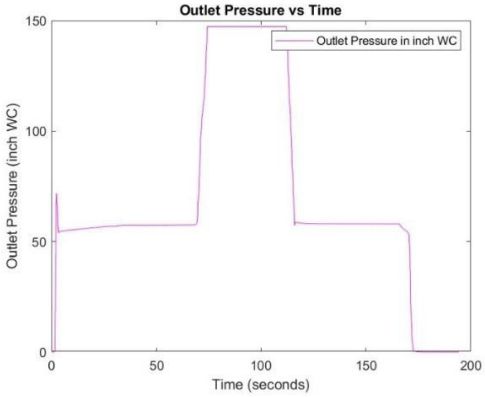
GTI ENERGY

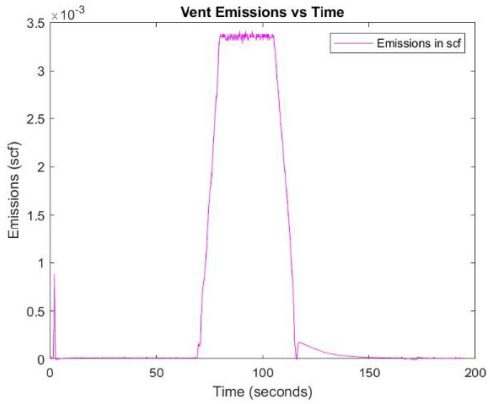

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
120
100
80
60
40
20
0
-20
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
22
20
18
16
14
12
10
8
6
4
2
75
80
85
90
95

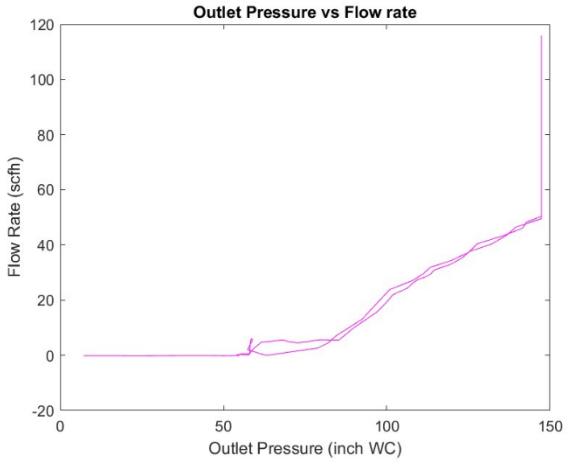
GTI ENERGY

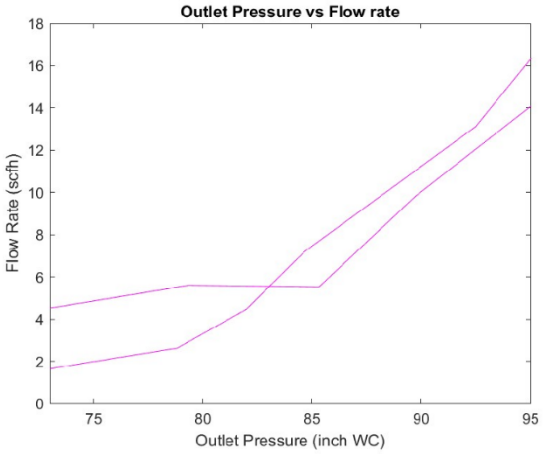
- 222489-049
  The volume of total emissions in 194.38 seconds is 1.1972 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 9.79 scfh.



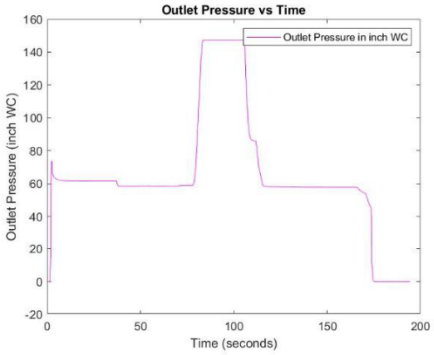


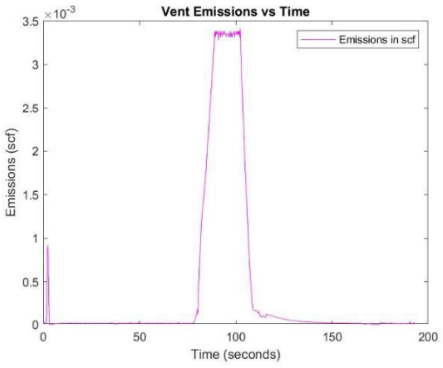
GTI ENERGY


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
120
100
80
60
40
20
0
-20
0
50
100
150

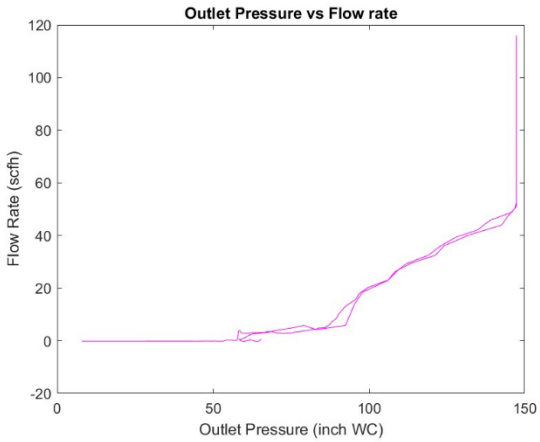

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
18
16
14
12
10
8
6
4
2
0
75
80
85
90
95

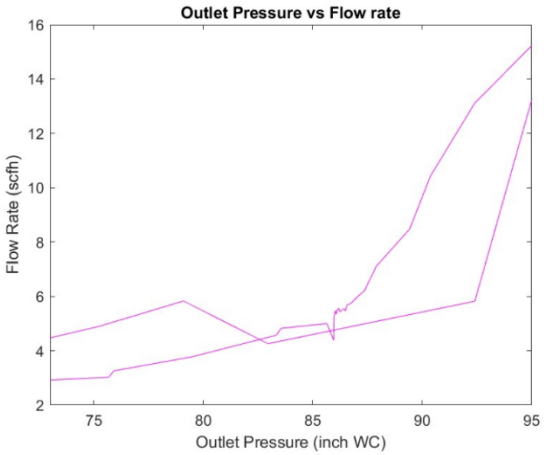
- 222489-050
  The volume of total emissions in 194.46 seconds is 0.7312 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 6.06 scfh.





GTI ENERGY

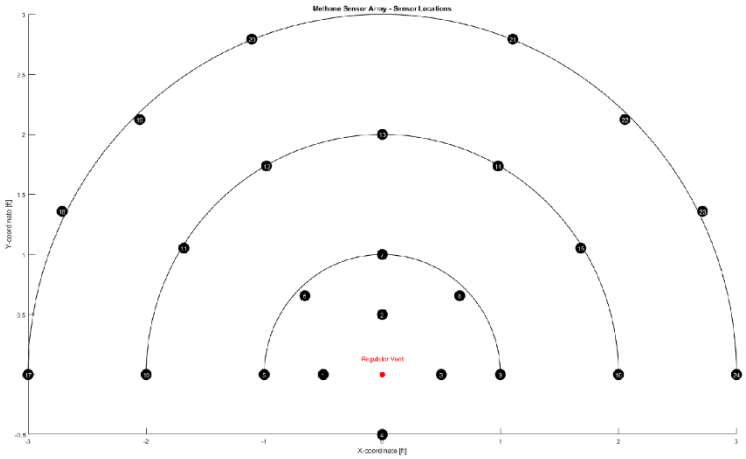

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
120
100
80
60
40
20
0
-20
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
16
14
12
10
8
6
4
2
75
80
85
90
95

GTI ENERGY

Methane Concentration Maps

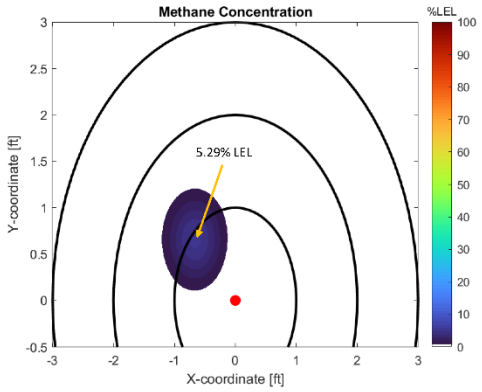
Sensor Locations



GTI ENERGY

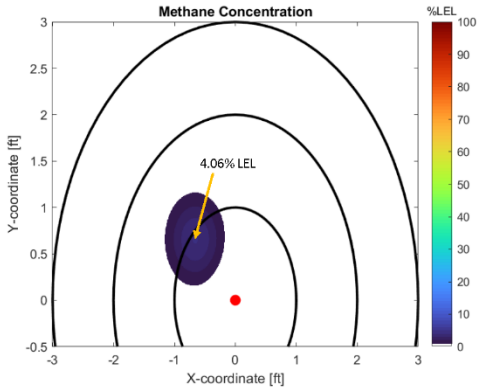
2-psig Outlet

	2 PSI	222489-049_multi lockup_sensor1 6in	Sigma = .3
IRV3	Normal Condition – Multi Lockup	Standard Array Configuration	6 in from vent

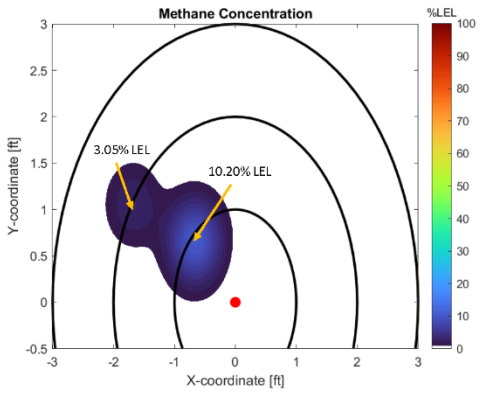


GTI ENERGY

	2 PSI	222489-049_multi lockup_sensor1 next to vent	Sigma = .3
IRV3	Normal Condition – Multi Lockup	Standard Array Configuration	1 in from vent

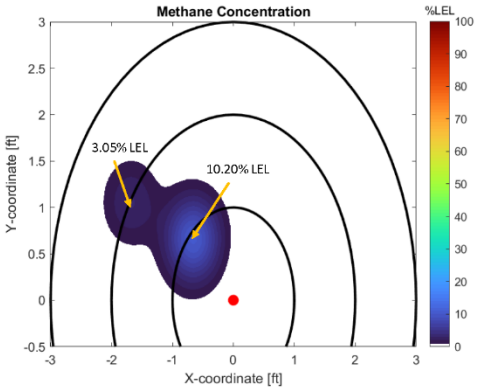


	2 PSI	222489-049_single lockup_sensor1 6in	Sigma = .3
IRV3	Normal Condition – Single Lockup	Standard Array Configuration	6 in from vent

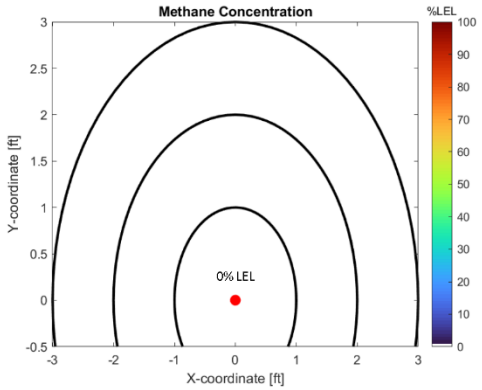


GTI ENERGY

	2 PSI	222489-049_single lockup_sensor1 next to vent	Sigma = .3
IRV3	Normal Condition – Single Lockup	Standard Array Configuration	1 in from vent

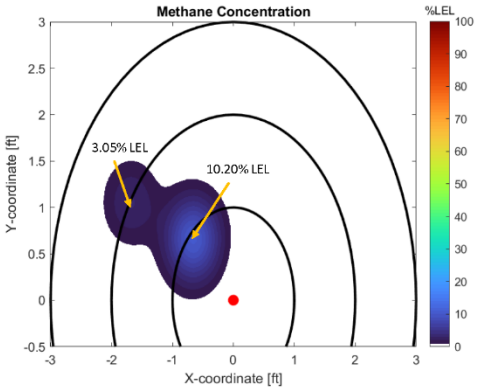


	2 PSI	222489-049_multi lockup_sensor1 next to vent retest	Sigma = .3
IRV3	Normal Condition – Multi Lockup	Standard Array Configuration	1 in from vent



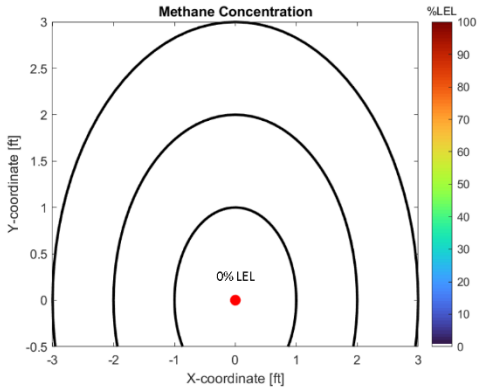
GTI ENERGY

	2 PSI	222489-049_single lockup_sensor1 next to vent retest	Sigma = .3
IRV3	Normal Condition – Single Lockup	Standard Array Configuration	1 in from vent



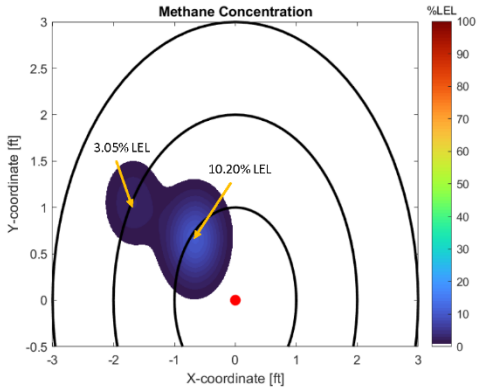
7" WC Outlet

	7 In-WC	222489-006_multi lockup_sensor1 next to vent	Sigma = .3
IRV3	Normal Condition – Multi Lockup	Standard Array Configuration	1 in from vent

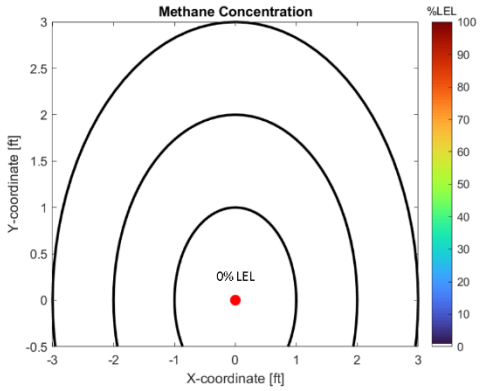


GTI ENERGY

	7 In-WC	222489-006_single lockup_sensor1 next to vent	Sigma = .3
IRV3	Normal Condition – Single Lockup	Standard Array Configuration	1 in from vent



	7 In-WC	222489-006_multi lockup_sensor1 next to vent retest	Sigma = .3
IRV3	Normal Condition – Multi Lockup	Standard Array Configuration	1 in from vent



GTI ENERGY

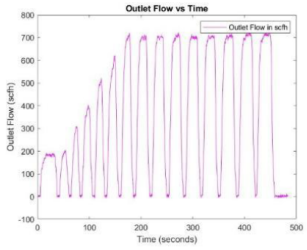
VL3

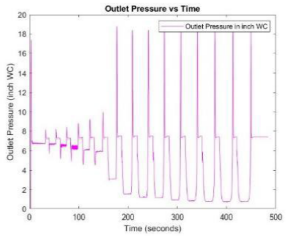
Modified Lockup Tests

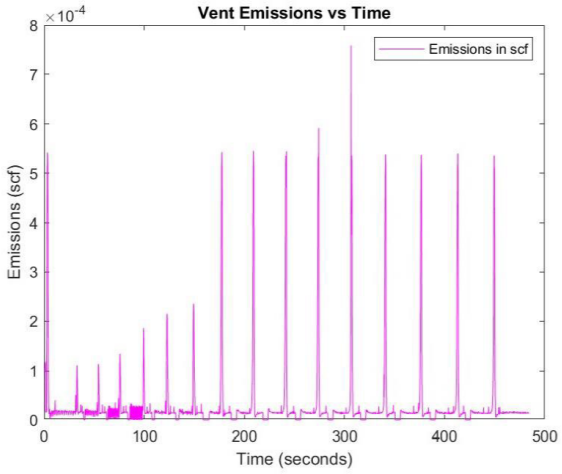
7" WC Outlet, 10-psig Inlet

- 222489-037

  The volume of total emissions in 483.92 seconds is 0.1329 scf.
  The flow rate of emissions is 0.9888 scfh.

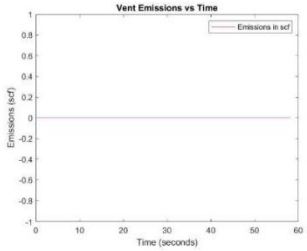


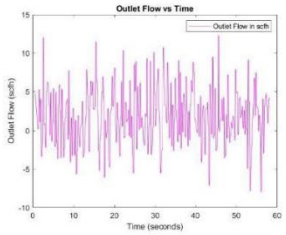


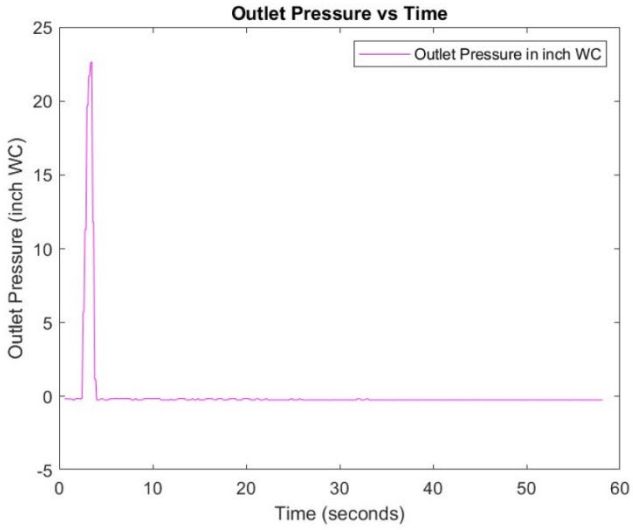


GTI ENERGY

- 222489-037_BV
  The volume of total emissions in 58.12 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.

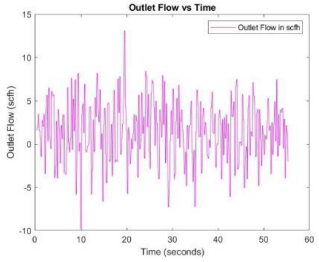


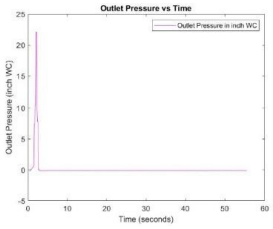


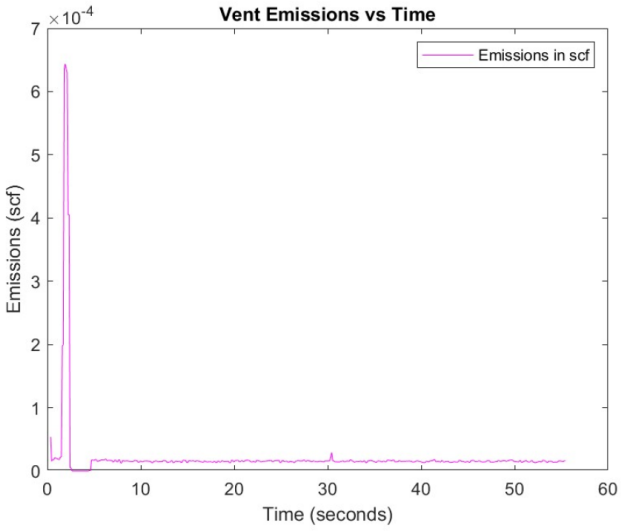


GTI ENERGY

- 222489-037_LD
  The volume of total emissions in 55.42 seconds is 0.0115 scf.
  The flow rate of emissions is 0.7499 scfh.

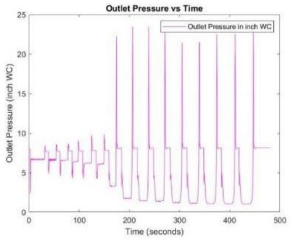


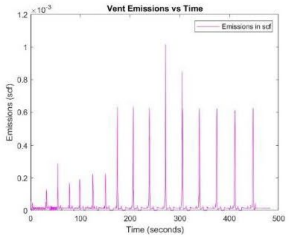


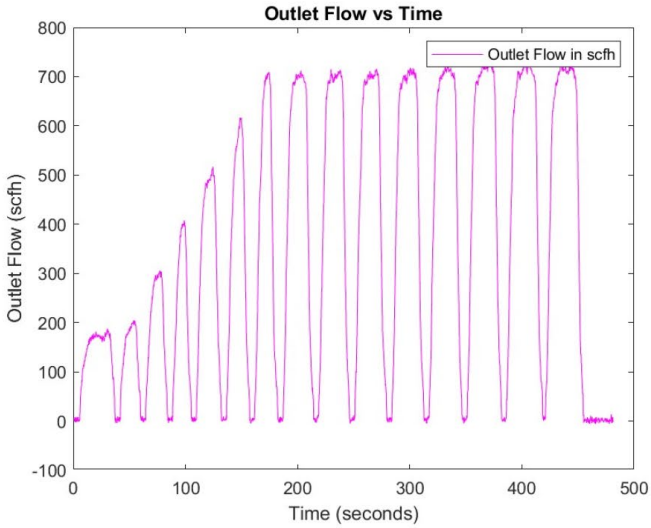


GTI ENERGY

- 222489-038
  The volume of total emissions in 481.71 seconds is 0.1406 scf.
  The flow rate of emissions is 1.0506 scfh.

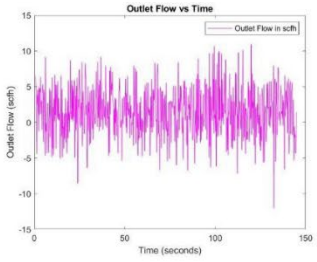


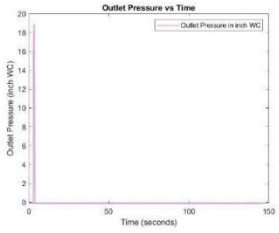


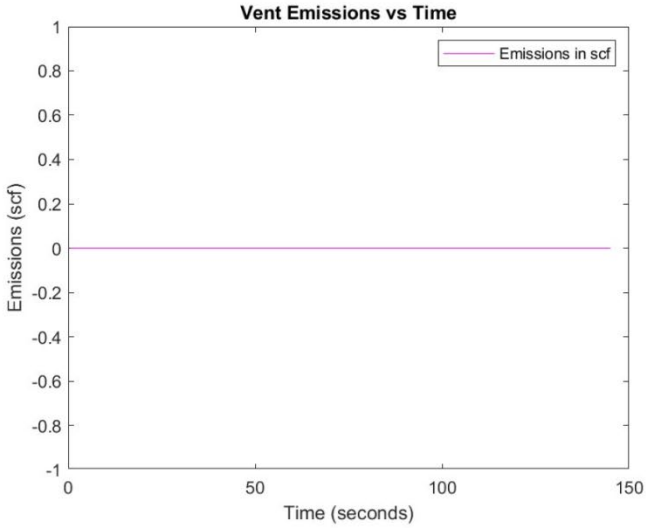


GTI ENERGY

- 222489-038_BV
  The volume of total emissions in 145.02 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.

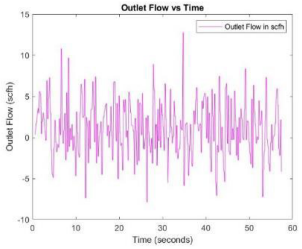


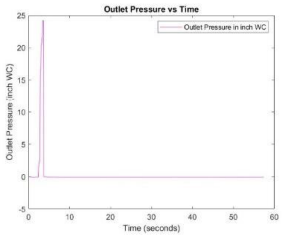


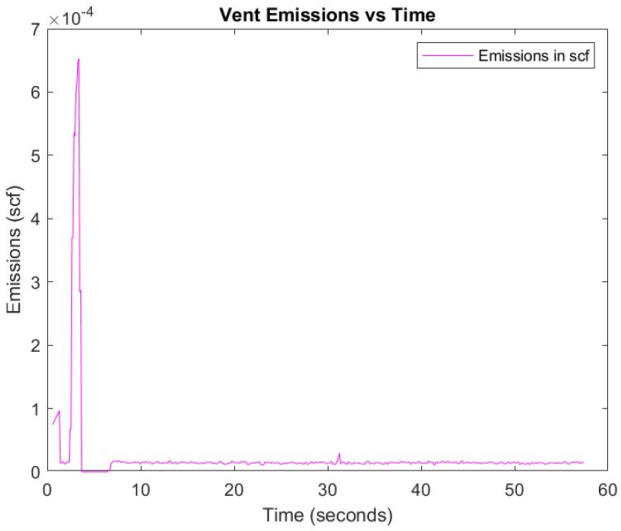


GTI ENERGY

- 222489-038_LD
  The volume of total emissions in 57.41 seconds is 0.0122 scf.
  The flow rate of emissions is 0.7664 scfh.





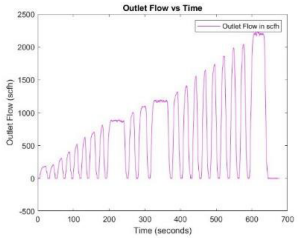


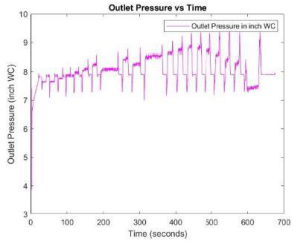
GTI ENERGY

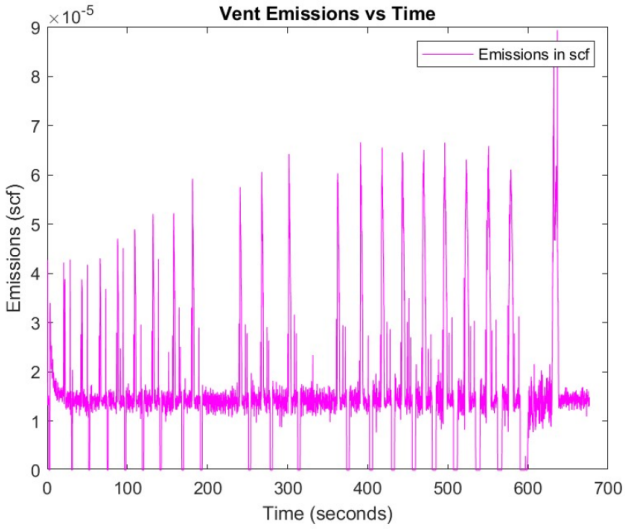
7" WC Outlet, 60-psig Inlet

- 222489-037

  The volume of total emissions in 676.71 seconds is 0.1040 scf.
  The flow rate of emissions is 0.5531 scfh.

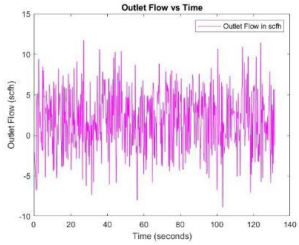


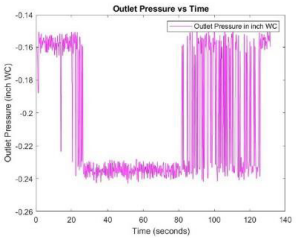


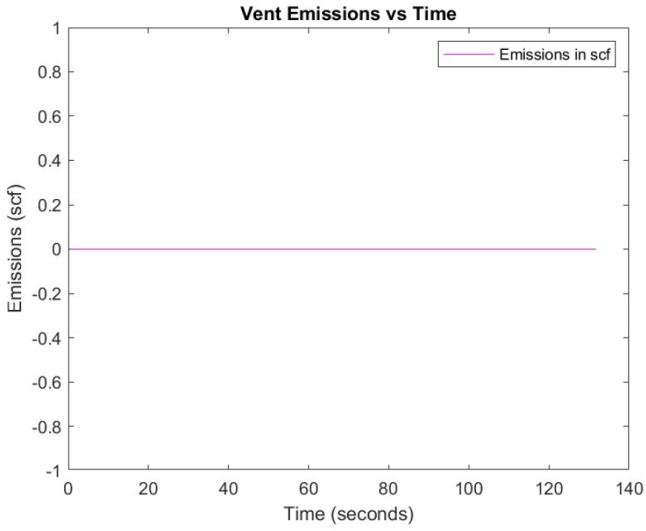


GTI ENERGY

- 222489-037_BV
  The volume of total emissions in 131.77 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.

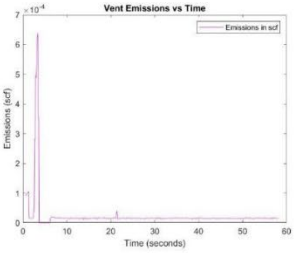


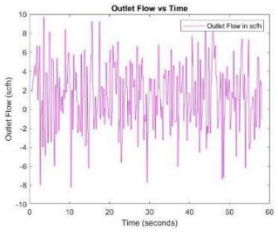


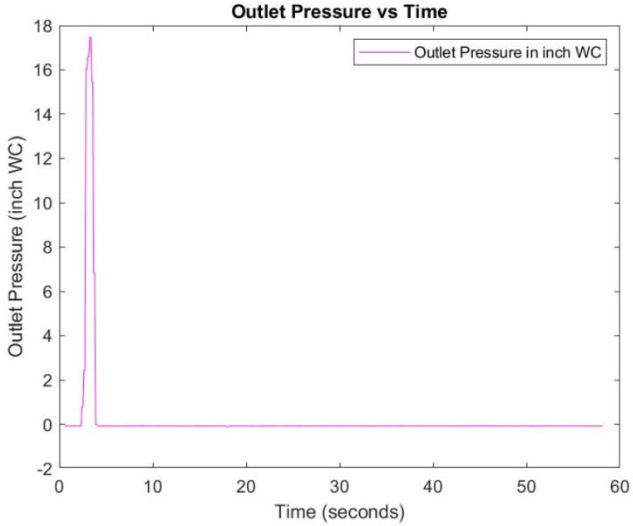


GTI ENERGY

- 222489-037_LD
  The volume of total emissions in 58.16 seconds is 0.0127 scf.
  The flow rate of emissions is 0.7844 scfh.

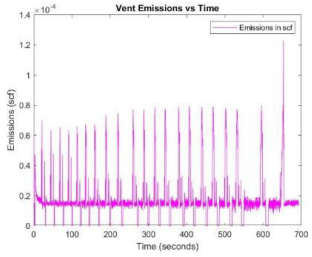


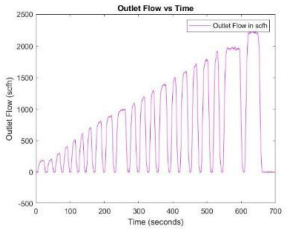


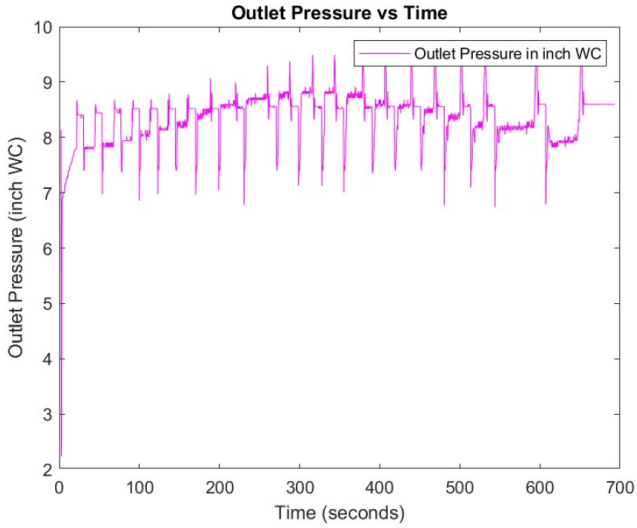


GTI ENERGY

- 222489-038
  The volume of total emissions in 693.22 seconds is 0.1188 scf.
  The flow rate of emissions is 0.6169 scfh.

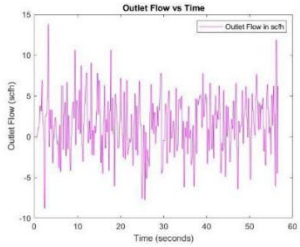


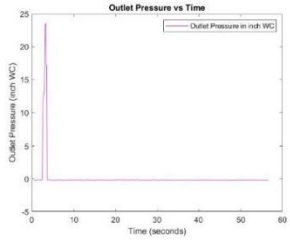


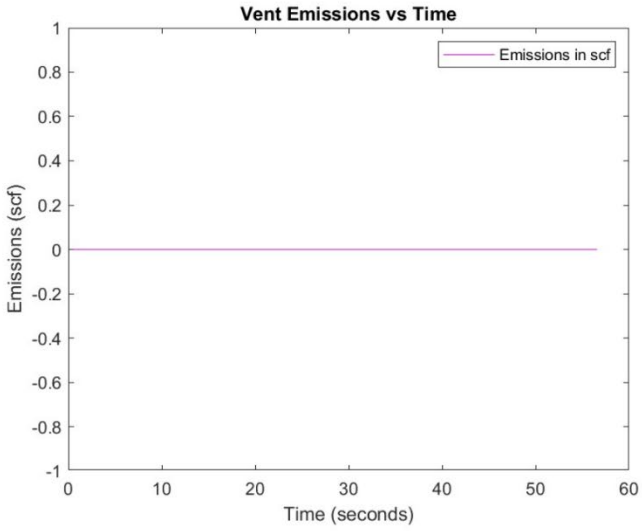


GTI ENERGY

- 222489-038_BV
  The volume of total emissions in 56.59 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.

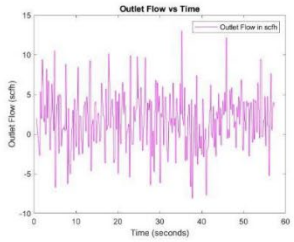


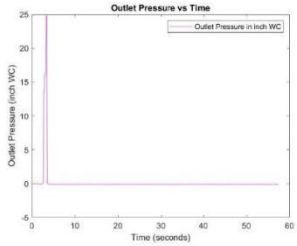


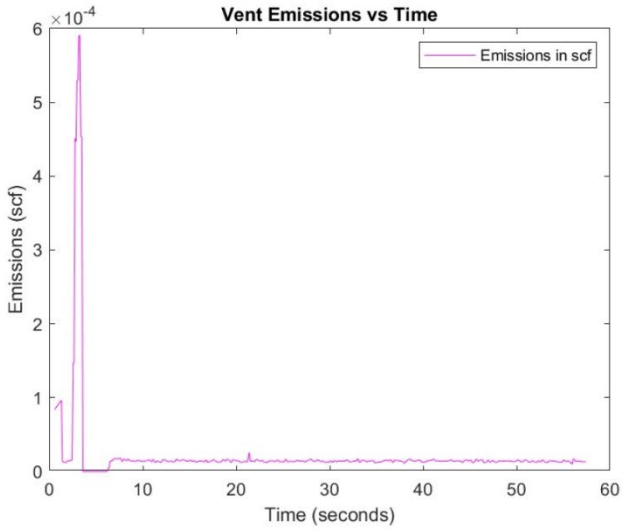


GTI ENERGY

- 222489-038_LD
  The volume of total emissions in 57.41 seconds is 0.0116 scf.
  The flow rate of emissions is 0.7281 scfh.





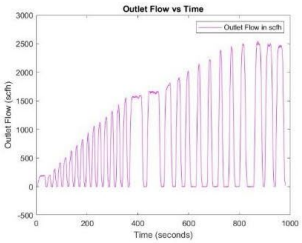


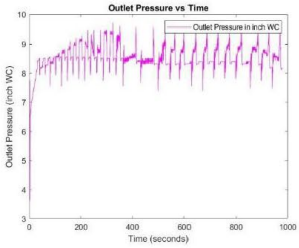
GTI ENERGY

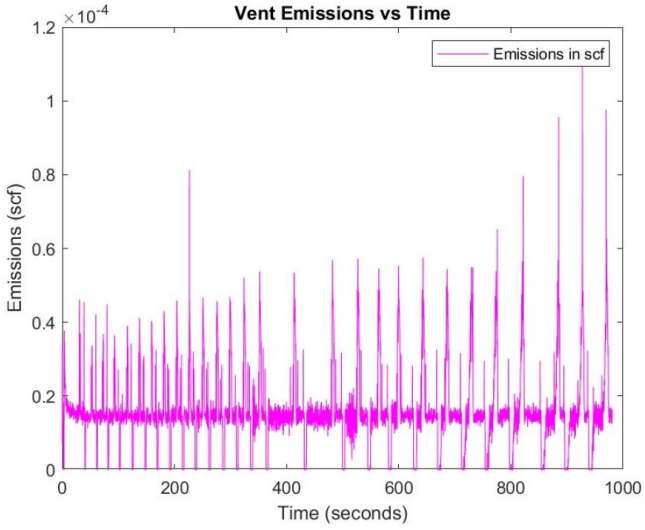
7" WC Outlet, 100-psig Inlet

- 222489-037

  The volume of total emissions in 980.62 seconds is 0.1474 scf.
  The flow rate of emissions is 0.5411 scfh.

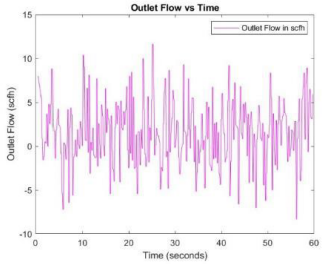


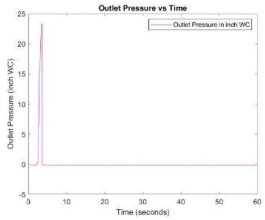


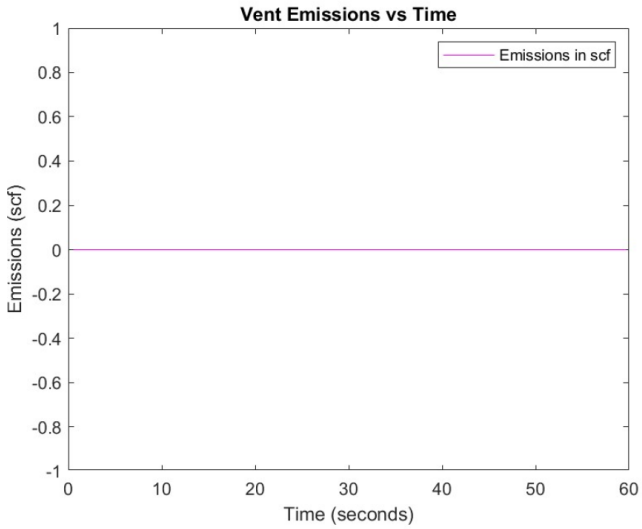


GTI ENERGY

- 222489-037_BV
  The volume of total emissions in 59.71 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.

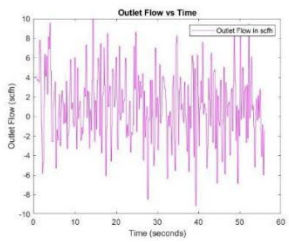


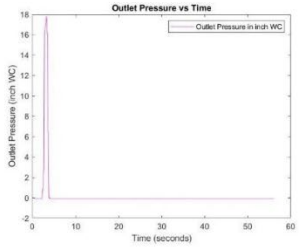


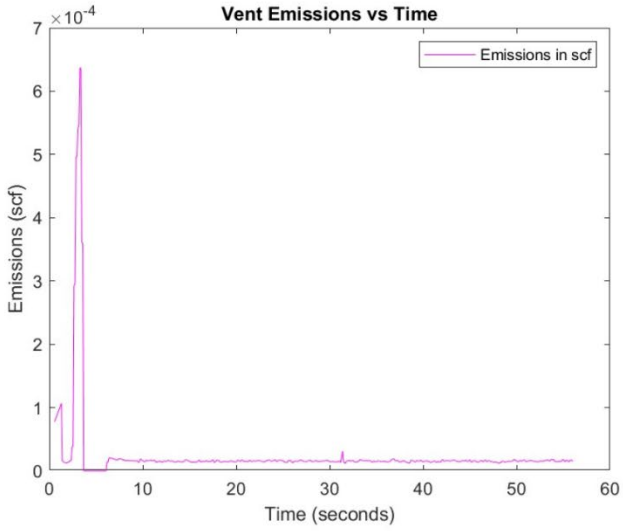


GTI ENERGY

- 222489-037_LD
  The volume of total emissions in 56.05 seconds is 0.0125 scf.
  The flow rate of emissions is 0.8024 scfh.

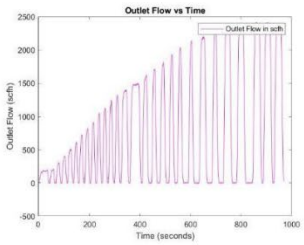


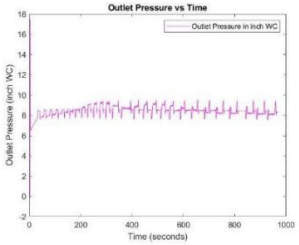


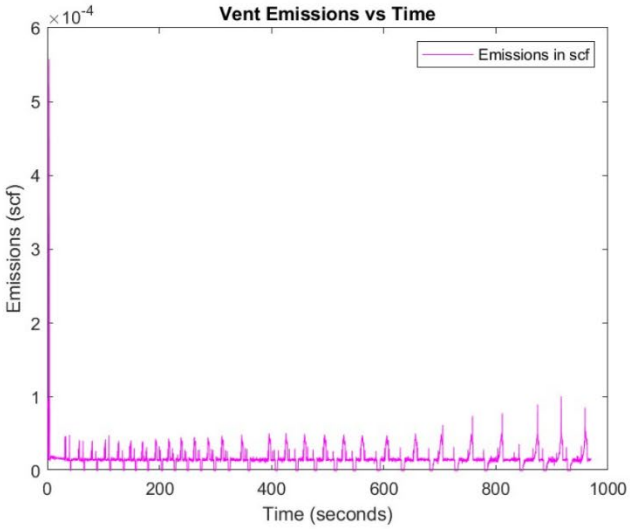


GTI ENERGY

- 222489-038
  VL3_222489-038_06_22_2023_13_06_49_1
  The volume of total emissions in 969.70 seconds is 0.1534 scf.
  The flow rate of emissions is 0.5693 scfh.

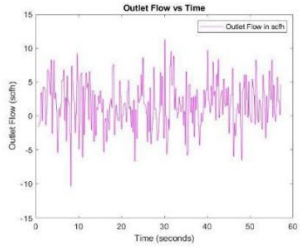


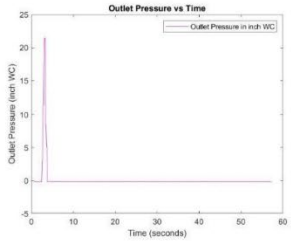


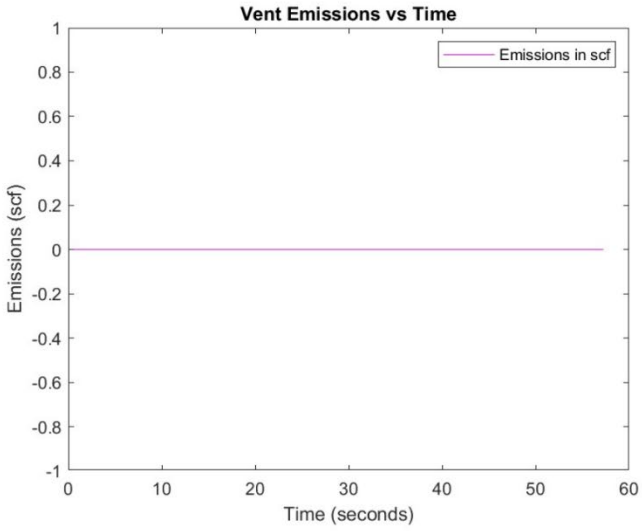


GTI ENERGY

- 222489-038_BV
  The volume of total emissions in 57.26 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.

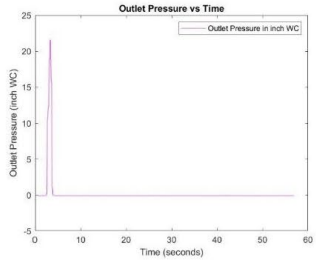


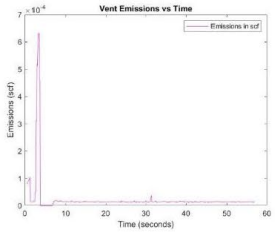


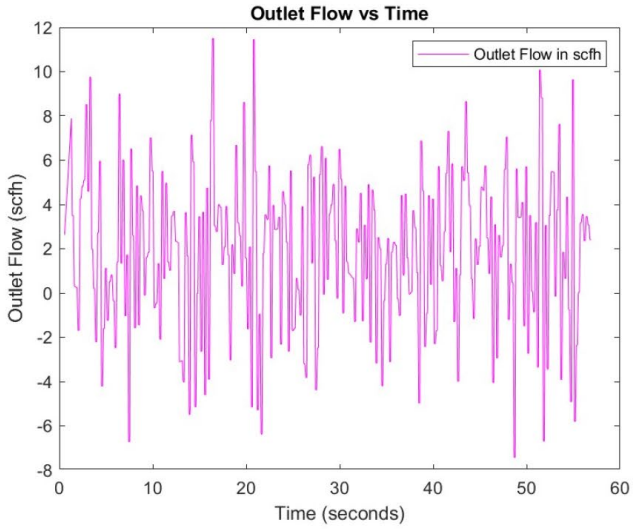


GTI ENERGY

- 222489-038_LD
  The volume of total emissions in 56.89 seconds is 0.0123 scf.
  The flow rate of emissions is 0.7759 scfh.





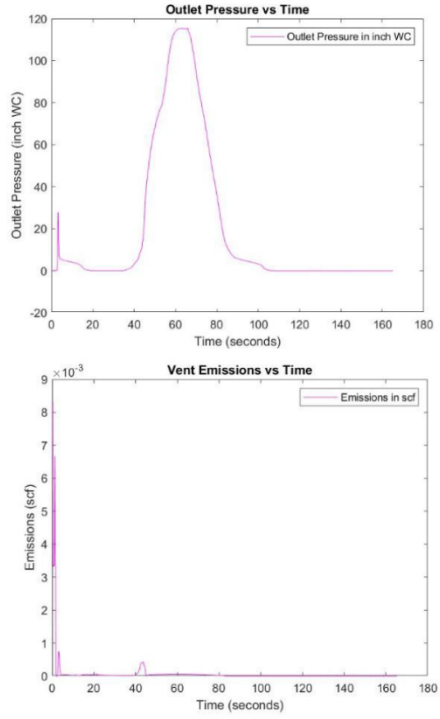


Relief Tests

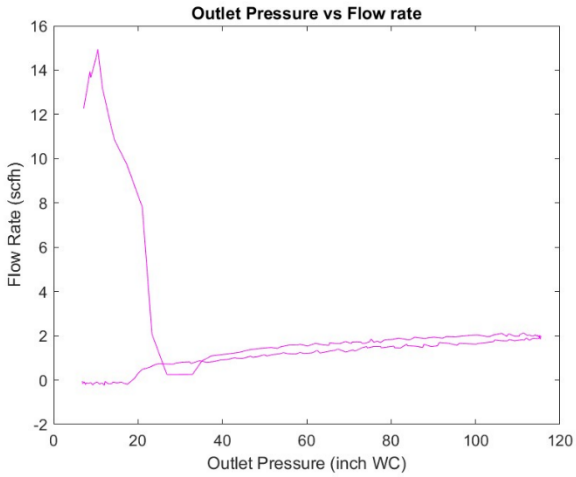
7" WC Outlet, 10-psig Inlet

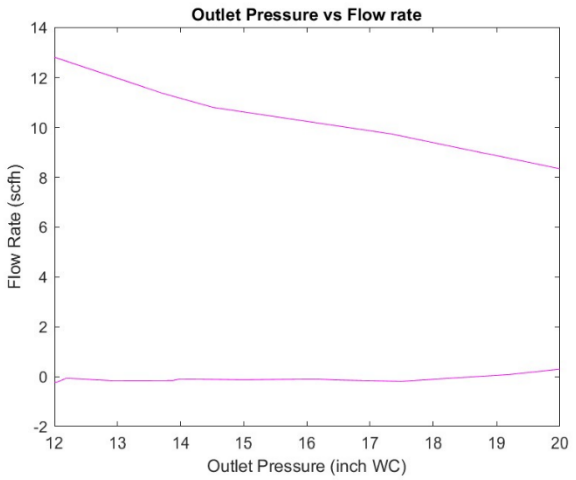
- 222489-037

  The volume of total emissions in 165.23 seconds is 0.0968 scf.
  The average flow rate of emissions at 18 inches WC is 4.78 scfh.



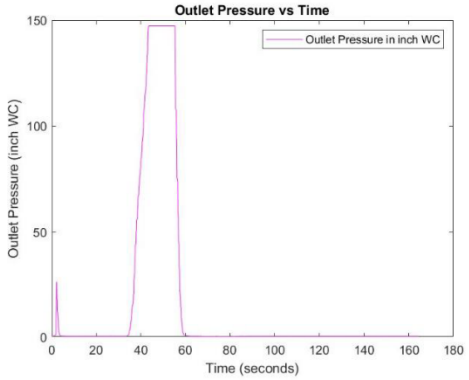
GTI ENERGY

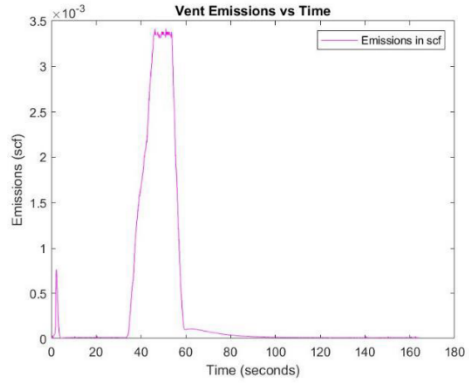

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
16
14
12
10
8
6
4
2
0
-2
0
20
40
60
80
100
120


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
14
12
10
8
6
4
2
0
-2
12
13
14
15
16
17
18
19
20

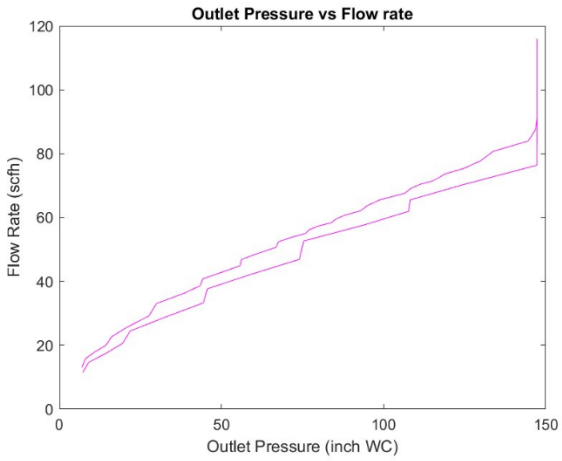
GTI ENERGY

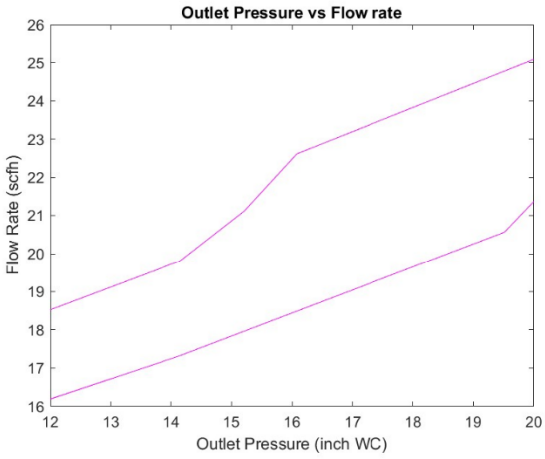
- 222489-037_DT
  The volume of total emissions in 164.28 seconds is 0.5616 scf.
  The average flow rate of emissions at 18 inches WC is 24.09 scfh.





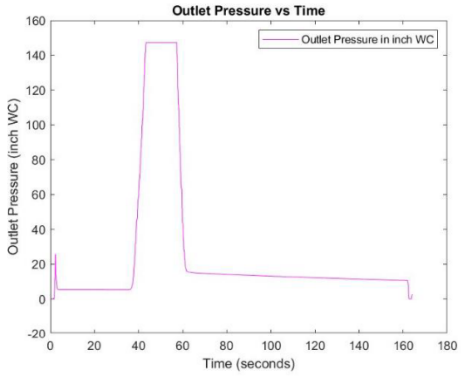
GTI ENERGY

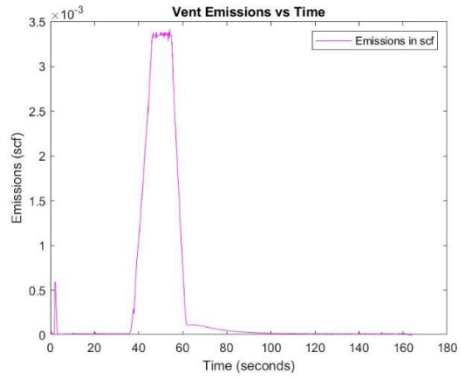

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
20
40
60
80
100
120
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
16
17
18
19
20
21
22
23
24
25
26
12
13
14
15
16
17
18
19
20

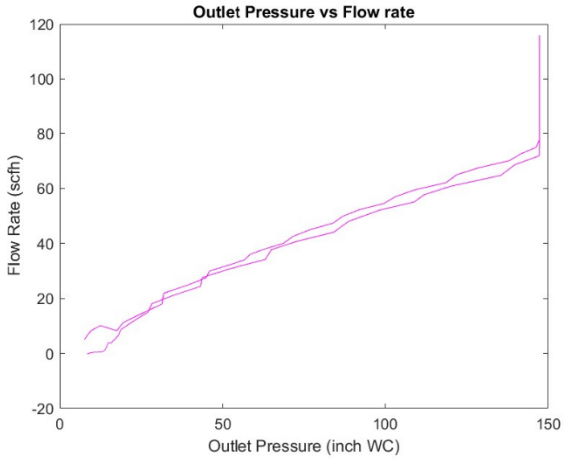
GTI ENERGY

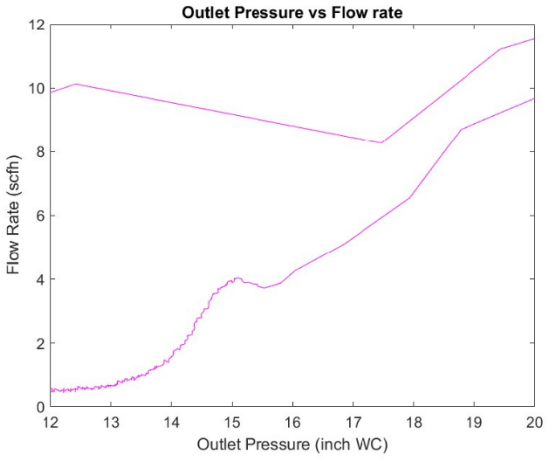
- 222489-037_LD
  The volume of total emissions in 164.22 seconds is 0.5682 scf.
  The average flow rate of emissions at 18 inches WC is 7.84 scfh.





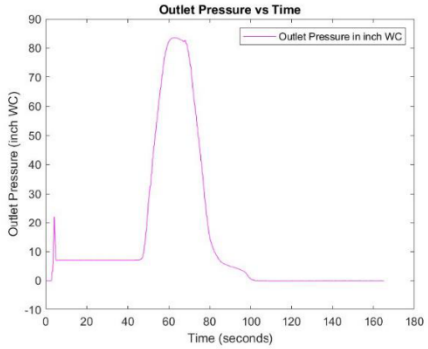
GTI ENERGY

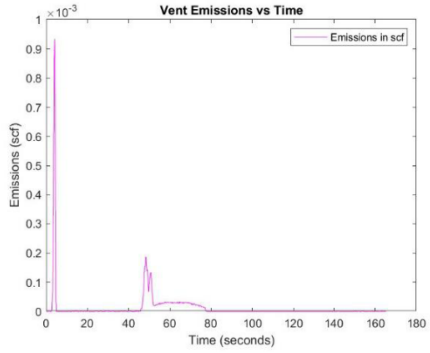

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
120
100
80
60
40
20
0
-20
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
12
10
8
6
4
2
0
12
13
14
15
16
17
18
19
20

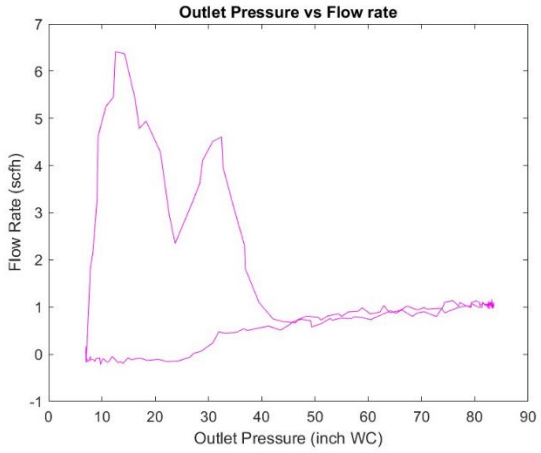
GTI ENERGY

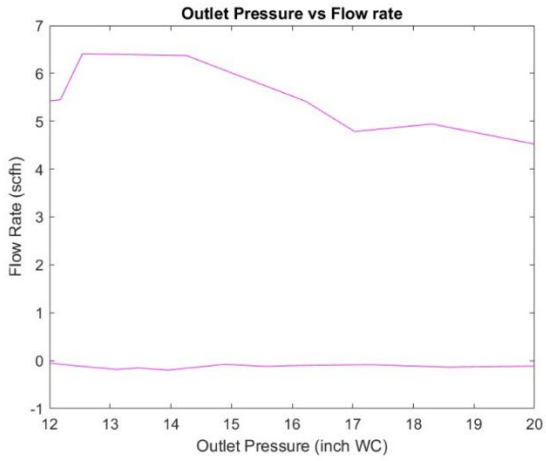
- 222489-038
  The volume of total emissions in 165.24 seconds is 0.0203 scf.
  The average flow rate of emissions at 18 inches WC is 1.88 scfh.





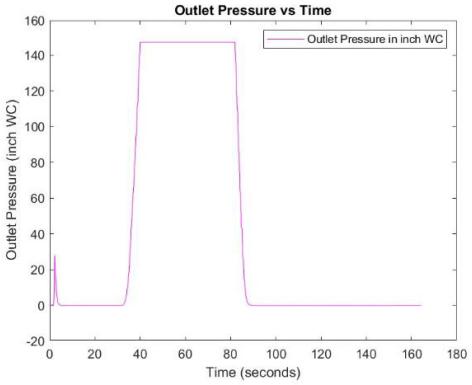
GTI ENERGY

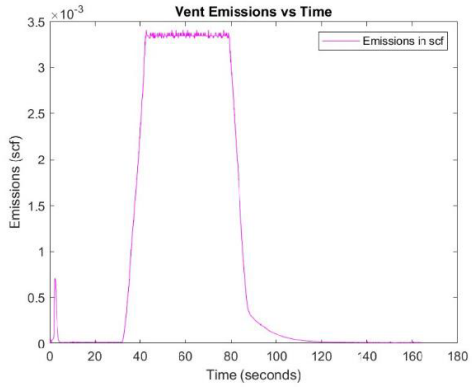

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
7
6
5
4
3
2
1
0
-1
0
10
20
30
40
50
60
70
80
90


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
7
6
5
4
3
2
1
0
-1
12
13
14
15
16
17
18
19
20

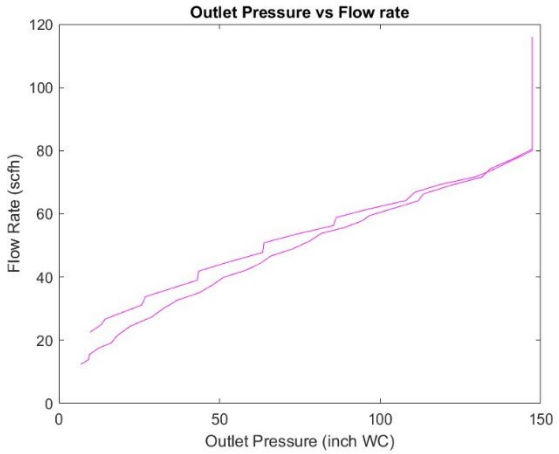
GTI ENERGY

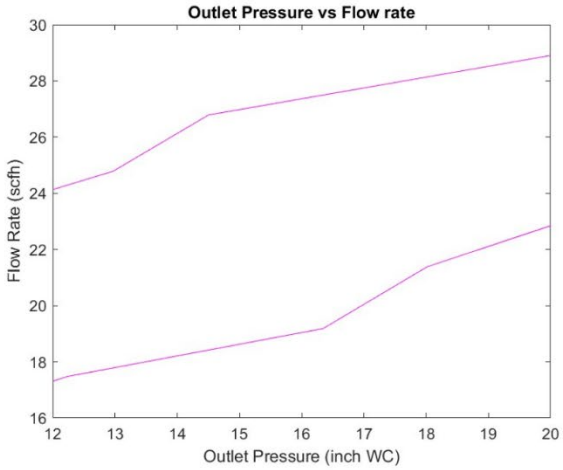
- 222489-038_DT
  The volume of total emissions in 164.27 seconds is 1.5229 scf.
  The average flow rate of emissions at 18 inches WC is 21.38 scfh.





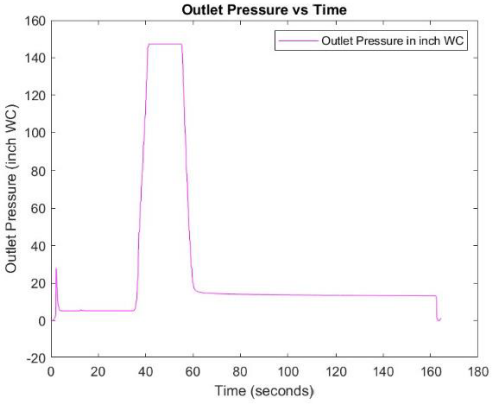
GTI ENERGY

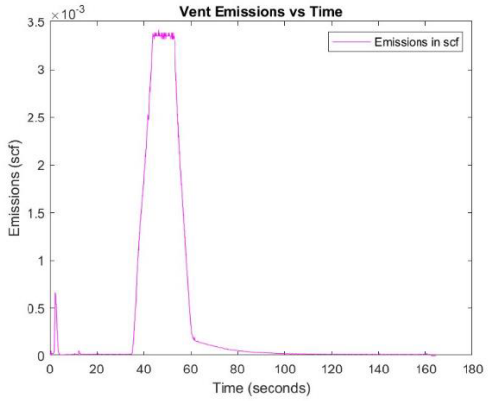

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
20
40
60
80
100
120
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
16
18
20
22
24
26
28
30
12
13
14
15
16
17
18
19
20

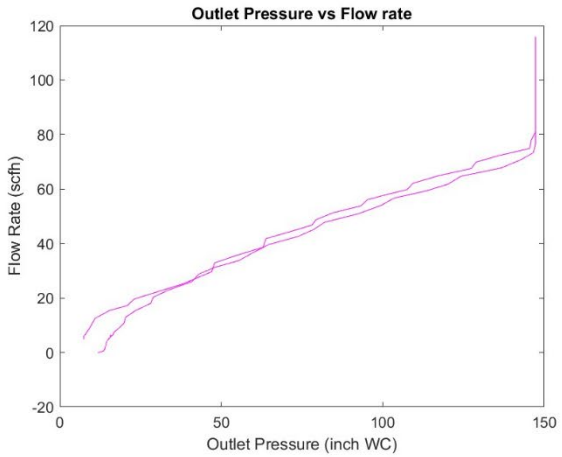
GTI ENERGY

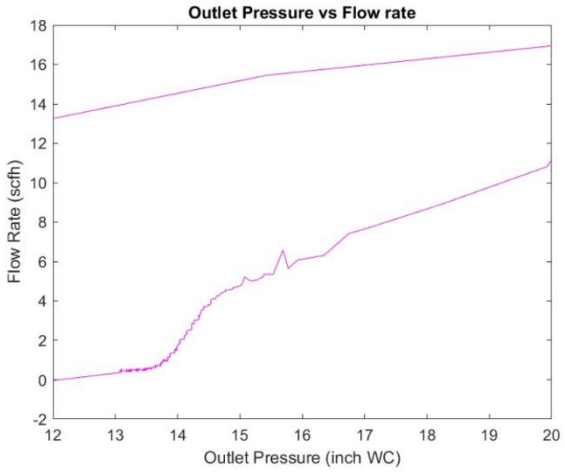
- 222489-038_LD
  The volume of total emissions in 164.42 seconds is 0.5954 scf.
  The average flow rate of emissions at 18 inches WC is 11.75 scfh.





GTI ENERGY


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
120
100
80
60
40
20
0
-20
0
50
100
150

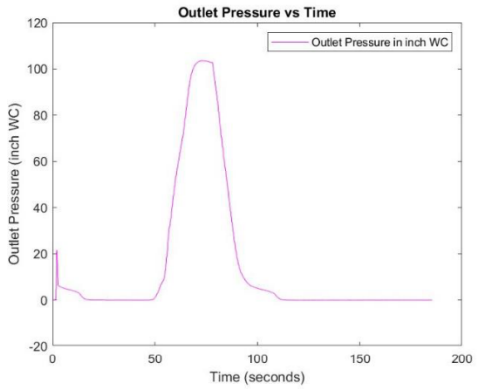

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
18
16
14
12
10
8
6
4
2
0
-2
12
13
14
15
16
17
18
19
20

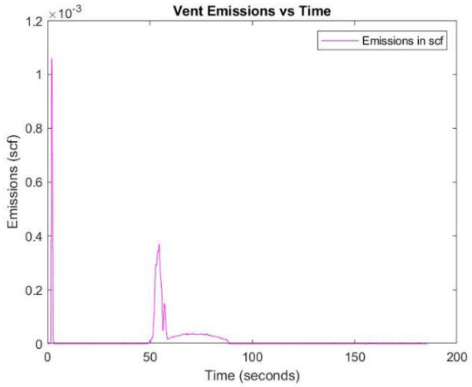
GTI ENERGY

7" WC Outlet, 60-psig Inlet

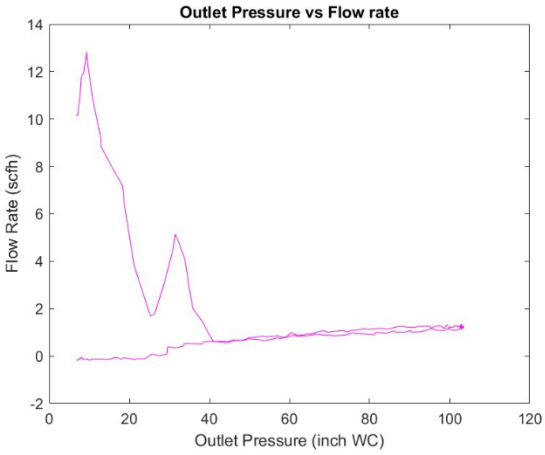
- 222489-037

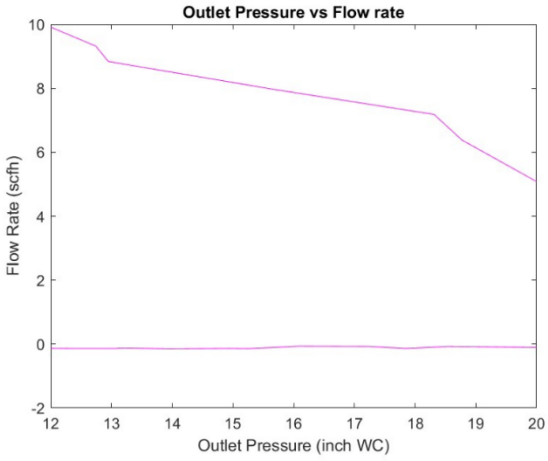
  The volume of total emissions in 185.44 seconds is 0.0289 scf.
  The average flow rate of emissions at 18 inches WC is 6.28 scfh.





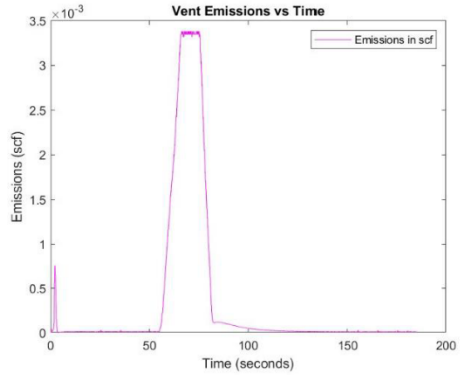
GTI ENERGY

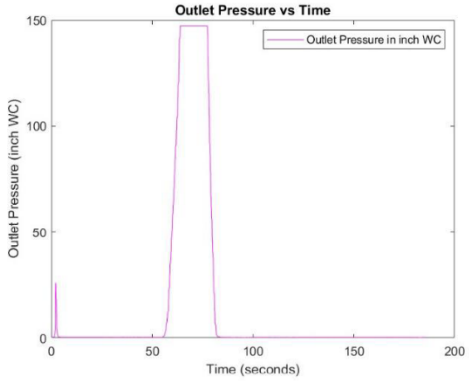

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
14
12
10
8
6
4
2
0
-2
0
20
40
60
80
100
120


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
10
8
6
4
2
0
-2
12
13
14
15
16
17
18
19
20

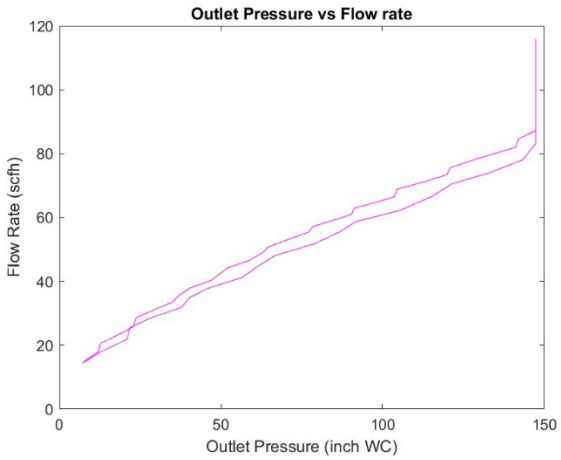
GTI ENERGY

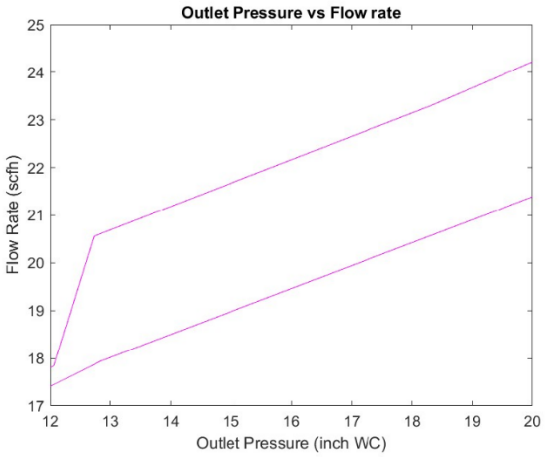
- 222489-037_DT
  The volume of total emissions in 185.41 seconds is 0.6094 scf.
  The average flow rate of emissions at 18 inches WC is 22.87 scfh.





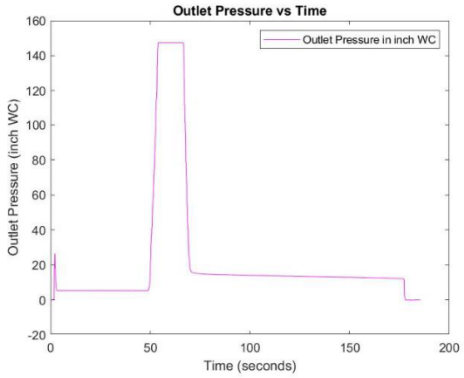
GTI ENERGY

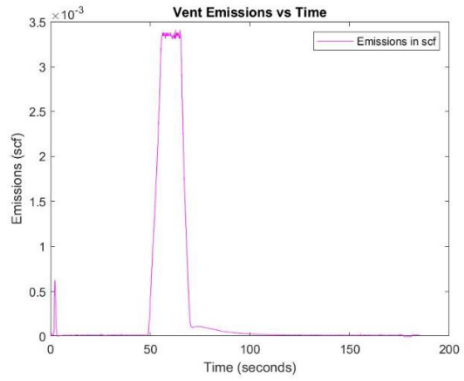

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
20
40
60
80
100
120
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
17
18
19
20
21
22
23
24
25
12
13
14
15
16
17
18
19
20

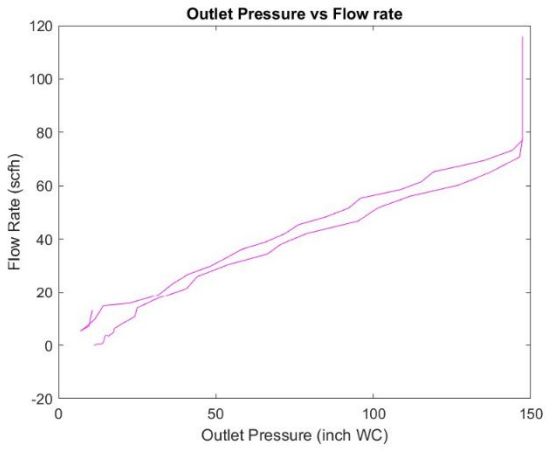
GTI ENERGY

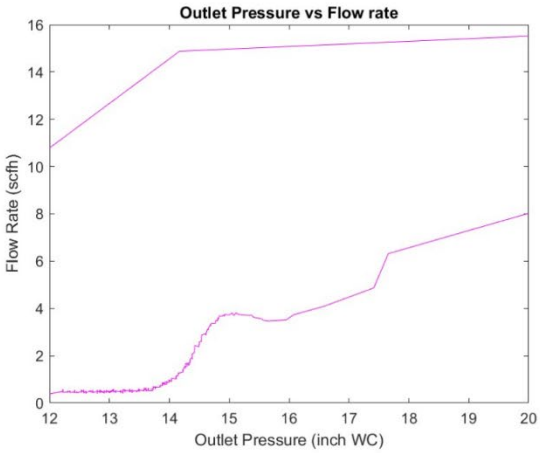
- 222489-037_LD
  The volume of total emissions in 185.36 seconds is 0.5180 scf.
  The average flow rate of emissions at 18 inches WC is 11.29 scfh.





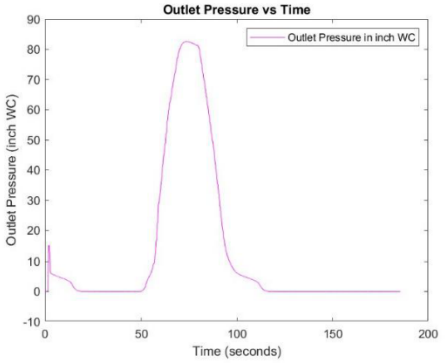
GTI ENERGY

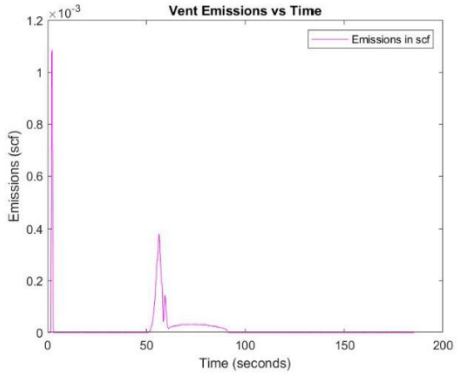

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
120
100
80
60
40
20
0
-20
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
16
14
12
10
8
6
4
2
0
12
13
14
15
16
17
18
19
20

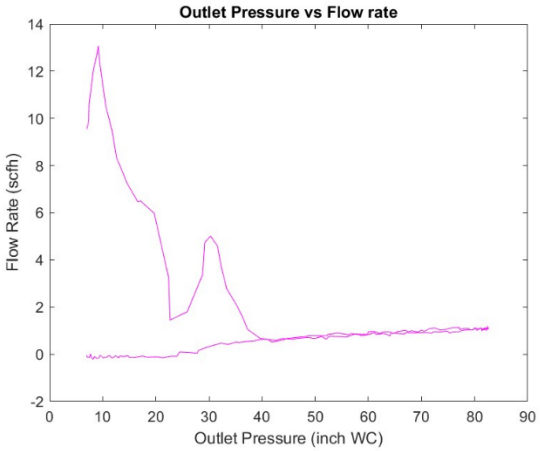
GTI ENERGY

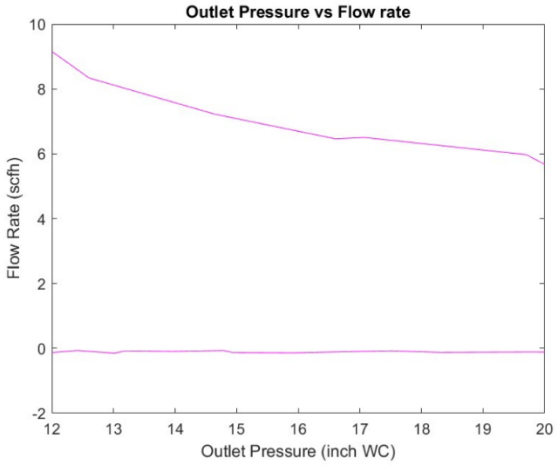
- 222489-038
  The volume of total emissions in 185.41 seconds is 0.0282 scf.
  The average flow rate of emissions at 18 inches WC is 1.55 scfh.





GTI ENERGY


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
14
12
10
8
6
4
2
0
-2
0
10
20
30
40
50
60
70
80
90

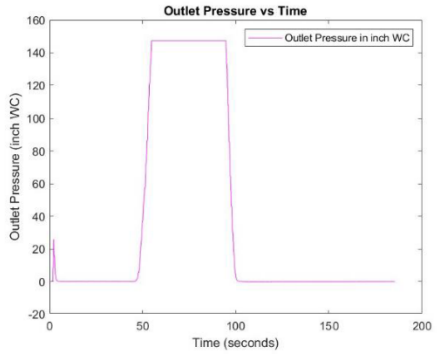

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
10
8
6
4
2
0
-2
12
13
14
15
16
17
18
19
20

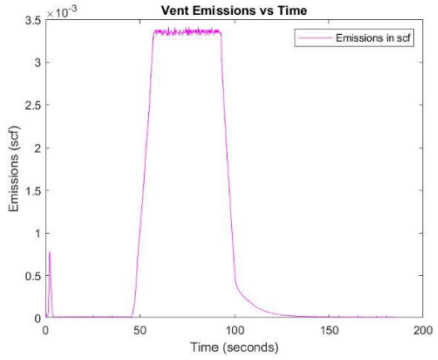
GTI ENERGY

- 222489-038_DT

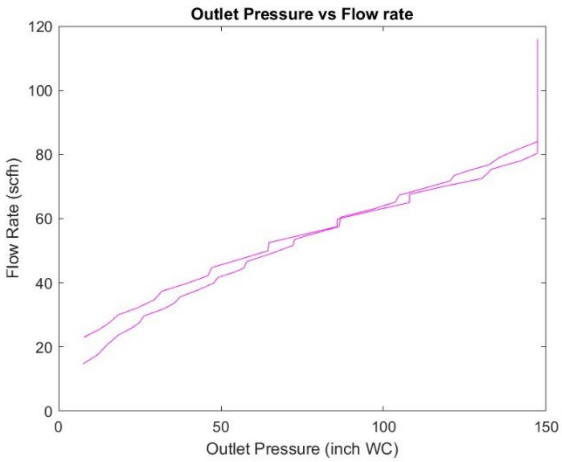
The volume of total emissions in 185.38 seconds is 1.4931 scf.

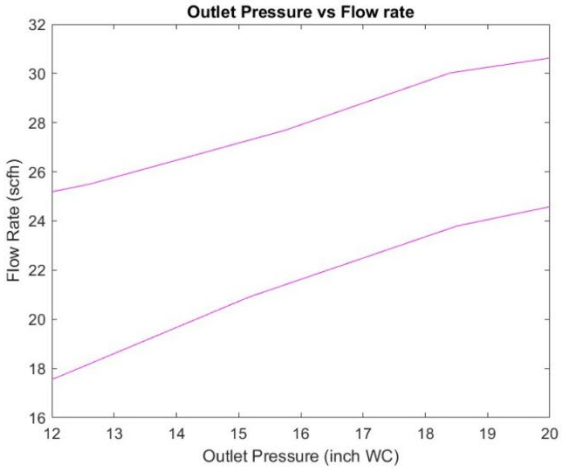
The average flow rate of emissions at 18 inches WC is 26.91 scfh.





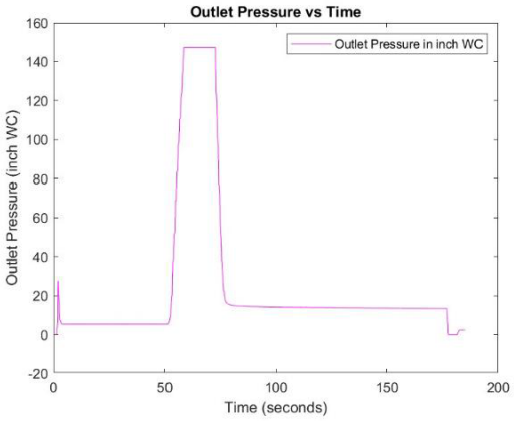
GTI ENERGY

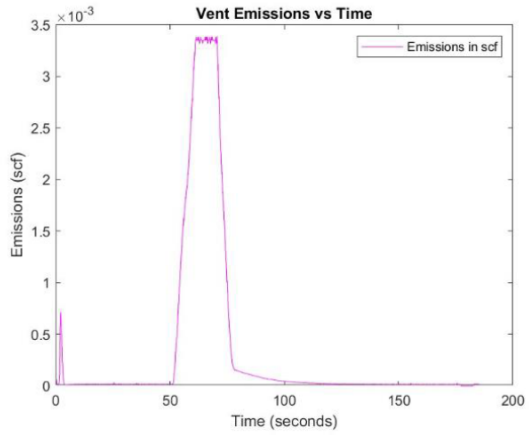

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
20
40
60
80
100
120
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
16
18
20
22
24
26
28
30
32
12
13
14
15
16
17
18
19
20

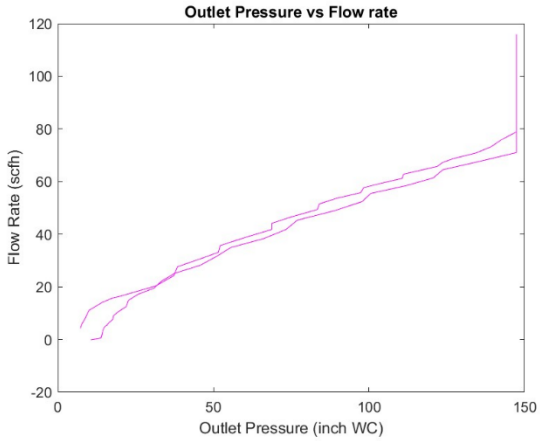
GTI ENERGY

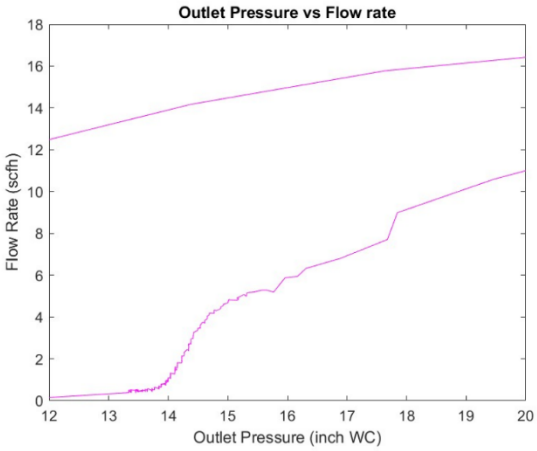
- 222489-038_LD
  The volume of total emissions in 185.36 seconds is 0.6042 scf.
  The average flow rate of emissions at 18 inches WC is 12.55 scfh.





GTI ENERGY


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
120
100
80
60
40
20
0
-20
0
50
100
150

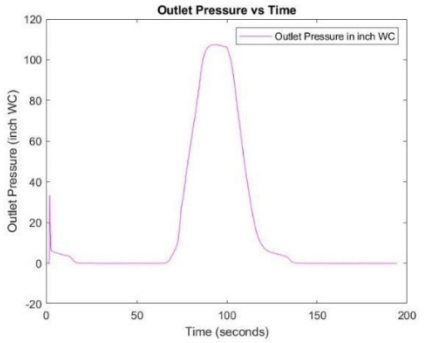

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
18
16
14
12
10
8
6
4
2
0
12
13
14
15
16
17
18
19
20

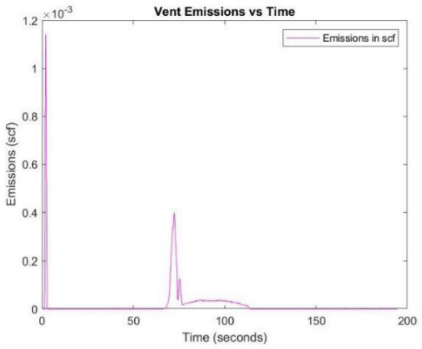
GTI ENERGY

7" WC Outlet, 100-psig Inlet

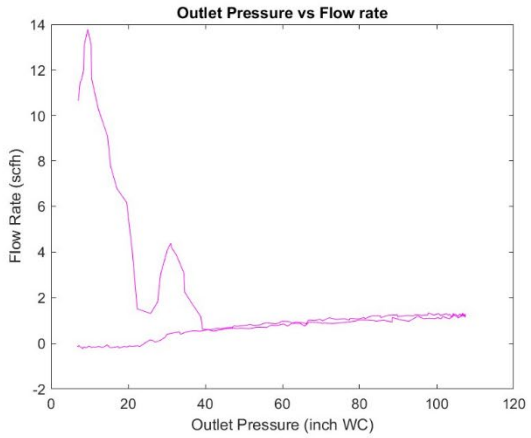
- 222489-037

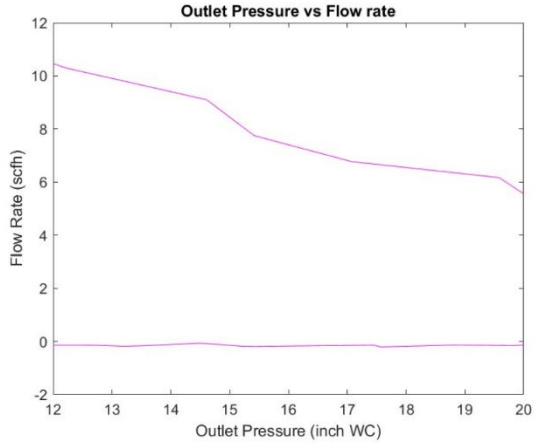
  The volume of total emissions in 194.43 seconds is 0.0312 scf.
  The average flow rate of emissions at 18 inches WC is 7.41 scfh.



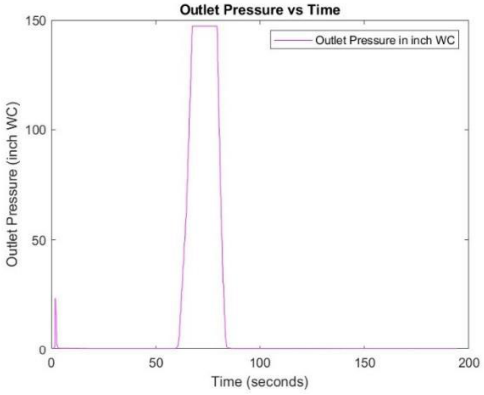


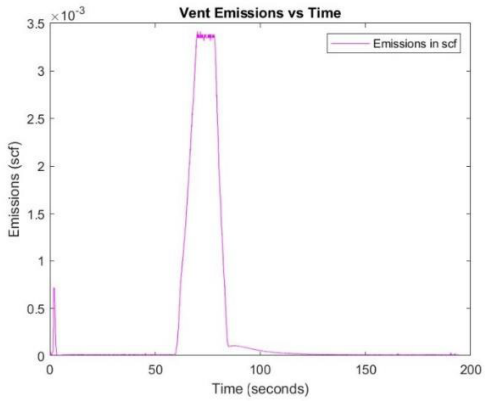
GTI ENERGY


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
14
12
10
8
6
4
2
0
-2
0
20
40
60
80
100
120

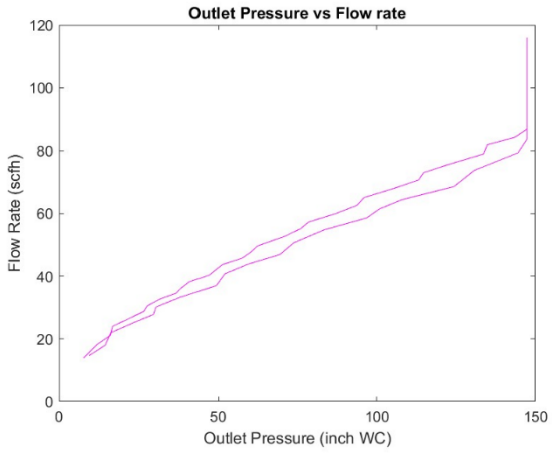

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
12
10
8
6
4
2
0
-2
12
13
14
15
16
17
18
19
20

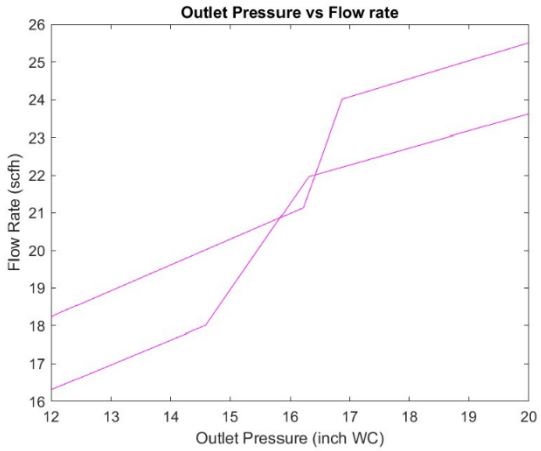
- 222489-037_DT
  The volume of total emissions in 194.36 seconds is 0.5625 scf.
  The average flow rate of emissions at 18 inches WC is 24.69 scfh.





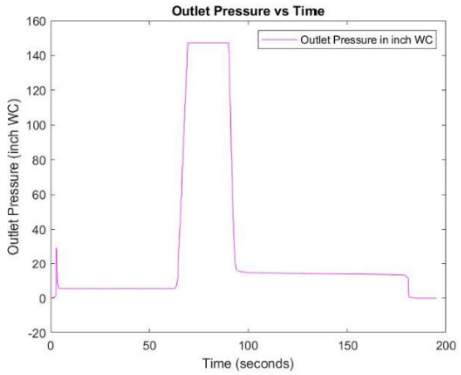
GTI ENERGY

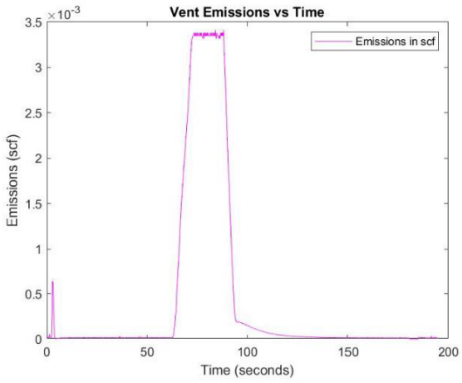

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
20
40
60
80
100
120
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
16
17
18
19
20
21
22
23
24
25
26
12
13
14
15
16
17
18
19
20

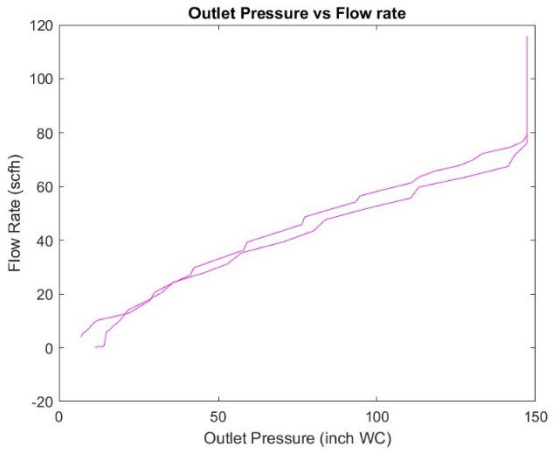
GTI ENERGY

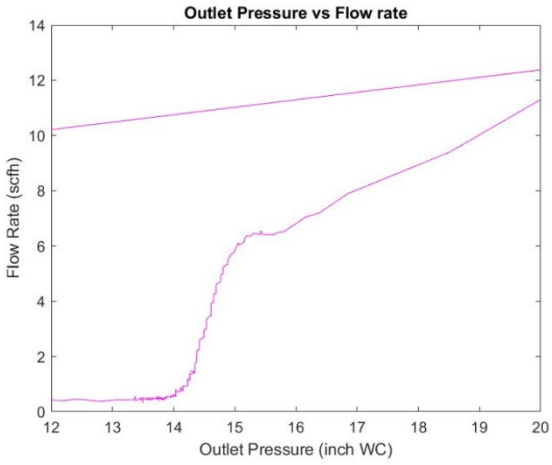
- 222489-037_LD
  The volume of total emissions in 195.37 seconds is 0.7975 scf.
  The average flow rate of emissions at 18 inches WC is 9.39 scfh.





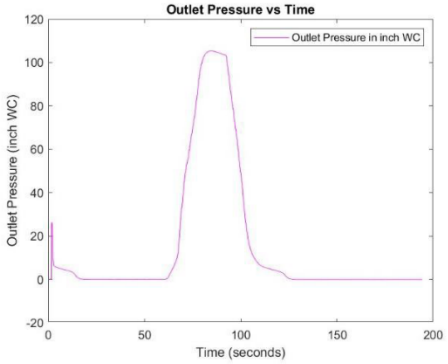
GTI ENERGY

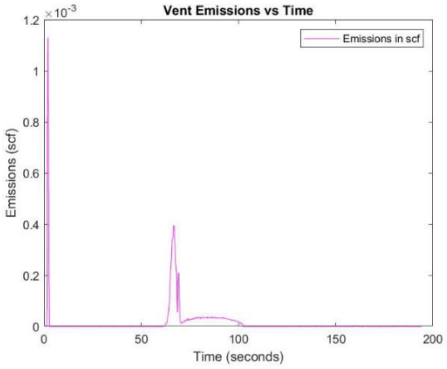

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
120
100
80
60
40
20
0
-20
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
14
12
10
8
6
4
2
0
12
13
14
15
16
17
18
19
20

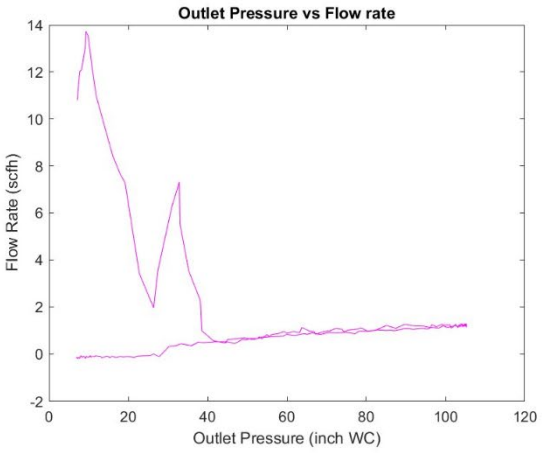
GTI ENERGY

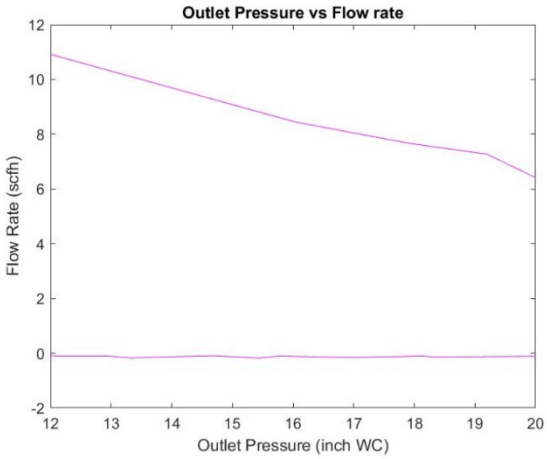
- 222489-038
  The volume of total emissions in 194.35 seconds is 0.0295 scf.
  The average flow rate of emissions at 18 inches WC is 2.47 scfh.



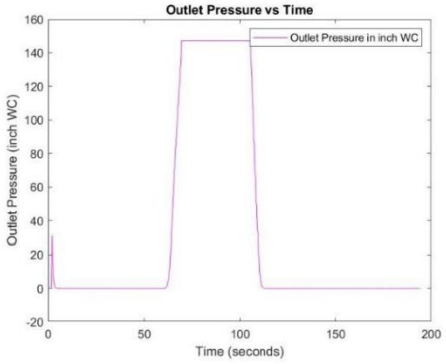


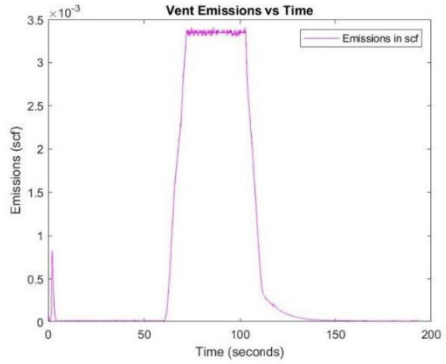
GTI ENERGY


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
14
12
10
8
6
4
2
0
-2
0
20
40
60
80
100
120

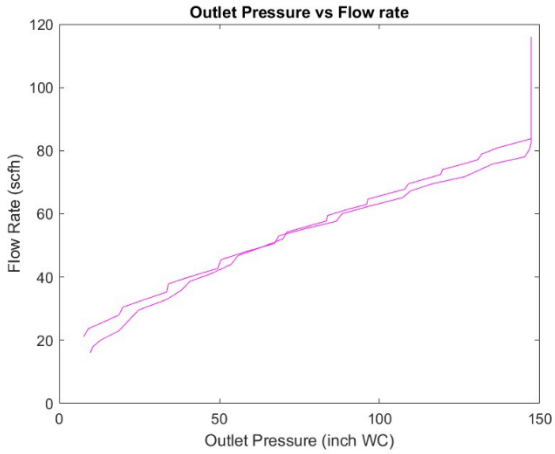

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
12
10
8
6
4
2
0
-2
12
13
14
15
16
17
18
19
20

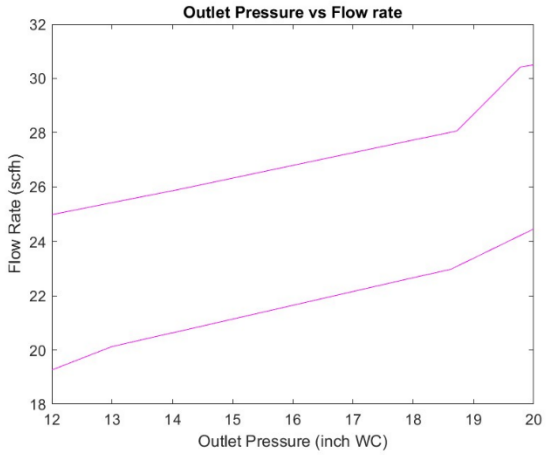
- 222489-038_DT
  The volume of total emissions in 194.35 seconds is 1.3648 scf.
  The average flow rate of emissions at 18 inches WC is 25.52 scfh.





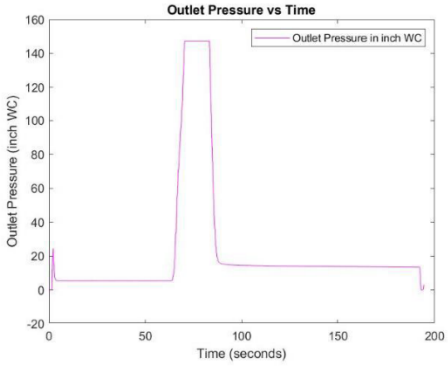
GTI ENERGY

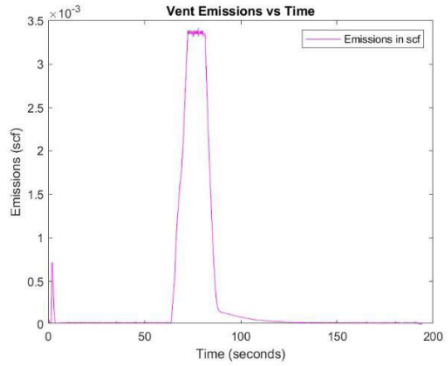

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
20
40
60
80
100
120
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
18
20
22
24
26
28
30
32
12
13
14
15
16
17
18
19
20

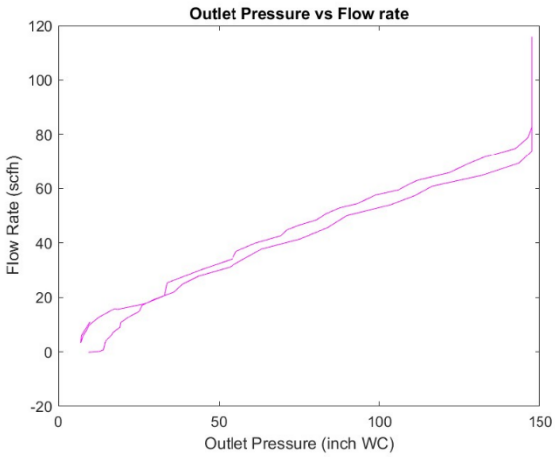
GTI ENERGY

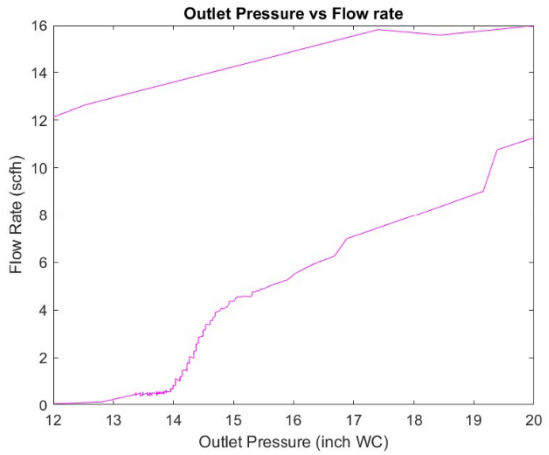
- 222489-038_LD
  The volume of total emissions in 194.43 seconds is 0.5586 scf.
  The average flow rate of emissions at 18 inches WC is 14.90 scfh.





GTI ENERGY

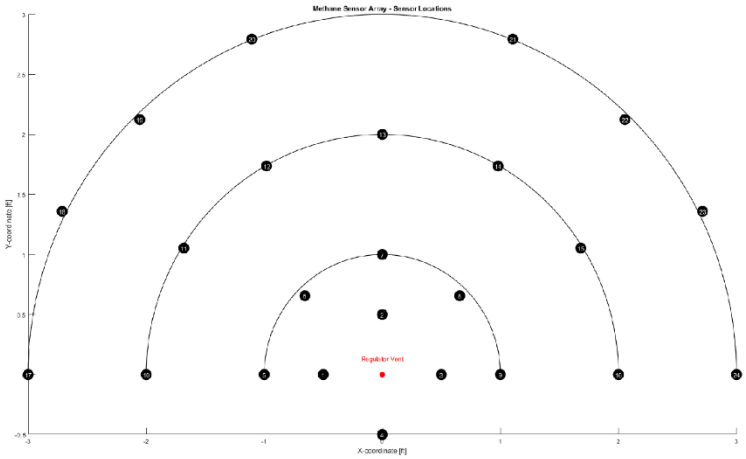

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
120
100
80
60
40
20
0
-20
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
16
14
12
10
8
6
4
2
0
12
13
14
15
16
17
18
19
20

GTI ENERGY

Methane Concentration Maps

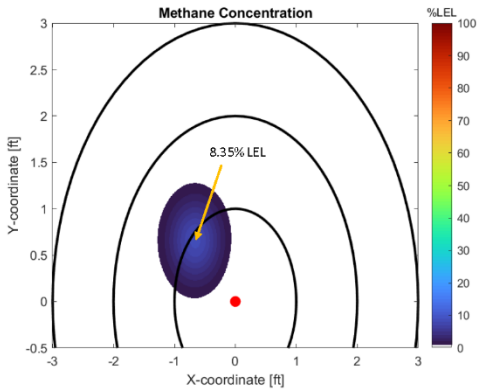
Sensor Locations



GTI ENERGY

7" WC Outlet

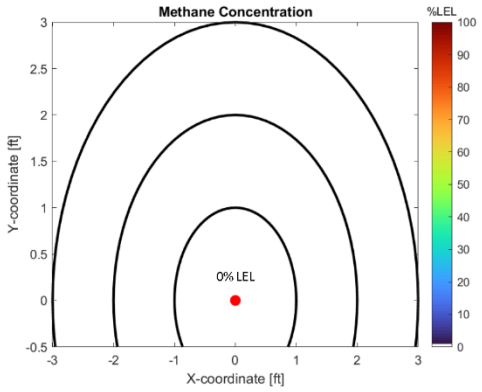
	7 In-WC	222489-037_multi lockup	Sigma = .3
VL3	Normal Condition – Multi Lockup	Standard Array Configuration	6 in from vent



	7 In-WC	222489-037_multi lockup_trial2	Sigma = .3

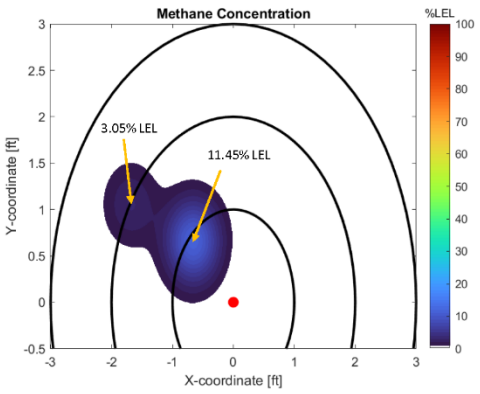
GTI ENERGY

VL3	Normal Condition – Multi Lockup	Standard Array Configuration	6 in from vent

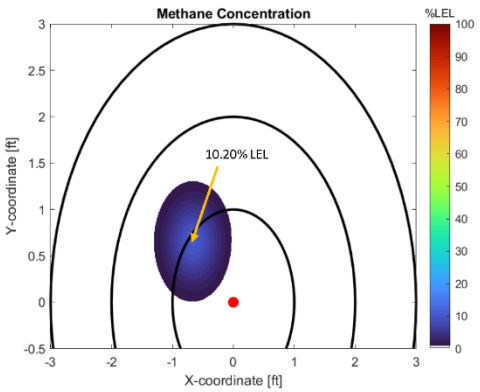


GTI ENERGY

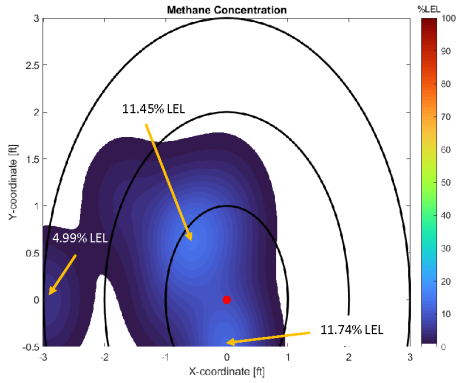
	7 In-WC	222489-037_single lockup	Sigma = .3
VL3	Normal Condition – Single Lockup	Standard Array Configuration	6 in from vent



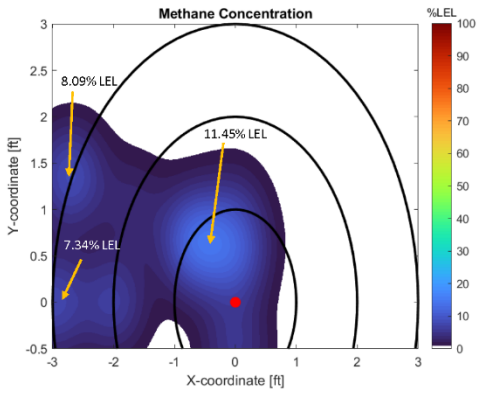
	7 In-WC	222489-037_single lockup_trial2	Sigma = .3
VL3	Normal Condition – Single Lockup	Standard Array Configuration	6 in from vent



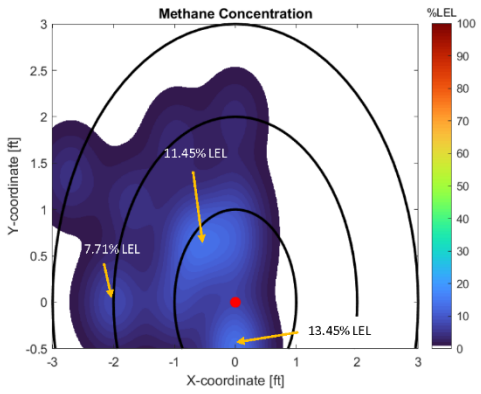
	7 In-WC	222489-037_LD_1	Sigma = .43
VL3	Lever Disconnect	Standard Array Configuration	6 in from vent



	7 In-WC	222489-037_LD_2	Sigma = .385
VL3	Lever Disconnect	Standard Array Configuration	6 in from vent

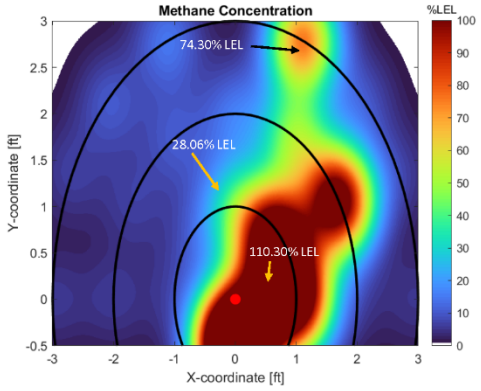


	7 In-WC	222489-037_LD_3	Sigma = .345
VL3	Lever Disconnect	Standard Array Configuration	6 in from vent

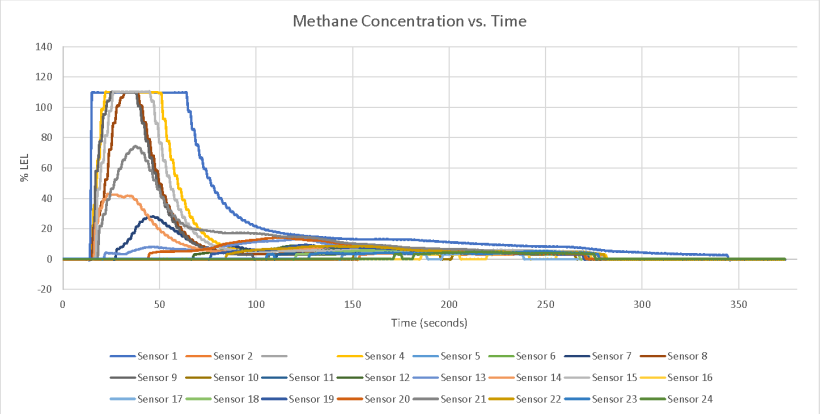


GTI ENERGY

	7 In-WC	222489-038_DT_1	Sigma = .4
VL3	Diaphragm Tear	Standard Array Configuration	6 in from vent

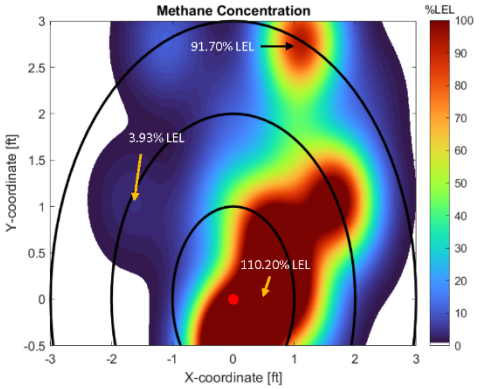


GTI ENERGY

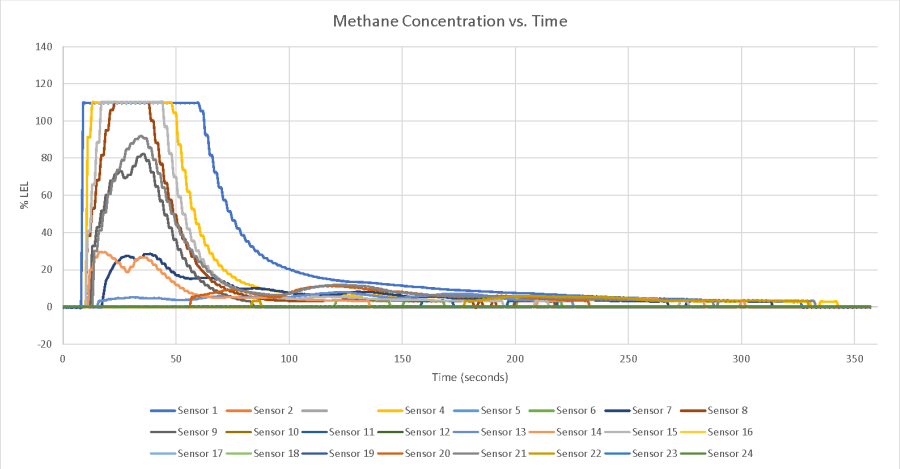

Methane Concentration vs. Time
% LEL
140
120
100
80
60
40
20
0
-20
0
50
100
150
200
250
300
350
Time (seconds)
Sensor 1
Sensor 2
Sensor 4
Sensor 5
Sensor 6
Sensor 7
Sensor 8
Sensor 9
Sensor 10
Sensor 11
Sensor 12
Sensor 13
Sensor 14
Sensor 15
Sensor 16
Sensor 17
Sensor 18
Sensor 19
Sensor 20
Sensor 21
Sensor 22
Sensor 23
Sensor 24

GTI ENERGY

	7 In-WC	222489-038_DT_2	Sigma = .42
VL3	Diaphragm Tear	Standard Array Configuration	6 in from vent

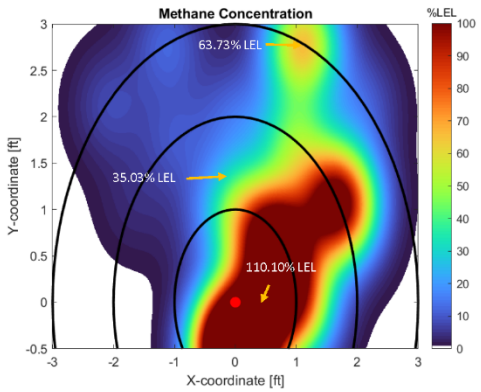


GTI ENERGY


Methane Concentration vs. Time
% LEL
Time (seconds)
Sensor 1
Sensor 2
Sensor 4
Sensor 5
Sensor 6
Sensor 7
Sensor 8
Sensor 9
Sensor 10
Sensor 11
Sensor 12
Sensor 13
Sensor 14
Sensor 15
Sensor 16
Sensor 17
Sensor 18
Sensor 19
Sensor 20
Sensor 21
Sensor 22
Sensor 23
Sensor 24

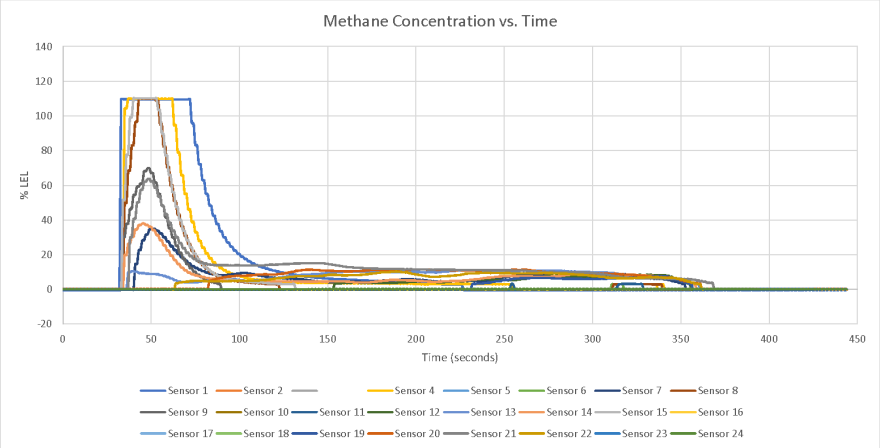
GTI ENERGY

	7 In-WC	222489-038_DT_3	Sigma = .42
VL3	Diaphragm Tear	Standard Array Configuration	6 in from vent



Commented [JW1]: Redo this one and pick a spot in the middle instead of two on the outer edge

GTI ENERGY


Methane Concentration vs. Time
% LEL
Time (seconds)
Sensor 1
Sensor 2
Sensor 4
Sensor 5
Sensor 6
Sensor 7
Sensor 8
Sensor 9
Sensor 10
Sensor 11
Sensor 12
Sensor 13
Sensor 14
Sensor 15
Sensor 16
Sensor 17
Sensor 18
Sensor 19
Sensor 20
Sensor 21
Sensor 22
Sensor 23
Sensor 24

GTI ENERGY

Appendix D – VL4 & VL5 Manufacturer Test Data

GTI ENERGY
solutions that transform

REPORT
GTI ENERGY PROJECT NUMBER 23059

Comparison of Compact Service Regulators – Results of Testing

VL4 & VL5 Summary

GTI Energy Technical Contact:
Joe Carlstrom
Joseph Irwin, PE
Tom Bates
Jake Witecha

1700 S. Mount Prospect Rd.
Des Plaines, Illinois 60018
www.gti.energy

Introduction

This report was created to review data obtained during PHMSA project 693JK32110001 and OTD project 5.22.j - Design and Placement of Compact Service Regulators with subject matter experts from the manufacturer. The following Part 1 and Part 2 matrix outlines the test methodology used to obtain data for analysis purposes for safe clearance distances.

Part 1 Test methodology

All testing was performed on the rig with air and software formula coefficients for natural gas.

Test	Standard/Procedure reference	Conditions	Test Criteria	Parameters
Modified Lock-Up Test	ANSI B109.4 -[5.3.5]	Temperature: Ambient; Inlet pressure: 10, 60, 100 psig; Flow: 100, 200, 300, until maximum manufacturer specifications [SCFH Air]	Outlet pressure Max 9"±0.5 iwc 2.15±0.15 psig (2psig reg.)	Lock up [iwc]
			Flow rate at vent 2.5 SCFH (vent limited) 100 SCFH (IRV)	Vent flow rate [SCFH]
Modified Relief Point Test	ANSI B109.4 -[5.3.8]	Temperature: Ambient; Inlet pressure: 10, 60, 100 psig; Outlet pressure: slowly increase until slam shut closes or maximum allowable pressure reached	Outlet pressure MAX 17"±0.5 iwc; 3.3±0.15iwc psig (2psig reg.)	Relief point [iwc]
			Flow rate at vent 2.5 SCFH (vent limited) 100 SCFH (IRV)	Vent flow rate [SCFH]

*2-psig VL5 models removed from modified relief point tests, tests to be redone.

GTI ENERGY

Part 2 Test Methodology

Testing was performed in an enclosed and controlled environment with natural gas. Safety rules were implemented to monitor and limit the amounts of natural gas. When an accumulation of natural gas greater than 100% LEL was detected by multiple sensors the natural gas source was terminated and the test concluded.

Single Lock-Up Test	ANSI B109.4 - [5.3.5]	**Temperature**: Ambient; **Inlet pressure**: 60 psig; **Flow Rate**: 390 SCFH (7 iwc reg.) 1260 SCFH (2 psig reg.) **Lockup condition**: One lock up induced, wait 30 seconds for gas concentration dissipate to 0% LEL, repeat 10 times.	Outlet pressure Max 9"±0.5 iwc (7 iwc reg.) 2.15±0.15 psig (2psig reg.)	Lock up pressure [iwc]
			Methane concentration at vent 0%LEL (vent limited) 3%LEL (IRV)	Methane Concentration [% LEL]
Multi Lock-Up Test	ANSI B109.4 - [5.3.5]	**Temperature**: Ambient; **Inlet pressure**: 60 psig; **Flow Rate**: 390 SCFH (7 iwc reg.) 1260 SCFH (2 psig reg.) **Lockup condition**: Two lock ups induced in quick succession, wait 30 seconds for gas concentration dissipate to 0%LEL, repeat 3 times, after 3 repetitions increase the number of lockups by 1 to a maximum of 4.	Outlet pressure Max 9"±0.5 iwc (7 inW/C reg.) 2.15±0.15 psig (2psig reg.)	Lock up pressure [inW/C]
			Methane concentration at vent 0%LEL (vent limited) 3%LEL (IRV)	Methane Concentration [% LEL]

Commented [JW1]: Part 2 failure modes were done differently than outlined in the test matrix. Upstream valve was opened for a small amount of time (10 seconds) then closed to prevent high gas concentration build up. Not quite sure how to word this better

Commented [JC2R1]: On Monday we can work on the language.

Summary

Modified Lockup Tests

Average Emission Rate [SCFH], Normal Conditions, 7" WC

Model	10-psig inlet	60-psig inlet	100-psig inlet
VL4	0.0912	0.0850	0.0720
VL5	0.0446	0.0437	0.0413

*Under abnormal conditions, OPSO was triggered

Average Emission Rate [SCFH], Normal Conditions, 2-psig

Model	10-psig inlet	60-psig inlet	100-psig inlet
VL4	0.2058	0.1242	0.1254
VL5	0.0746	0.0495	0.0432

*Under abnormal conditions, OPSO was triggered

Relief Tests

Average Emission Rate [SCFH], Normal Conditions, 7" WC

Model	10-psig inlet	60-psig inlet	100-psig inlet
VL4	7.7700	8.4633	7.6200
VL5	6.4967	6.1300	5.7733

Average Emission Rate [SCFH], Primary Diaphragm Tear, 7" WC

Commented [JW3]: Need to separate averages of primary diaphragm tear (DT1) from primary and secondary diaphragm tear (DT2)

Model	10-psig inlet	60-psig inlet	100-psig inlet
VL4	11.5633	11.4950	10.8833
VL5	13.5567	13.3600	13.2567

Average Emission Rate [SCFH], Primary and Secondary Diaphragm Tear, 7" WC

Model	10-psig inlet	60-psig inlet	100-psig inlet
VL4	NA*	25.2900	21.5967
VL5	9.6700	11.2800	8.9500

*Flow rate exceeded flow meter range

Average Emission Rate [SCFH], Lever Disconnect, 7" WC

Model	10-psig inlet	60-psig inlet	100-psig inlet
VL4	0.000	0.000	0.000
VL5	10.2400	10.1433	10.4967

Average Emission Rate [SCFH], Normal Conditions, 2-psig

Model	10-psig inlet	60-psig inlet	100-psig inlet
VL4	0.2100	11.2650	11.1367
VL5	12.6400	12.6333	12.4867

Average Emission Rate [SCFH], Primary Diaphragm Tear, 2-psig

Commented [JW4]: Need to separate averages of primary diaphragm tear (DT1) from primary and secondary diaphragm tear (DT2)

Model	10-psig inlet	60-psig inlet	100-psig inlet
VL4	23.6267	22.5067	24.7433
VL5	8.4700	4.4833	8.5700

Average Emission Rate [SCFH], Primary and Secondary Diaphragm Tear, 2-psig

Model	10-psig inlet	60-psig inlet	100-psig inlet
VL4	N/A*	N/A*	N/A*
VL5	N/A*	N/A*	N/A*

*Flow rate exceeded flow meter range

Average Emission Rate [SCFH], Lever Disconnect, 2-psig

Model	10-psig inlet	60-psig inlet	100-psig inlet
VL4	0.0333	0.2750	0.1500
VL5	11.9507	18.5400	18.3133

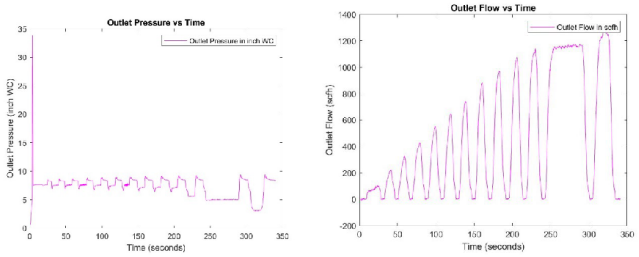
GTI ENERGY

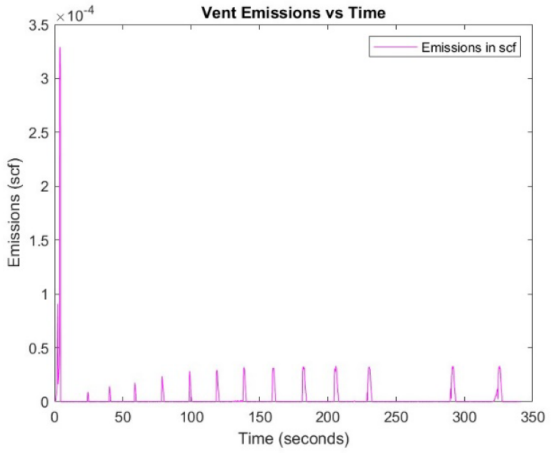
VL4

Modified Lockup Tests

7" WC Outlet, 10-psig Inlet

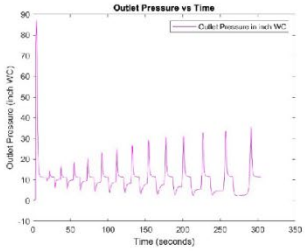
- 222489-007
  The volume of total emissions in 341.00 seconds is 0.0086 scf.
  The flow rate of emissions is 0.0908 scfh.

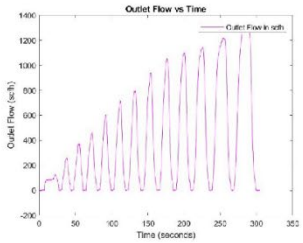


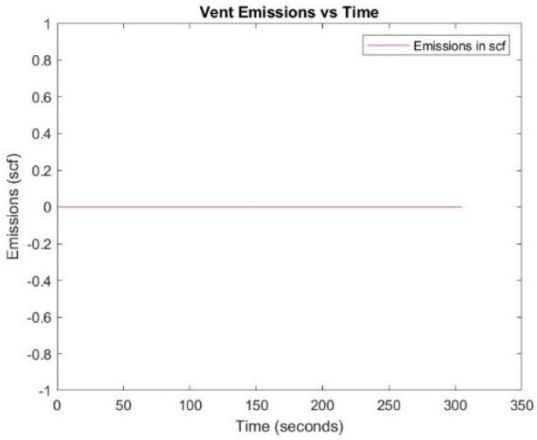


- 222489-007-BV

The volume of total emissions in 304.92 seconds is 0.0000 scf.
The flow rate of emissions is 0.0000 scfh.







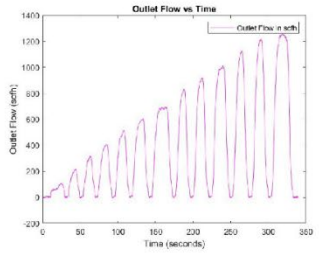
GTI ENERGY

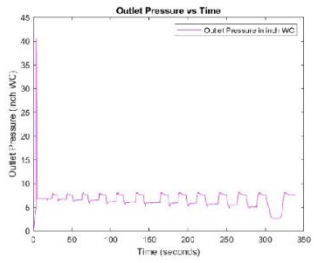
- 222489-008

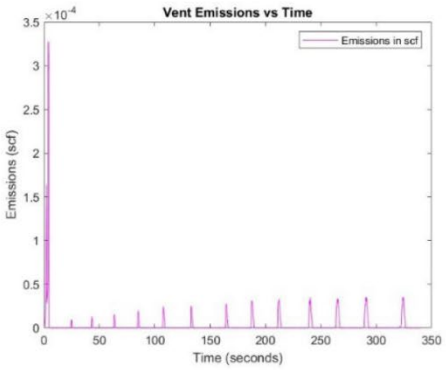
  VL4_22489-008_08_11_2022_09_23_15_1

The volume of total emissions in 339.74 seconds is 0.0088 scf.

The flow rate of emissions is 0.0930 scfh.



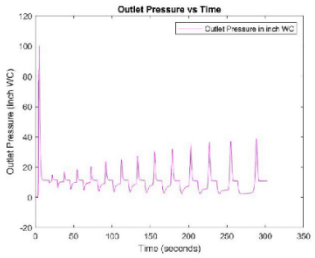


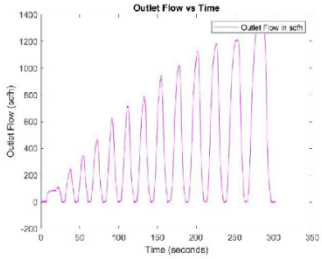


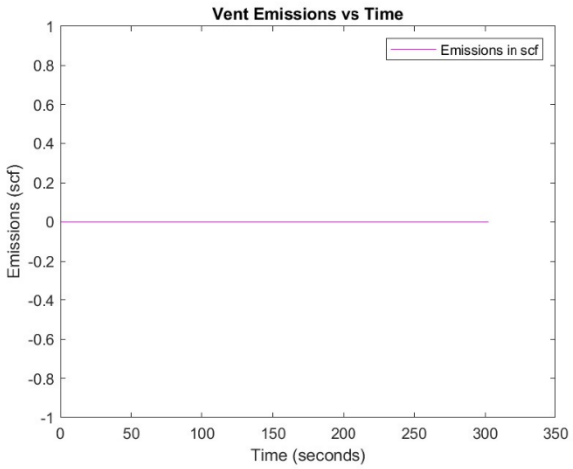
GTI ENERGY

- 222489-008-BV

The volume of total emissions in 302.31 seconds is 0.0000 scf.
The flow rate of emissions is 0.0000 scfh.

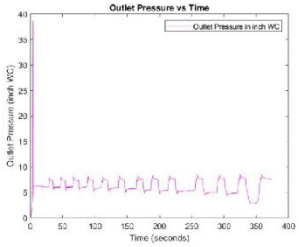


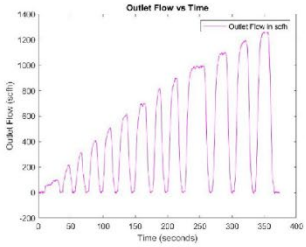


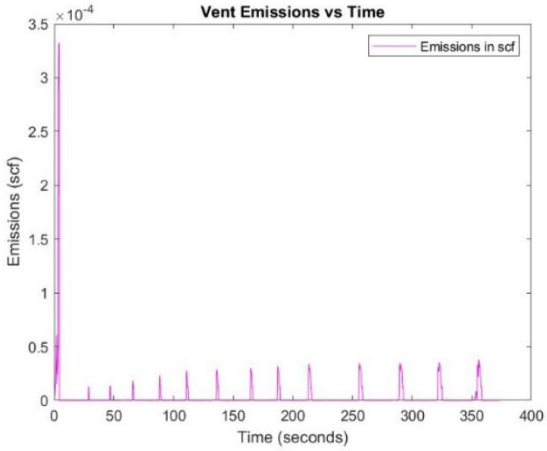


GTI ENERGY

- 222489-009
  The volume of total emissions in 373.38 seconds is 0.0093 scf.
  The flow rate of emissions is 0.0897 scfh.

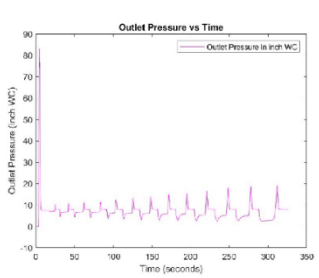


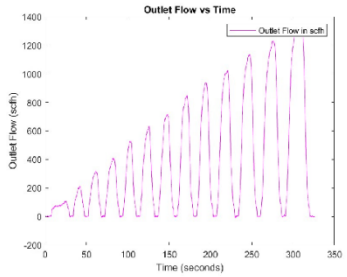


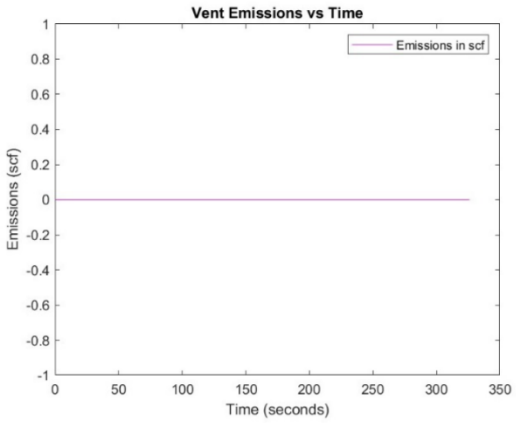


GTI ENERGY

- 222489-009-BV
  The volume of total emissions in 326.09 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.



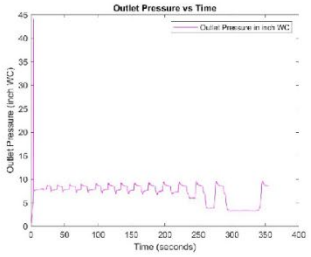


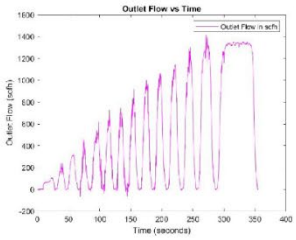


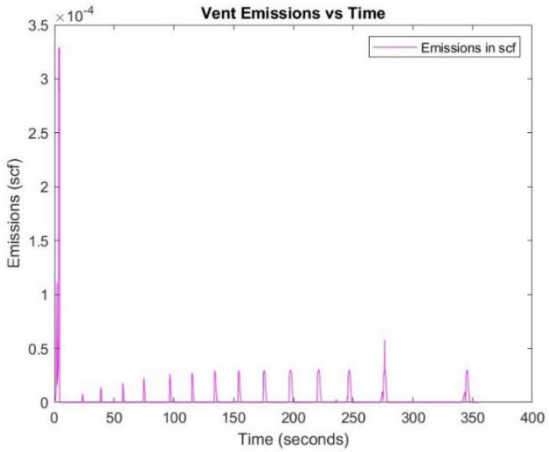
GTI ENERGY

7″ WC Outlet, 60-psig Inlet

- 222489-007
  The volume of total emissions in 355.19 seconds is 0.0090 scf.
  The flow rate of emissions is 0.0912 scfh.

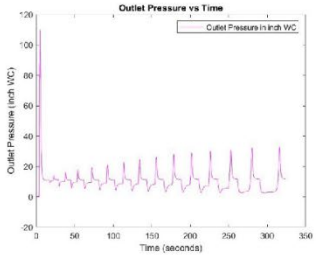


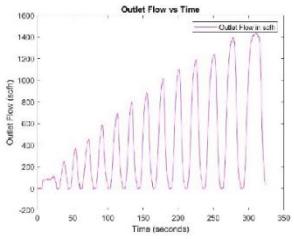


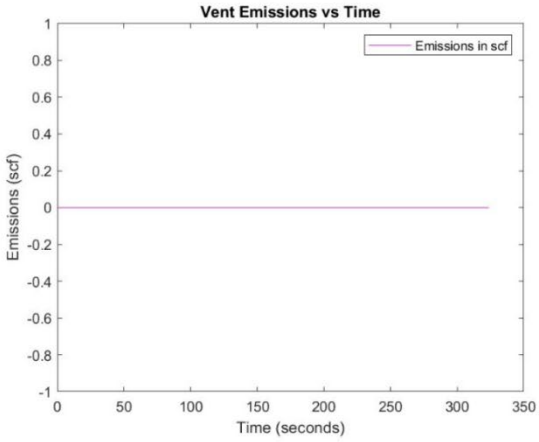


GTI ENERGY

- 222489-007-BV
  The volume of total emissions in 323.77 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.

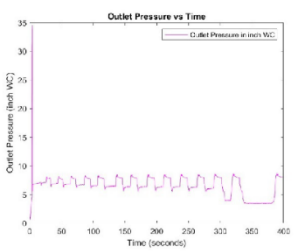


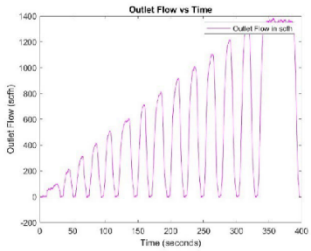


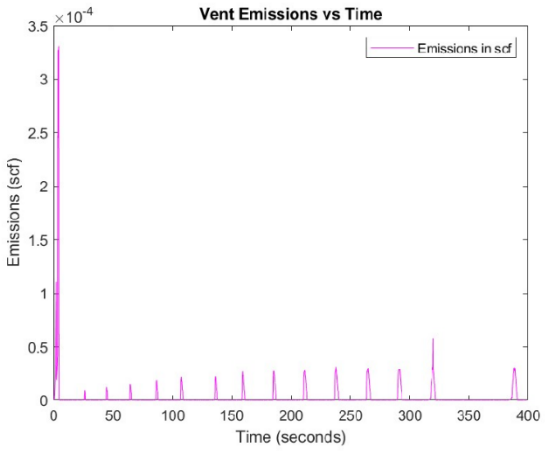


GTI ENERGY

- 222489-008
  The volume of total emissions in 398.90 seconds is 0.0088 scf.
  The flow rate of emissions is 0.0796 scfh.

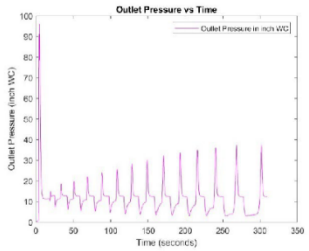


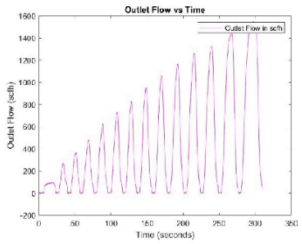


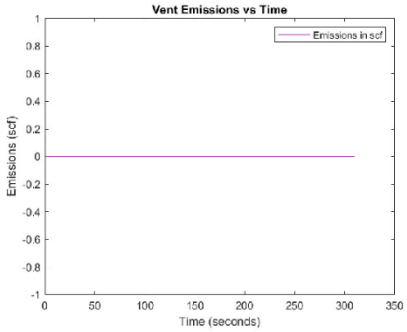


GTI ENERGY

- 222489-008-BV
  The volume of total emissions in 309.75 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.

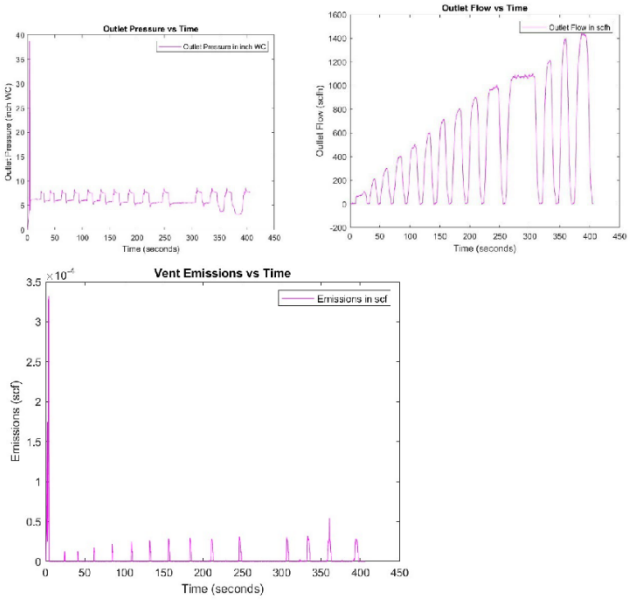






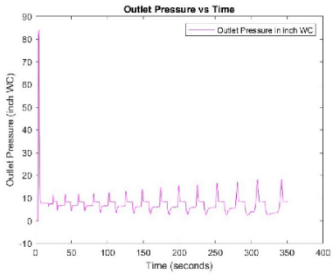
GTI ENERGY

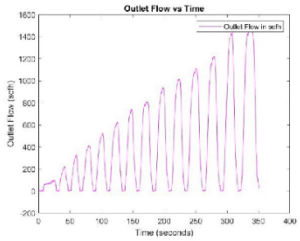
- 222489-009
  The volume of total emissions in 405.95 seconds is 0.0095 scf.
  The flow rate of emissions is 0.0841 scfh.

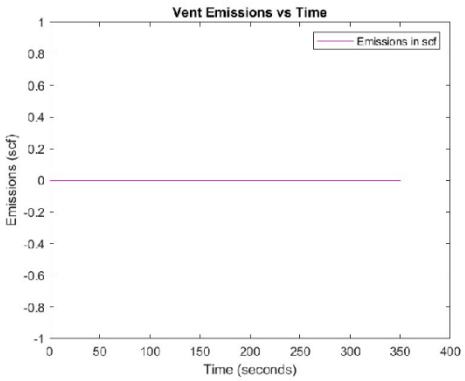


GTI ENERGY

- 222489-009-BV
  The volume of total emissions in 350.58 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.



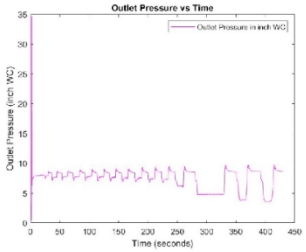


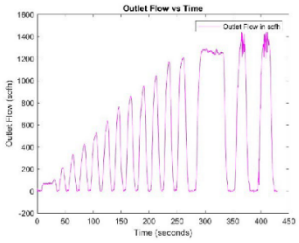


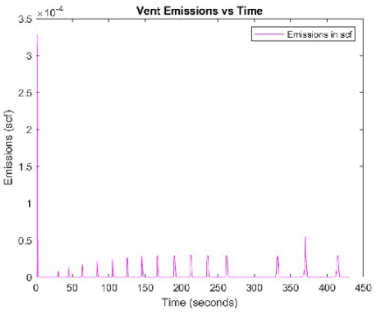
GTI ENERGY

7" WC Outlet, 100-psig Inlet

- 222489-007
  The volume of total emissions in 430.20 seconds is 0.0086 scf.
  The flow rate of emissions is 0.0717 scfh.

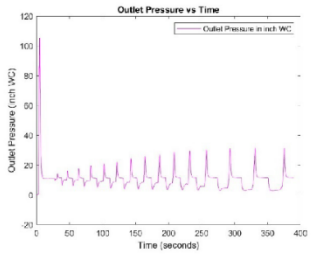


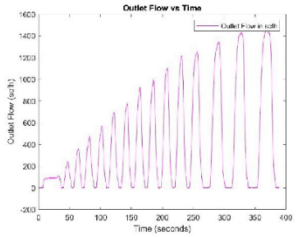


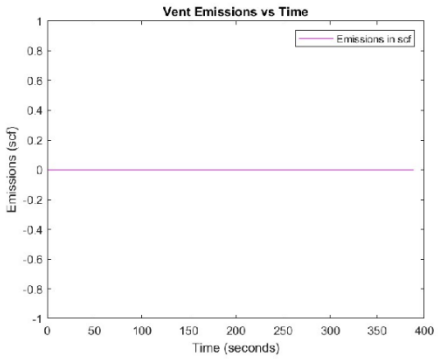


GTI ENERGY

- 222489-007-BV
  The volume of total emissions in 389.12 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.

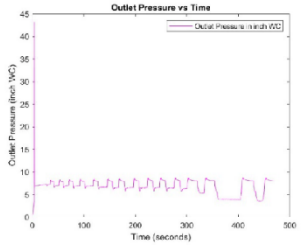


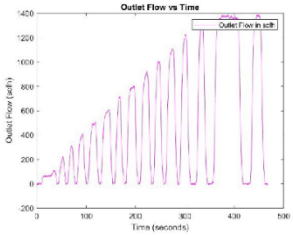


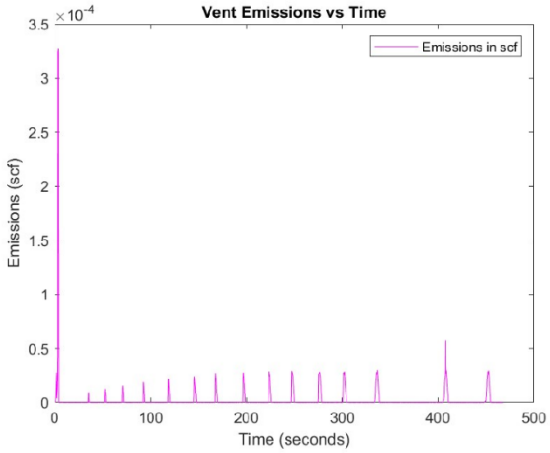


GTI ENERGY

- 222489-008
  The volume of total emissions in 468.10 seconds is 0.0089 scf.
  The flow rate of emissions is 0.0687 scfh.

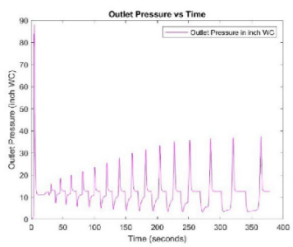


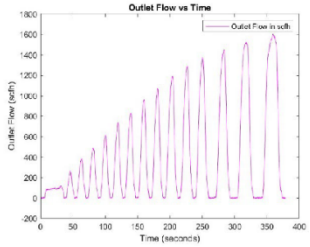


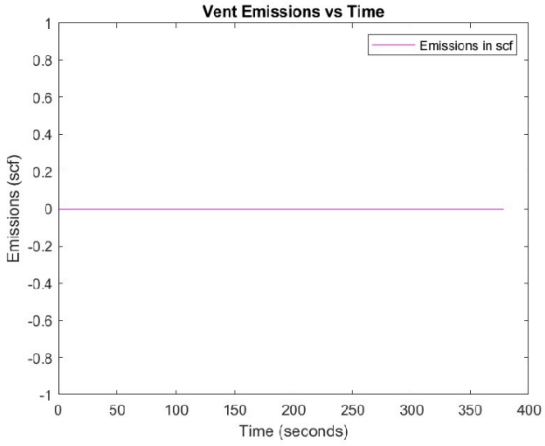


GTI ENERGY

- 222489-008-BV
  The volume of total emissions in 378.70 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.

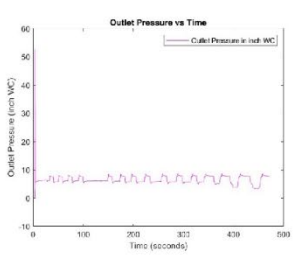


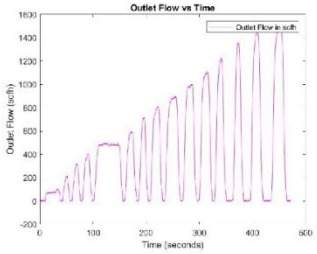


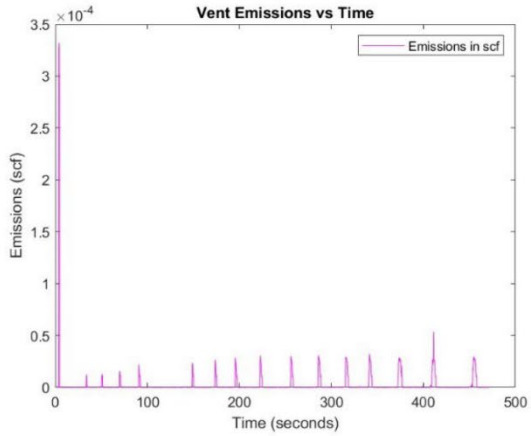


GTI ENERGY

- 222489-009
  The volume of total emissions in 471.28 seconds is 0.0099 scf.
  The flow rate of emissions is 0.0757 scfh.

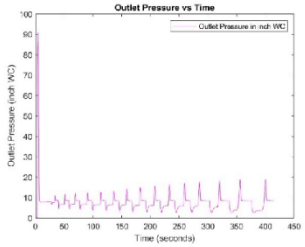


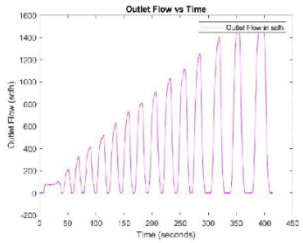


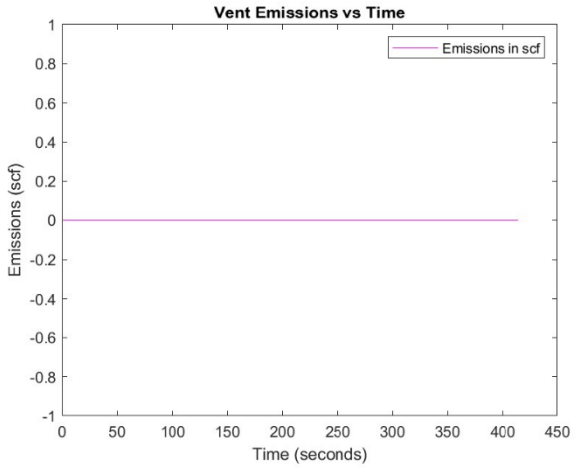


GTI ENERGY

- 222489-009-BV
  The volume of total emissions in 414.57 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.



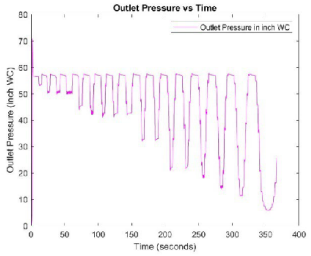


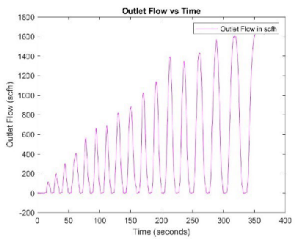


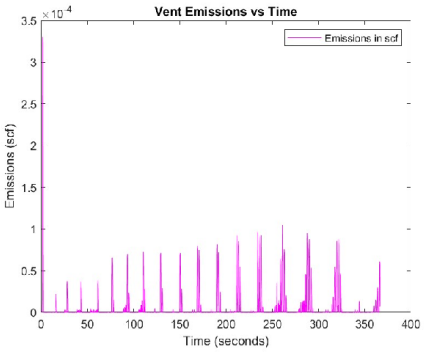
GTI ENERGY

2-psig Outlet, 10-psig Inlet

- 22489-010
  The volume of total emissions in 366.56 seconds is 0.0188 scf.
  The flow rate of emissions is 0.1851 scfh.

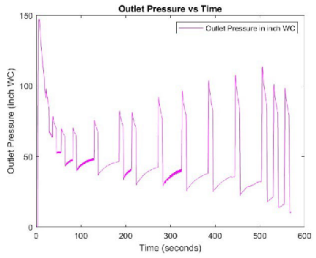


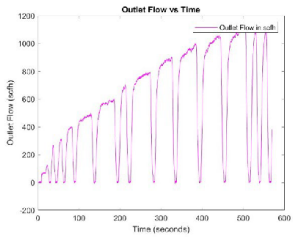


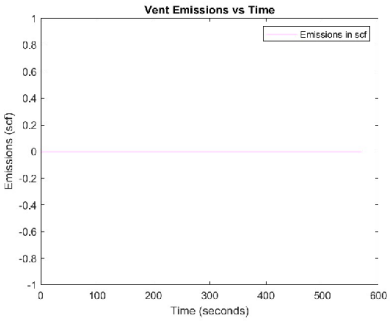


GTI ENERGY

- 22489-010_BV
  The volume of total emissions in 570.19 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.

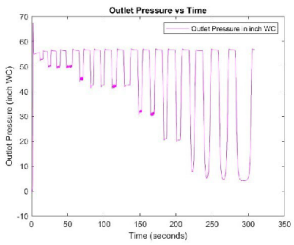


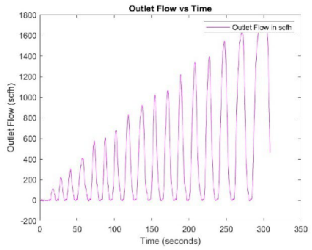


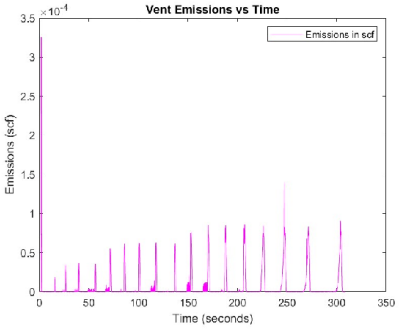


GTI ENERGY

- 22489-011
  The volume of total emissions in 308.75 seconds is 0.0186 scf.
  The flow rate of emissions is 0.2174 scfh.

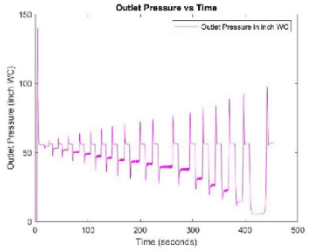


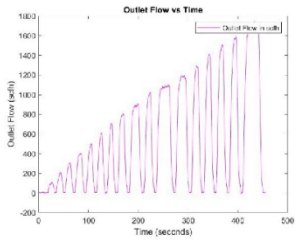


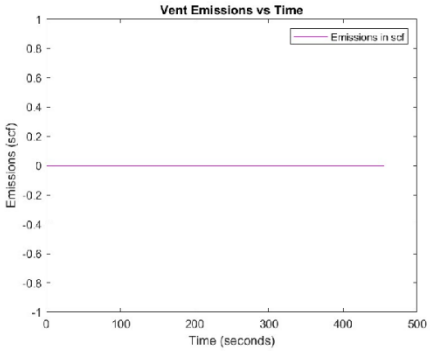


GTI ENERGY

- 22489-011_BV
  The volume of total emissions in 455.54 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.

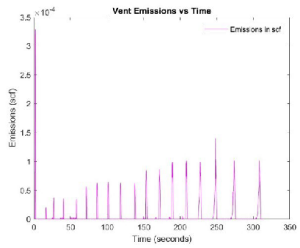


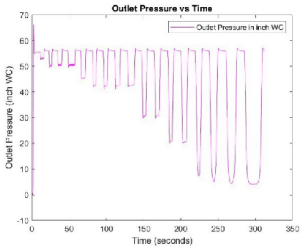


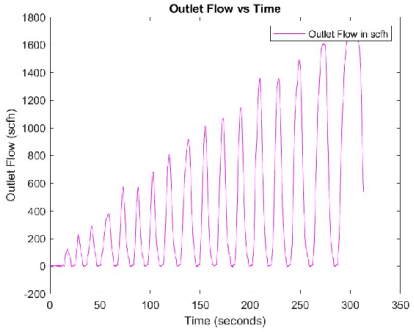


GTI ENERGY

- 22489-012
  The volume of total emissions in 313.17 seconds is 0.0187 scf.
  The flow rate of emissions is 0.2150 scfh.

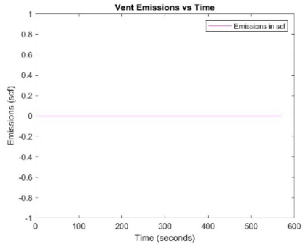


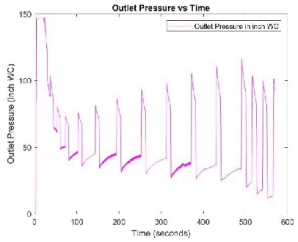


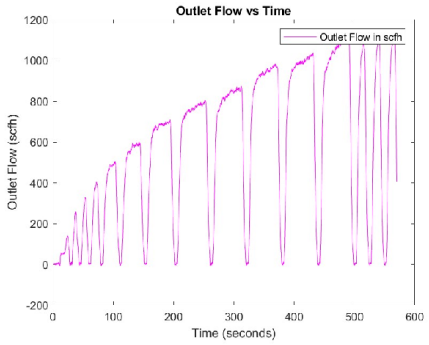


GTI ENERGY

- 22489-012_BV
  The volume of total emissions in 570.42 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.



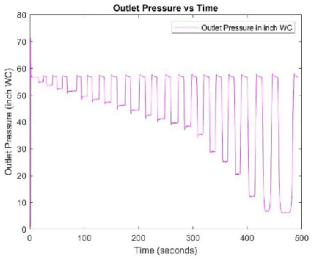


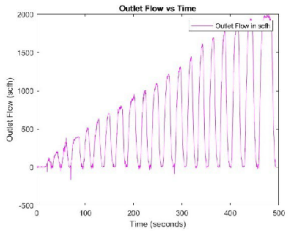


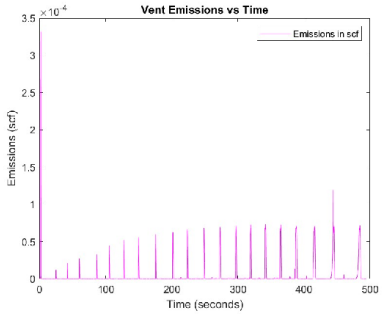
GTI ENERGY

2-psig Outlet, 60-psig Inlet

- 22489-010
  The volume of total emissions in 493.92 seconds is 0.0185 scf.
  The flow rate of emissions is 0.1351 scfh.

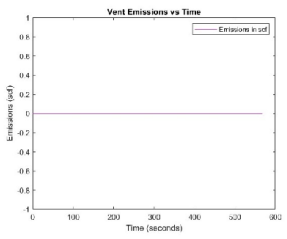


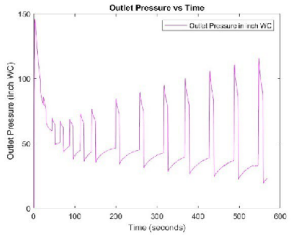


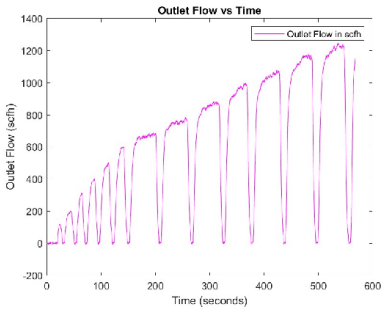


GTI ENERGY

- 22489-010_BV
  The volume of total emissions in 568.29 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.

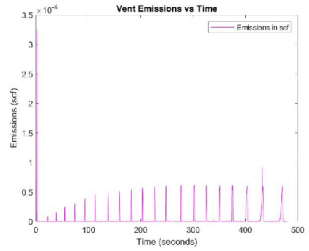


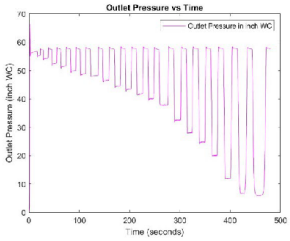


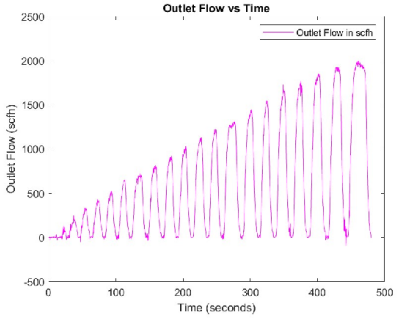


GTI ENERGY

- 22489-011
  The volume of total emissions in 479.97 seconds is 0.0158 scf.
  The flow rate of emissions is 0.1185 scfh.

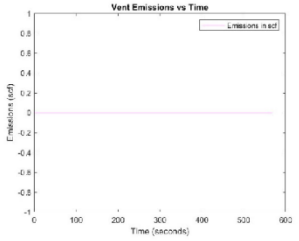


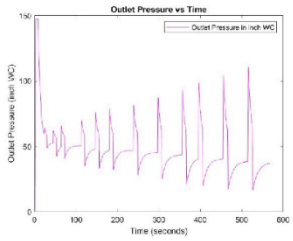


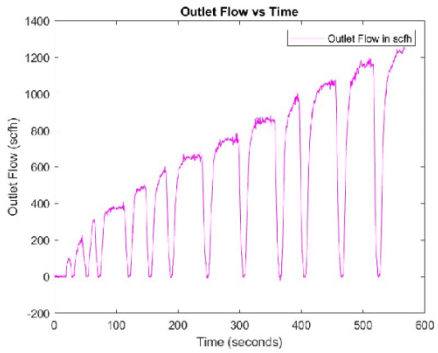


GTI ENERGY

- 22489-011_BV
  The volume of total emissions in 567.65 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.

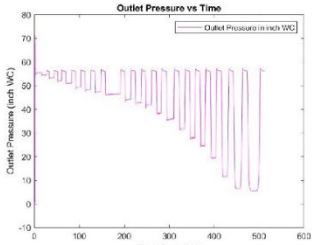


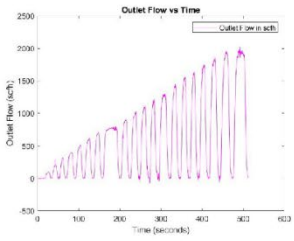


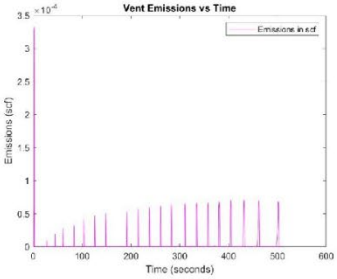


GTI ENERGY

- 22489-012
  The volume of total emissions in 511.79 seconds is 0.0169 scf.
  The flow rate of emissions is 0.1190 scfh.

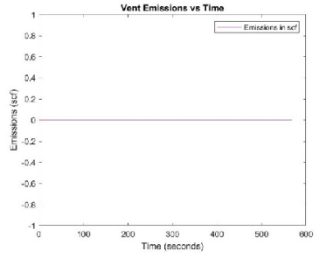


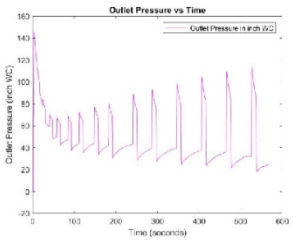


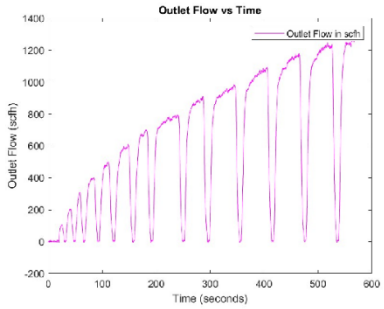


GTI ENERGY

- 22489-012_BV
  The volume of total emissions in 568.01 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.



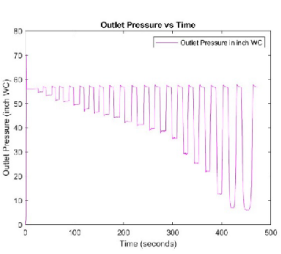


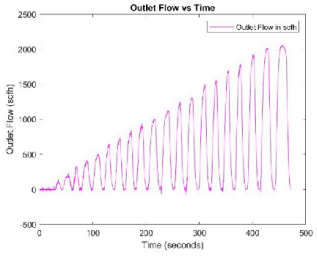


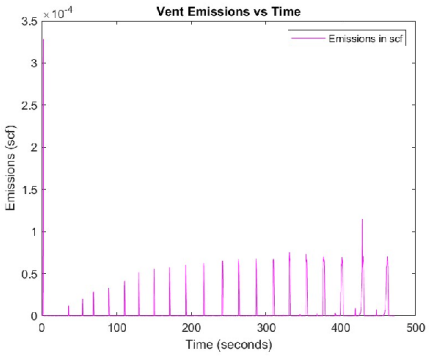
GTI ENERGY

2-psig Outlet, 100-psig Inlet

- 22489-010
  The volume of total emissions in 471.93 seconds is 0.0180 scf.
  The flow rate of emissions is 0.1376 scfh.

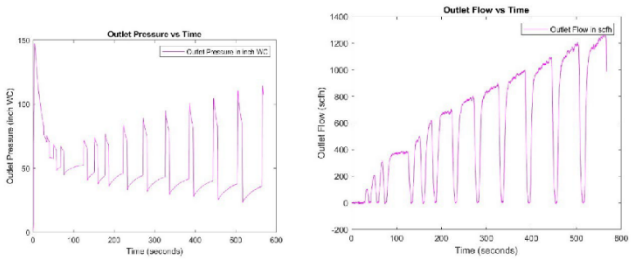


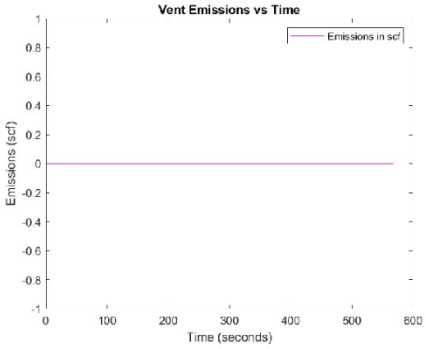




GTI ENERGY

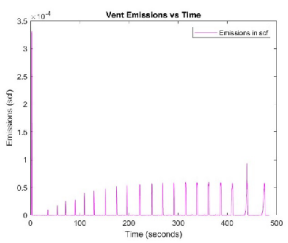
- 22489-010_BV
  The volume of total emissions in 568.02 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.

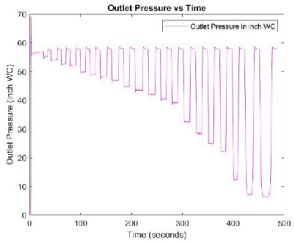


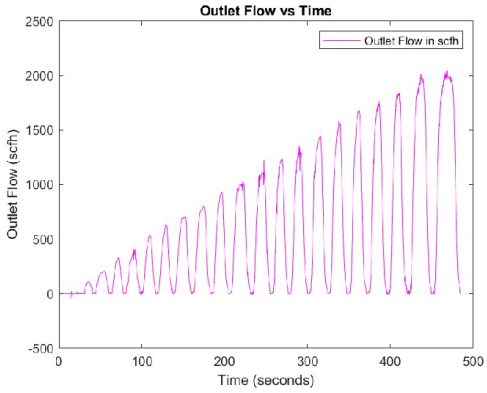


GTI ENERGY

- 22489-011
  The volume of total emissions in 484.98 seconds is 0.0155 scf.
  The flow rate of emissions is 0.1153 scfh.

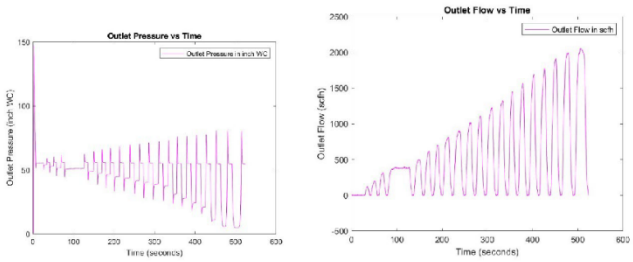


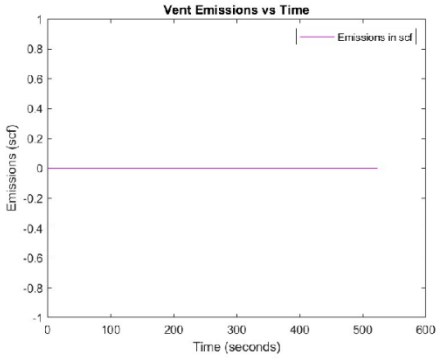




GTI ENERGY

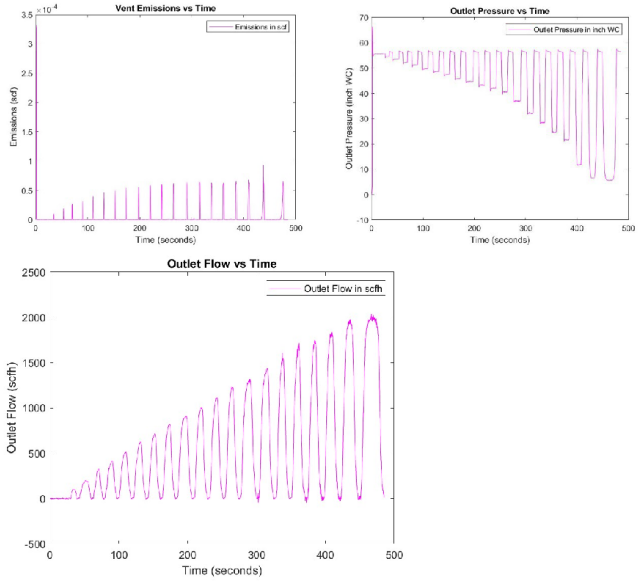
- 22489-011_BV
  The volume of total emissions in 523.88 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.





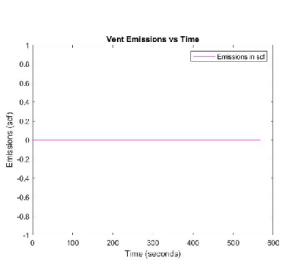
GTI ENERGY

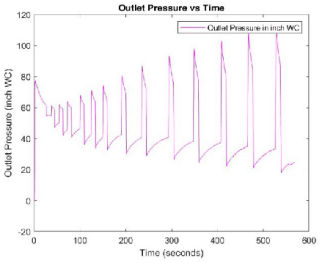
- 22489-012
  The volume of total emissions in 485.43 seconds is 0.0166 scf.
  The flow rate of emissions is 0.1232 scfh.

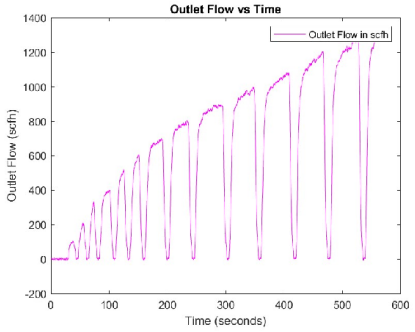


GTI ENERGY

- 22489-012_BV
  The volume of total emissions in 568.08 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.





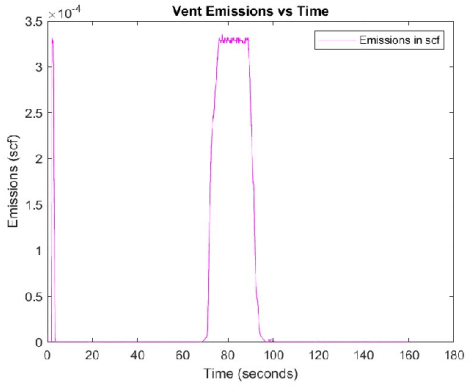


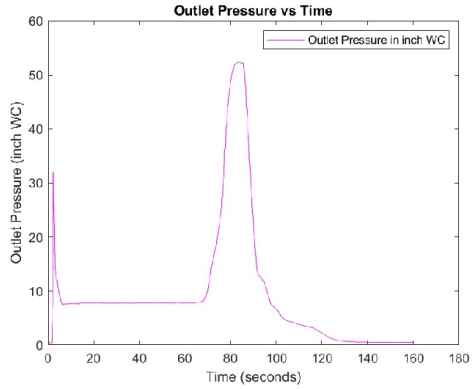
GTI ENERGY

Relief Tests

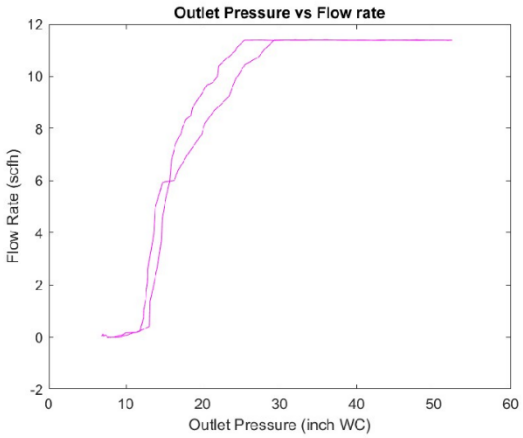
7" WC Outlet, 10-psig Inlet

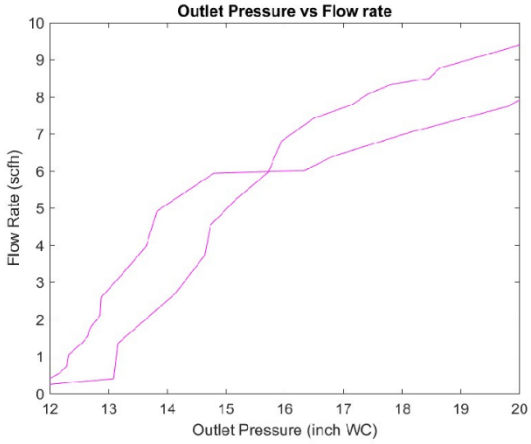
- **222489-007_2**
  The volume of total emissions in 160.24 seconds is 0.0629 scf.
  The average flow rate of emissions at 18 inches WC is 7.05 scfh.





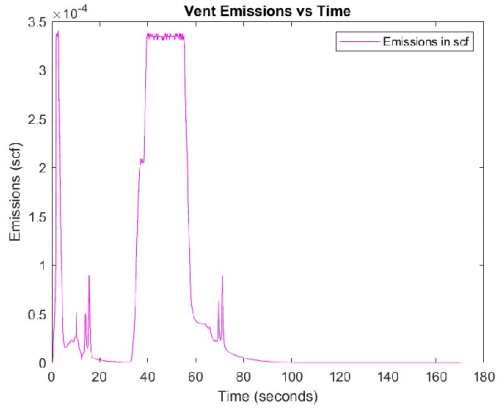
GTI ENERGY

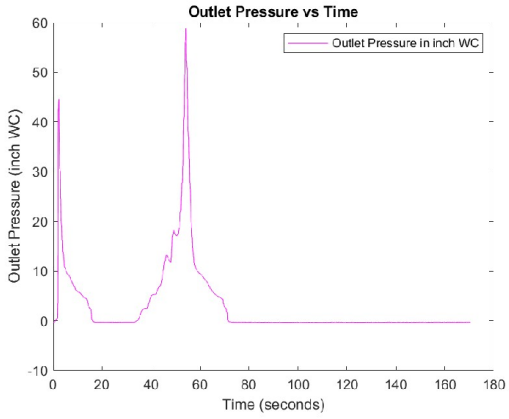

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
12
10
8
6
4
2
0
-2
0
10
20
30
40
50
60


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
10
9
8
7
6
5
4
3
2
1
0
12
13
14
15
16
17
18
19
20

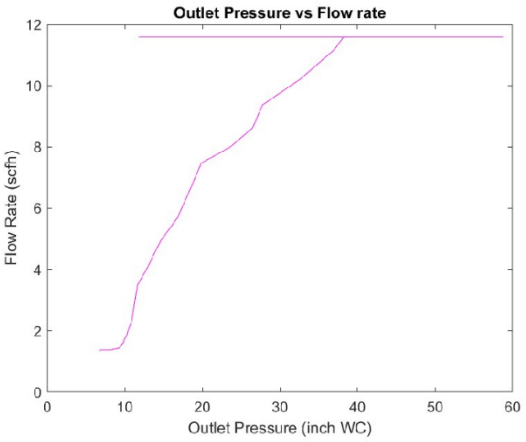
GTI ENERGY

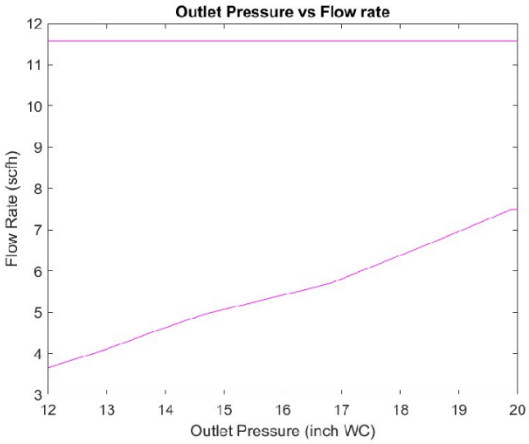
- **222489-007_DT1**
  The volume of total emissions in 170.32 seconds is 0.0807 scf.
  The average flow rate of emissions at 18 inches WC is 11.58 scfh.





GTI ENERGY

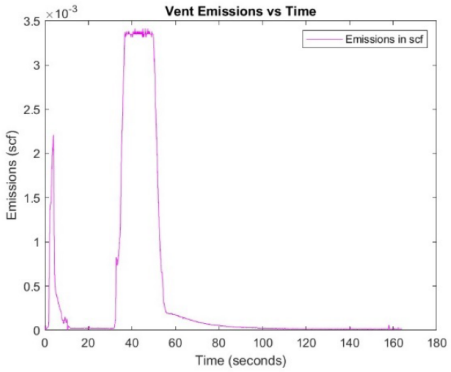

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
2
4
6
8
10
12
0
10
20
30
40
50
60

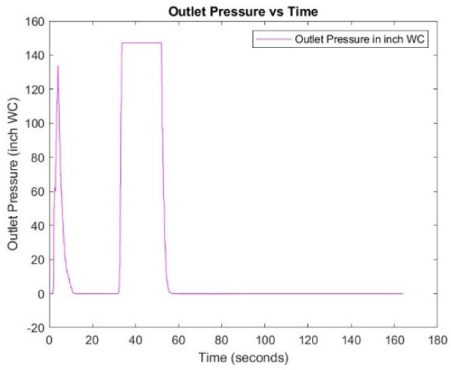

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
3
4
5
6
7
8
9
10
11
12
12
13
14
15
16
17
18
19
20

GTI ENERGY

- 222489-007_DT2

The volume of total emissions in 164.19 seconds is 0.6643 scf.

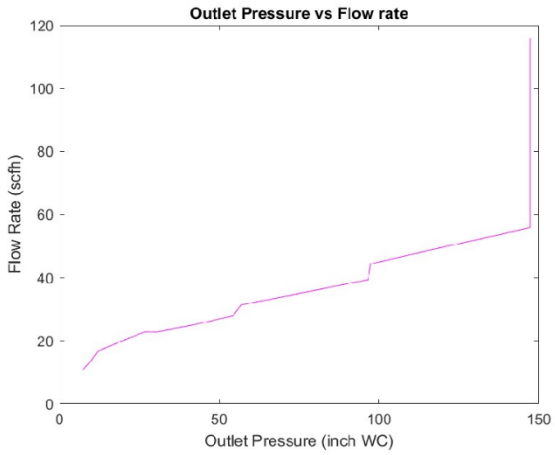


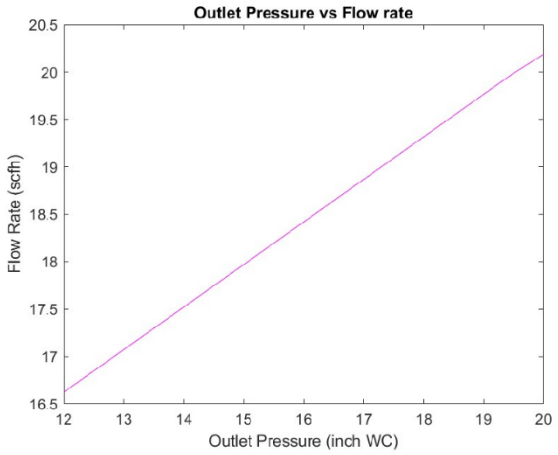


Commented [JW5]: No data points between 17.8 and 18.2 in WC to calculate average. Currently we are not interpolating in between data points for part 1

Commented [JW6R5]: I tried widening the range to 17-19" WC and still couldn't calculate the avg

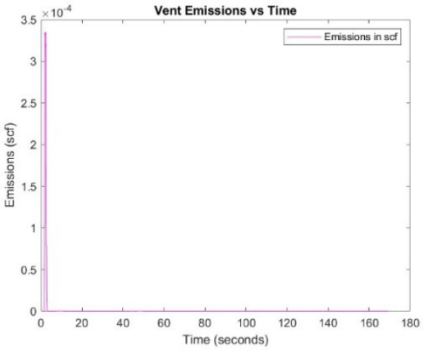
GTI ENERGY

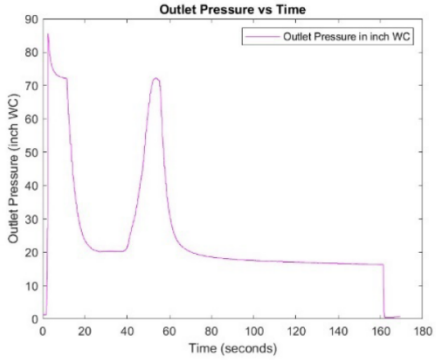

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
20
40
60
80
100
120
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
16.5
17
17.5
18
18.5
19
19.5
20
20.5
12
13
14
15
16
17
18
19
20

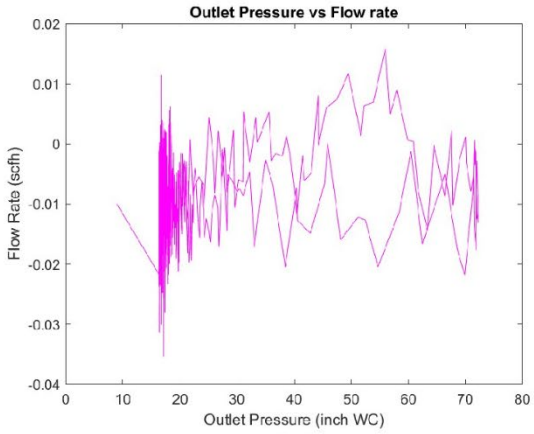
GTI ENERGY

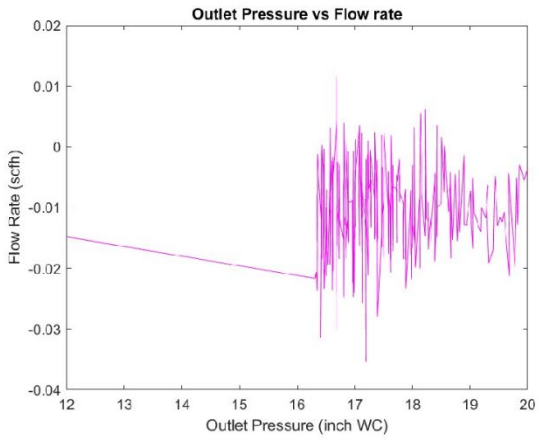
- **222489-007_LD**
  The volume of total emissions in 169.34 seconds is 0.0024 scf.
  The average flow rate of emissions at 18 inches WC is -0.01 scfh.





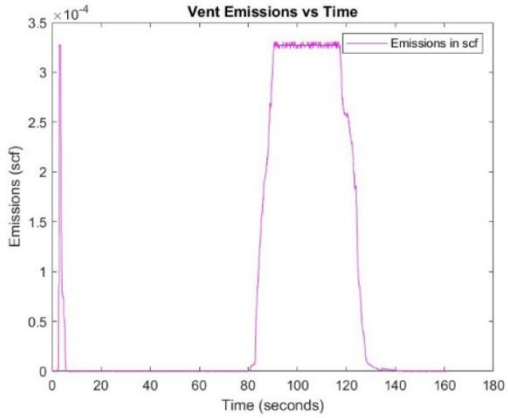
GTI ENERGY

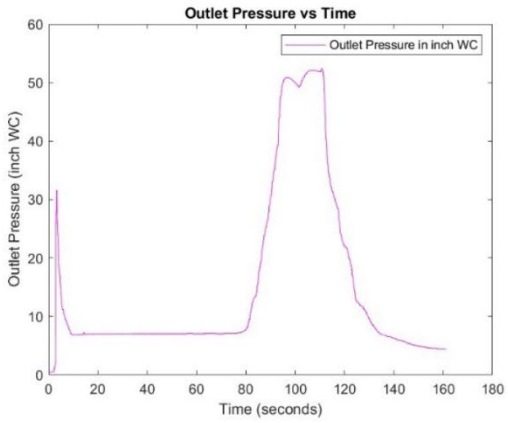

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0.02
0.01
0
-0.01
-0.02
-0.03
-0.04
0
10
20
30
40
50
60
70
80


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0.02
0.01
0
-0.01
-0.02
-0.03
-0.04
12
13
14
15
16
17
18
19
20

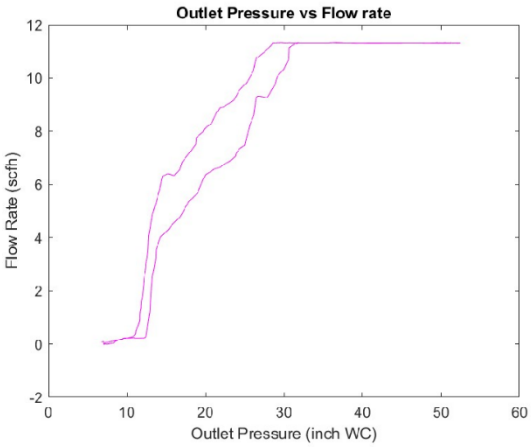
GTI ENERGY

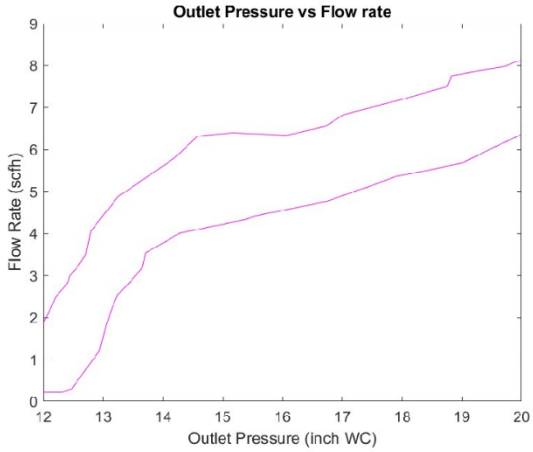
- **222489-008_2**
  The volume of total emissions in 161.26 seconds is 0.1211 scf.
  The average flow rate of emissions at 18 inches WC is 6.28 scfh.





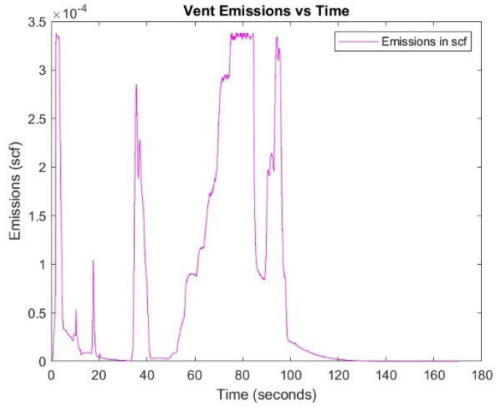
GTI ENERGY

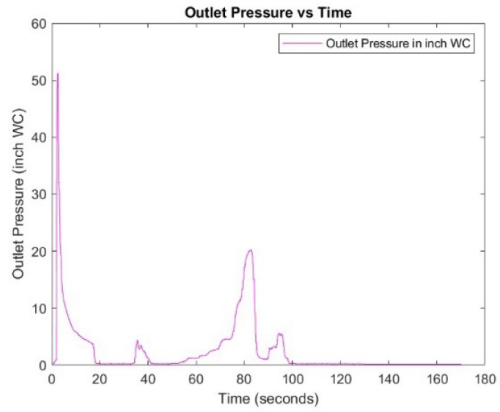

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
12
10
8
6
4
2
0
-2
0
10
20
30
40
50
60


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
9
8
7
6
5
4
3
2
1
0
12
13
14
15
16
17
18
19
20

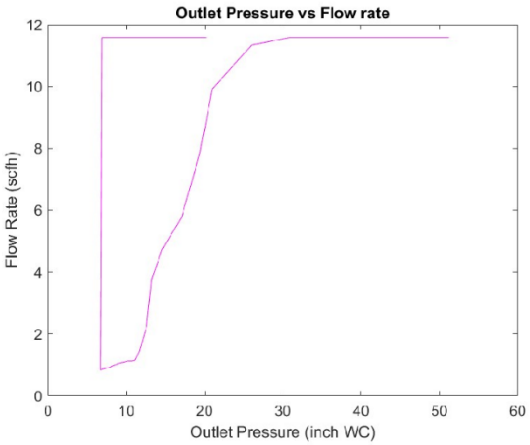
GTI ENERGY

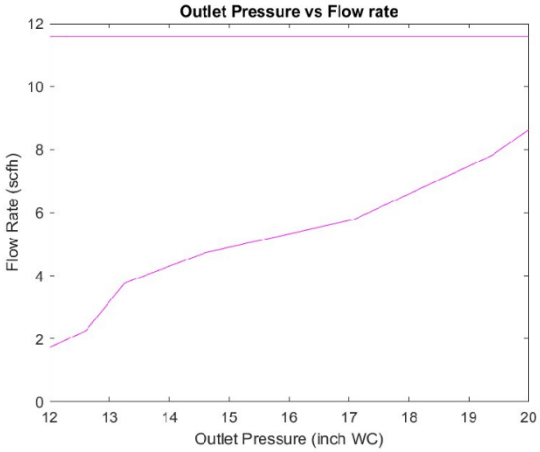
- **222489-008_DT1**
  The volume of total emissions in 170.36 seconds is 0.1096 scf.
  The average flow rate of emissions at 18 inches WC is 11.58 scfh.





GTI ENERGY

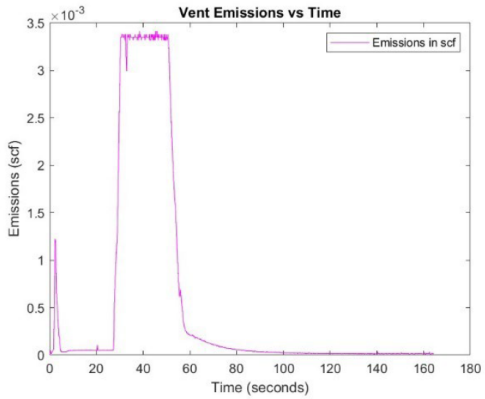

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
2
4
6
8
10
12
0
10
20
30
40
50
60

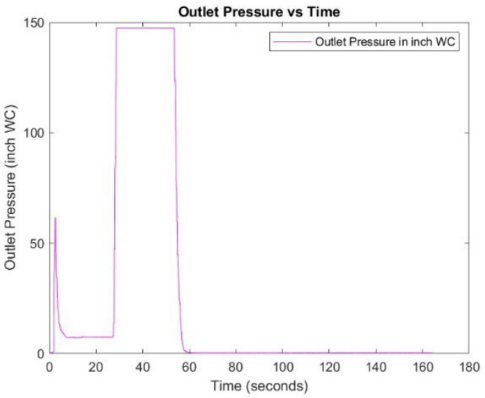

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
2
4
6
8
10
12
12
13
14
15
16
17
18
19
20

GTI ENERGY

- 222489-008_DT2

  The volume of total emissions in 164.31 seconds is 0.8677 scf.

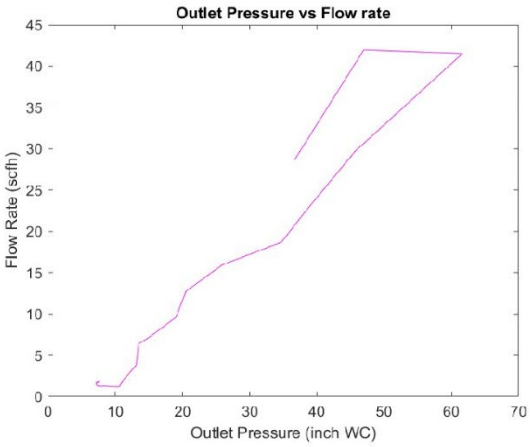


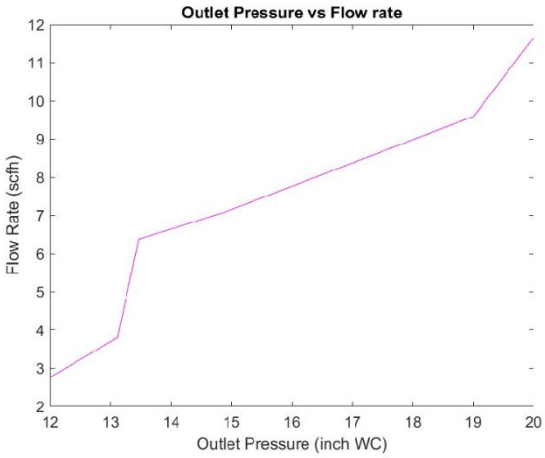


Commented [JW7]: No data points between 17.8 and 18.2 in WC to calculate avg

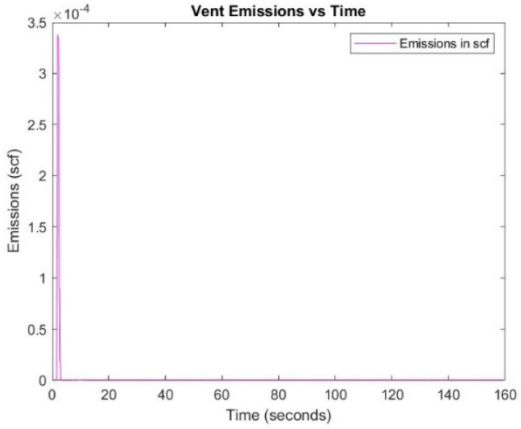
Commented [JW8R7]: Widened the range to 17-19" WC and still couldn't calculate avg

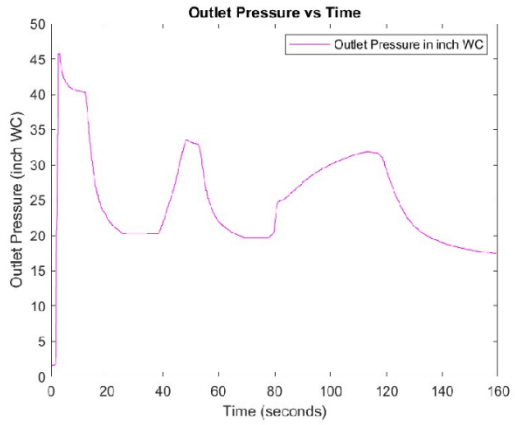
GTI ENERGY


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
5
10
15
20
25
30
35
40
45
0
10
20
30
40
50
60
70

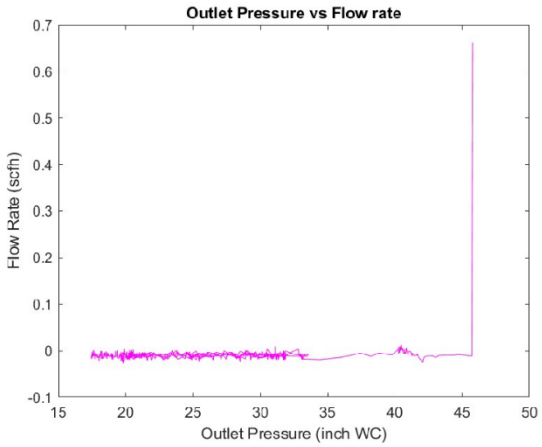

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
2
3
4
5
6
7
8
9
10
11
12
12
13
14
15
16
17
18
19
20

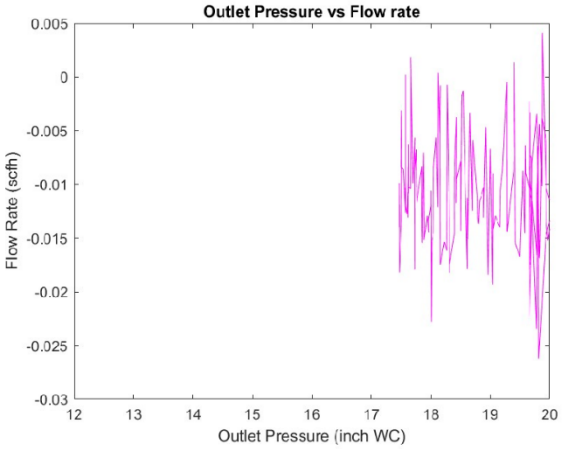
- **222489-008_LD**
  The volume of total emissions in 159.22 seconds is 0.0025 scf.
  The average flow rate of emissions at 18 inches WC is -0.01 scfh.





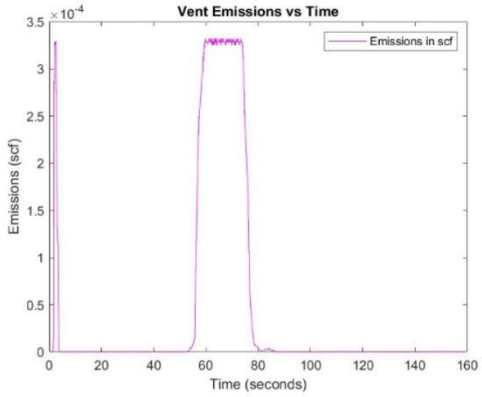
GTI ENERGY

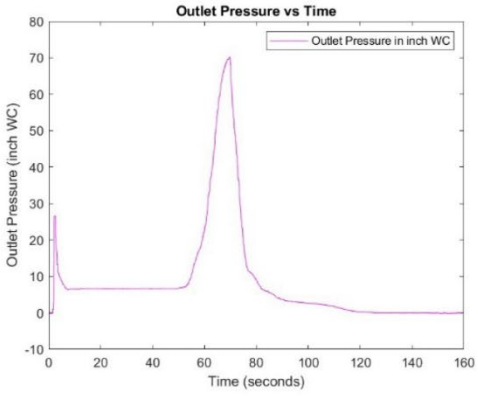

Outlet Pressure vs Flow rate
Flow Rate (scfh)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
15
20
25
30
35
40
45
50
Outlet Pressure (inch WC)


Outlet Pressure vs Flow rate
Flow Rate (scfh)
0.005
0
-0.005
-0.01
-0.015
-0.02
-0.025
-0.03
12
13
14
15
16
17
18
19
20
Outlet Pressure (inch WC)

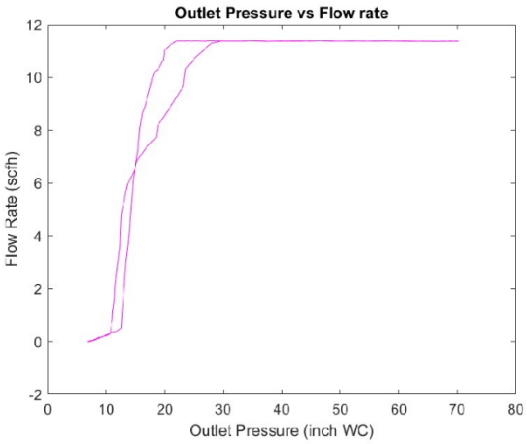
GTI ENERGY

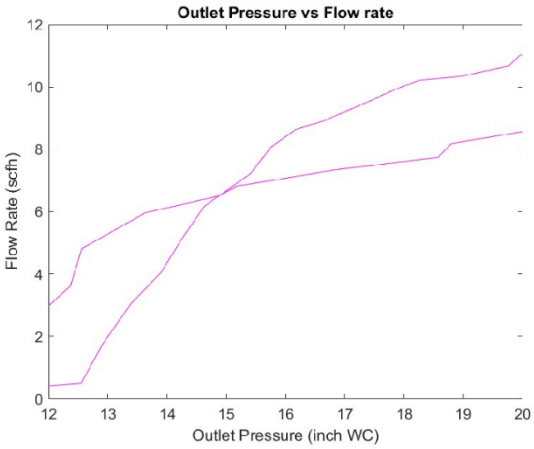
- **222489-009_2**
  The volume of total emissions in 159.34 seconds is 0.0647 scf.
  The average flow rate of emissions at 18 inches WC is 9.98 scfh.





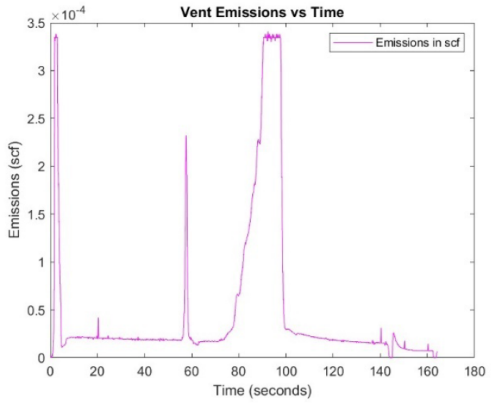
GTI ENERGY

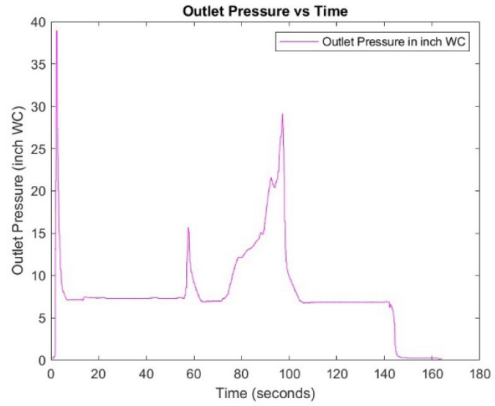

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
12
10
8
6
4
2
0
-2
0
10
20
30
40
50
60
70
80


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
12
10
8
6
4
2
0
12
13
14
15
16
17
18
19
20

- **222489-009_DT1**

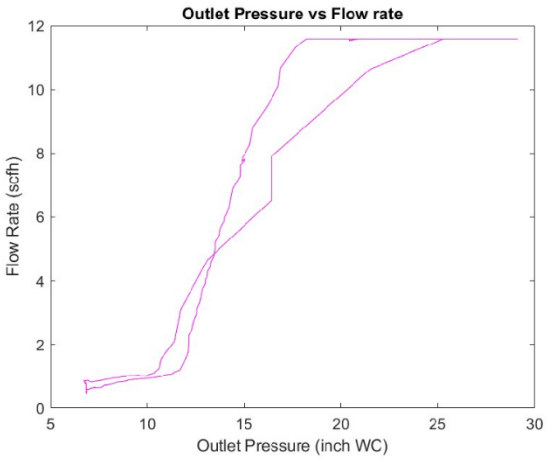
  The volume of total emissions in 164.20 seconds is 0.0750 scf.
  The average flow rate of emissions at 18 inches WC is 11.53 scfh.

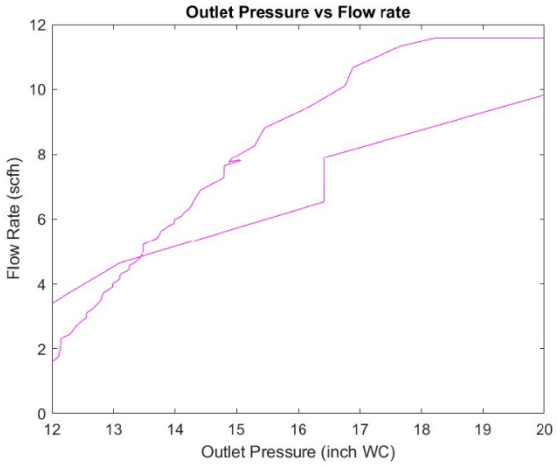




Commented [JW9]: No data points between range for average calculation

GTI ENERGY


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
2
4
6
8
10
12
5
10
15
20
25
30

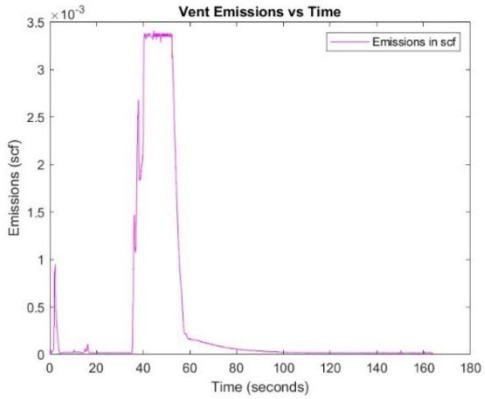

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
2
4
6
8
10
12
12
13
14
15
16
17
18
19
20

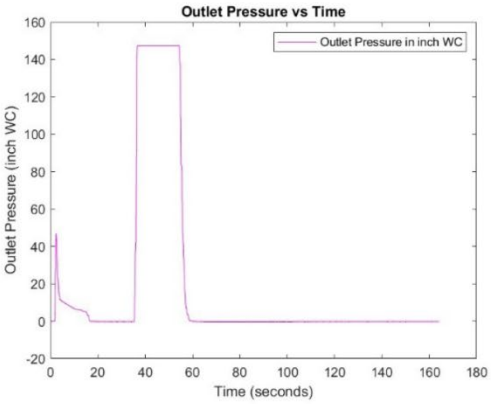
GTI ENERGY

- 222489-009_DT2

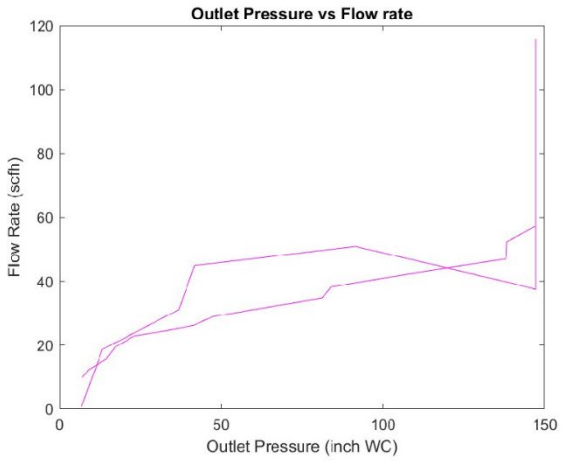
Commented [JW10]: Data out of range

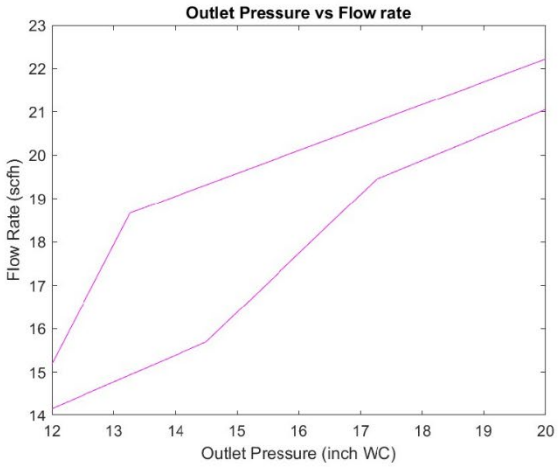
The volume of total emissions in 164.20 seconds is 0.6016 scf.





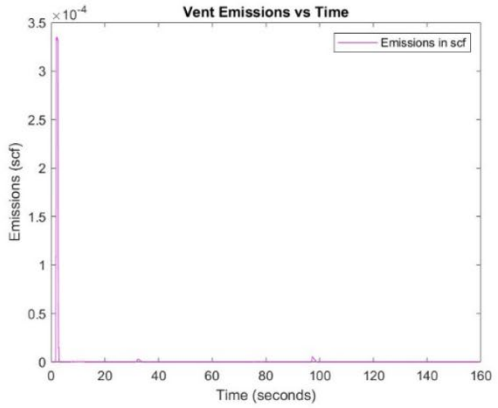
GTI ENERGY

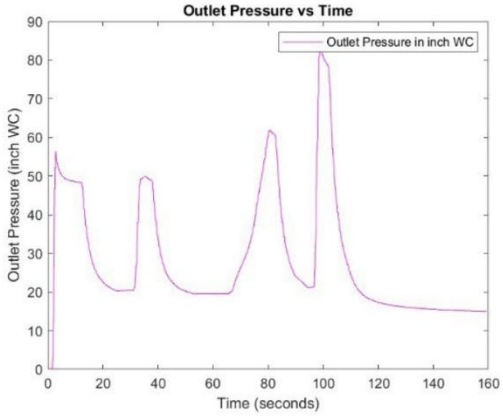

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
20
40
60
80
100
120
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
14
15
16
17
18
19
20
21
22
23
12
13
14
15
16
17
18
19
20

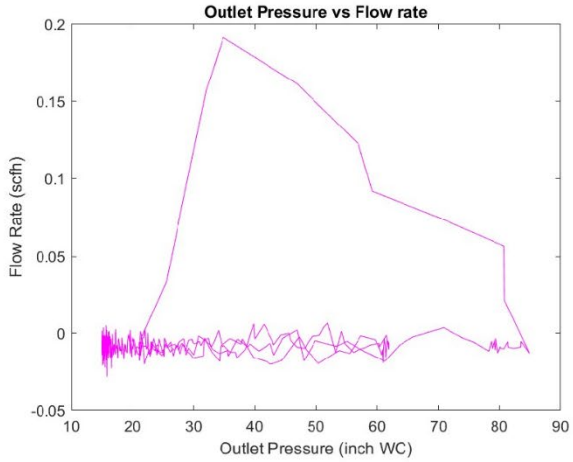
GTI ENERGY

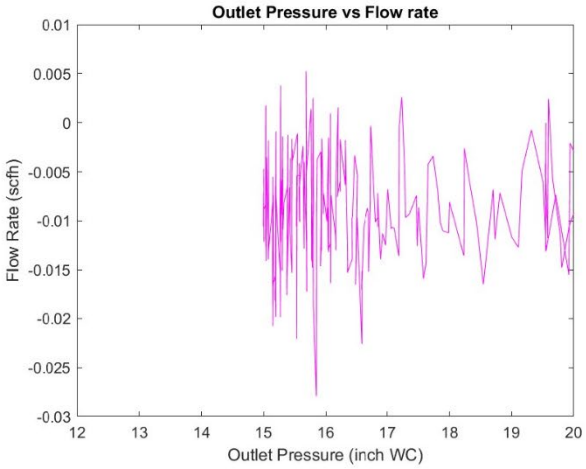
- **222489-009_LD**
  The volume of total emissions in 159.24 seconds is 0.0025 scf.
  The average flow rate of emissions at 18 inches WC is -0.01 scfh.





GTI ENERGY


Outlet Pressure vs Flow rate
Flow Rate (scfh)
0.2
0.15
0.1
0.05
0
-0.05
10
20
30
40
50
60
70
80
90
Outlet Pressure (inch WC)

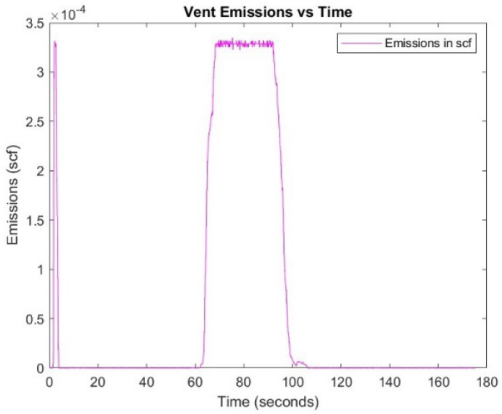

Outlet Pressure vs Flow rate
Flow Rate (scfh)
0.01
0.005
0
-0.005
-0.01
-0.015
-0.02
-0.025
-0.03
12
13
14
15
16
17
18
19
20
Outlet Pressure (inch WC)

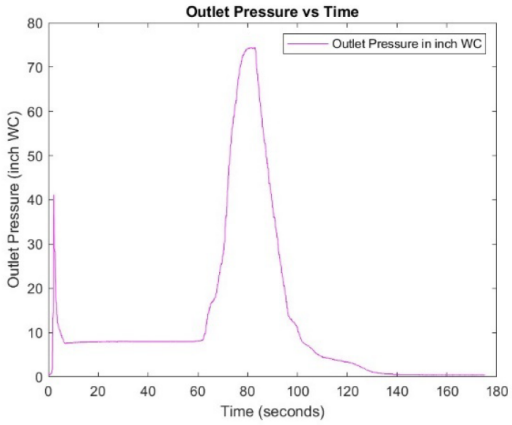
GTI ENERGY

7″ WC Outlet, 60-psig Inlet

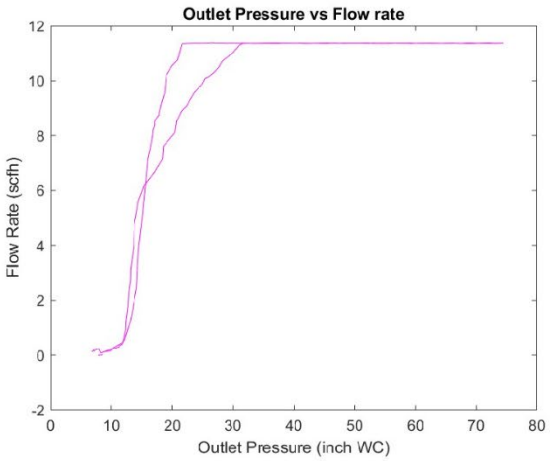
- **222489-007_2**

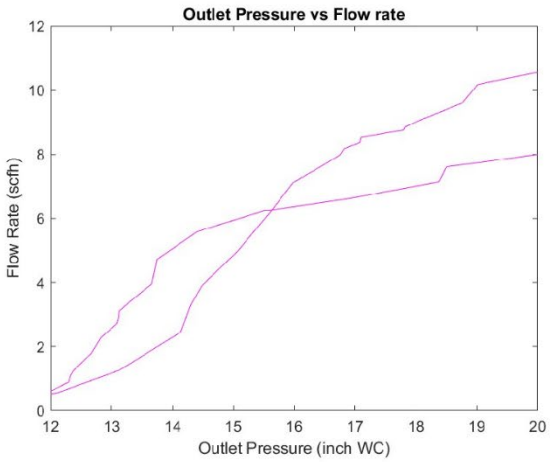
  The volume of total emissions in 175.35 seconds is 0.1020 scf.
  The average flow rate of emissions at 18 inches WC is 8.93 scfh.





GTI ENERGY


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
12
10
8
6
4
2
0
-2
0
10
20
30
40
50
60
70
80

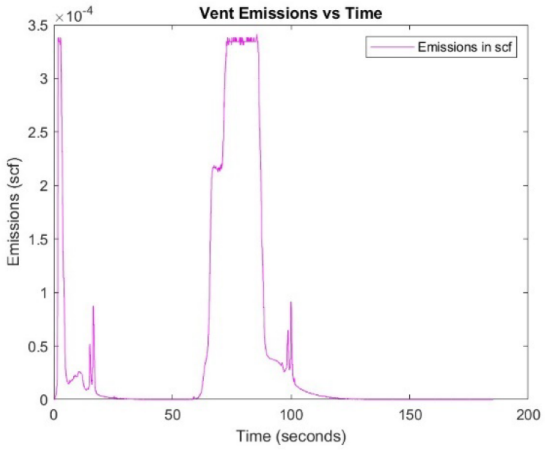

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
12
10
8
6
4
2
0
12
13
14
15
16
17
18
19
20

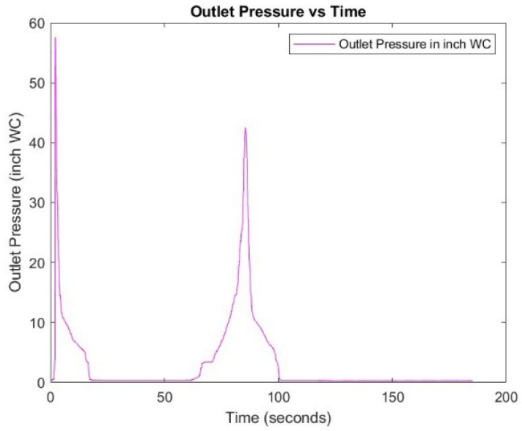
GTI ENERGY

- 222489-007_DT1

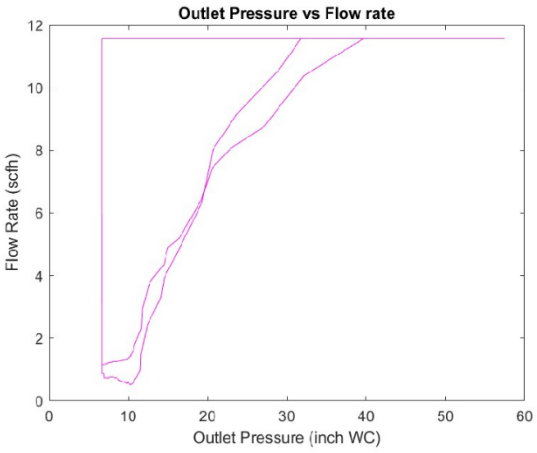
  The volume of total emissions in 185.29 seconds is 0.0801 scf.

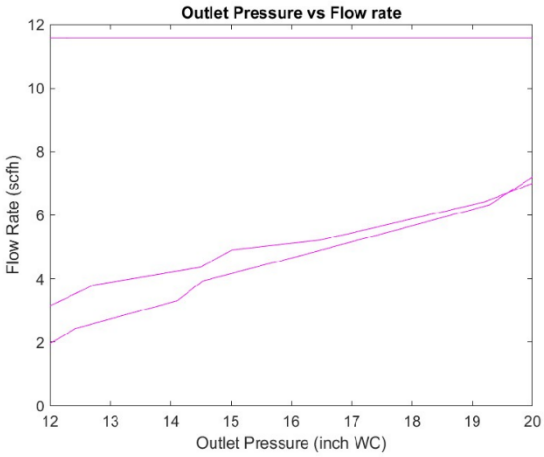
Commented [JW11]: Data out of range for average calculation





GTI ENERGY


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
2
4
6
8
10
12
0
10
20
30
40
50
60

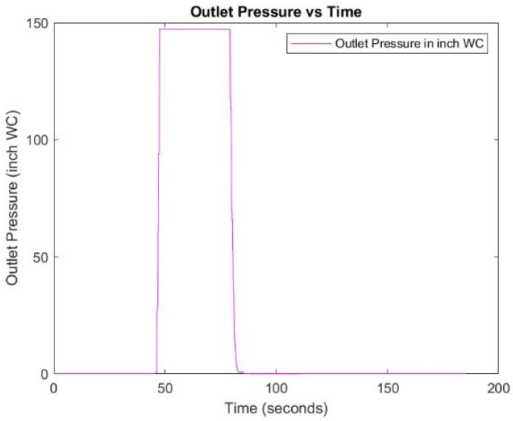

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
2
4
6
8
10
12
12
13
14
15
16
17
18
19
20

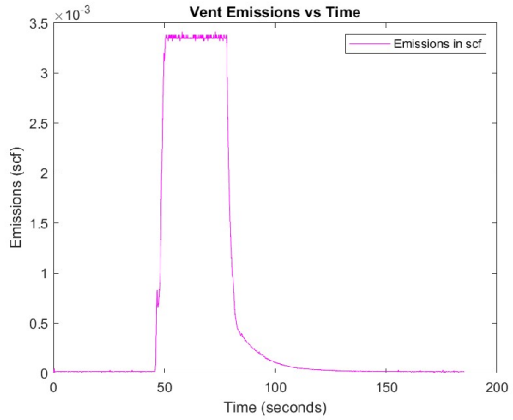
GTI ENERGY

- 222489-007_DT2

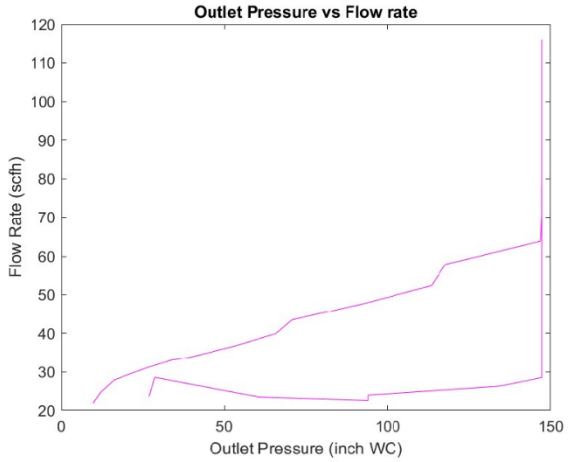
  The volume of total emissions in 185.38 seconds is 1.0879 scf.

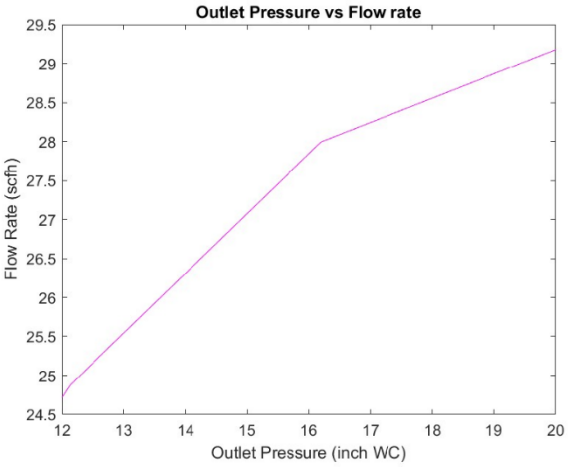
Commented [JW12]: Data out of range





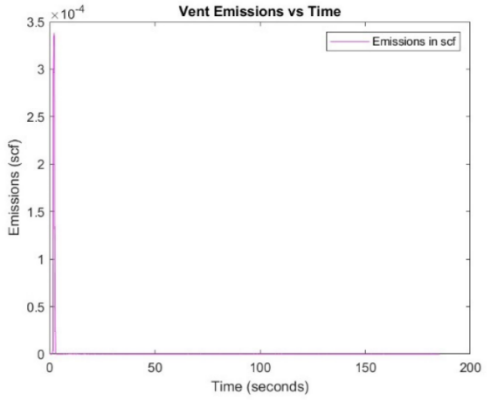
GTI ENERGY

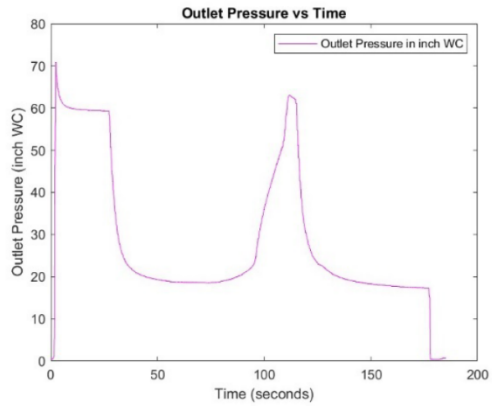

Outlet Pressure vs Flow rate
Flow Rate (scfh)
120
110
100
90
80
70
60
50
40
30
20
0
50
100
150
Outlet Pressure (inch WC)


Outlet Pressure vs Flow rate
Flow Rate (scfh)
29.5
29
28.5
28
27.5
27
26.5
26
25.5
25
24.5
12
13
14
15
16
17
18
19
20
Outlet Pressure (inch WC)

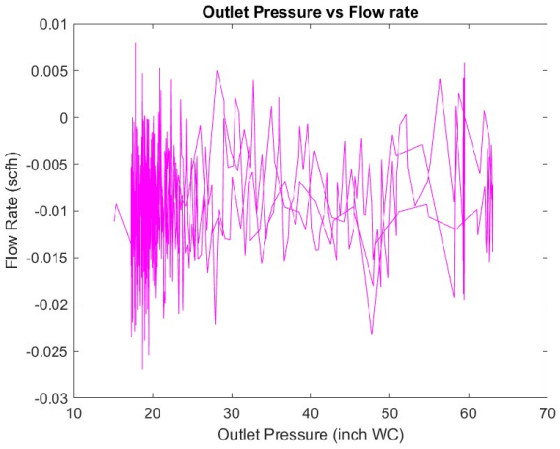
GTI ENERGY

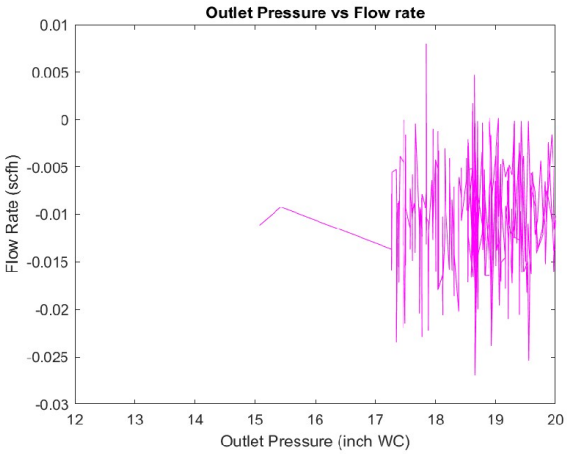
- **222489-007_LD**
  The volume of total emissions in 185.42 seconds is 0.0023 scf.
  The average flow rate of emissions at 18 inches WC is -0.01 scfh.



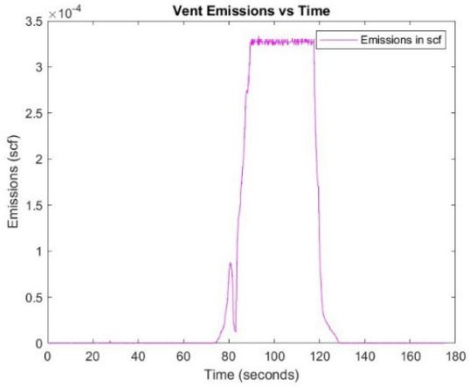


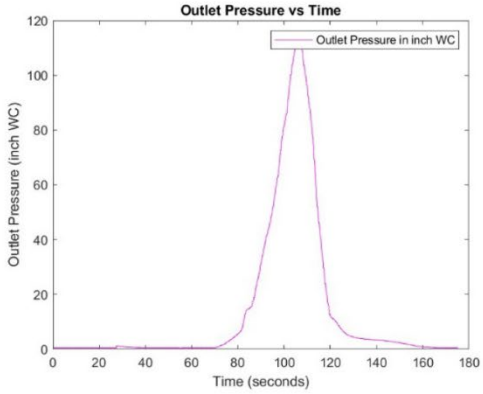
GTI ENERGY


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0.01
0.005
0
-0.005
-0.01
-0.015
-0.02
-0.025
-0.03
10
20
30
40
50
60
70

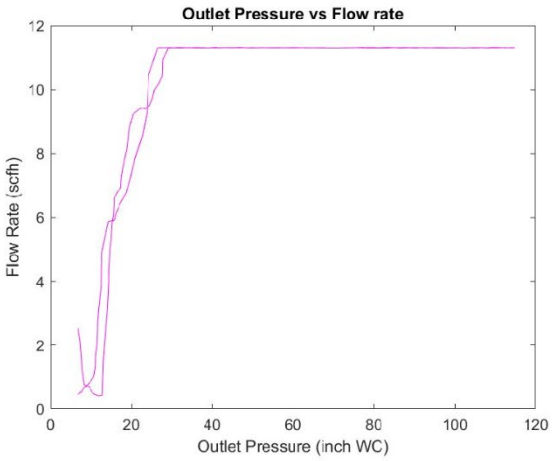

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0.01
0.005
0
-0.005
-0.01
-0.015
-0.02
-0.025
-0.03
12
13
14
15
16
17
18
19
20

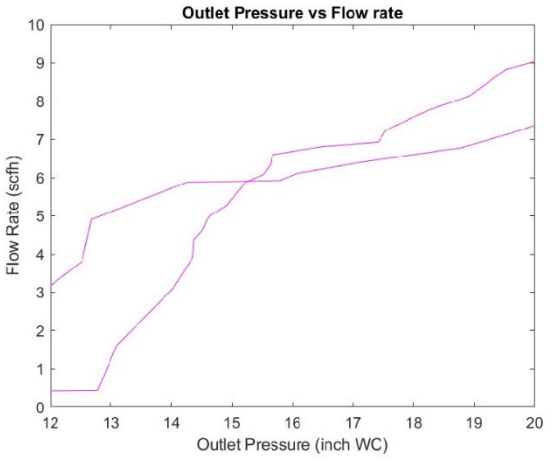
- **222489-008_2**
  The volume of total emissions in 175.32 seconds is 0.1101 scf.
  The average flow rate of emissions at 18 inches WC is 7.51 scfh.





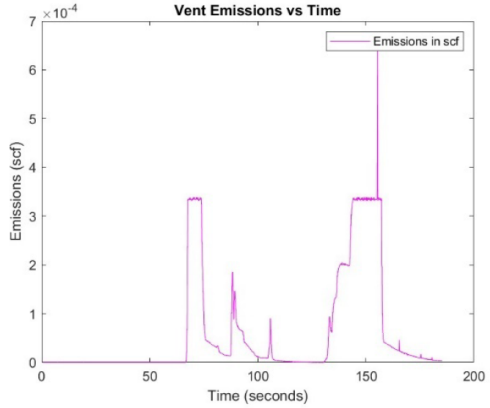
GTI ENERGY

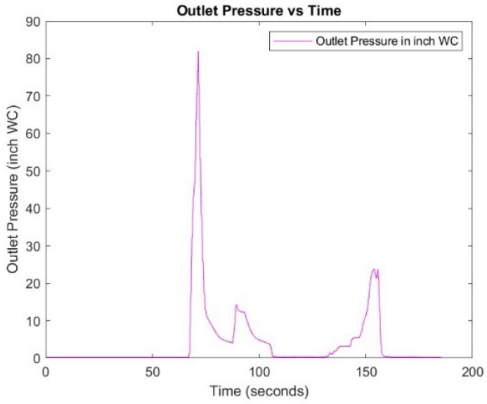

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
2
4
6
8
10
12
0
20
40
60
80
100
120


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
1
2
3
4
5
6
7
8
9
10
12
13
14
15
16
17
18
19
20

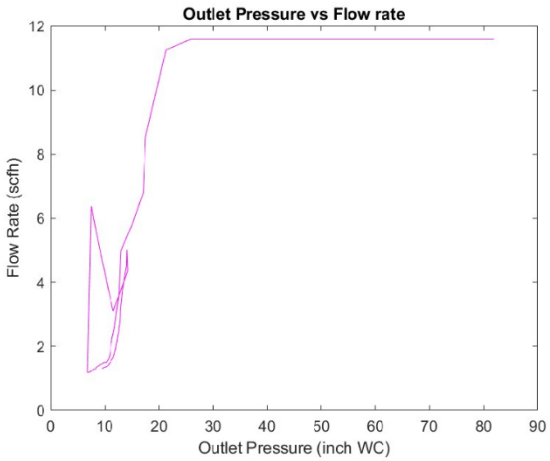
GTI ENERGY

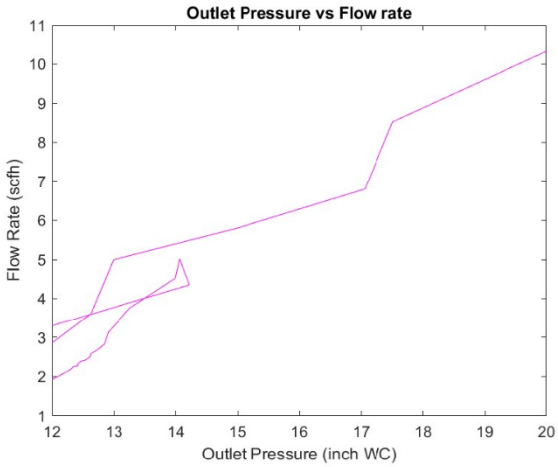
- **222489-008_DT1**
  The volume of total emissions in 185.39 seconds is 0.1022 scf.
  The average flow rate of emissions at 18 inches WC is 11.58 scfh.





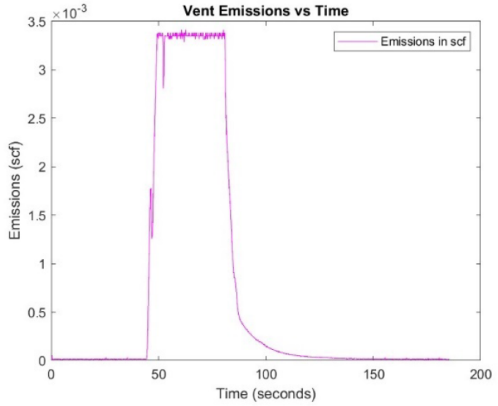
GTI ENERGY

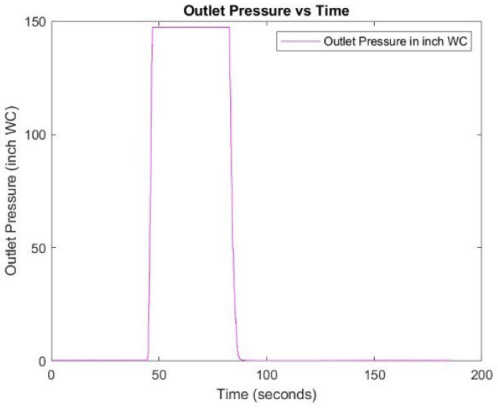

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
2
4
6
8
10
12
0
10
20
30
40
50
60
70
80
90


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20

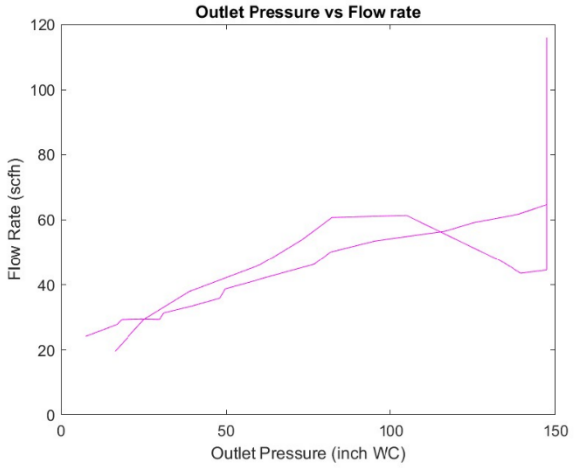
GTI ENERGY

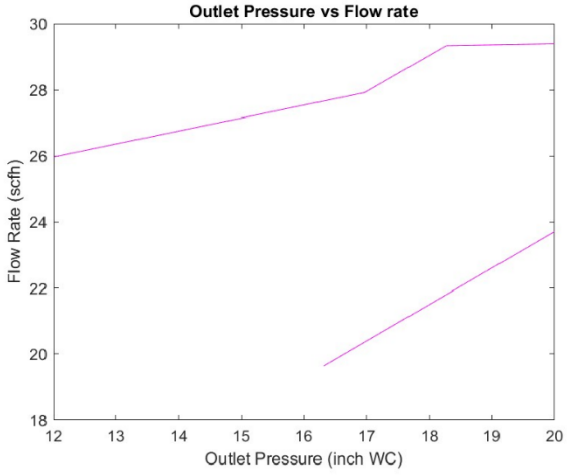
- **222489-008_DT2**
  The volume of total emissions in 185.40 seconds is 1.2438 scf.
  The average flow rate of emissions at 18 inches WC is 29.35 scfh.





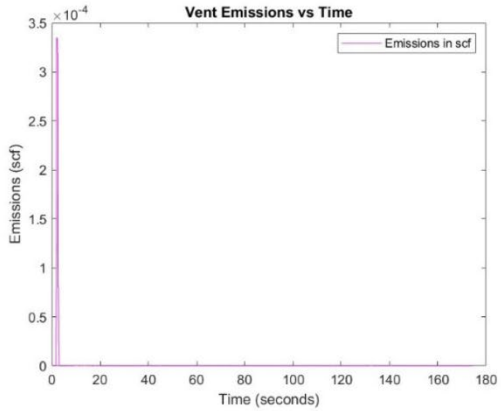
GTI ENERGY

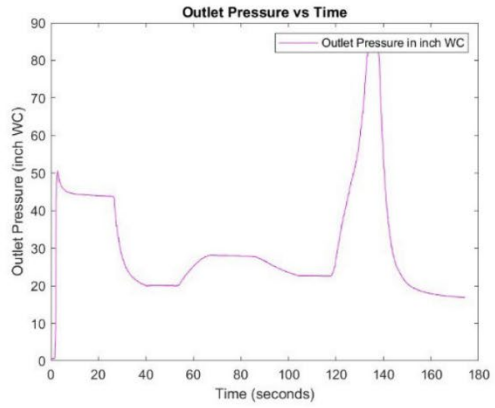

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
20
40
60
80
100
120
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
18
20
22
24
26
28
30
12
13
14
15
16
17
18
19
20

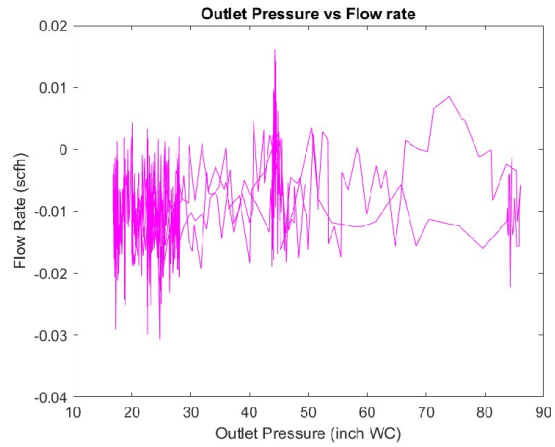
GTI ENERGY

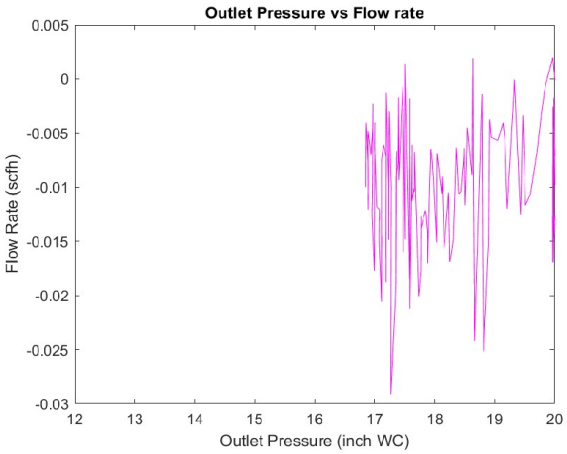
- **222489-008_LD**
  The volume of total emissions in 174.32 seconds is 0.0024 scf.
  The average flow rate of emissions at 18 inches WC is -0.01 scfh.





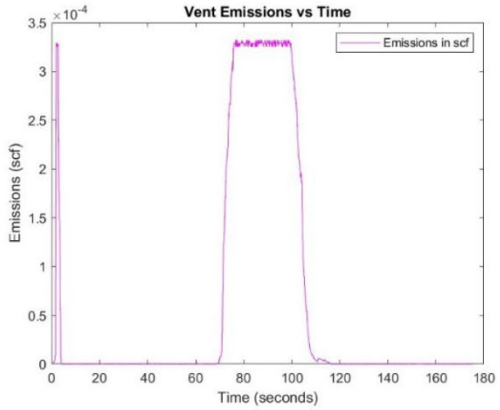
GTI ENERGY

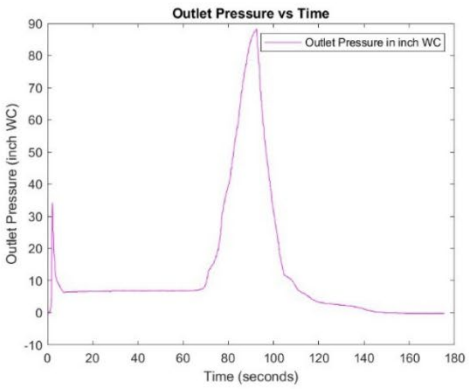

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0.02
0.01
0
-0.01
-0.02
-0.03
-0.04
10
20
30
40
50
60
70
80
90


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0.005
0
-0.005
-0.01
-0.015
-0.02
-0.025
-0.03
12
13
14
15
16
17
18
19
20

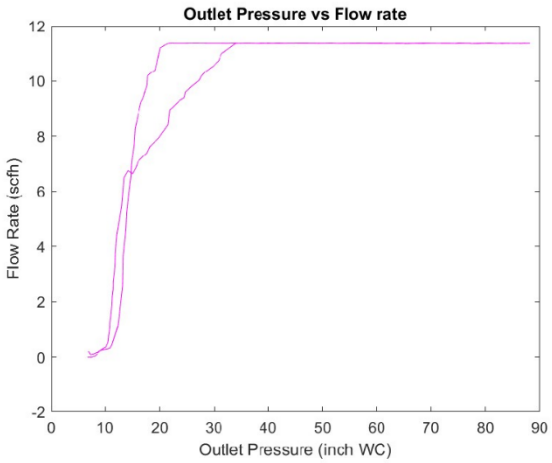
GTI ENERGY

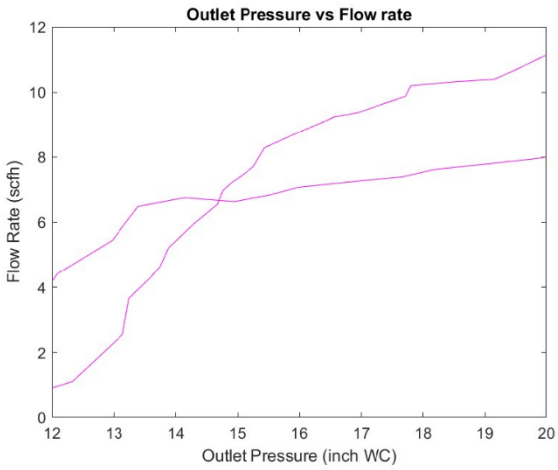
- **222489-009_2**
  The volume of total emissions in 175.44 seconds is 0.1040 scf.
  The average flow rate of emissions at 18 inches WC is 8.95 scfh.





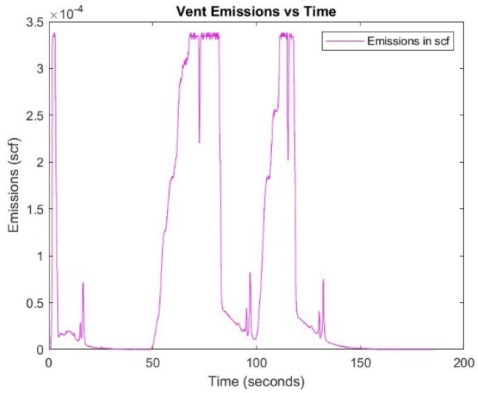
GTI ENERGY

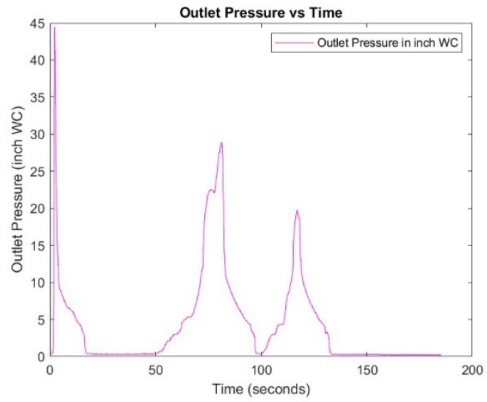

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
12
10
8
6
4
2
0
-2
0
10
20
30
40
50
60
70
80
90


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
12
10
8
6
4
2
0
12
13
14
15
16
17
18
19
20

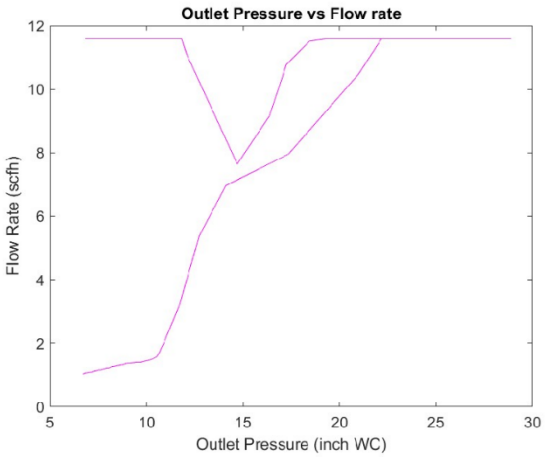
GTI ENERGY

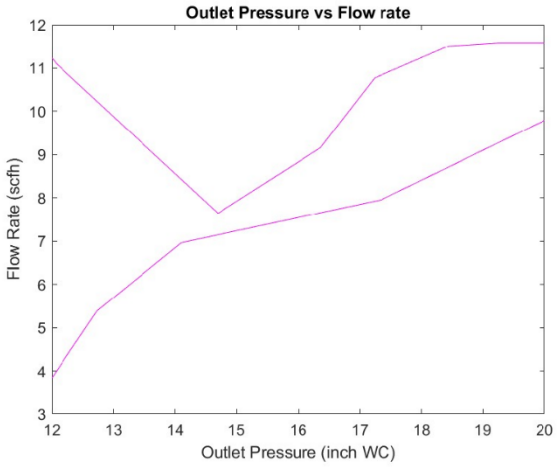
- **222489-009_DT1**
  The volume of total emissions in 185.47 seconds is 0.1367 scf.
  The average flow rate of emissions at 18 inches WC is 11.41 scfh.





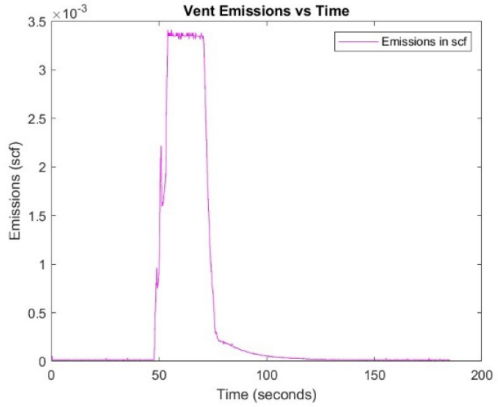
GTI ENERGY

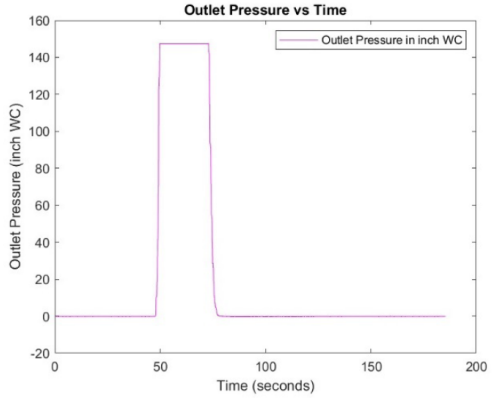

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
2
4
6
8
10
12
5
10
15
20
25
30


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
3
4
5
6
7
8
9
10
11
12
12
13
14
15
16
17
18
19
20

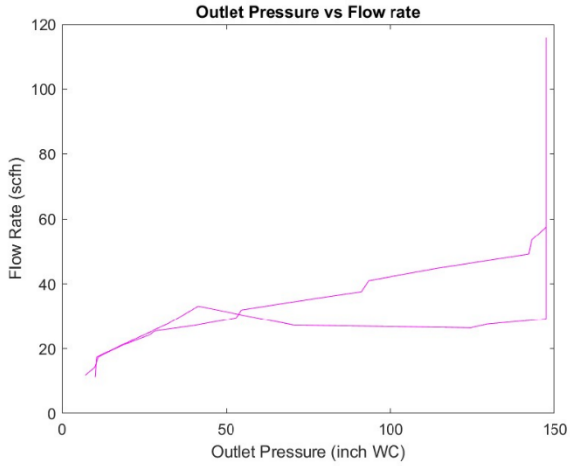
GTI ENERGY

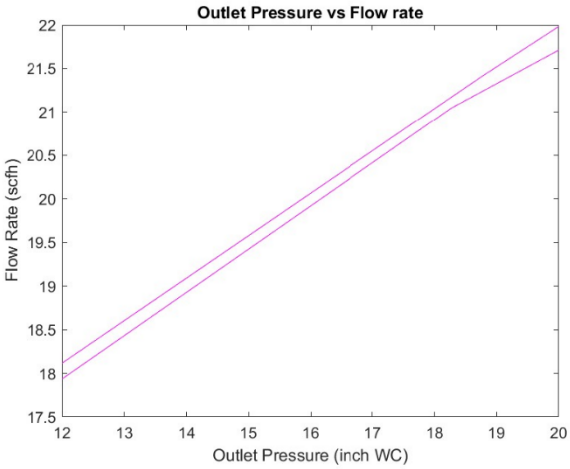
- **222489-009_DT2**
  The volume of total emissions in 185.39 seconds is 0.7602 scf.
  The average flow rate of emissions at 18 inches WC is 21.23 scfh.





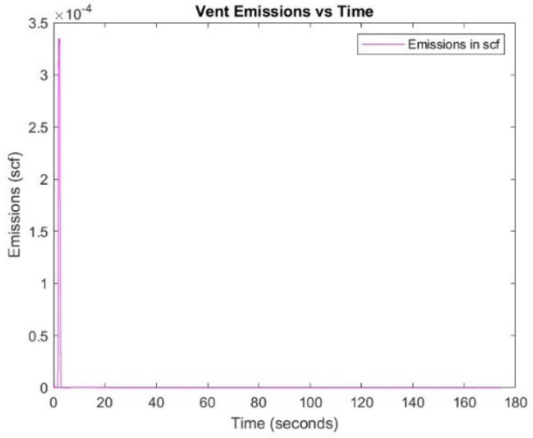
GTI ENERGY

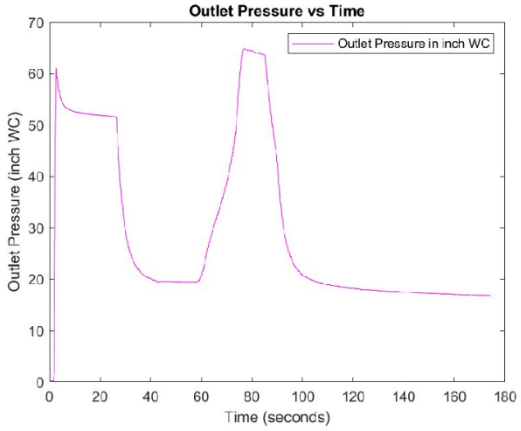

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
20
40
60
80
100
120
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
17.5
18
18.5
19
19.5
20
20.5
21
21.5
22
12
13
14
15
16
17
18
19
20

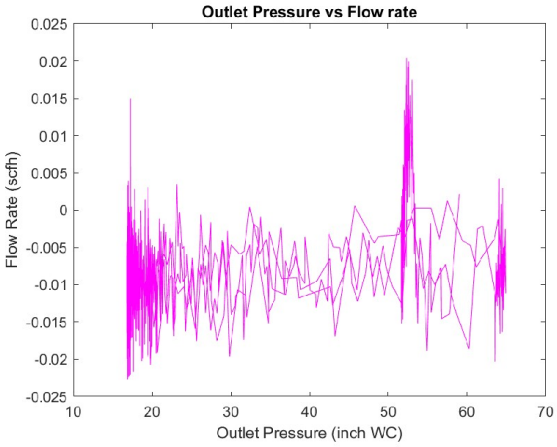
GTI ENERGY

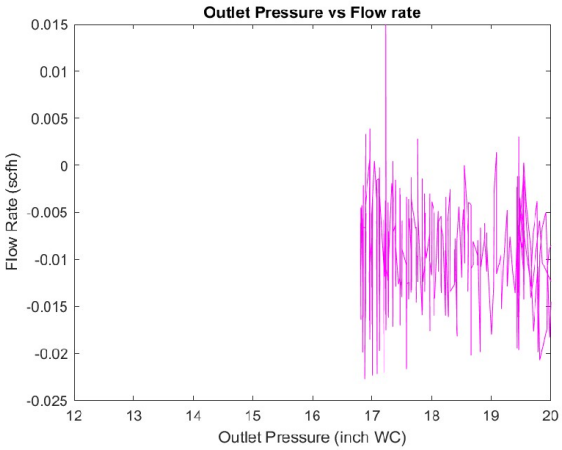
- **222489-009_LD**
  The volume of total emissions in 174.37 seconds is 0.0024 scf.
  The average flow rate of emissions at 18 inches WC is -0.01 scfh.





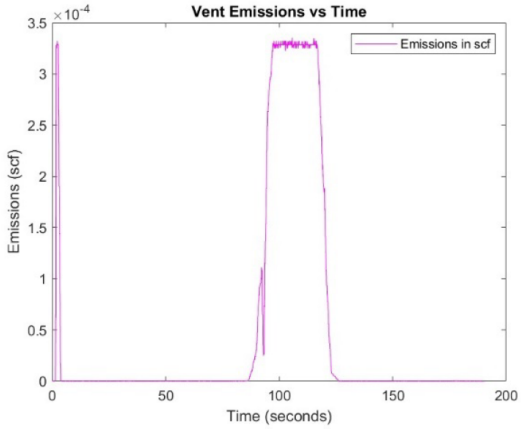
GTI ENERGY

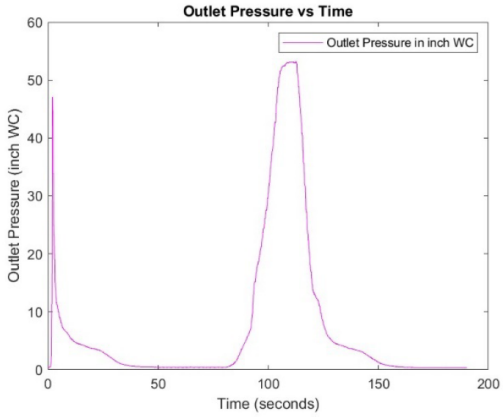

Outlet Pressure vs Flow rate
Flow Rate (scfh)
0.025
0.02
0.015
0.01
0.005
0
-0.005
-0.01
-0.015
-0.02
-0.025
10
20
30
40
50
60
70
Outlet Pressure (inch WC)


Outlet Pressure vs Flow rate
Flow Rate (scfh)
0.015
0.01
0.005
0
-0.005
-0.01
-0.015
-0.02
-0.025
12
13
14
15
16
17
18
19
20
Outlet Pressure (inch WC)

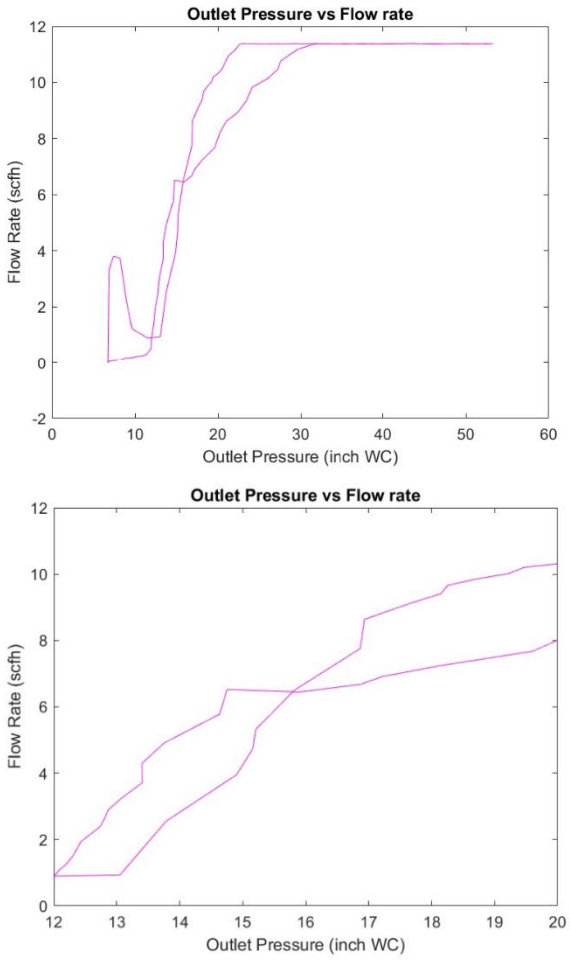
7" WC Outlet, 100-psig Inlet

- **222489-007_2**
  The volume of total emissions in 190.38 seconds is 0.0886 scf.
  The average flow rate of emissions at 18 inches WC is 8.86 scfh.



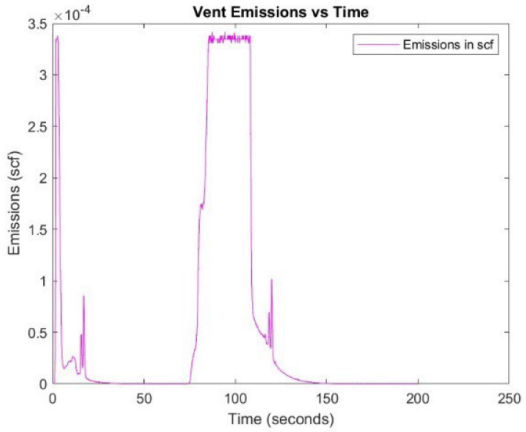


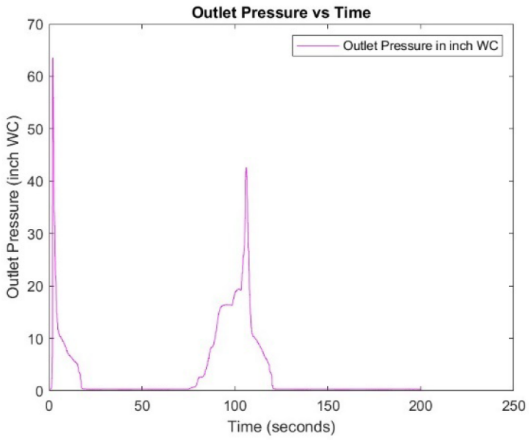
GTI ENERGY


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)

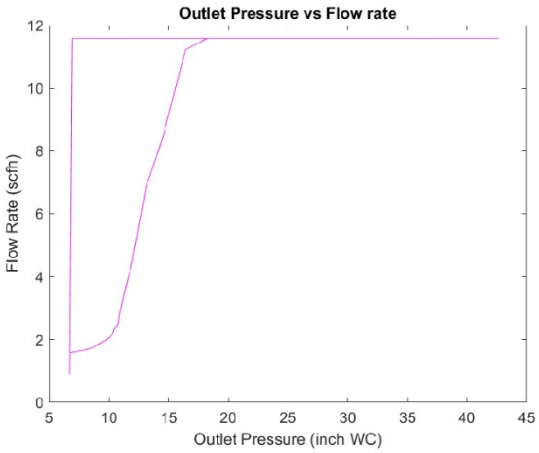
GTI ENERGY

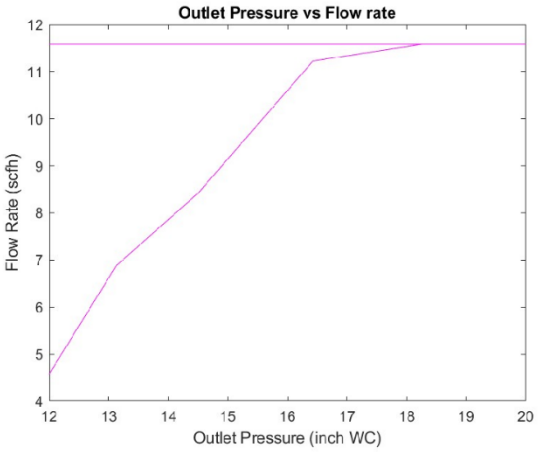
- **222489-007_DT1**
  The volume of total emissions in 200.50 seconds is 0.1057 scf.
  The average flow rate of emissions at 18 inches WC is 11.58 scfh.





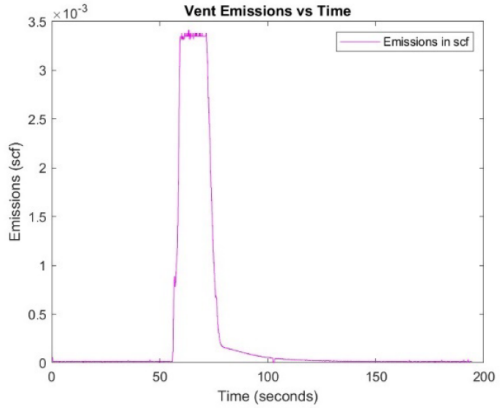
GTI ENERGY

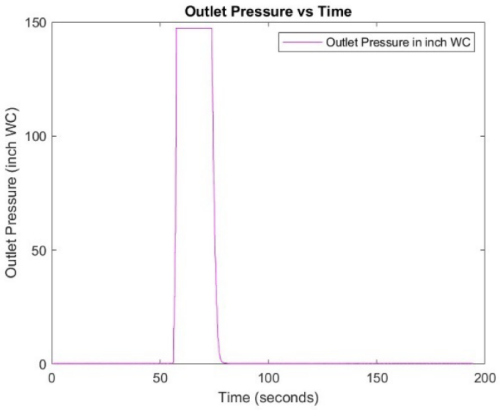

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
2
4
6
8
10
12
5
10
15
20
25
30
35
40
45


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
4
5
6
7
8
9
10
11
12
12
13
14
15
16
17
18
19
20

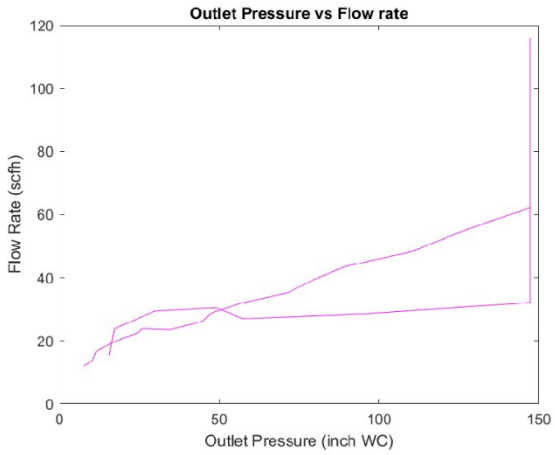
GTI ENERGY

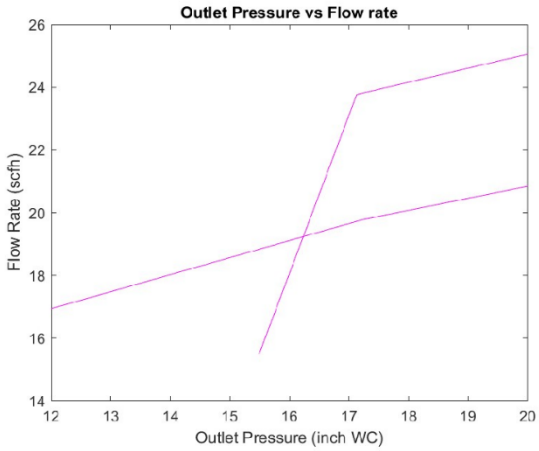
- **222489-007_DT2**
  The volume of total emissions in 194.46 seconds is 0.5721 scf.
  The average flow rate of emissions at 18 inches WC is 21.77 scfh.





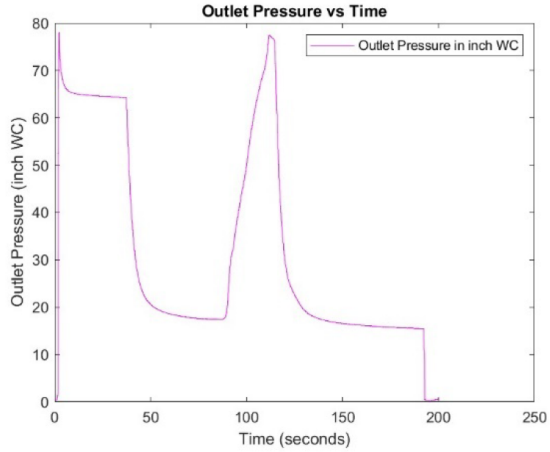
GTI ENERGY

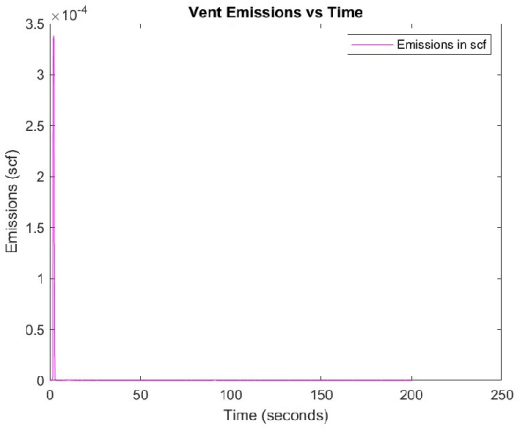

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
20
40
60
80
100
120
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
14
16
18
20
22
24
26
12
13
14
15
16
17
18
19
20

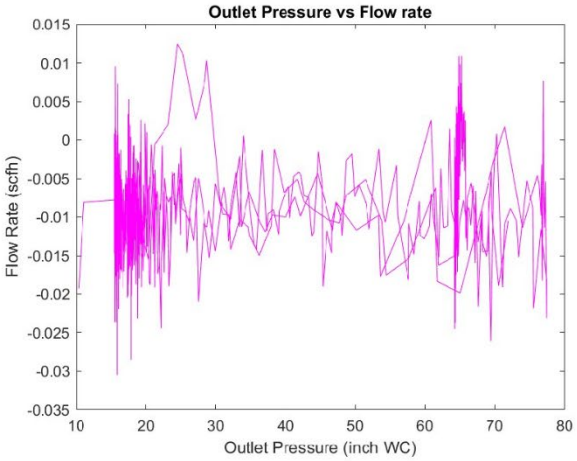
GTI ENERGY

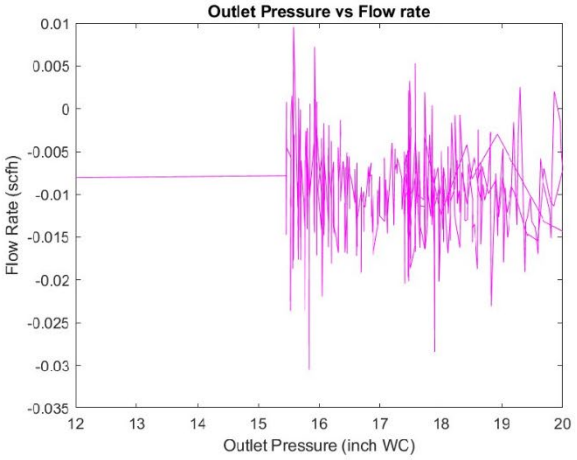
- **222489-007_LD**
  The volume of total emissions in 200.42 seconds is 0.0023 scf.
  The average flow rate of emissions at 18 inches WC is -0.01 scfh.





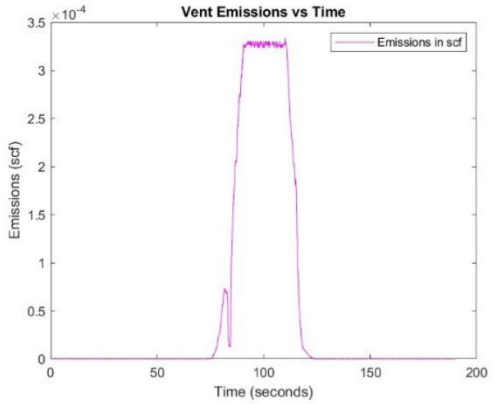
GTI ENERGY

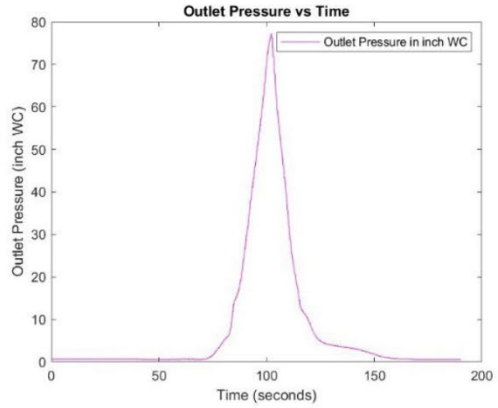

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0.015
0.01
0.005
0
-0.005
-0.01
-0.015
-0.02
-0.025
-0.03
-0.035
10
20
30
40
50
60
70
80


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0.01
0.005
0
-0.005
-0.01
-0.015
-0.02
-0.025
-0.03
-0.035
12
13
14
15
16
17
18
19
20

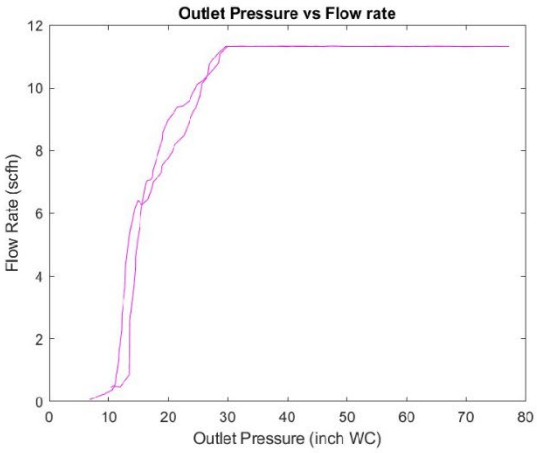
GTI ENERGY

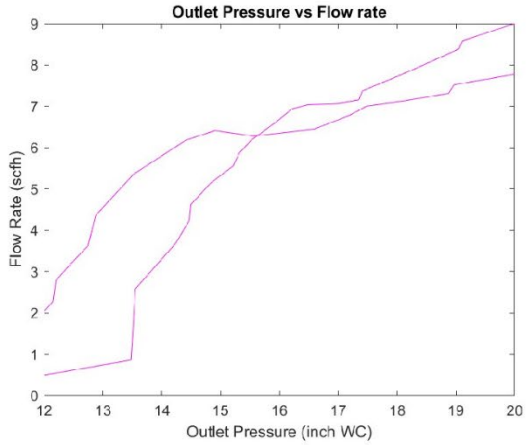
- **222489-008_2**
  The volume of total emissions in 190.28 seconds is 0.0917 scf.
  The average flow rate of emissions at 18 inches WC is 7.27 scfh.





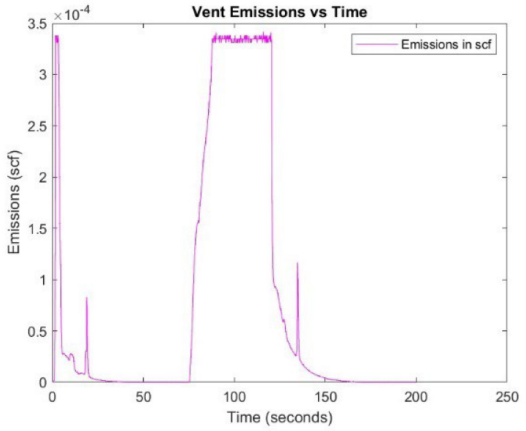
GTI ENERGY

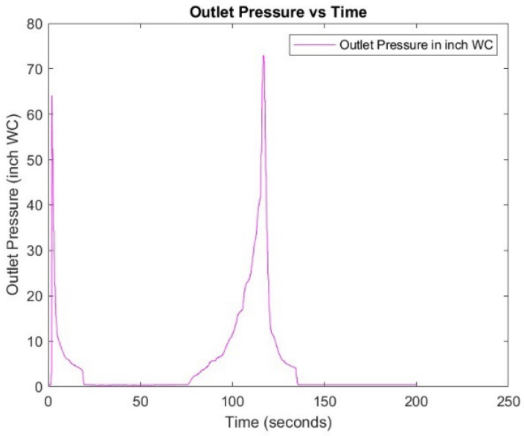

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
2
4
6
8
10
12
0
10
20
30
40
50
60
70
80


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
1
2
3
4
5
6
7
8
9
12
13
14
15
16
17
18
19
20

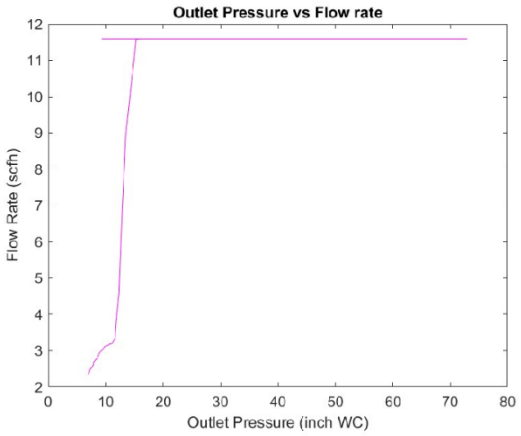
GTI ENERGY

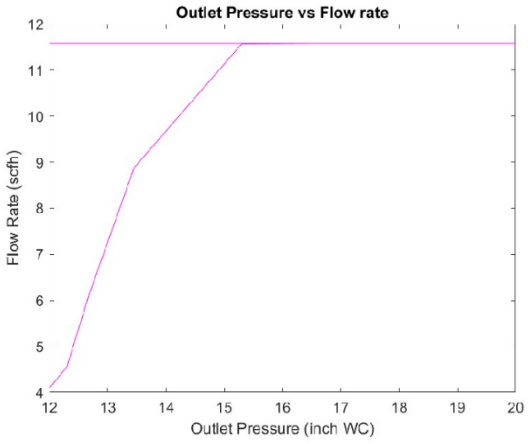
- **222489-008_DT1**
  The volume of total emissions in 200.41 seconds is 0.1491 scf.
  The average flow rate of emissions at 18 inches WC is 10.64 scfh.





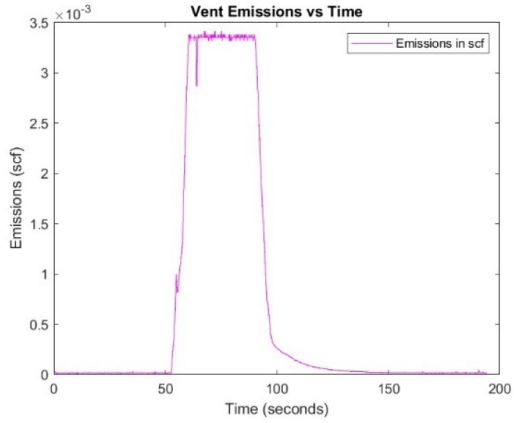
GTI ENERGY

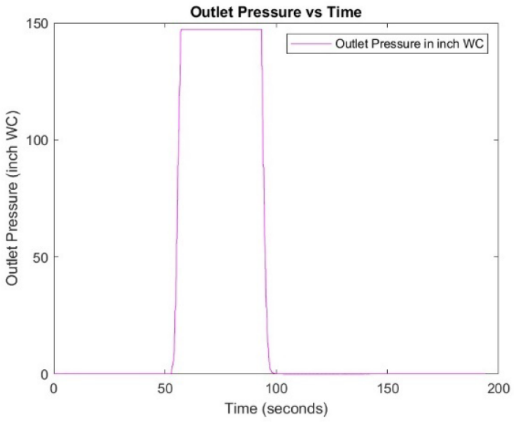

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
12
11
10
9
8
7
6
5
4
3
2
0
10
20
30
40
50
60
70
80


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
12
11
10
9
8
7
6
5
4
12
13
14
15
16
17
18
19
20

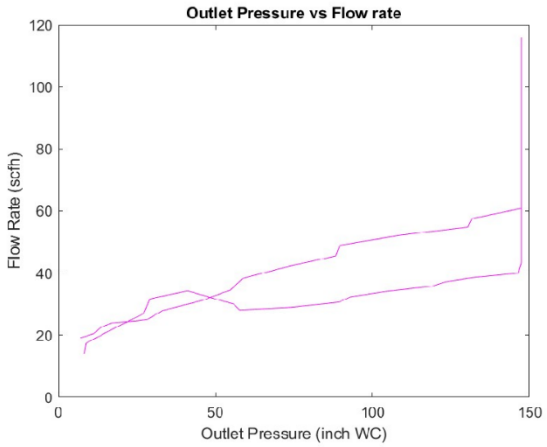
GTI ENERGY

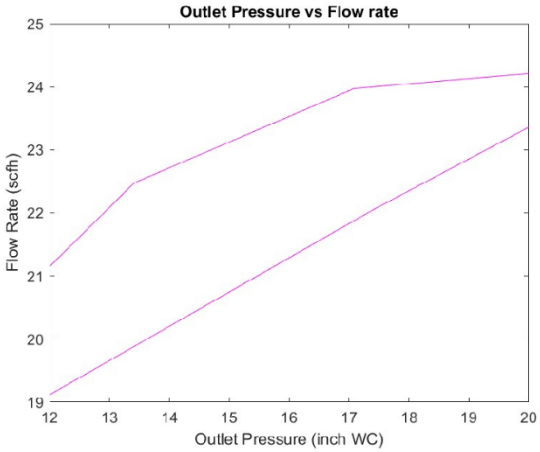
- **222489-008_DT2**
  The volume of total emissions in 194.37 seconds is 1.2292 scf.
  The average flow rate of emissions at 18 inches WC is 23.01 scfh.





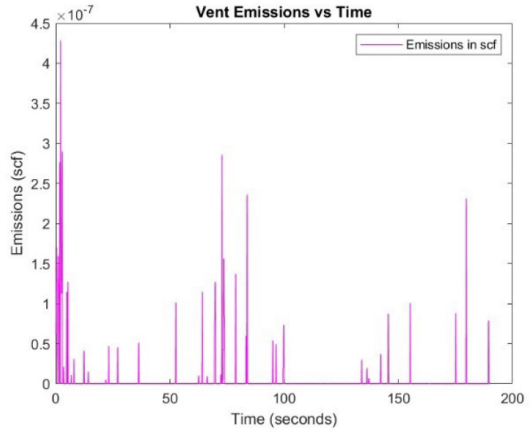
GTI ENERGY

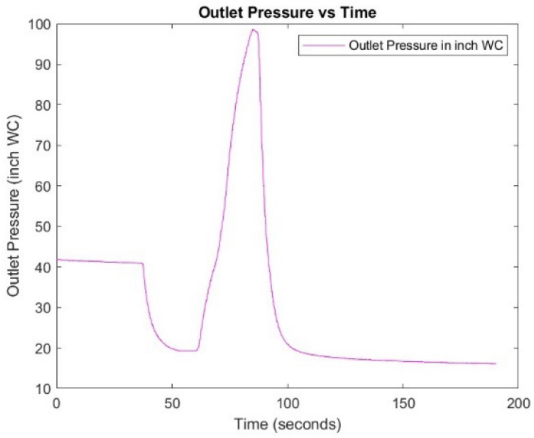

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
20
40
60
80
100
120
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
19
20
21
22
23
24
25
12
13
14
15
16
17
18
19
20

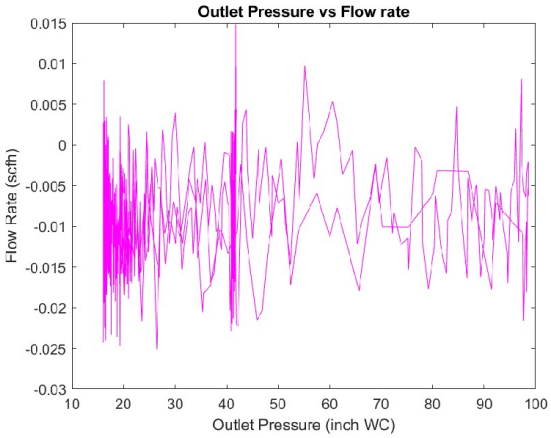
GTI ENERGY

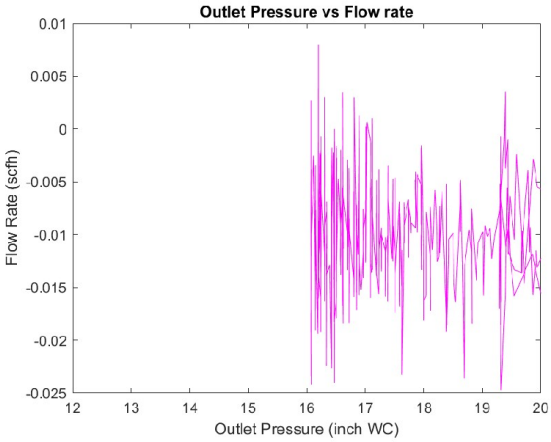
- **222489-008_LD**
  The volume of total emissions in 190.22 seconds is 0.0000 scf.
  The average flow rate of emissions at 18 inches WC is -0.01 scfh





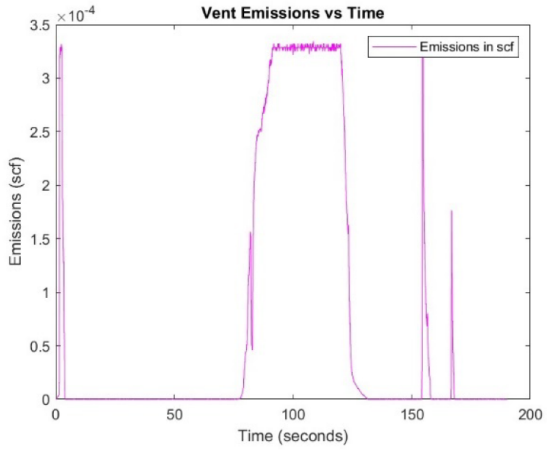
GTI ENERGY

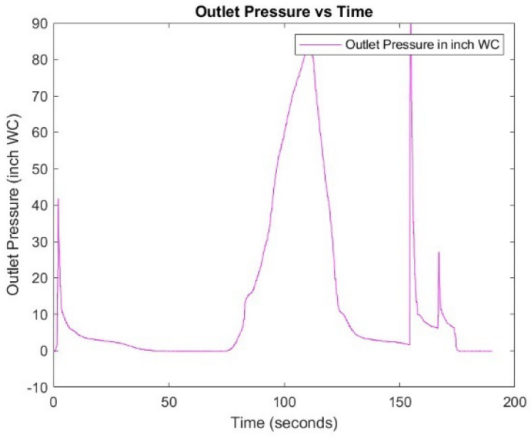

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0.015
0.01
0.005
0
-0.005
-0.01
-0.015
-0.02
-0.025
-0.03
10
20
30
40
50
60
70
80
90
100


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0.01
0.005
0
-0.005
-0.01
-0.015
-0.02
-0.025
12
13
14
15
16
17
18
19
20

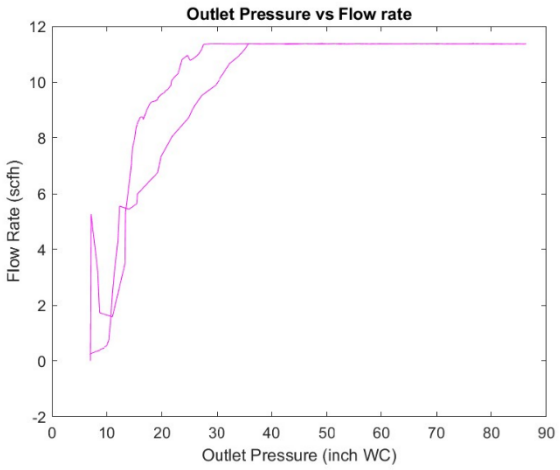
GTI ENERGY

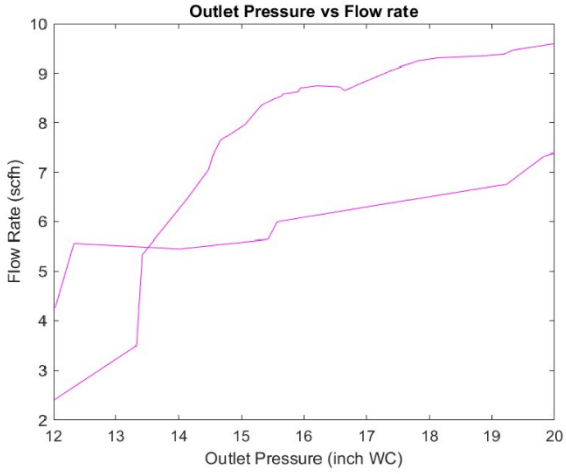
- **222489-009_2**
  The volume of total emissions in 190.31 seconds is 0.1337 scf.
  The average flow rate of emissions at 18 inches WC is 6.73 scfh.





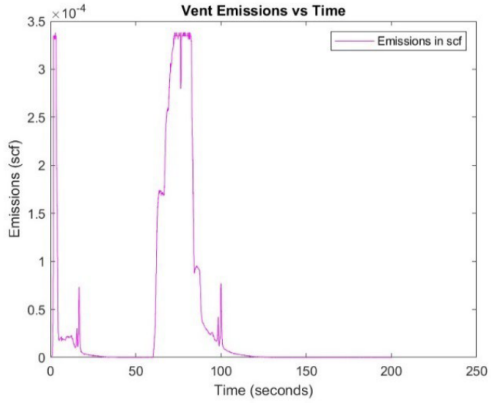
GTI ENERGY

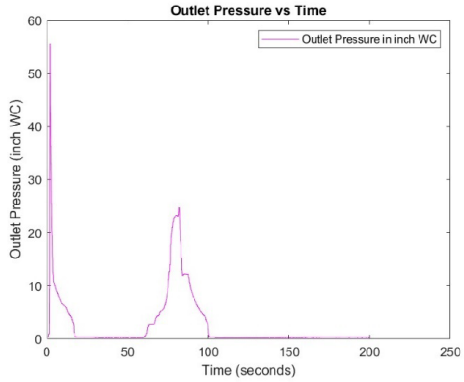

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
12
10
8
6
4
2
0
-2
0
10
20
30
40
50
60
70
80
90


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
10
9
8
7
6
5
4
3
2
12
13
14
15
16
17
18
19
20

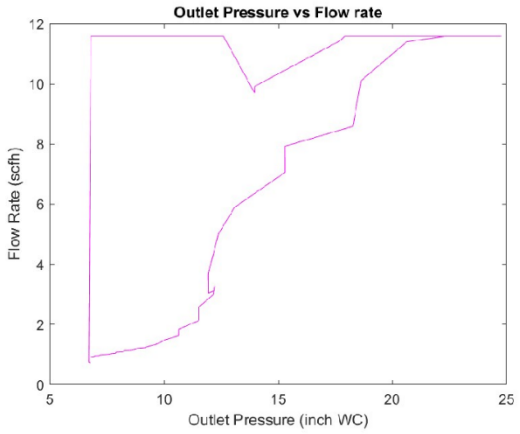
GTI ENERGY

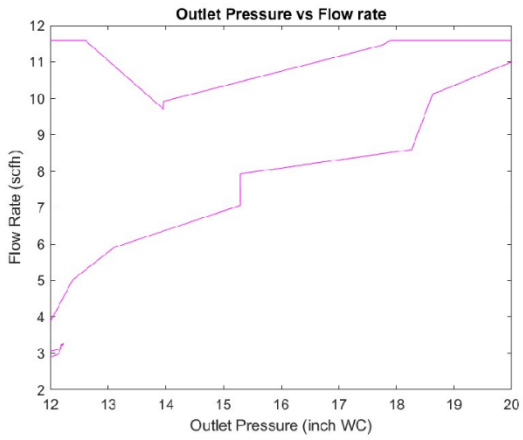
- **222489-009_DT1**
  The volume of total emissions in 200.50 seconds is 0.0764 scf.
  The average flow rate of emissions at 18 inches WC is 10.43 scfh.





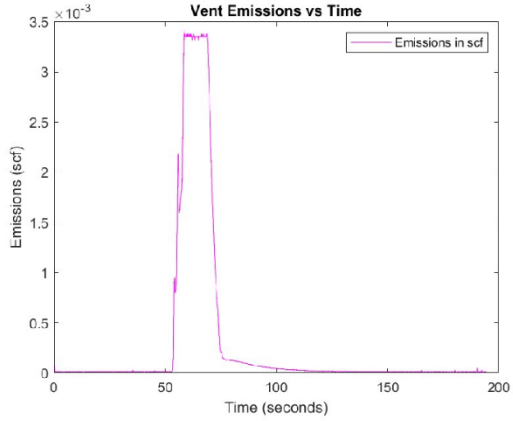
GTI ENERGY

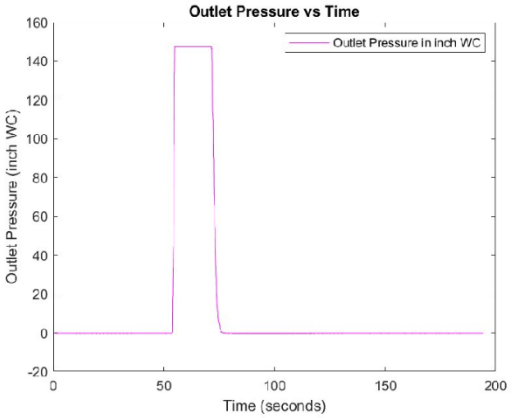

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
2
4
6
8
10
12
5
10
15
20
25


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
2
3
4
5
6
7
8
9
10
11
12
12
13
14
15
16
17
18
19
20

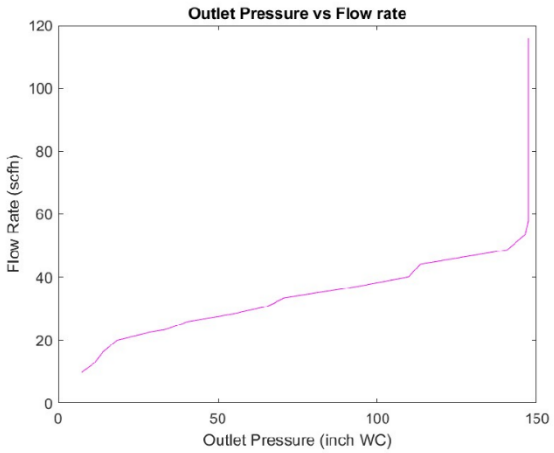
GTI ENERGY

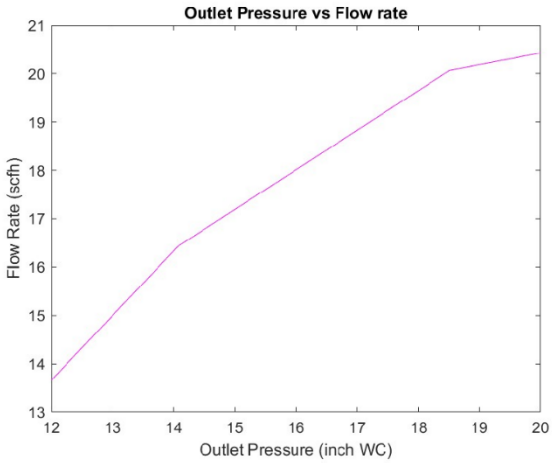
- **222489-009_DT2**
  The volume of total emissions in 194.43 seconds is 0.5482 scf.
  The average flow rate of emissions at 18 inches WC is 20.01 scfh.





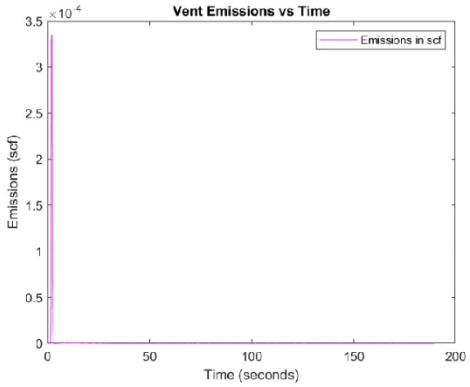
GTI ENERGY

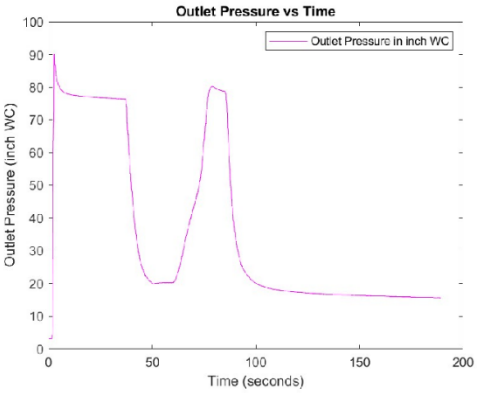

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
20
40
60
80
100
120
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
13
14
15
16
17
18
19
20
21
12
13
14
15
16
17
18
19
20

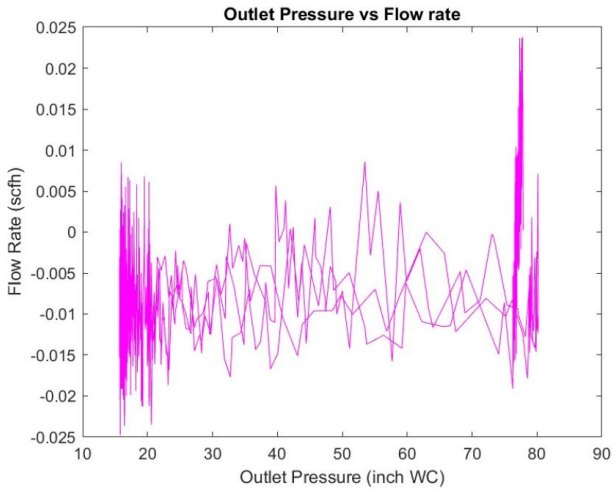
GTI ENERGY

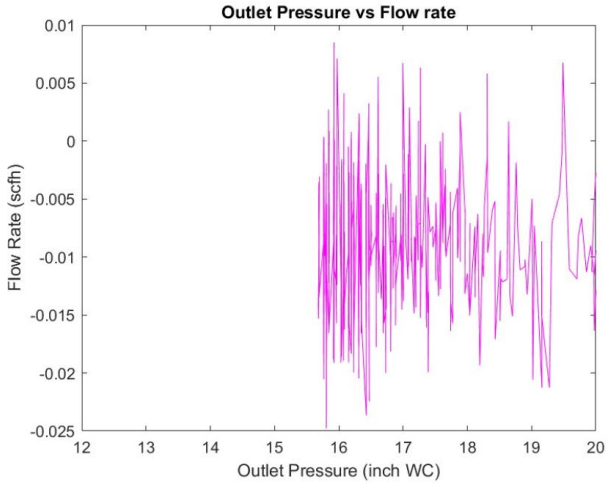
- **222489-009_LD**
  The volume of total emissions in 189.34 seconds is 0.0020 scf.
  The average flow rate of emissions at 18 inches WC is -0.01 scfh.





GTI ENERGY


Outlet Pressure vs Flow rate
Flow Rate (scfh)
0.025
0.02
0.015
0.01
0.005
0
-0.005
-0.01
-0.015
-0.02
-0.025
10
20
30
40
50
60
70
80
90
Outlet Pressure (inch WC)

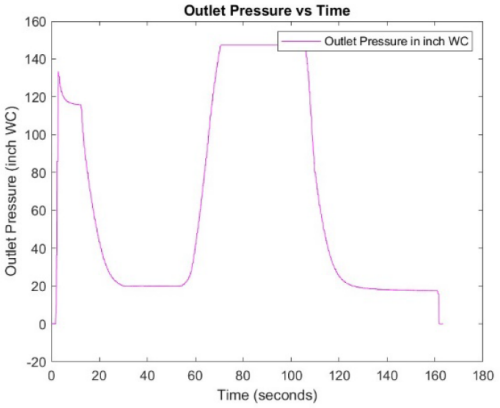

Outlet Pressure vs Flow rate
Flow Rate (scfh)
0.01
0.005
0
-0.005
-0.01
-0.015
-0.02
-0.025
12
13
14
15
16
17
18
19
20
Outlet Pressure (inch WC)

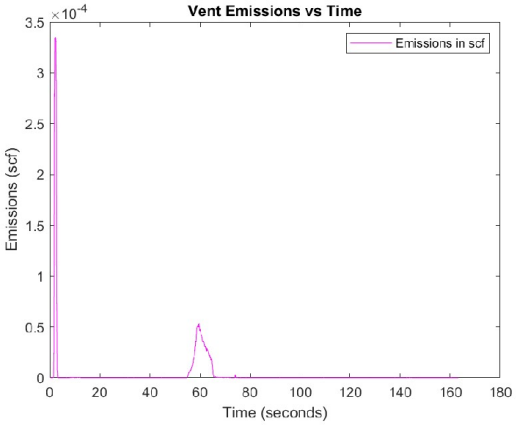
GTI ENERGY

2-psig Outlet, 10-psig Inlet

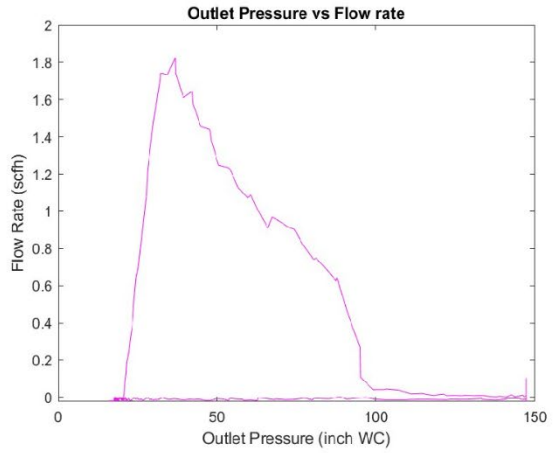
- **222489-010**

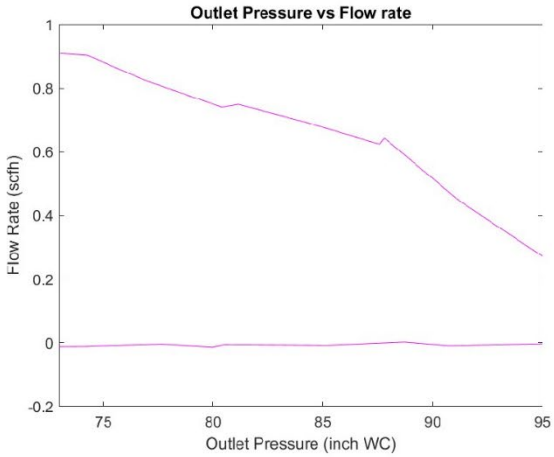
  The volume of total emissions in 163.29 seconds is 0.0053 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 0.21 scfh.



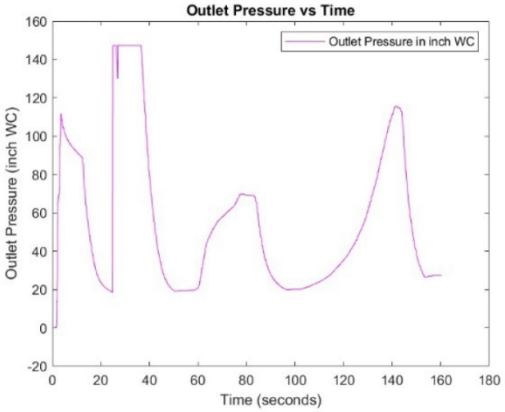


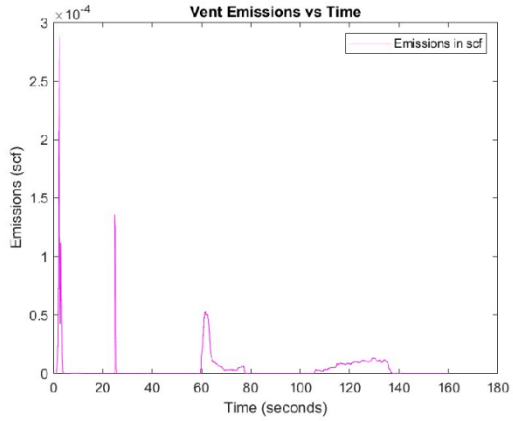
GTI ENERGY


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
0
50
100
150

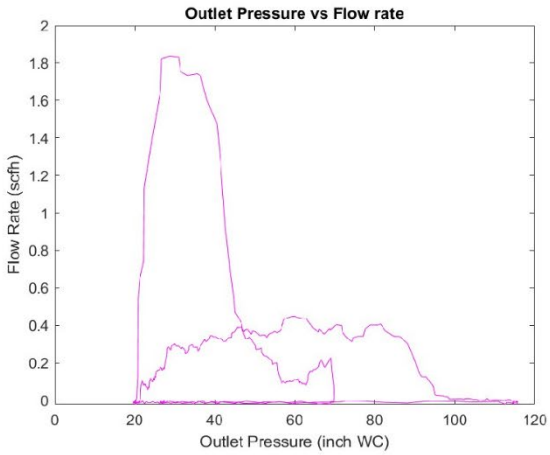

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
-0.2
0
0.2
0.4
0.6
0.8
1
75
80
85
90
95

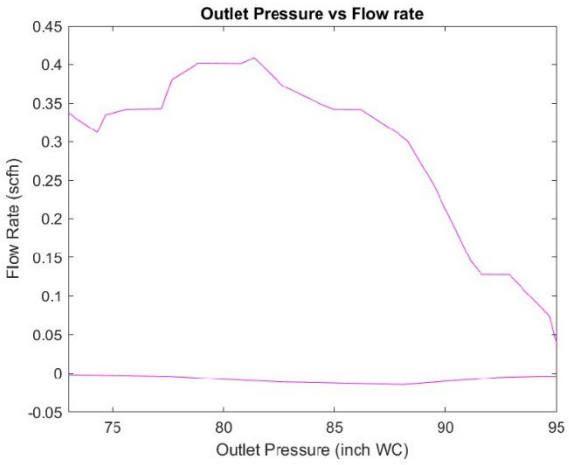
- **222489-010_LD**
  The volume of total emissions in 160.30 seconds is 0.0070 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 0.07 scfh.





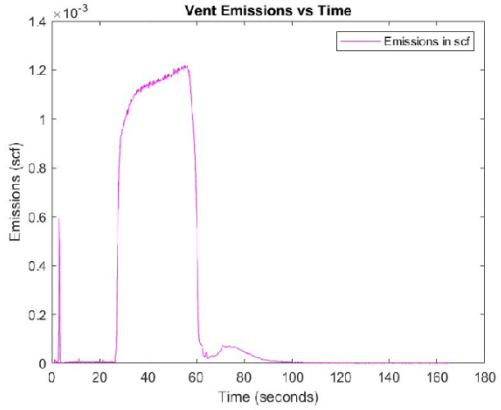
GTI ENERGY

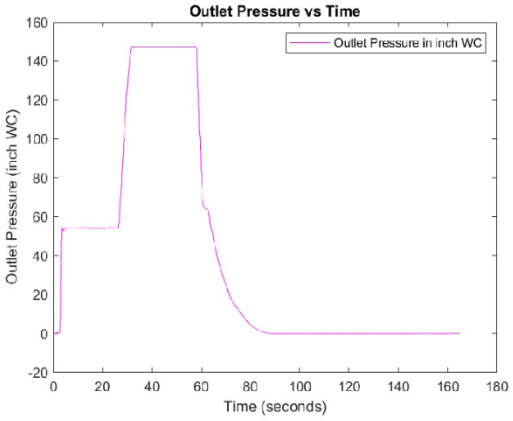

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
0
20
40
60
80
100
120


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
-0.05
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
75
80
85
90
95

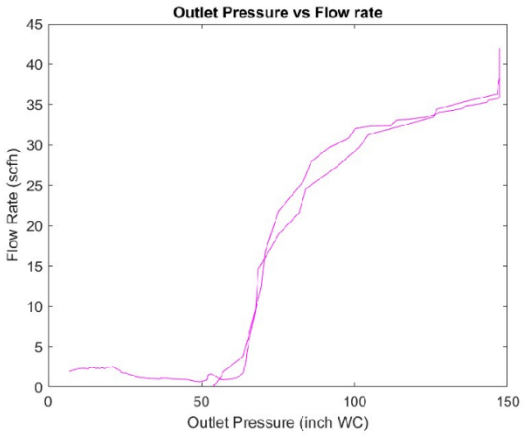
GTI ENERGY

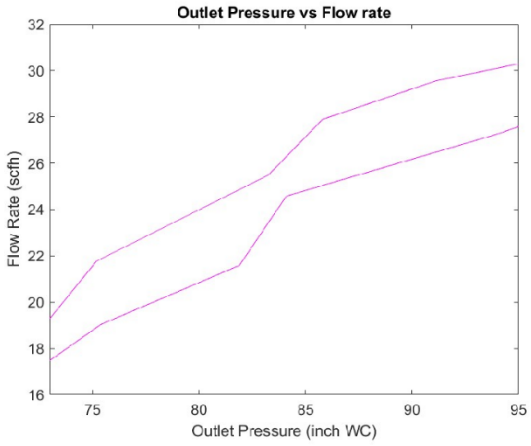
- **222489-010_DT1**
  The volume of total emissions in 165.28 seconds is 0.3710 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 29.56 scfh.





GTI ENERGY

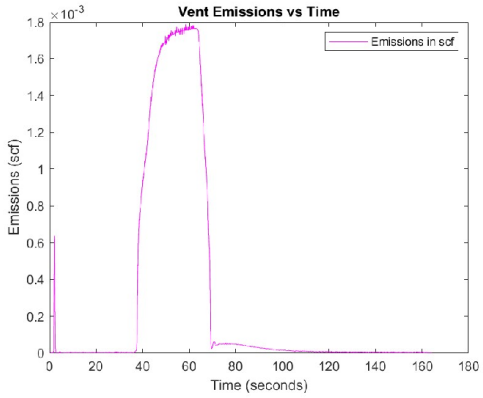

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
5
10
15
20
25
30
35
40
45
0
50
100
150

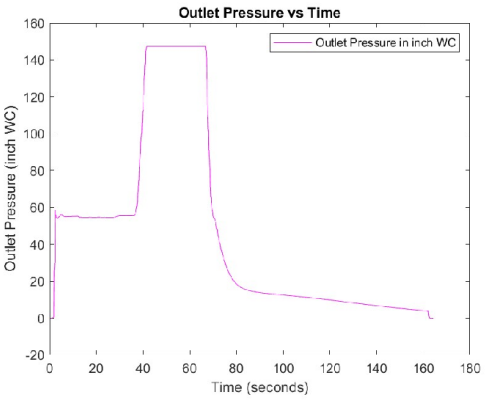

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
16
18
20
22
24
26
28
30
32
75
80
85
90
95

GTI ENERGY

- **222489-011_DT1**

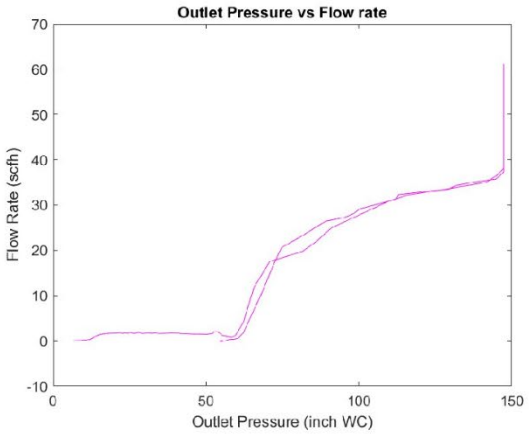
  The volume of total emissions in 164.34 seconds is 0.4605 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 24.67 scfh.

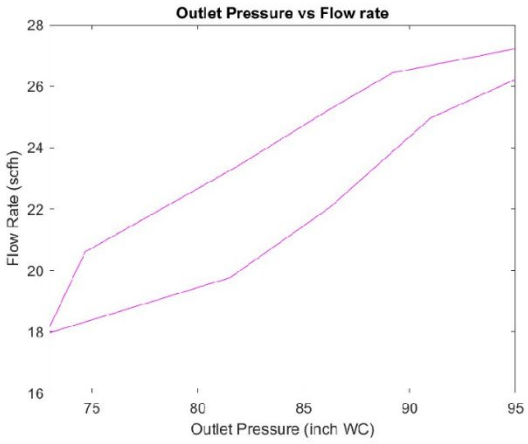




Commented [JW13]: Need to double check 2 psi diaphragm tear tests. May have exceeded flow meter range

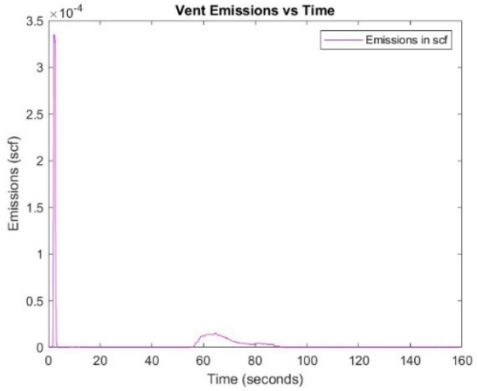
GTI ENERGY

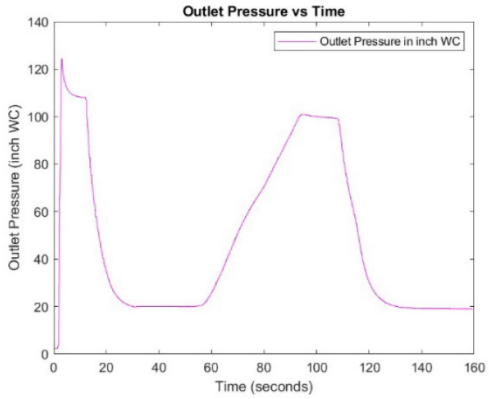

Outlet Pressure vs Flow rate
Flow Rate (scfh)
70
60
50
40
30
20
10
0
-10
0
50
100
150
Outlet Pressure (inch WC)


Outlet Pressure vs Flow rate
Flow Rate (scfh)
28
26
24
22
20
18
16
75
80
85
90
95
Outlet Pressure (inch WC)

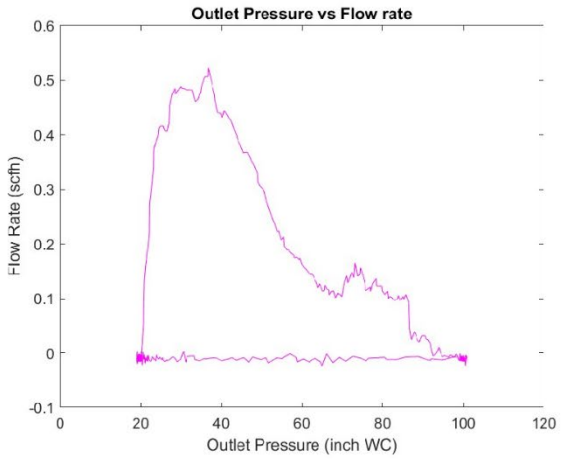
GTI ENERGY

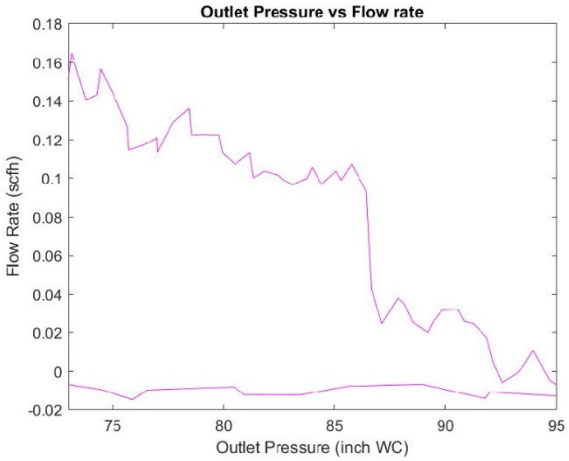
- **222489-011_LD**
  The volume of total emissions in 159.28 seconds is 0.0048 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 0.03 scfh.





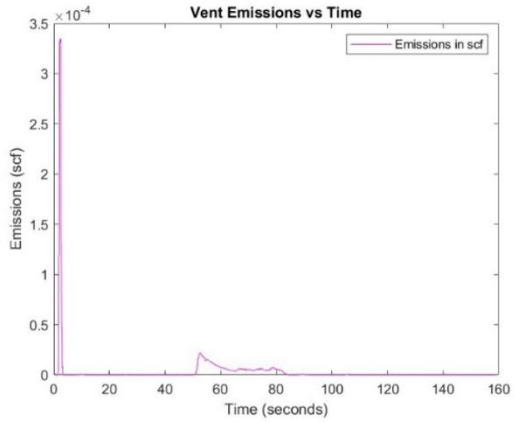
GTI ENERGY

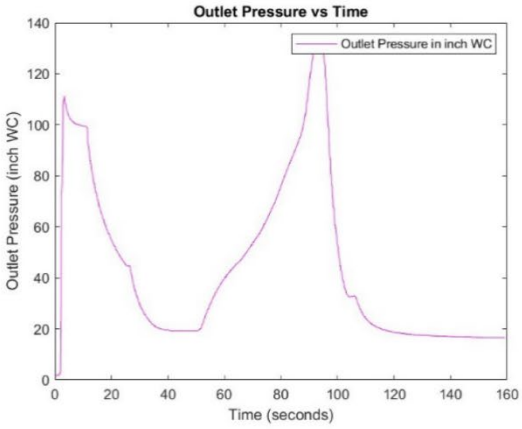

Outlet Pressure vs Flow rate
Flow Rate (scfh)
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
0
20
40
60
80
100
120
Outlet Pressure (inch WC)


Outlet Pressure vs Flow rate
Flow Rate (scfh)
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
-0.02
75
80
85
90
95
Outlet Pressure (inch WC)

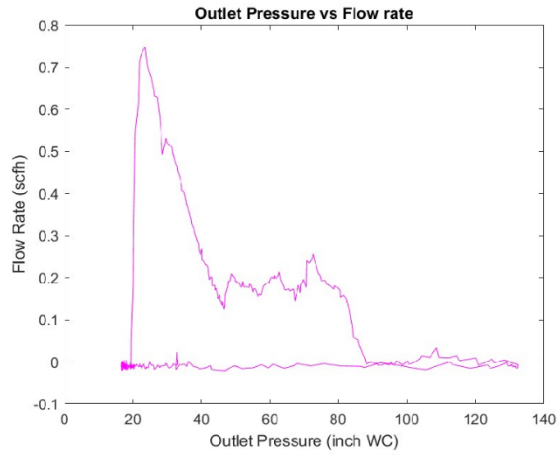
GTI ENERGY

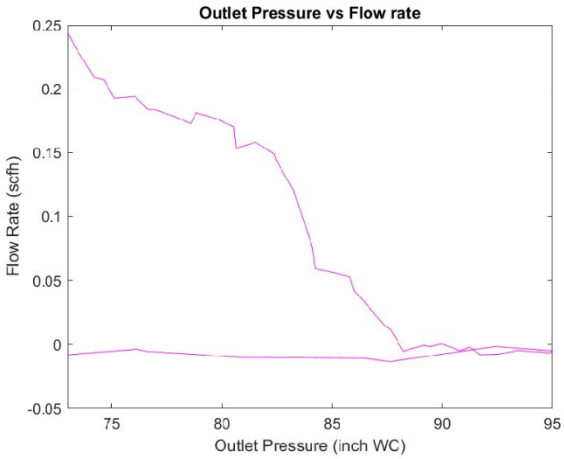
- **222489-012_LD**
  The volume of total emissions in 159.22 seconds is 0.0050 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 0.00 scfh.





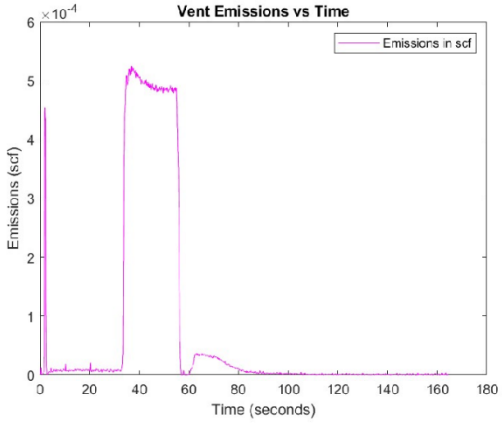
GTI ENERGY

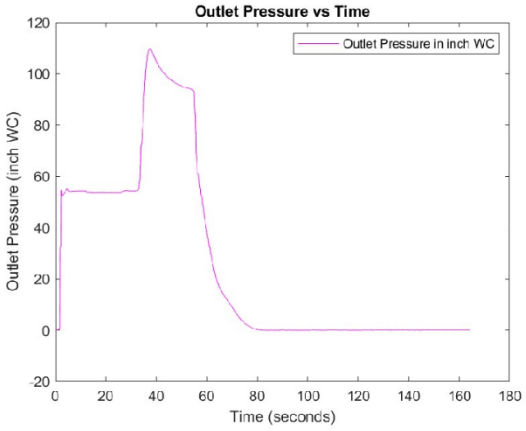

Outlet Pressure vs Flow rate
Flow Rate (scfh)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
0
20
40
60
80
100
120
140
Outlet Pressure (inch WC)


Outlet Pressure vs Flow rate
Flow Rate (scfh)
0.25
0.2
0.15
0.1
0.05
0
-0.05
75
80
85
90
95
Outlet Pressure (inch WC)

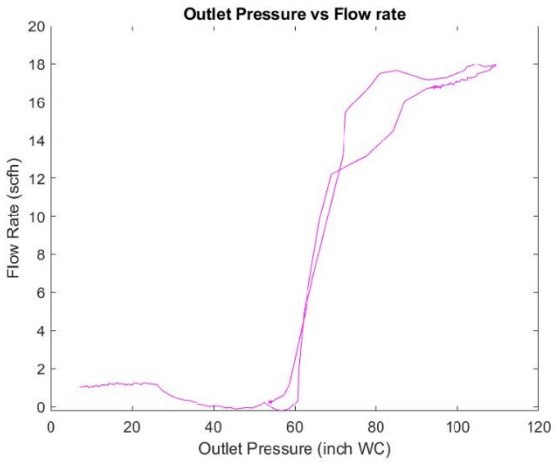
GTI ENERGY

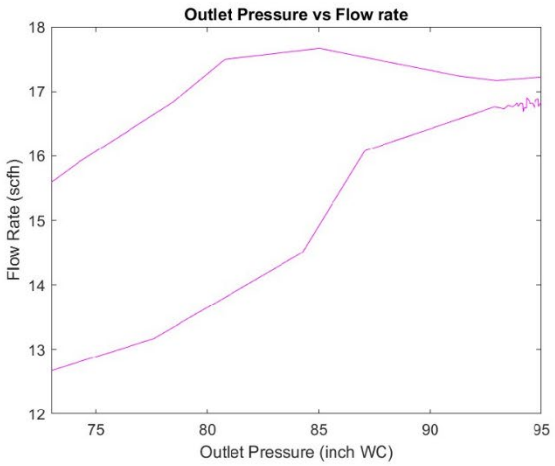
- **222489-012_DT1**
  The volume of total emissions in 164.34 seconds is 0.1163 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 16.65 scfh.





GTI ENERGY


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
2
4
6
8
10
12
14
16
18
20
0
20
40
60
80
100
120


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
12
13
14
15
16
17
18
75
80
85
90
95

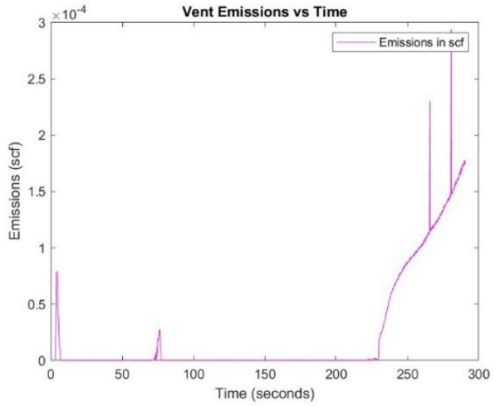
GTI ENERGY

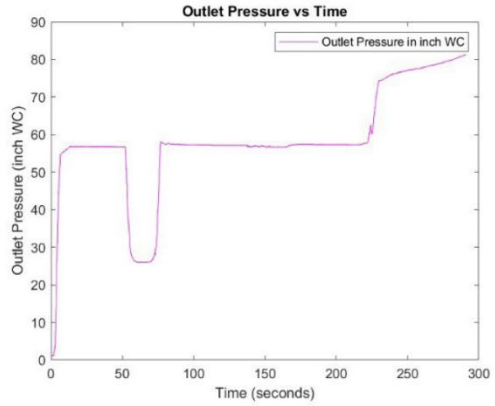
2-psig Outlet, 60-psig Inlet

- 222489-010

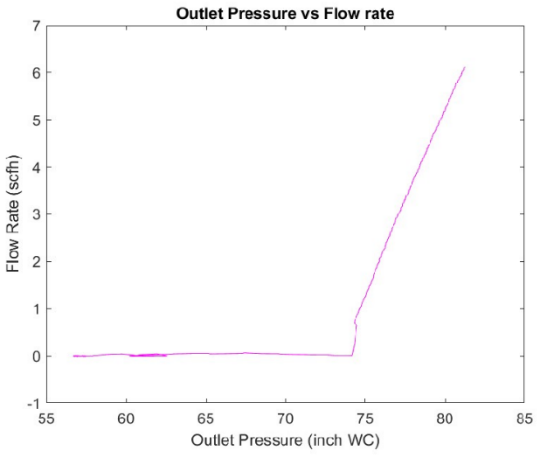
The volume of total emissions in 290.52 seconds is 0.0624 scf.

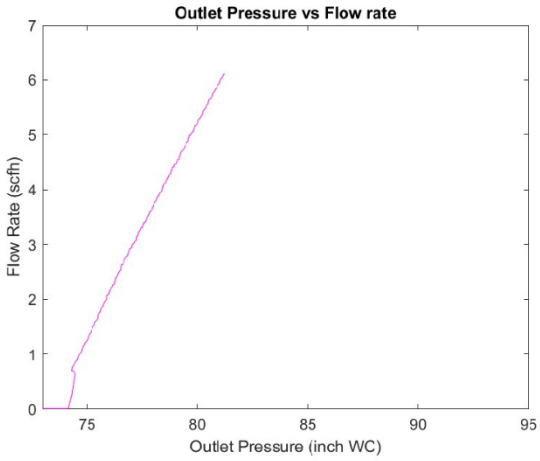
Commented [JW14]: No data within range to calculate avg





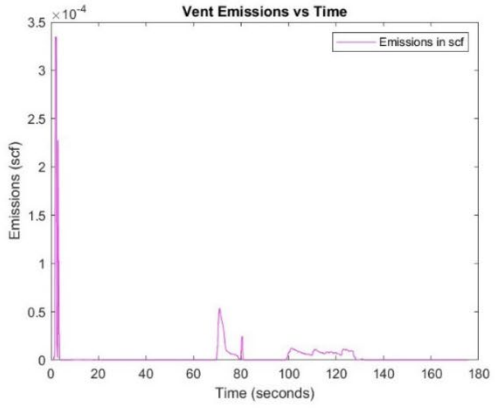
GTI ENERGY

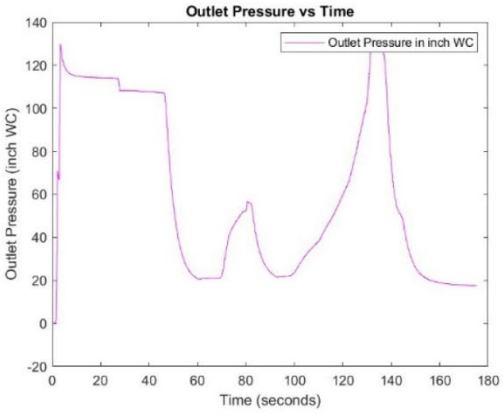

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
7
6
5
4
3
2
1
0
-1
55
60
65
70
75
80
85


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
7
6
5
4
3
2
1
0
75
80
85
90
95

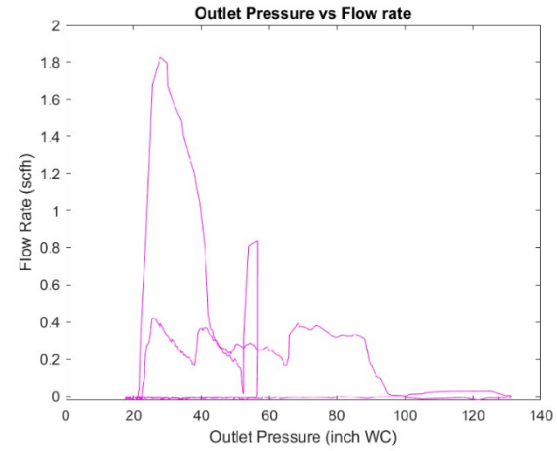
GTI ENERGY

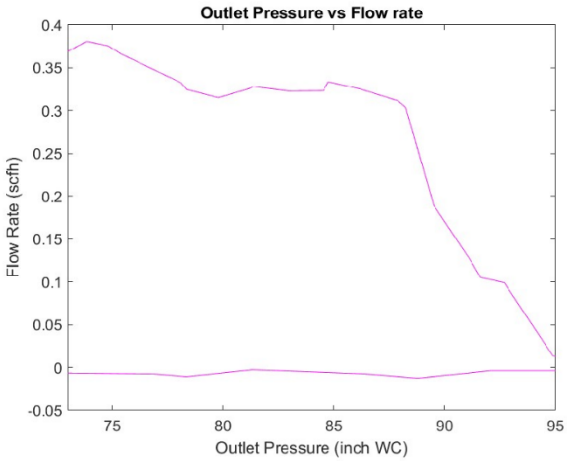
- **222489-010_LD**
  The volume of total emissions in 175.34 seconds is 0.0068 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 0.15 scfh.





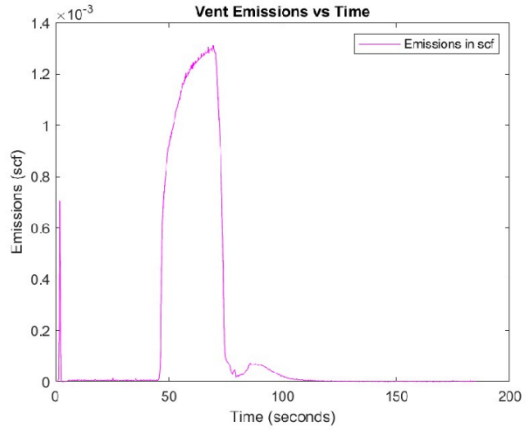
GTI ENERGY

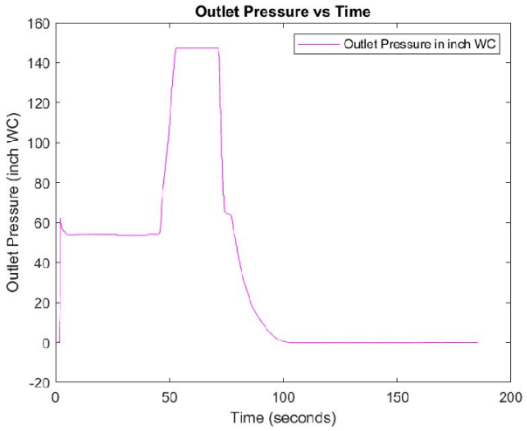

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
0
20
40
60
80
100
120
140


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
-0.05
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
75
80
85
90
95

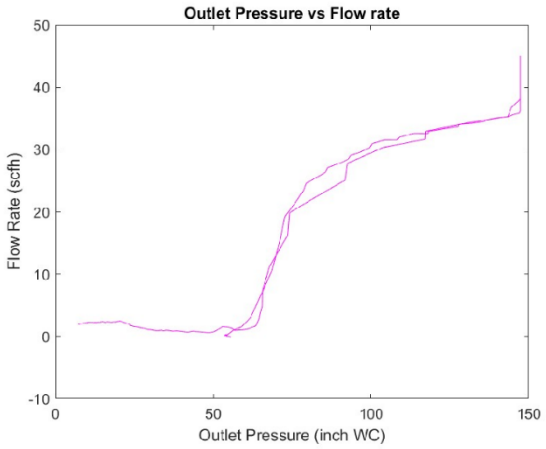
GTI ENERGY

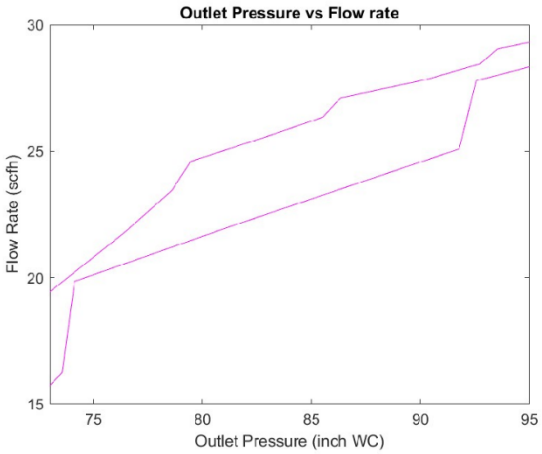
- **222489-010_DT1**
  The volume of total emissions in 185.40 seconds is 0.3126 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 27.47 scfh.





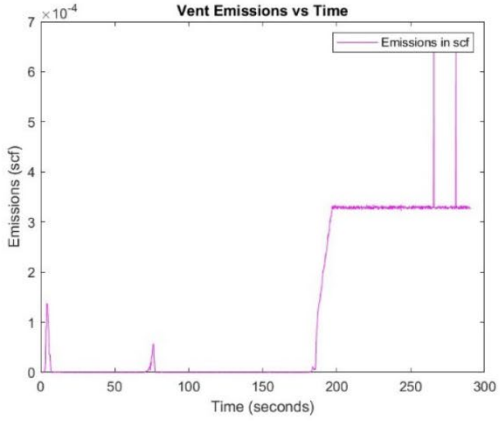
GTI ENERGY

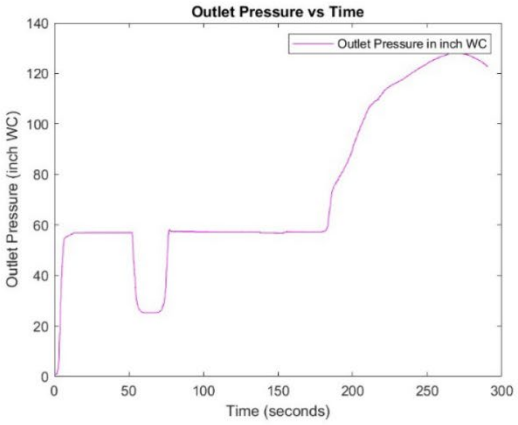

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
50
40
30
20
10
0
-10
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
30
25
20
15
75
80
85
90
95

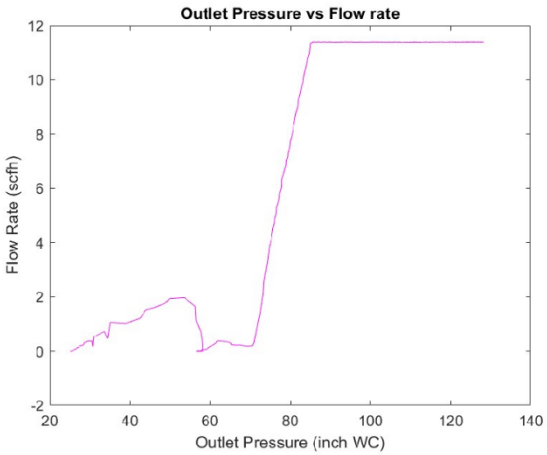
GTI ENERGY

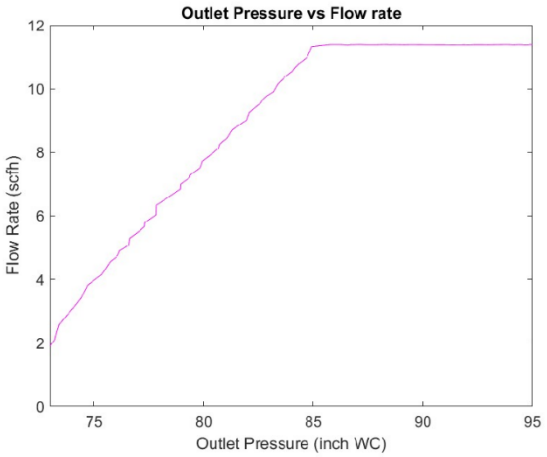
- **222489-011**
  The volume of total emissions in 290.60 seconds is 0.3223 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 11.39 scfh.





GTI ENERGY


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
12
10
8
6
4
2
0
-2
20
40
60
80
100
120
140

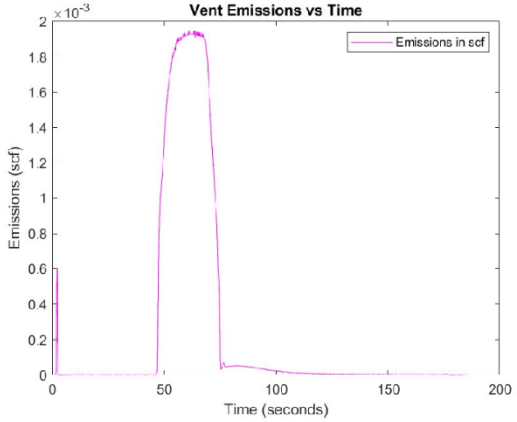

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
12
10
8
6
4
2
0
75
80
85
90
95

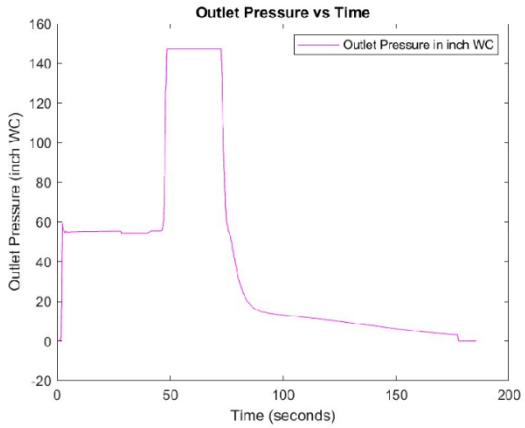
GTI ENERGY

- **222489-011_DT1**

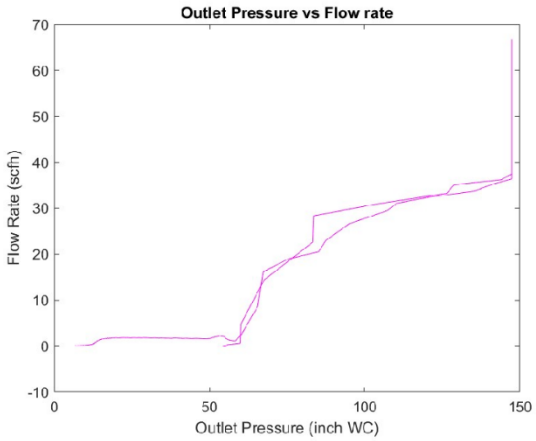
The volume of total emissions in 185.43 seconds is 0.4474 scf.
The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 23.07 scfh.

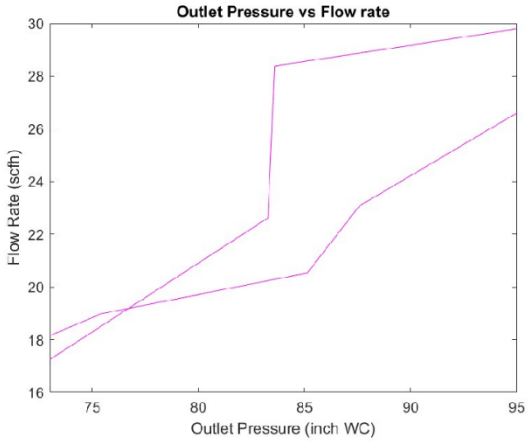
Commented [JW15]: Need to double check 2 psi diaphragm tear tests. May have exceeded flow meter range





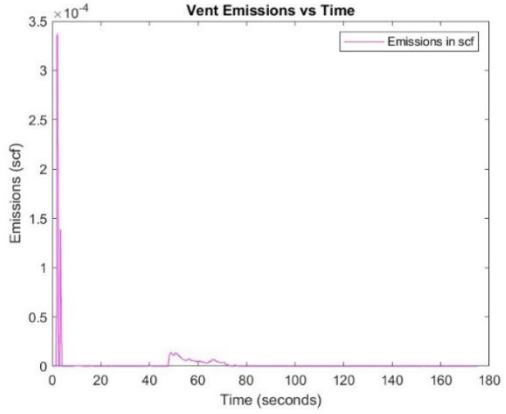
GTI ENERGY

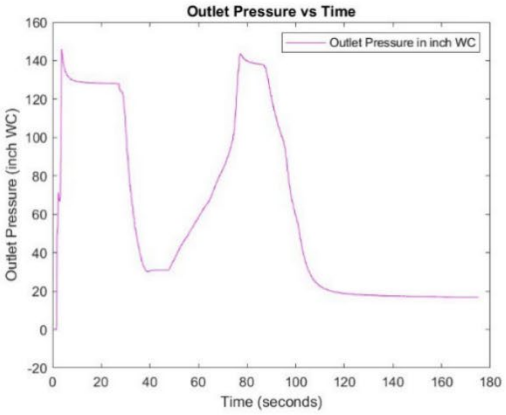

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
70
60
50
40
30
20
10
0
-10
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
30
28
26
24
22
20
18
16
75
80
85
90
95

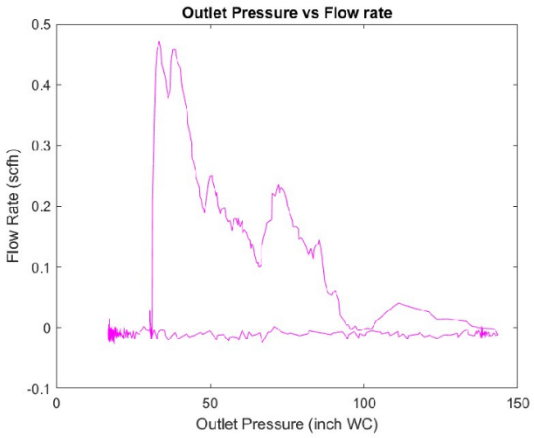
GTI ENERGY

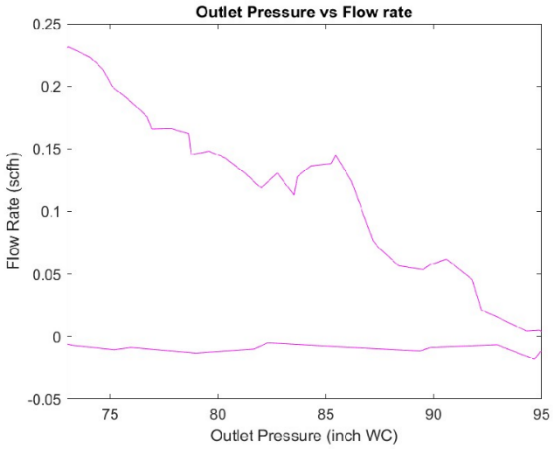
- **222489-011_LD**
  The volume of total emissions in 175.32 seconds is 0.0040 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 0.40 scfh.





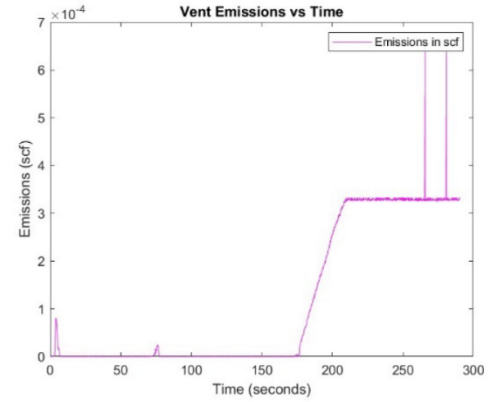
GTI ENERGY

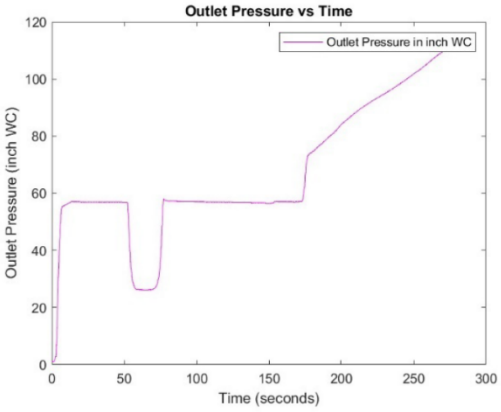

Outlet Pressure vs Flow rate
Flow Rate (scfh)
0.5
0.4
0.3
0.2
0.1
0
-0.1
0
50
100
150
Outlet Pressure (inch WC)


Outlet Pressure vs Flow rate
Flow Rate (scfh)
0.25
0.2
0.15
0.1
0.05
0
-0.05
75
80
85
90
95
Outlet Pressure (inch WC)

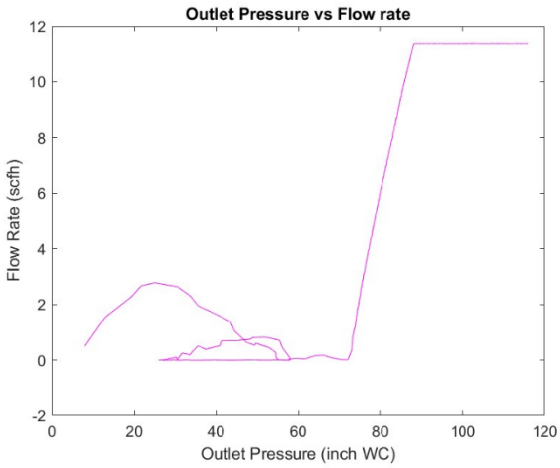
GTI ENERGY

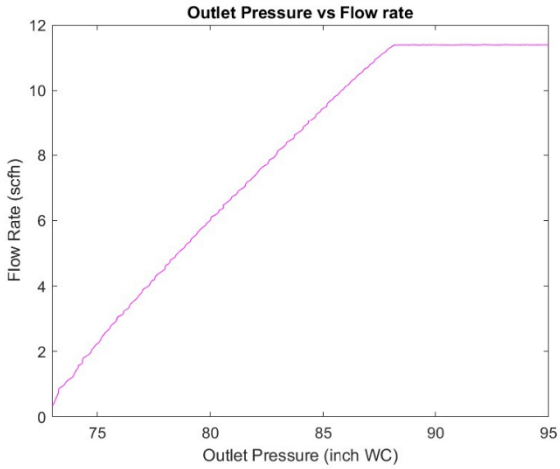
- **222489-012**
  The volume of total emissions in 290.55 seconds is 0.3159 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 11.14 scfh.





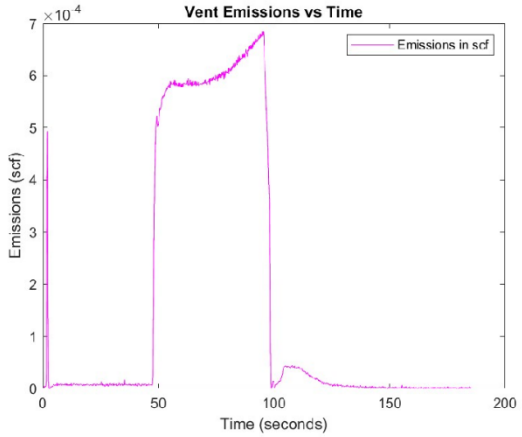
GTI ENERGY

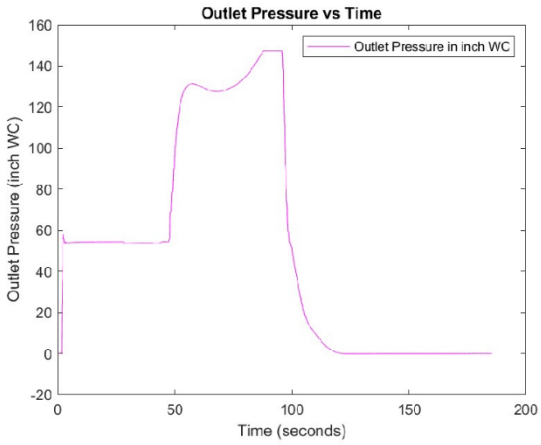

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
12
10
8
6
4
2
0
-2
0
20
40
60
80
100
120


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
12
10
8
6
4
2
0
75
80
85
90
95

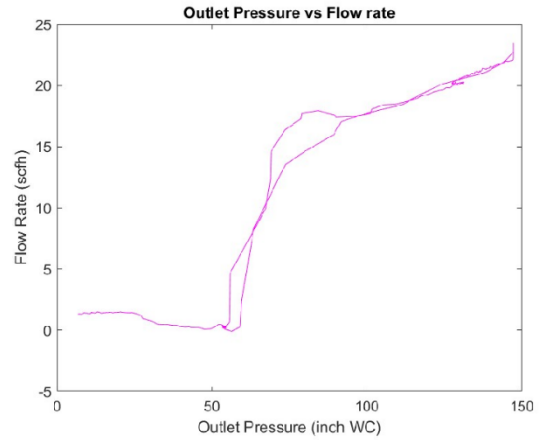
GTI ENERGY

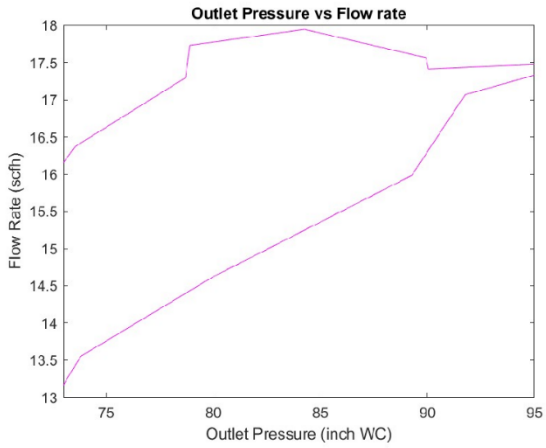
- **222489-012_DT1**
  The volume of total emissions in 185.40 seconds is 0.2997 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 16.98 scfh.





GTI ENERGY


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
25
20
15
10
5
0
-5
0
50
100
150

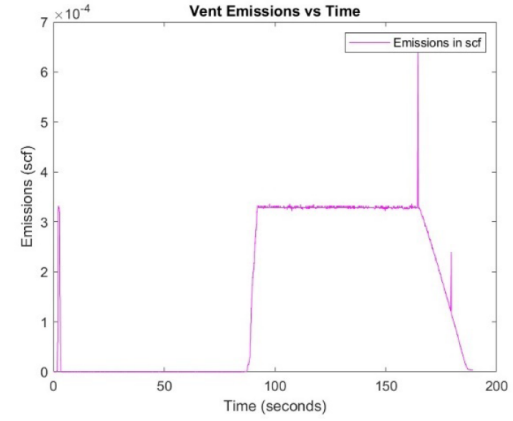

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
18
17.5
17
16.5
16
15.5
15
14.5
14
13.5
13
75
80
85
90
95

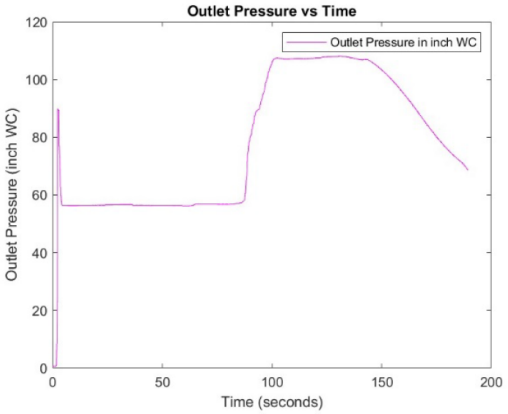
GTI ENERGY

2-psig Outlet, 100-psig Inlet

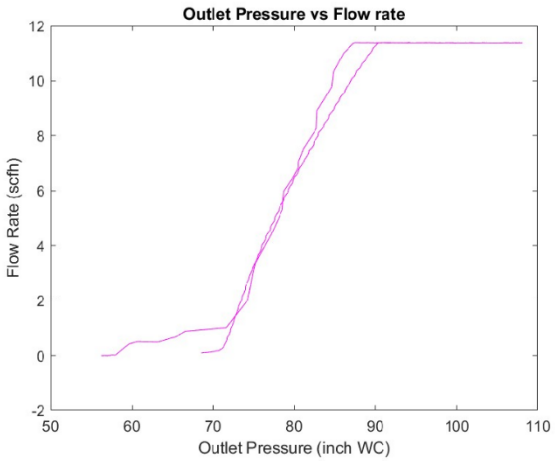
- **222489-010**

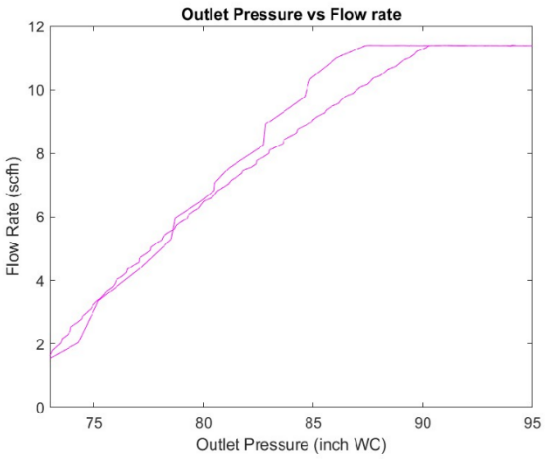
  The volume of total emissions in 189.41 seconds is 0.2768 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 10.95 scfh.





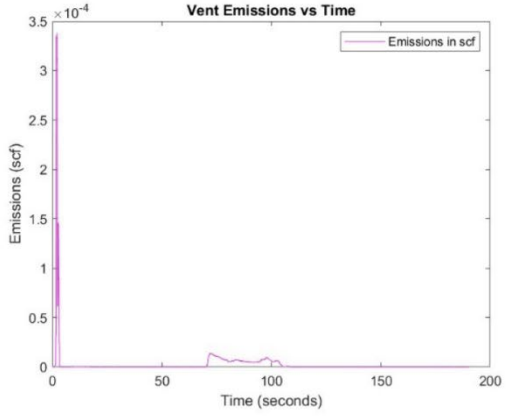
GTI ENERGY

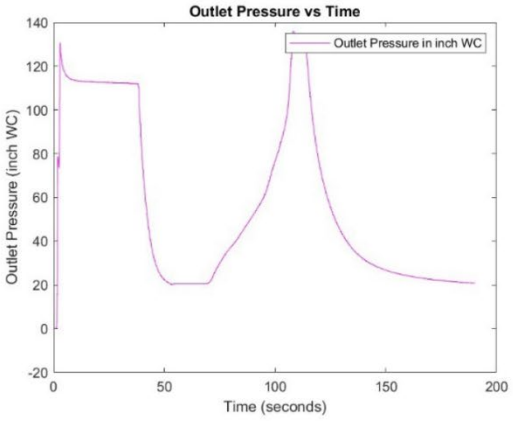

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
12
10
8
6
4
2
0
-2
50
60
70
80
90
100
110


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
12
10
8
6
4
2
0
75
80
85
90
95

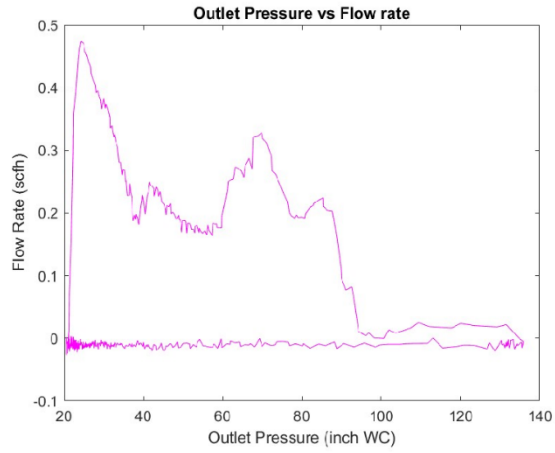
GTI ENERGY

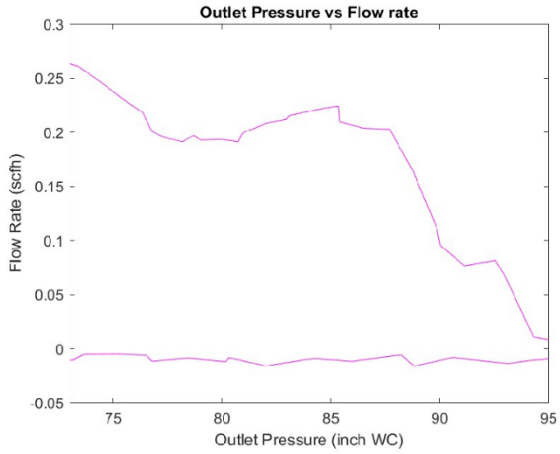
- **222489-010_LD**
  The volume of total emissions in 190.29 seconds is 0.0050 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 0.08 scfh.





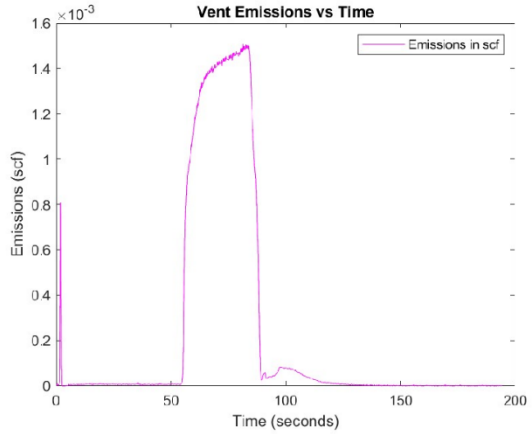
GTI ENERGY

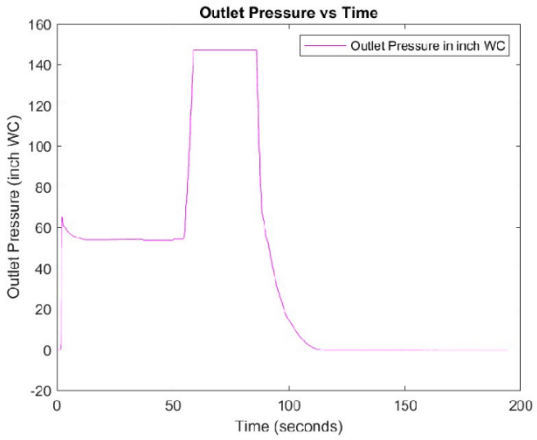

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0.5
0.4
0.3
0.2
0.1
0
-0.1
20
40
60
80
100
120
140


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
75
80
85
90
95

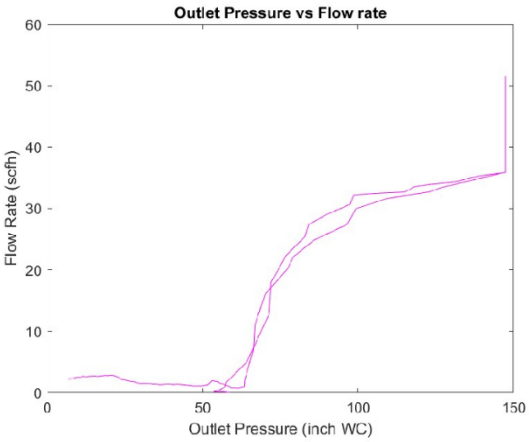
GTI ENERGY

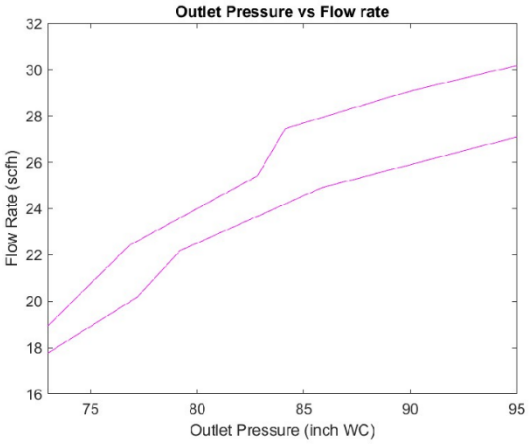
- **222489-010_DT1**
  The volume of total emissions in 194.45 seconds is 0.4280 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 29.06 scfh.





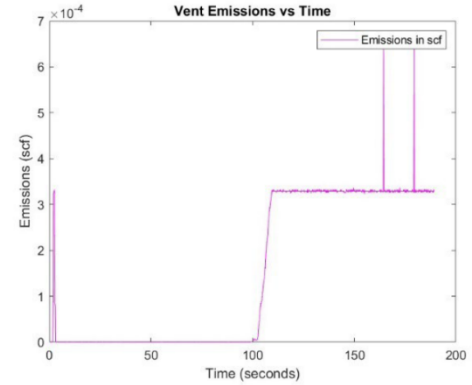
GTI ENERGY

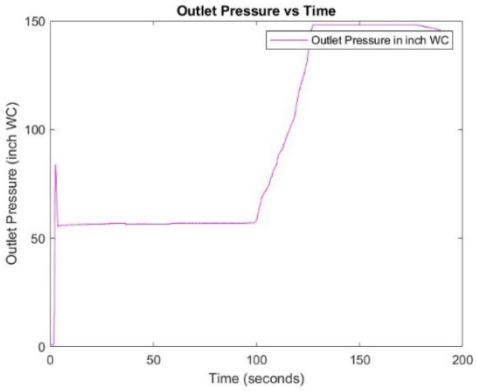

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
10
20
30
40
50
60
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
16
18
20
22
24
26
28
30
32
75
80
85
90
95

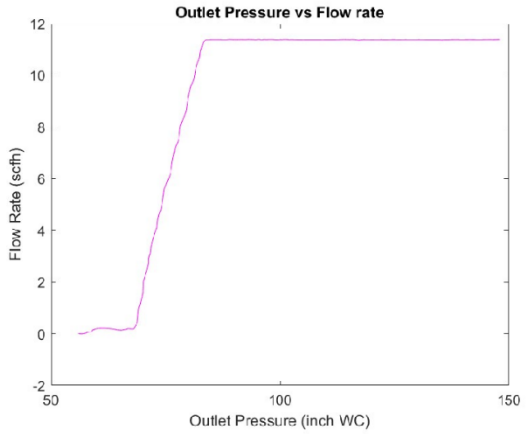
GTI ENERGY

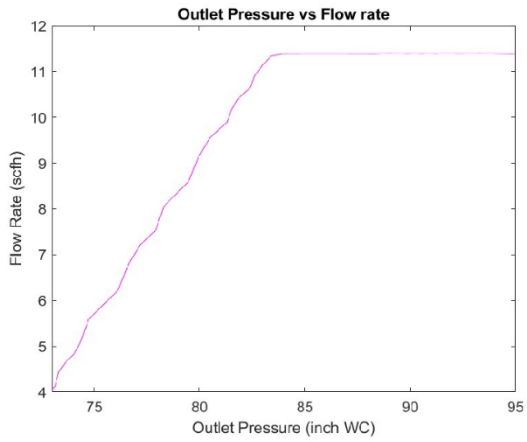
- **222489-011**
  The volume of total emissions in 189.40 seconds is 0.2671 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 11.39 scfh.





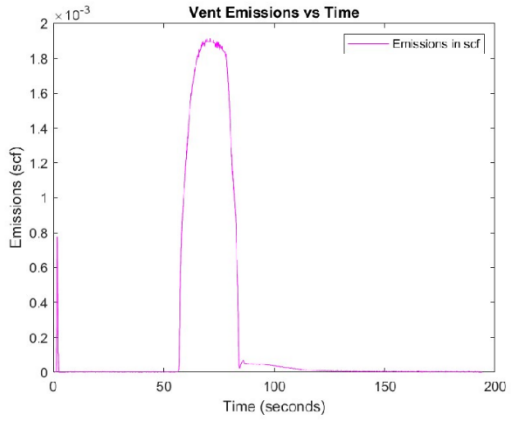
GTI ENERGY

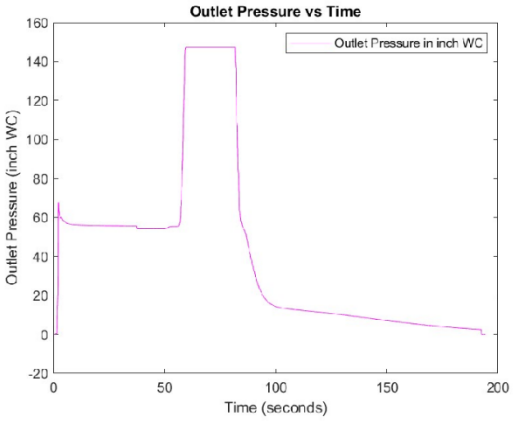

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
12
10
8
6
4
2
0
-2
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
12
11
10
9
8
7
6
5
4
75
80
85
90
95

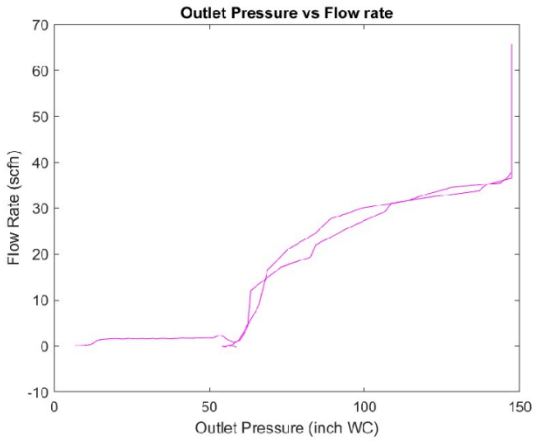
GTI ENERGY

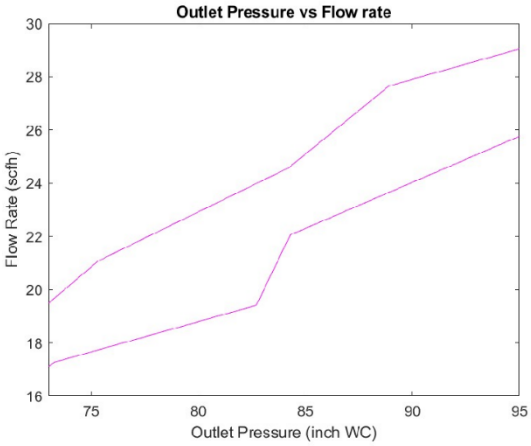
- **222489-011_DT1**
  The volume of total emissions in 194.34 seconds is 0.4173 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 27.66 scfh.





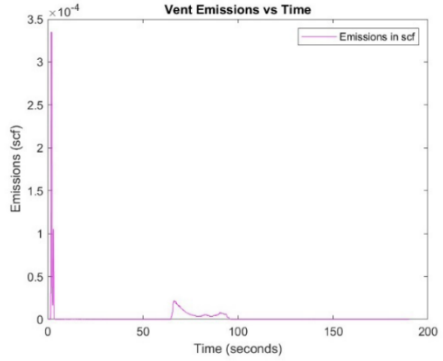
GTI ENERGY

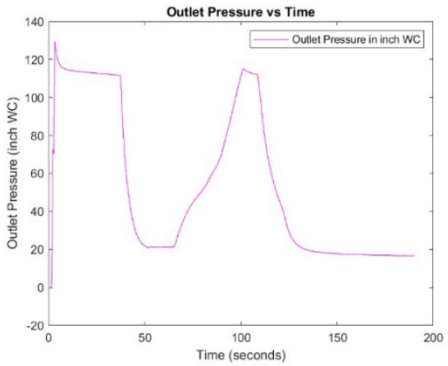

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
70
60
50
40
30
20
10
0
-10
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
30
28
26
24
22
20
18
16
75
80
85
90
95

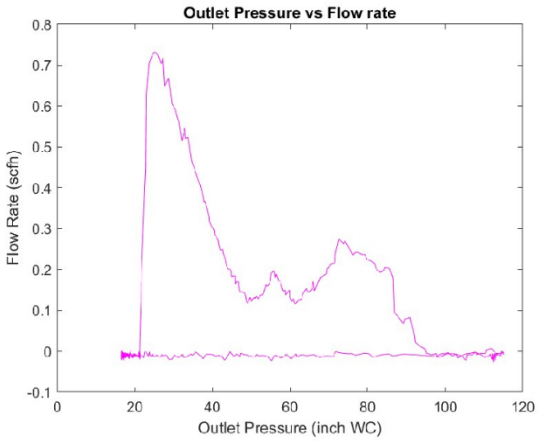
GTI ENERGY

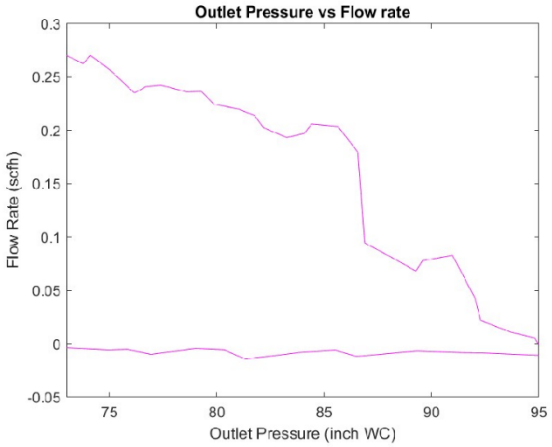
- **222489-011_LD**
  The volume of total emissions in 190.34 seconds is 0.0045 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 0.35 scfh





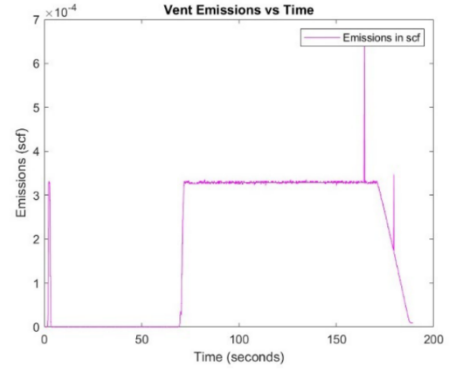
GTI ENERGY

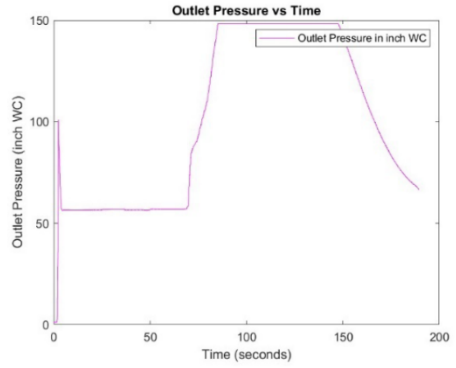

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
0
20
40
60
80
100
120


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
75
80
85
90
95

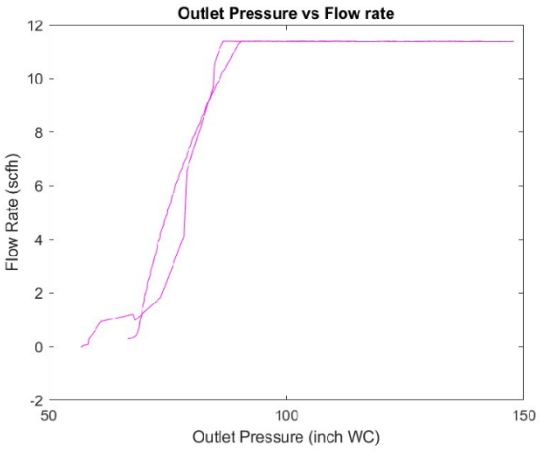
GTI ENERGY

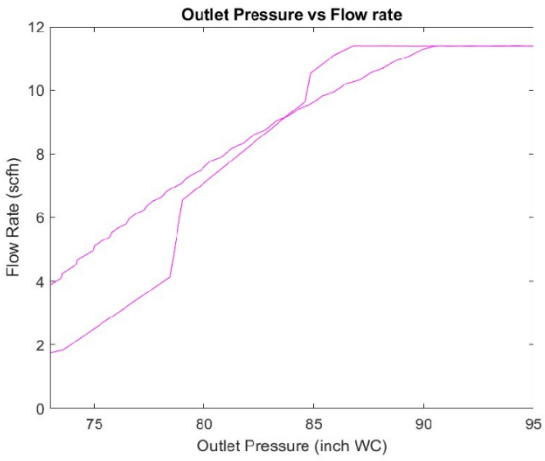
- **222489-012**
  The volume of total emissions in 189.37 seconds is 0.3482 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 11.07 scfh.





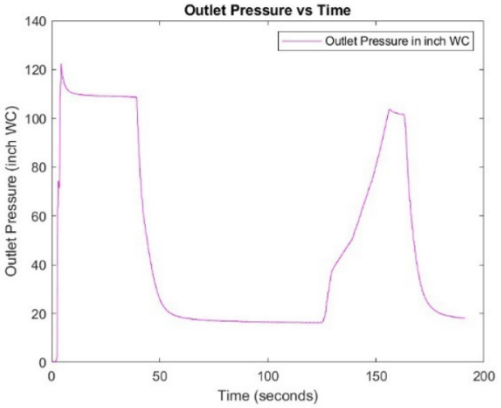
GTI ENERGY

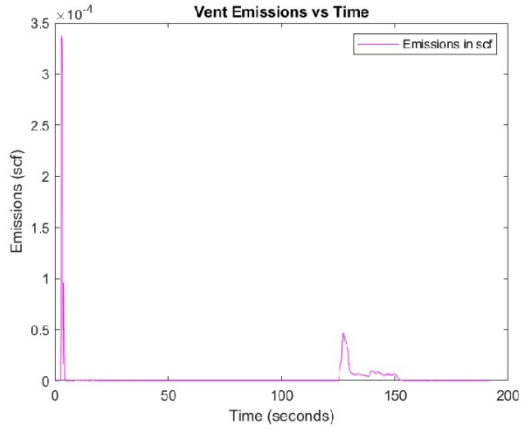

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
12
10
8
6
4
2
0
-2
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
12
10
8
6
4
2
0
75
80
85
90
95

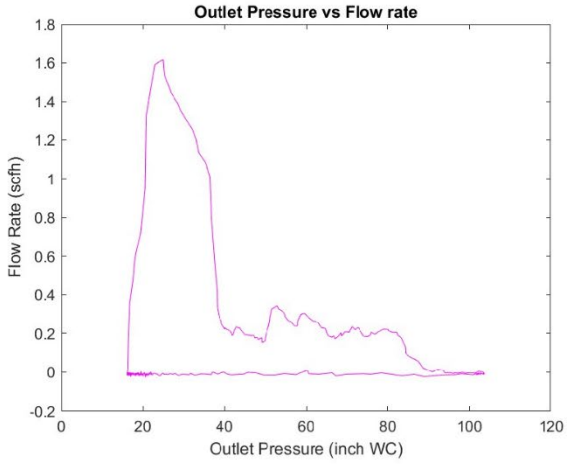
GTI ENERGY

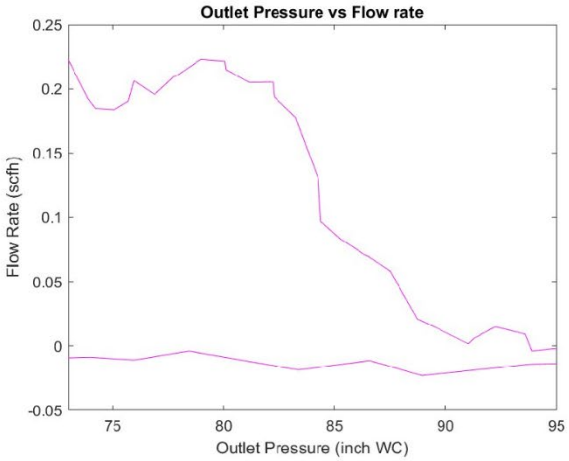
- **222489-012_LD**
  The volume of total emissions in 191.25 seconds is 0.0052 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 0.02 scfh.





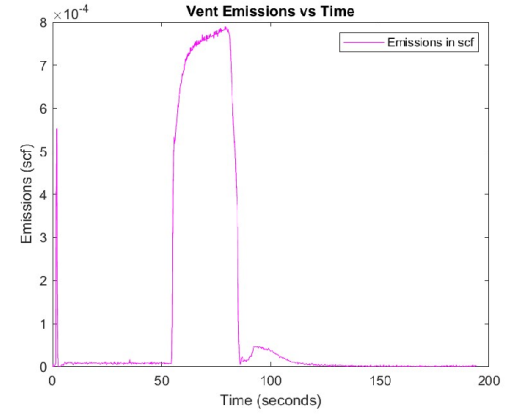
GTI ENERGY

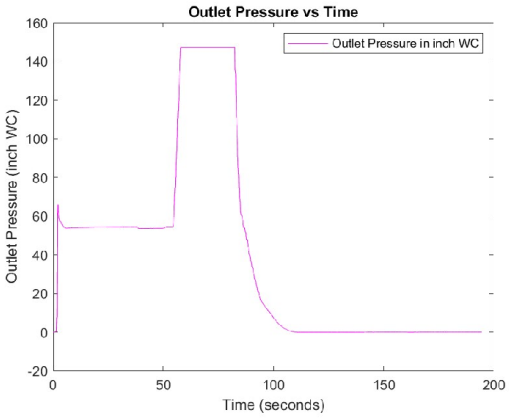

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
0
20
40
60
80
100
120


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0.25
0.2
0.15
0.1
0.05
0
-0.05
75
80
85
90
95

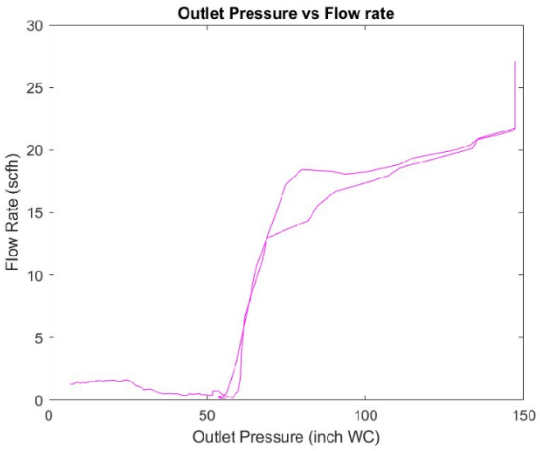
GTI ENERGY

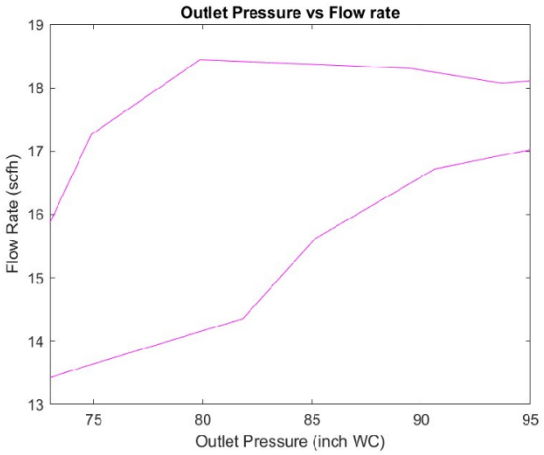
- **222489-012_DT1**
  The volume of total emissions in 194.47 seconds is 0.2174 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 17.51 scfh.





GTI ENERGY


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
5
10
15
20
25
30
0
50
100
150

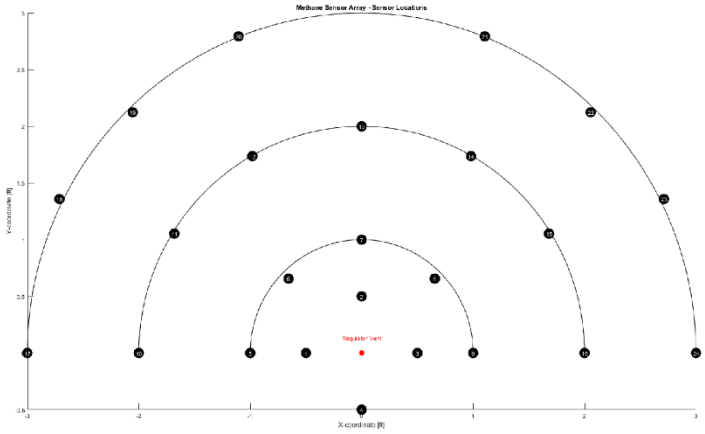

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
13
14
15
16
17
18
19
75
80
85
90
95

GTI ENERGY

Methane Concentration Maps

Sensor Locations

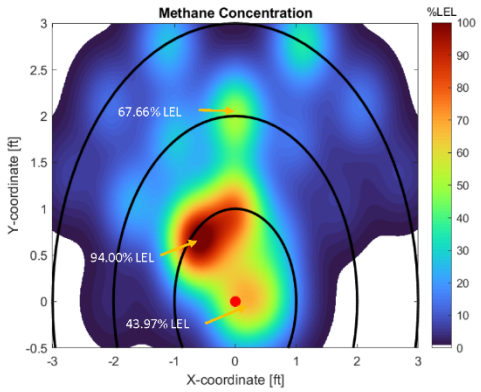
Commented [JW16]: Added sensor locations



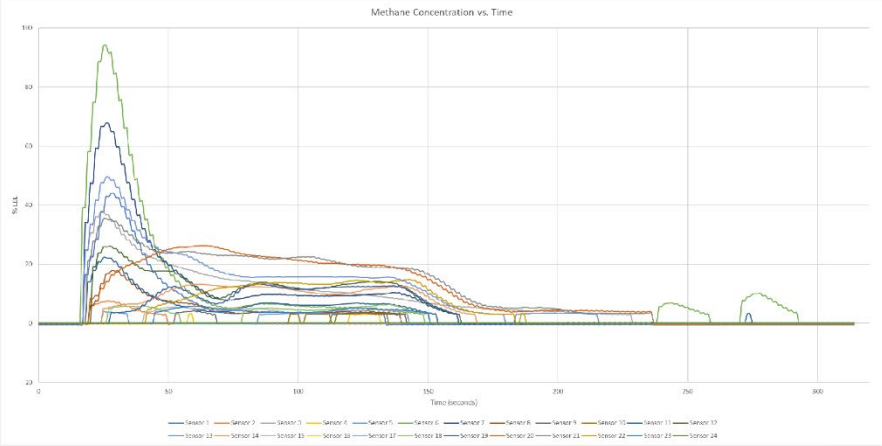
GTI ENERGY

7" WC Outlet

	7 in-WC	222489-009_DT1_sensor1 next to vent	Sigma = .34
VL5	Primary Diaphragm Tear	Standard Array Configuration	1 in from vent

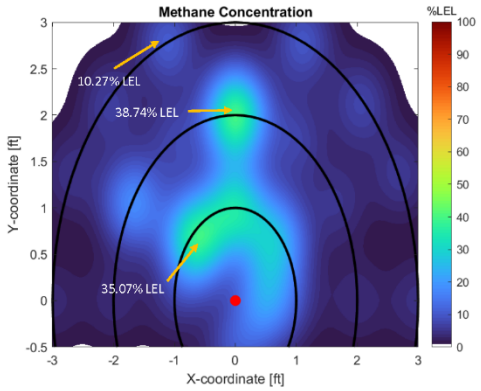


GTI ENERGY


Methane Concentration vs. Time
100
80
60
40
20
0
%LEL
0
50
100
150
200
250
300
Time (seconds)
Sensor 1
Sensor 2
Sensor 3
Sensor 4
Sensor 5
Sensor 6
Sensor 7
Sensor 8
Sensor 9
Sensor 10
Sensor 11
Sensor 12
Sensor 13
Sensor 14
Sensor 15
Sensor 16
Sensor 17
Sensor 18
Sensor 19
Sensor 20
Sensor 21
Sensor 22
Sensor 23
Sensor 24

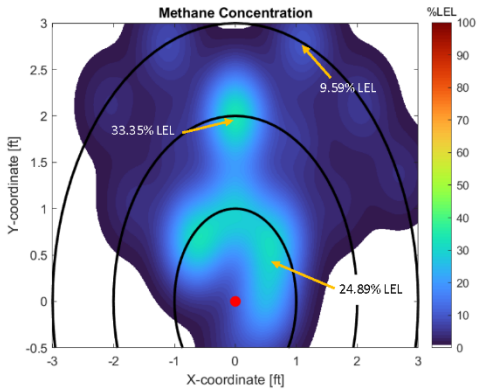
GTI ENERGY

	7 in-WC	222489-009_DT1_2	Sigma = .35
VL5	Primary Diaphragm Tear	Standard Array Configuration	6 in from vent



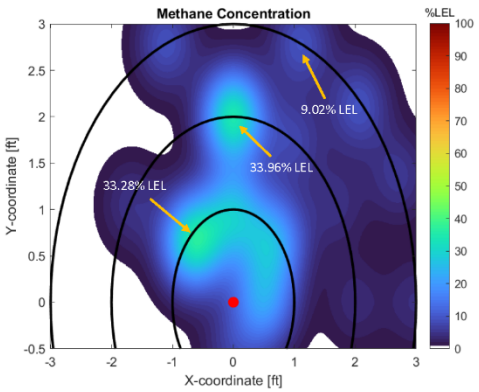
GTI ENERGY

	7 in-WC	222489-009_DT1_3	Sigma = .35
VL5	Primary Diaphragm Tear	Standard Array Configuration	6 in from vent

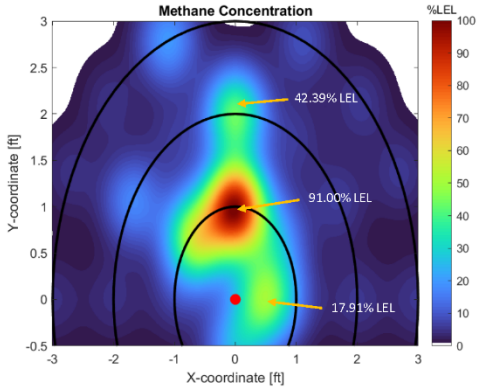


GTI ENERGY

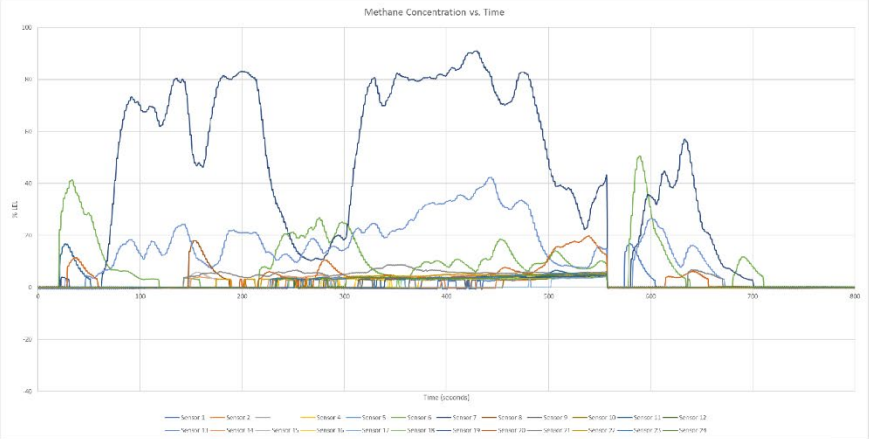
	7 in-WC	222489-009_DT1_4	Sigma = .35
VL5	Primary Diaphragm Tear	Standard Array Configuration	6 in from vent



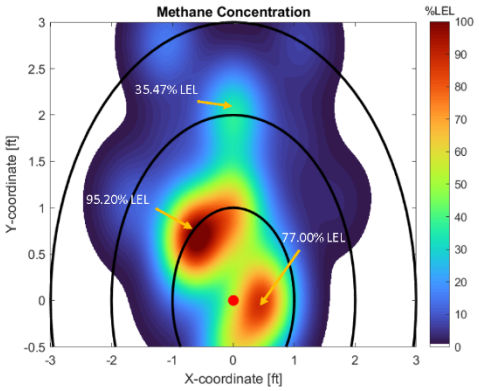
	7 in-WC	222489-007_DT2_trial1	Sigma = .34
VL5	Primary and Secondary Diaphragm Tear	Standard Array Configuration	6 in from vent



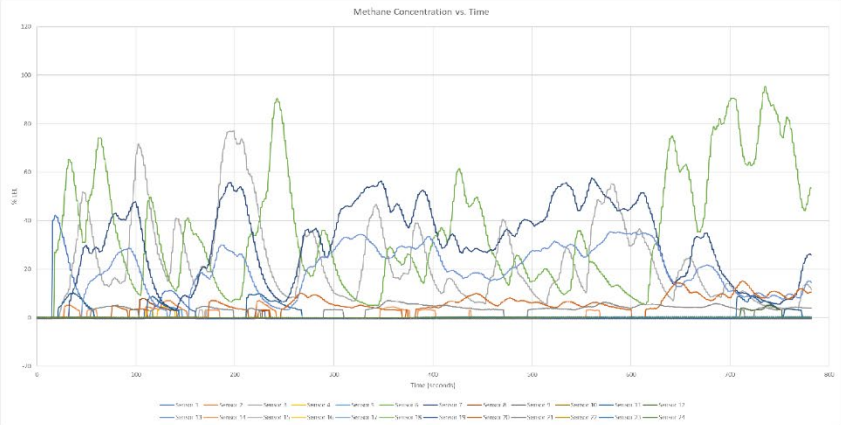
GTI ENERGY


Methane Concentration vs. Time
% LEL
Time (seconds)

	7 in-WC	222489-007_DT2_trial2	Sigma = .36
VL5	Primary and Secondary Diaphragm Tear	Standard Array Configuration	6 in from vent

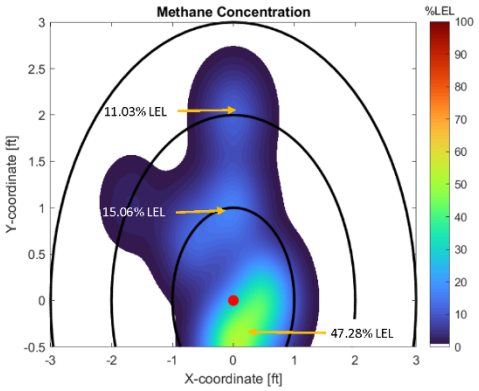


GTI ENERGY

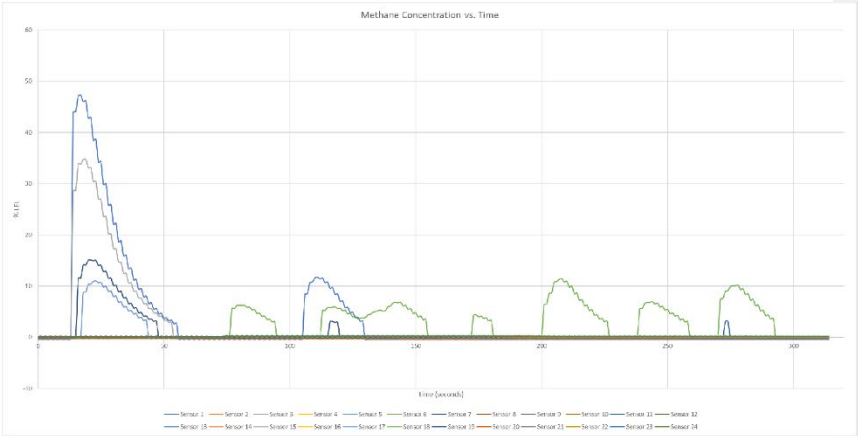

Methane Concentration vs. Time
120
100
80
60
40
20
0
-20
% LEL
0
200
400
600
800
1000
Time (seconds)
Sensor 1
Sensor 2
Sensor 3
Sensor 4
Sensor 5
Sensor 6
Sensor 7
Sensor 8
Sensor 9
Sensor 10
Sensor 11
Sensor 12
Sensor 13
Sensor 14
Sensor 15
Sensor 16
Sensor 17
Sensor 18
Sensor 19
Sensor 20
Sensor 21
Sensor 22
Sensor 23
Sensor 24

GTI ENERGY

	7 in-WC	222489-007_DT2_trial3 (opso triggered)	Sigma = .34
VL5	Primary and Secondary Diaphragm Tear	Standard Array Configuration	6 in from vent

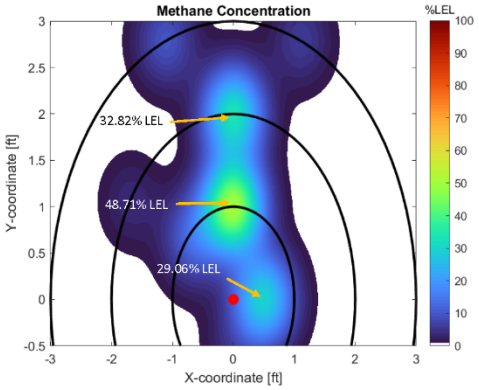


GTI ENERGY


Methane Concentration vs. Time
60
50
40
30
20
10
0
-10
0
50
100
150
200
250
300
Time [seconds]
Sensor 1
Sensor 2
Sensor 3
Sensor 4
Sensor 5
Sensor 6
Sensor 7
Sensor 8
Sensor 9
Sensor 10
Sensor 11
Sensor 12
Sensor 13
Sensor 14
Sensor 15
Sensor 16
Sensor 17
Sensor 18
Sensor 19
Sensor 20
Sensor 21
Sensor 22
Sensor 23
Sensor 24

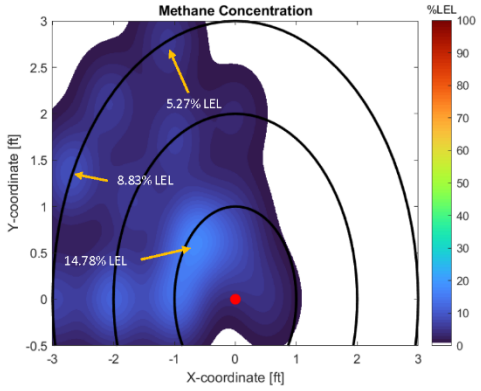
GTI ENERGY

	7 in-WC	222489-008_DT2	Sigma = .34
VL5	Primary and Secondary Diaphragm Tear	Standard Array Configuration	6 in from vent



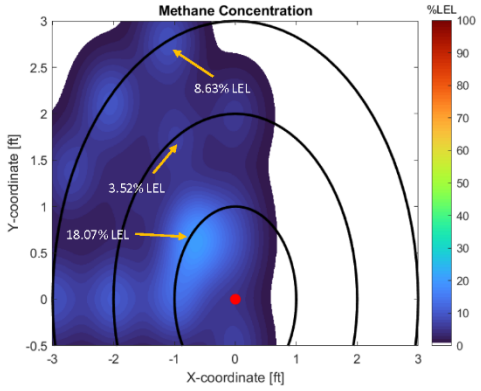
GTI ENERGY

	7 in-WC	222489-007_LD_1	Sigma = .35
VL5	Lever Disconnect	Standard Array Configuration	6 in from vent



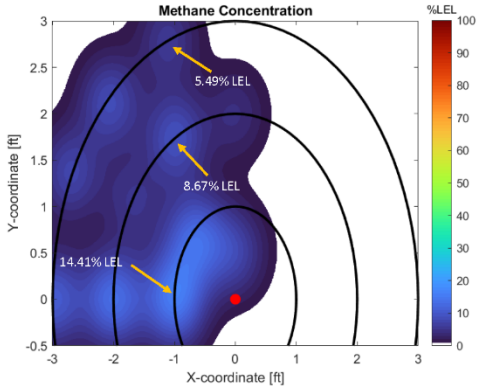
GTI ENERGY

	7 in-WC	222489-007_LD_2	Sigma = .35
VL5	Lever Disconnect	Standard Array Configuration	6 in from vent



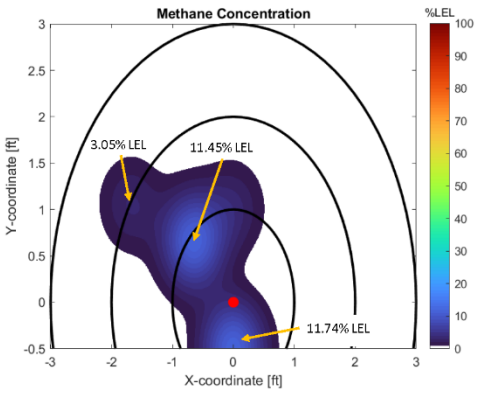
GTI ENERGY

	7 in-WC	222489-007_LD_3	Sigma = .35
VL5	Lever Disconnect	Standard Array Configuration	6 in from vent



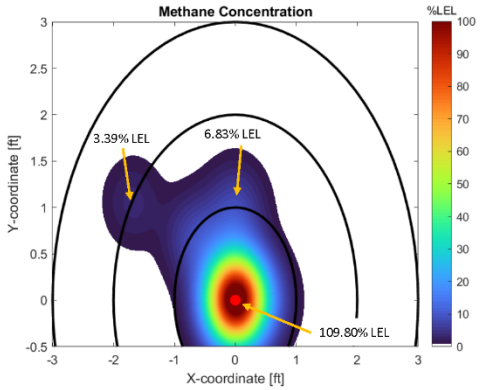
GTI ENERGY

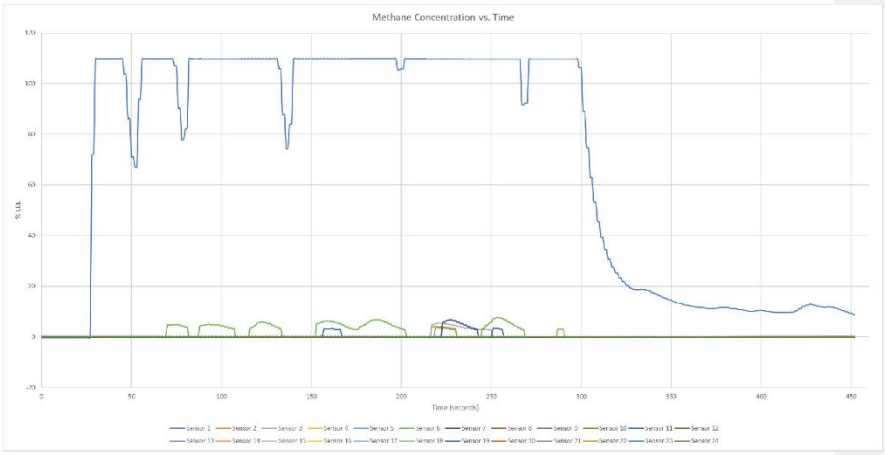
	7 in-WC	222489-009_multi lockup	Sigma = .34
VL5	Normal Condition – Multi Lockup	Standard Array Configuration	6 in from vent



GTI ENERGY

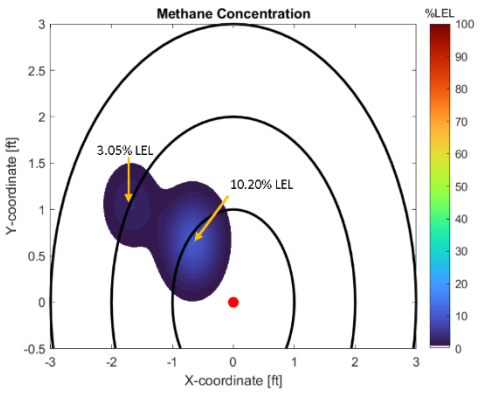
	7 in-WC	222489-009_multi lockup_sensor1 next to vent	Sigma = .32
VL5	Normal Condition – Multi Lockup	Standard Array Configuration	1 in from vent



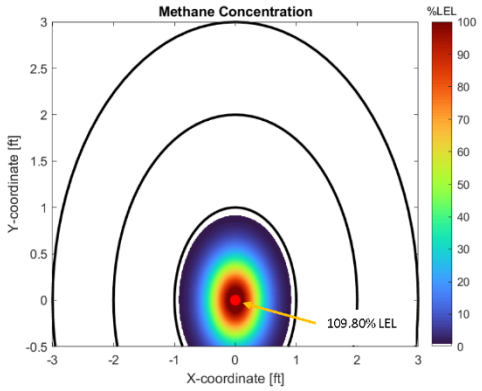

Methane Concentration vs. Time
% LEL
Time (seconds)
0
50
100
150
200
250
300
350
400
450

GTI ENERGY

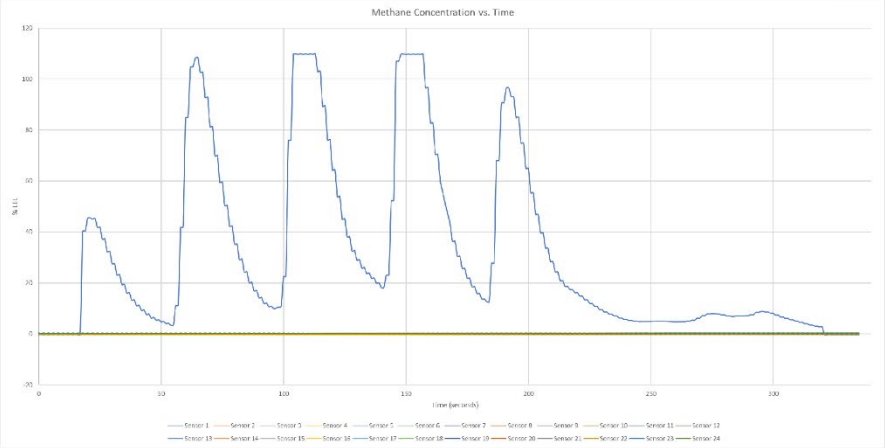
	7 in-WC	222489-009_single lockup	Sigma = .3
VL5	Normal Condition – Single Lockup	Standard Array Configuration	6 in from vent



	7 in-WC	222489-009_single lockup_sensor1 next to vent	Sigma = .3
VL5	Normal Condition – Single Lockup	Standard Array Configuration	1 in from vent

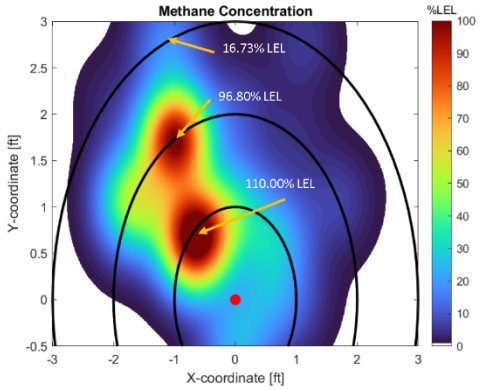


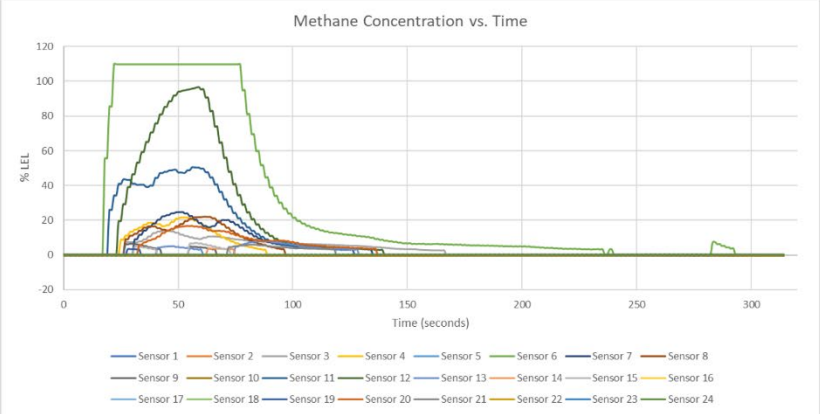
GTI ENERGY


Methane Concentration vs. Time
120
100
80
60
40
20
0
-20
% LEL
0
50
100
150
200
250
300
Time (seconds)
Sensor 1
Sensor 2
Sensor 3
Sensor 4
Sensor 5
Sensor 6
Sensor 7
Sensor 8
Sensor 9
Sensor 10
Sensor 11
Sensor 12
Sensor 13
Sensor 14
Sensor 15
Sensor 16
Sensor 17
Sensor 18
Sensor 19
Sensor 20
Sensor 21
Sensor 22
Sensor 23
Sensor 24

2-psig Outlet

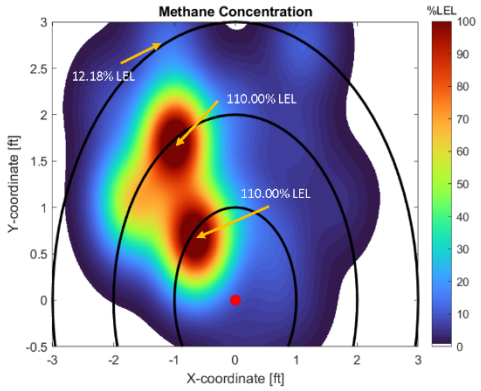
	2 PSI	222489-010_DT1_1	Sigma = .385
VL5	Primary Diaphragm Tear	Standard Array Configuration	6 in from vent



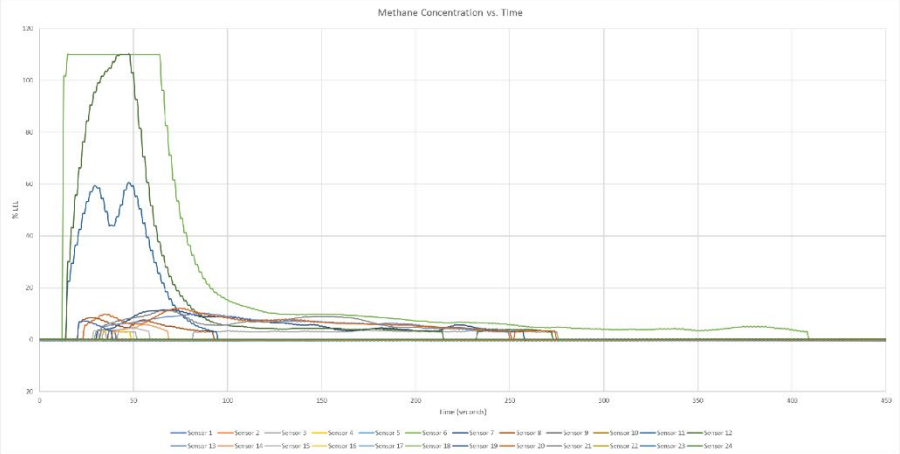

Methane Concentration vs. Time
% LEL
120
100
80
60
40
20
0
-20
0
50
100
150
200
250
300
Time (seconds)
Sensor 1
Sensor 2
Sensor 3
Sensor 4
Sensor 5
Sensor 6
Sensor 7
Sensor 8
Sensor 9
Sensor 10
Sensor 11
Sensor 12
Sensor 13
Sensor 14
Sensor 15
Sensor 16
Sensor 17
Sensor 18
Sensor 19
Sensor 20
Sensor 21
Sensor 22
Sensor 23
Sensor 24

GTI ENERGY

	2 PSI	222489-010_DT1_2	Sigma = .385
VL5	Primary Diaphragm Tear	Standard Array Configuration	6 in from vent

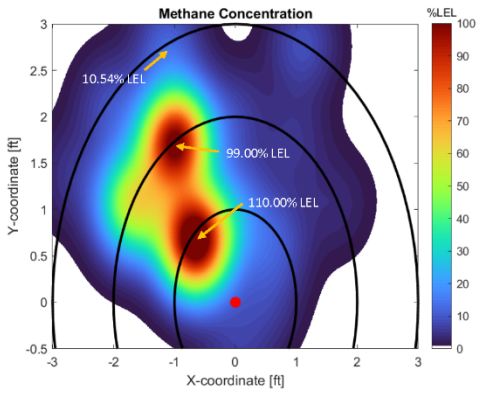


GTI ENERGY

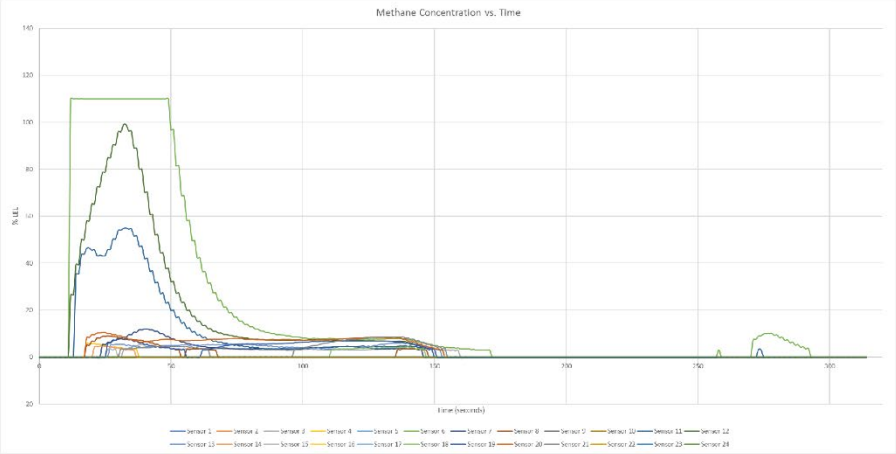

Methane Concentration vs. Time
% LEL
Time [seconds]
Sensor 1
Sensor 2
Sensor 3
Sensor 4
Sensor 5
Sensor 6
Sensor 7
Sensor 8
Sensor 9
Sensor 10
Sensor 11
Sensor 12
Sensor 13
Sensor 14
Sensor 15
Sensor 16
Sensor 17
Sensor 18
Sensor 19
Sensor 20
Sensor 21
Sensor 22
Sensor 23
Sensor 24

GTI ENERGY

	2 PSI	222489-010_DT1_3	Sigma = .385
VL5	Primary Diaphragm Tear	Standard Array Configuration	6 in from vent

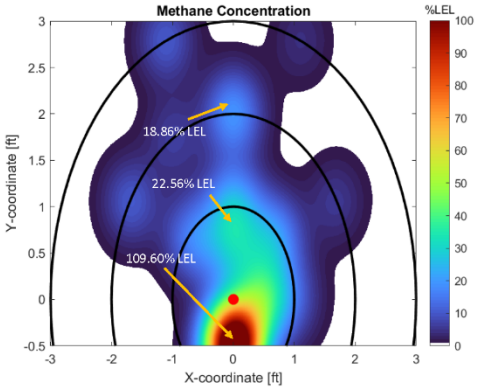


GTI ENERGY

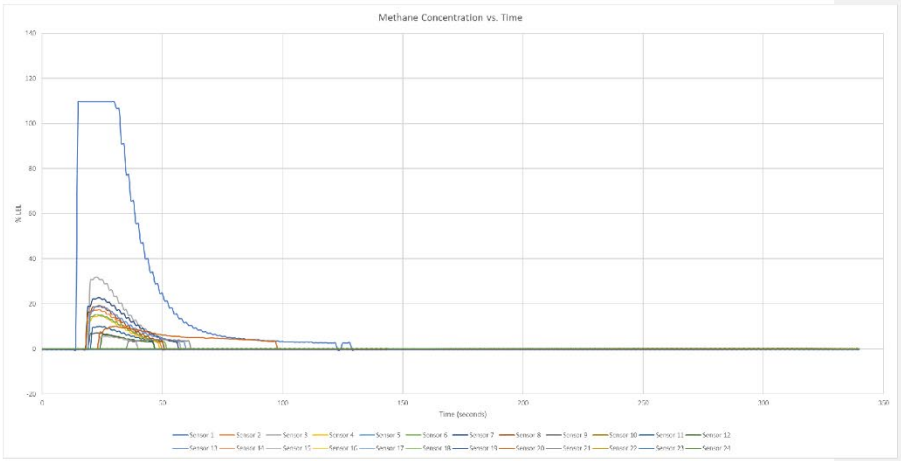


GTI ENERGY

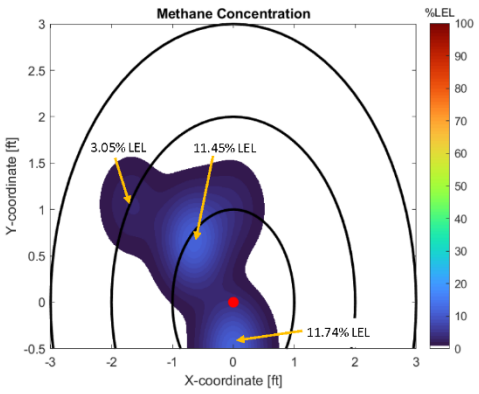
	2 PSI	222489-010_DT2	Sigma = .32
VL5	Primary and Secondary Diaphragm Tear	Standard Array Configuration	6 in from vent



GTI ENERGY

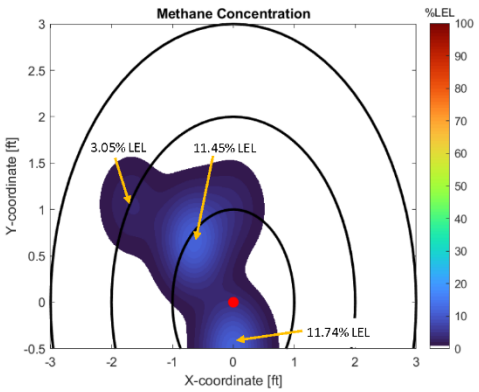

Methane Concentration vs. Time
Time (seconds)

	2 PSI	222489-011_LD_1	Sigma = .34
VL5	Lever Disconnect	Standard Array Configuration	6 in from vent



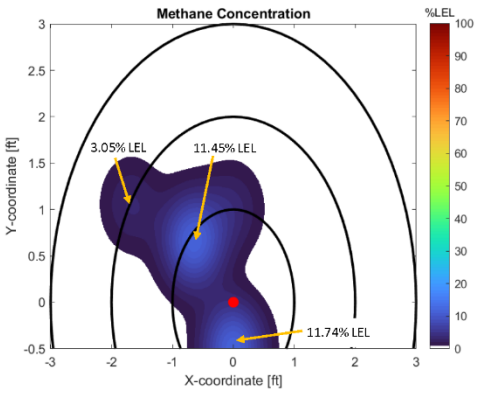
GTI ENERGY

	2 PSI	222489-011_LD_2	Sigma = .34
VL5	Lever Disconnect	Standard Array Configuration	6 in from vent



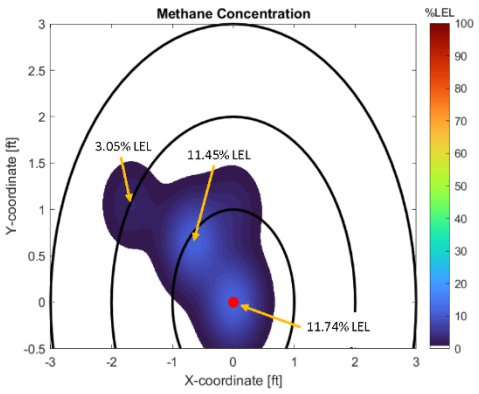
GTI ENERGY

	2 PSI	222489-011_LD_3	Sigma = .34
VL5	Lever Disconnect	Standard Array Configuration	6 in from vent



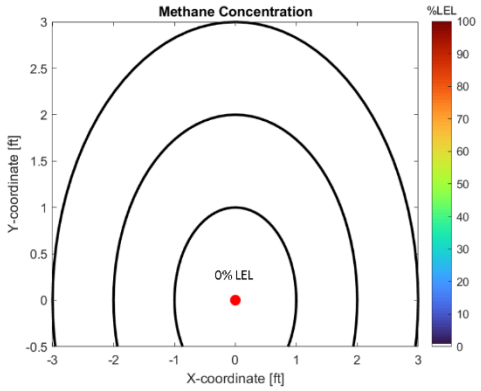
GTI ENERGY

	2 PSI	222489-011_LD_4_sensor1 next to vent	Sigma = .31
VL5	Lever Disconnect	Standard Array Configuration	1 in from vent



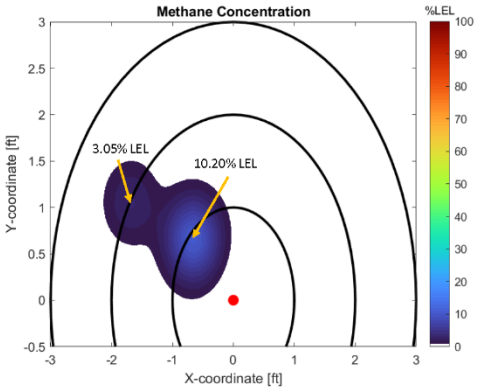
GTI ENERGY

	2 PSI	222489-010_multi lockup_sensor1 next to vent	Sigma = .3
VL5	Normal Condition – Multi Lockup	Standard Array Configuration	1 in from vent

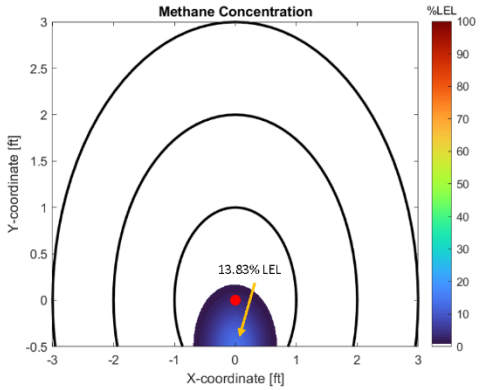


GTI ENERGY

	2 PSI	222489-010_single lockup_sensor1 next to vent	Sigma = .3
VL5	Normal Condition – Single Lockup	Standard Array Configuration	1 in from vent

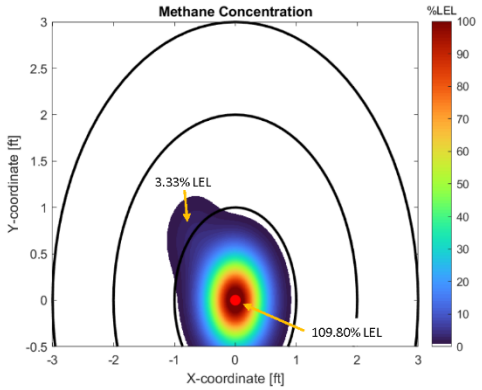


	2 PSI	222489-012_multi lockup_w solenoid_sensor1 6in	Sigma = .3
VL5	Normal Condition – Multi Lockup	Standard Array Configuration	6 in from vent

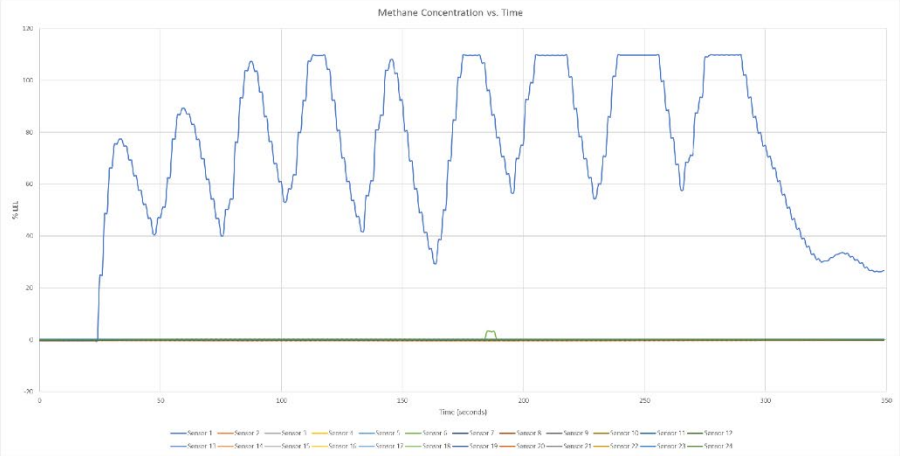


GTI ENERGY

	2 PSI	222489-012_multi lockup_w solenoid_sensor1 next to vent	Sigma = .3
VL5	Normal Condition – Multi Lockup	Standard Array Configuration	1 in from vent

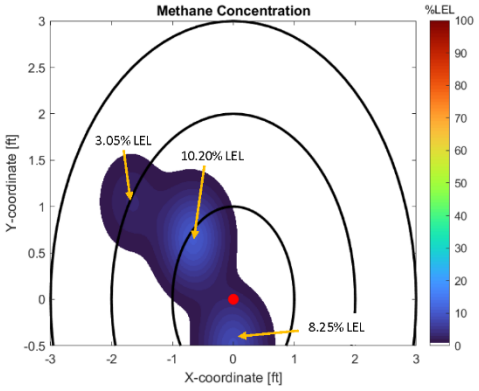


GTI ENERGY



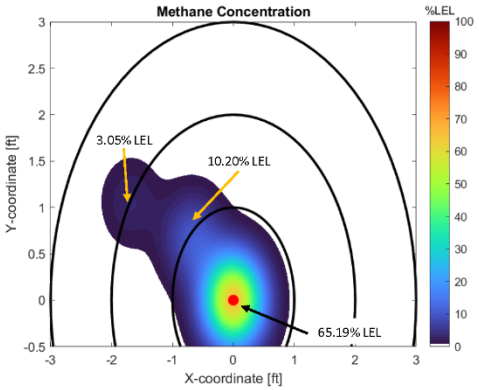
GTI ENERGY

	2 PSI	222489-012_single lockup_w solenoid_sensor1 6in	Sigma = .34
VL5	Normal Condition – Single Lockup	Standard Array Configuration	6 in from vent

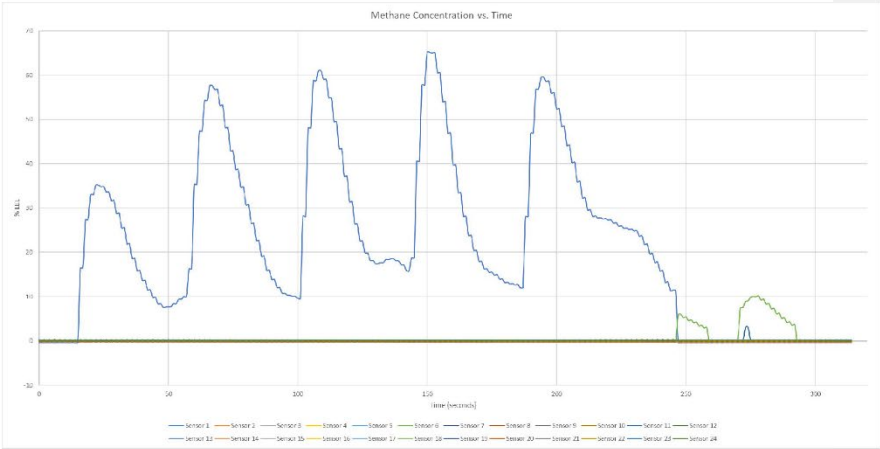


GTI ENERGY

	2 PSI	222489-012_single lockup_w solenoid_sensor1 next to vent	Sigma = .32
VL5	Normal Condition – Single Lockup	Standard Array Configuration	1 in from vent

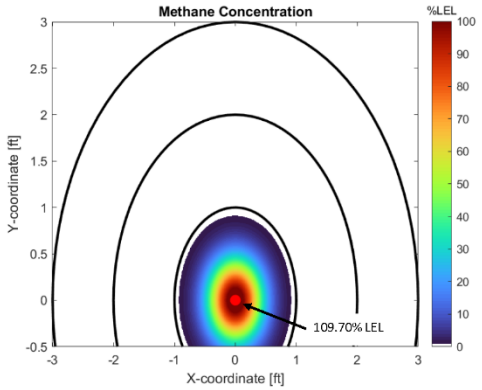


GTI ENERGY

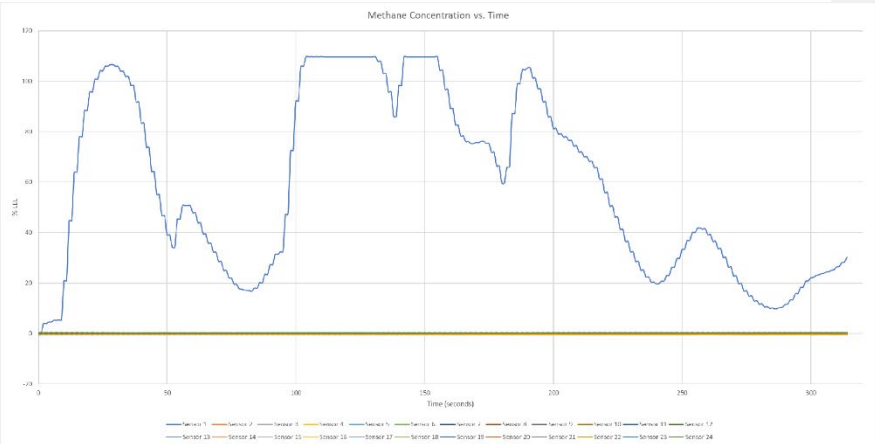

Methane Concentration vs. Time
% LEL
Time [seconds]
0
50
100
150
200
250
300
Sensor 1
Sensor 2
Sensor 3
Sensor 4
Sensor 5
Sensor 6
Sensor 7
Sensor 8
Sensor 9
Sensor 10
Sensor 11
Sensor 12
Sensor 13
Sensor 14
Sensor 15
Sensor 16
Sensor 17
Sensor 18
Sensor 19
Sensor 20
Sensor 21
Sensor 22
Sensor 23
Sensor 24

GTI ENERGY

	2 PSI	222489-012_single lockup_w solenoid_sensor1 next to vent_2	Sigma = .3
VL5	Normal Condition – Single Lockup	Standard Array Configuration	1 in from vent



GTI ENERGY

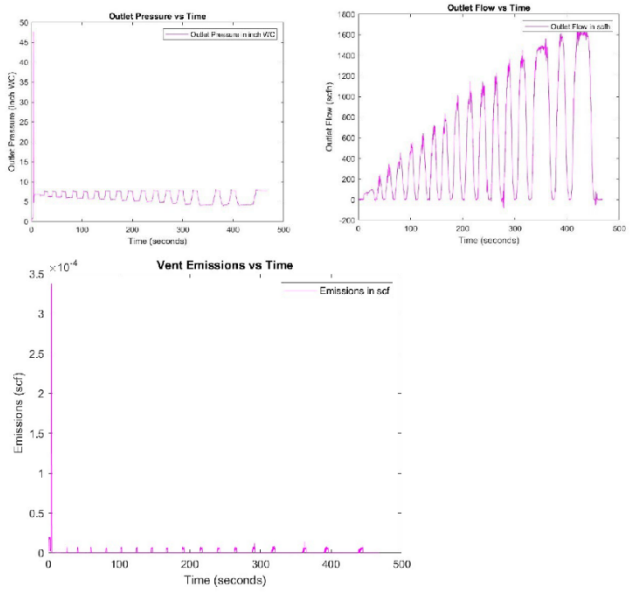

Methane Concentration vs. Time
120
100
80
60
40
20
0
-20
% LEL
0
50
100
150
200
250
300
Time (seconds)
Sensor 1
Sensor 2
Sensor 3
Sensor 4
Sensor 5
Sensor 6
Sensor 7
Sensor 8
Sensor 9
Sensor 10
Sensor 11
Sensor 12
Sensor 13
Sensor 14
Sensor 15
Sensor 16
Sensor 17
Sensor 18
Sensor 19
Sensor 20
Sensor 21
Sensor 22
Sensor 23
Sensor 24

GTI ENERGY

Modified Lockup Tests

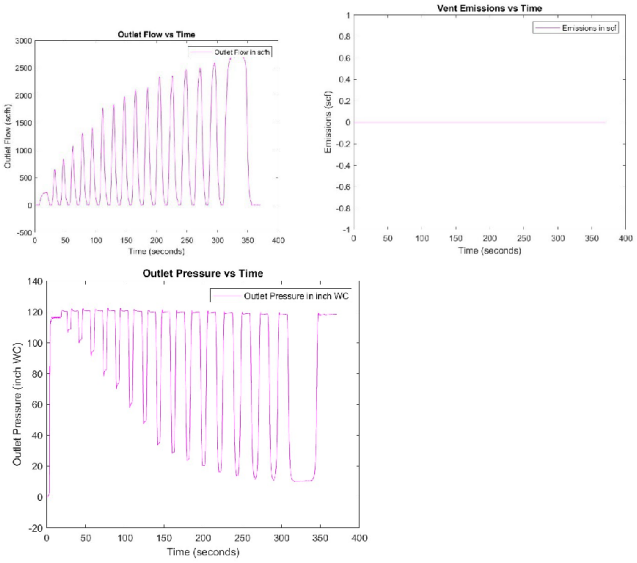
7" WC Outlet, 10-psig Inlet

- 222489-031
  The volume of total emissions in 468.14 seconds is 0.0051 scf.
  The flow rate of emissions is 0.0395 scfh.



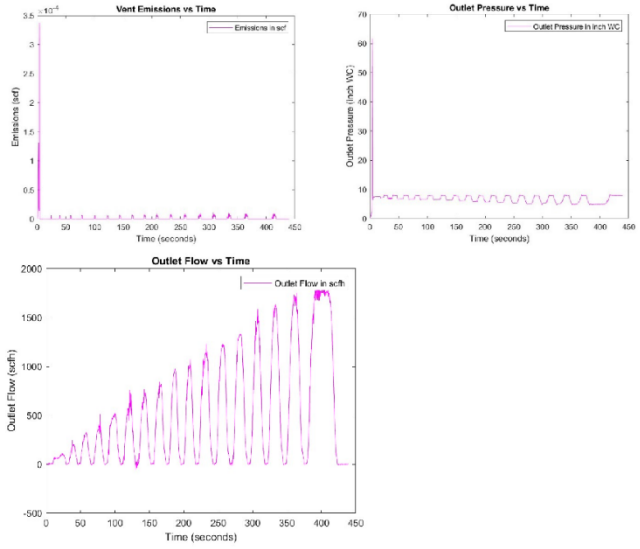
GTI ENERGY

- 222489-031_BV
  The volume of total emissions in 370.58 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.



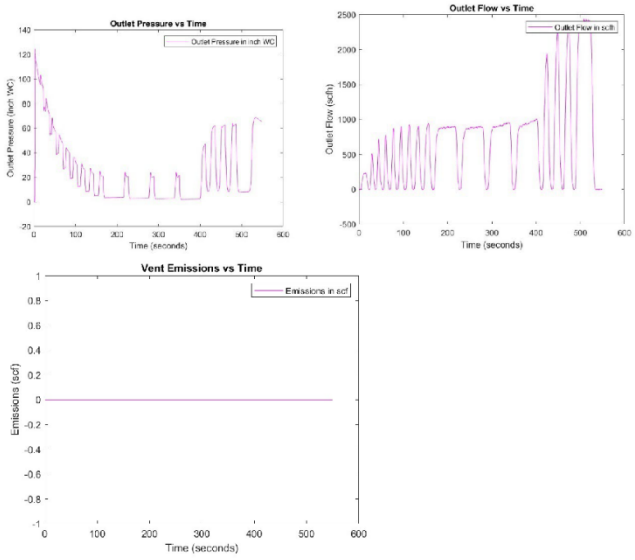
GTI ENERGY

- 222489-032
  The volume of total emissions in 439.86 seconds is 0.0057 scf.
  The flow rate of emissions is 0.0468 scfh.



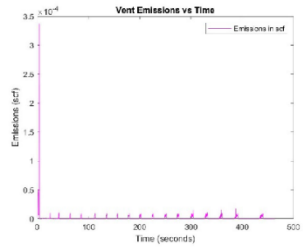
GTI ENERGY

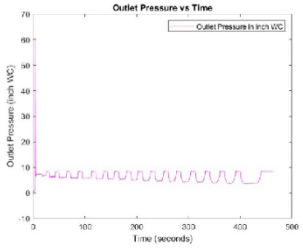
- 222489-032_BV
  The volume of total emissions in 549.47 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.

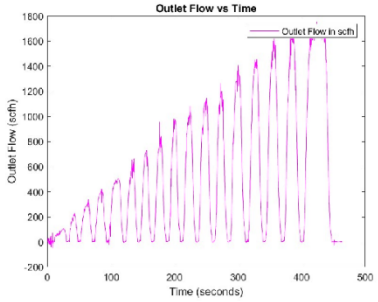


GTI ENERGY

- 222489-033
  The volume of total emissions in 463.62 seconds is 0.0061 scf.
  The flow rate of emissions is 0.0475 scfh.

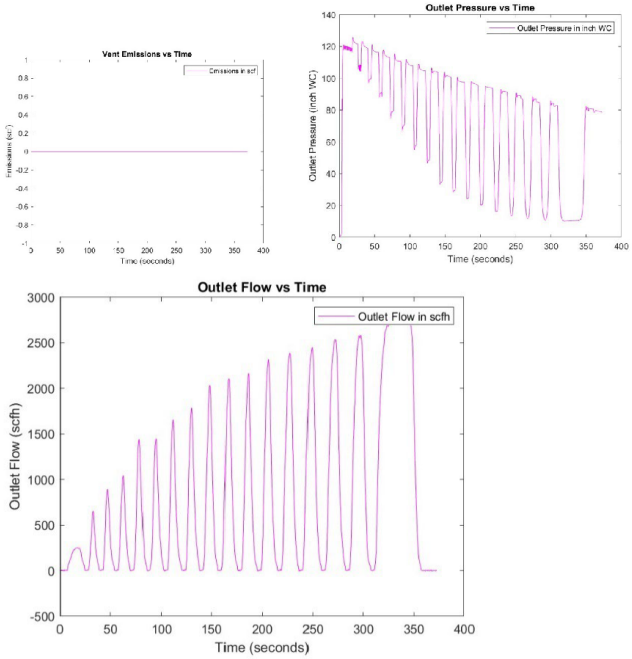






GTI ENERGY

- 222489-033_BV
  The volume of total emissions in 372.66 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.

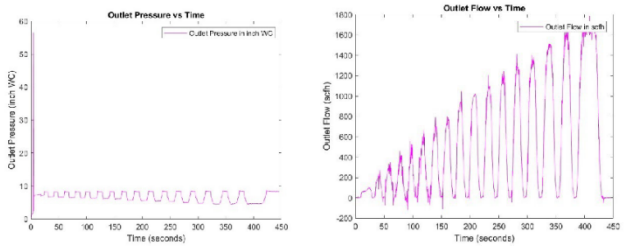


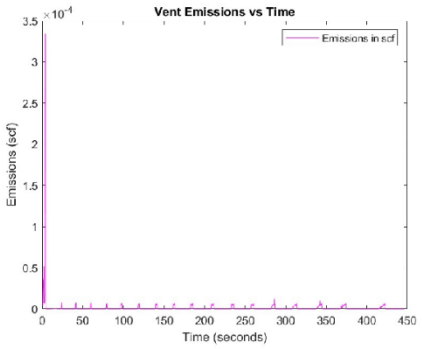
GTI ENERGY

7" WC Outlet, 60-psig Inlet

- 222489-031

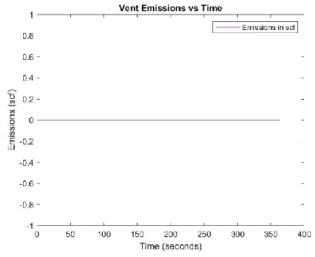
  The volume of total emissions in 446.15 seconds is 0.0052 scf.
  The flow rate of emissions is 0.0423 scfh.

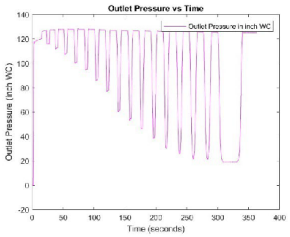


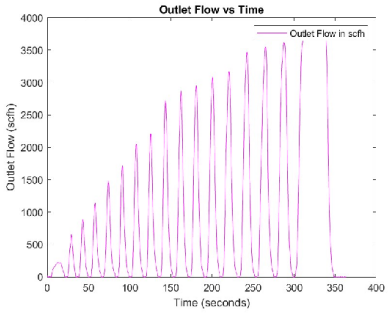


GTI ENERGY

- 222489-031_BV
  The volume of total emissions in 363.46 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.

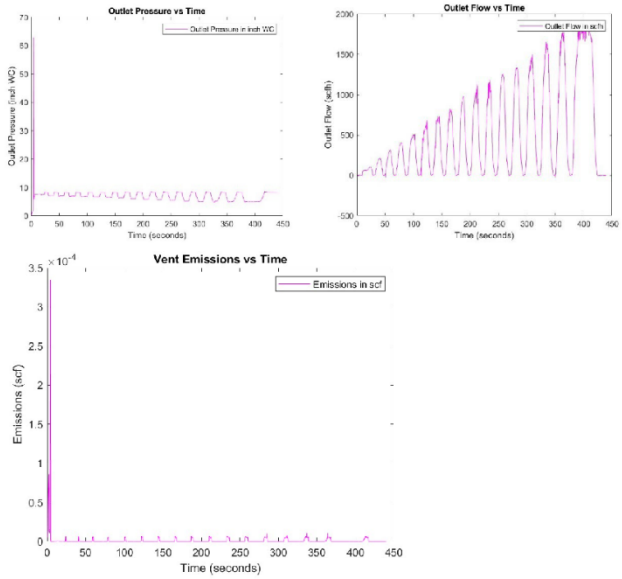






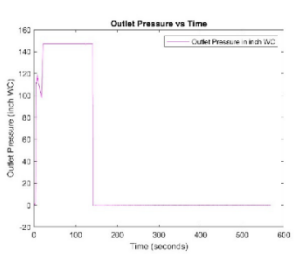
GTI ENERGY

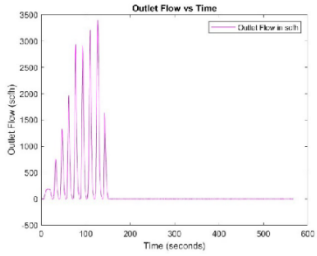
- 222489-032
  The volume of total emissions in 440.20 seconds is 0.0055 scf.
  The flow rate of emissions is 0.0446 scfh.

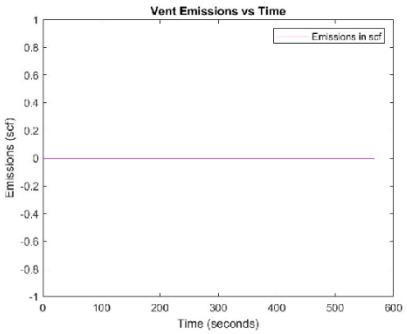


GTI ENERGY

- 222489-032_BV
  The volume of total emissions in 568.07 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.

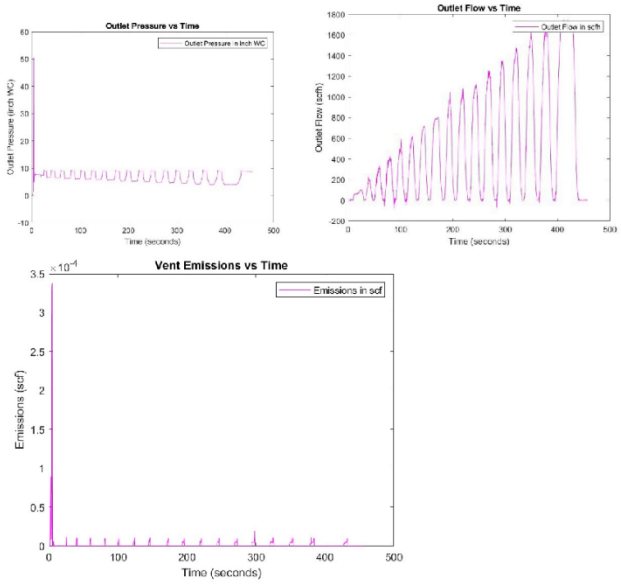






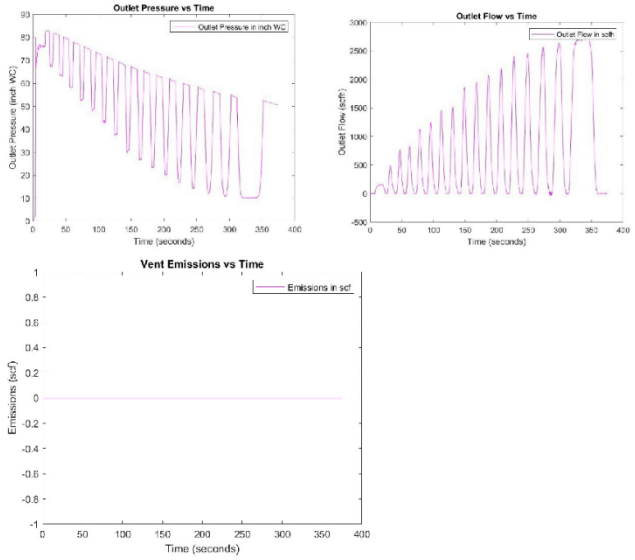
GTI ENERGY

- 222489-033
  The volume of total emissions in 456.20 seconds is 0.0056 scf.
  The flow rate of emissions is 0.0441 scfh.



GTI ENERGY

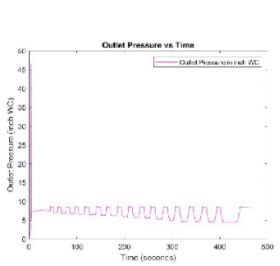
- 222489-033_BV
  The volume of total emissions in 374.85 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.

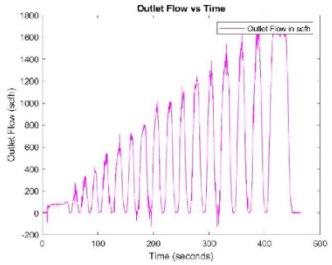


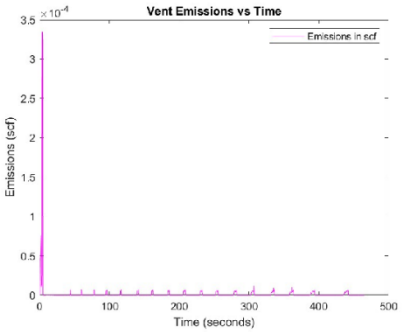
GTI ENERGY

7" WC Outlet, 100-psig Inlet

- 222489-031
  The volume of total emissions in 465.20 seconds is 0.0053 scf.
  The flow rate of emissions is 0.0412 scfh.

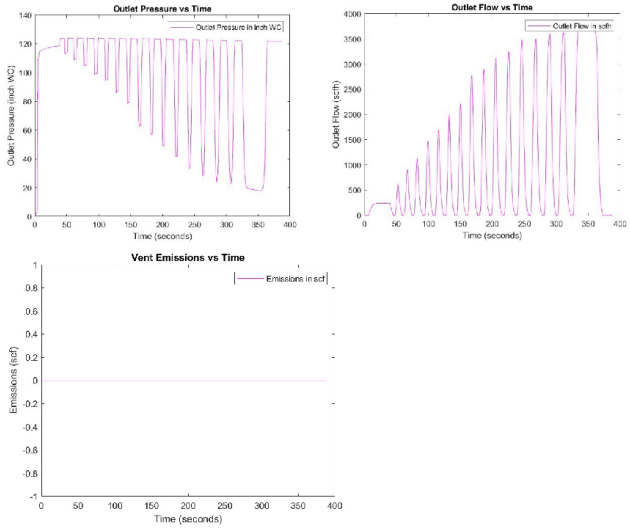






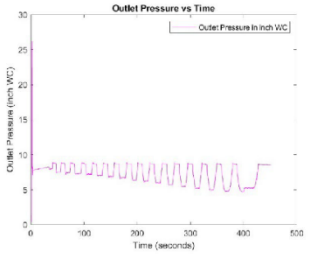
GTI ENERGY

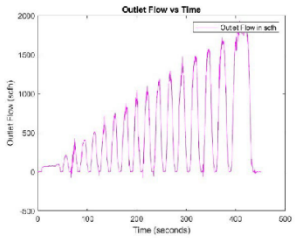
- 222489-031_BV
  The volume of total emissions in 387.42 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.

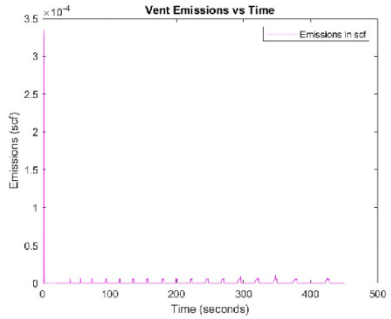


GTI ENERGY

- 222489-032
  The volume of total emissions in 450.98 seconds is 0.0047 scf.
  The flow rate of emissions is 0.0373 scfh.

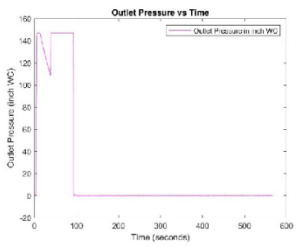


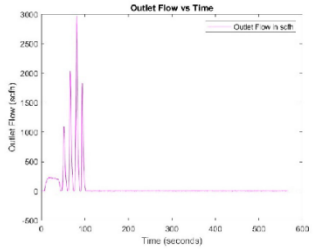


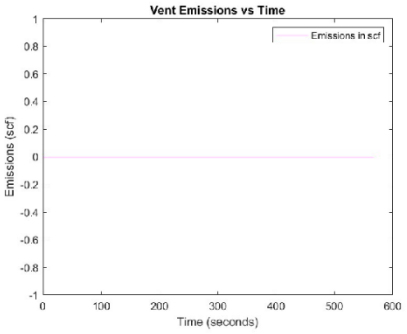


GTI ENERGY

- 222489-032_BV
  The volume of total emissions in 567.19 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.

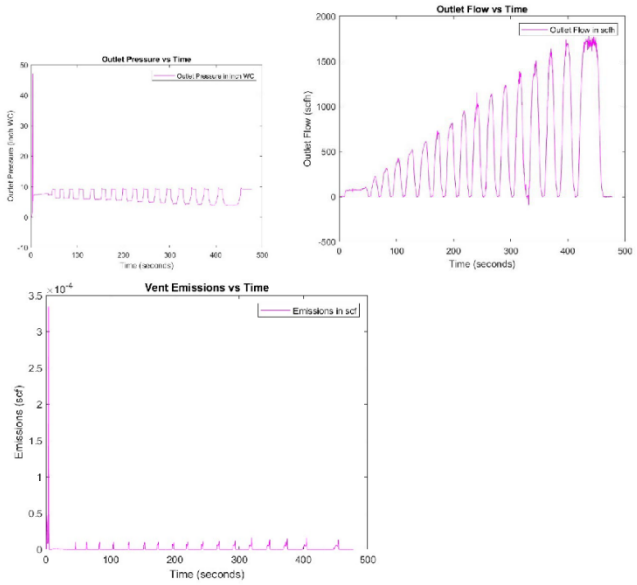






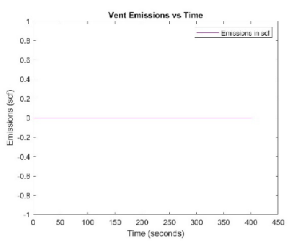
GTI ENERGY

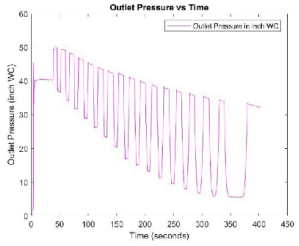
- 222489-033
  The volume of total emissions in 477.30 seconds is 0.0060 scf.
  The flow rate of emissions is 0.0455 scfh.

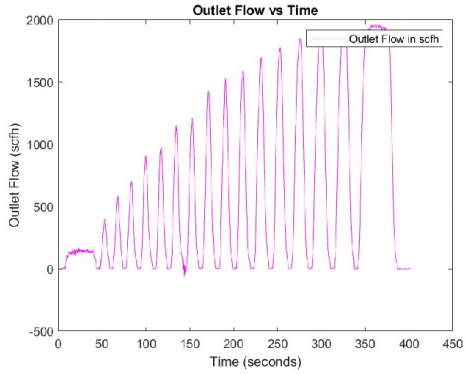


GTI ENERGY

- 222489-033_BV
  The volume of total emissions in 402.51 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.



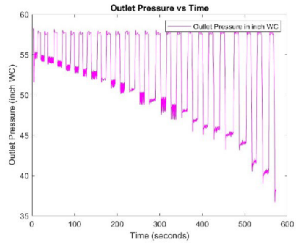


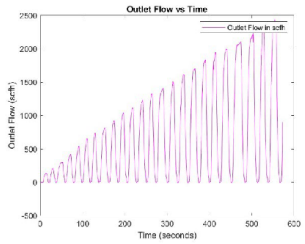


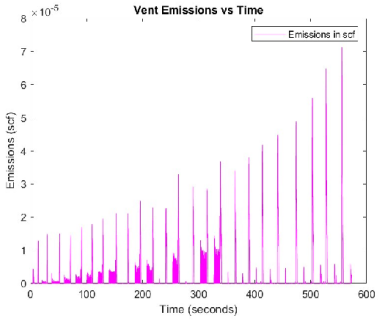
GTI ENERGY

2-psig Outlet, 10-psig Inlet

- 222489-034
  The volume of total emissions in 572.95 seconds is 0.0104 scf.
  The flow rate of emissions is 0.0654 scfh.

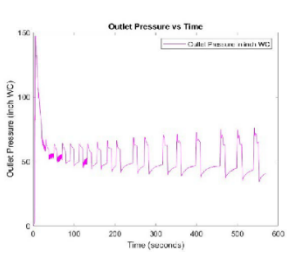


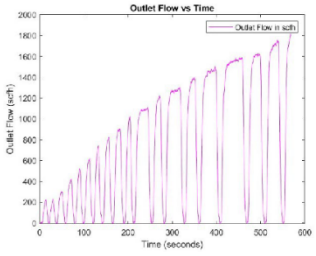


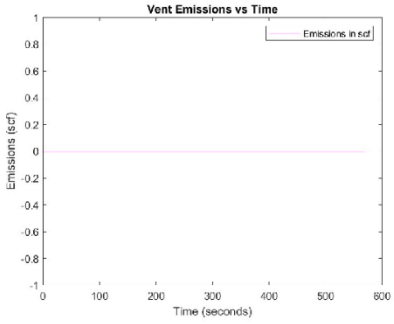


GTI ENERGY

- 222489-034_BV
  The volume of total emissions in 568.74 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.

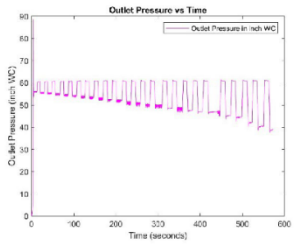


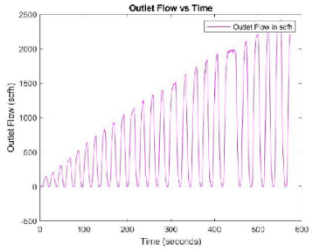


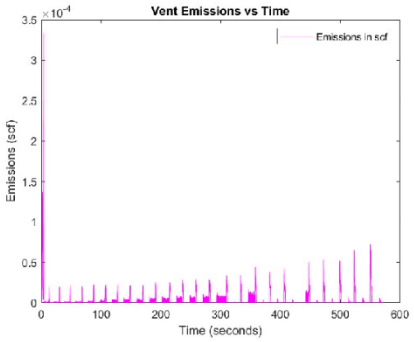


GTI ENERGY

- 222489-035
  The volume of total emissions in 572.93 seconds is 0.0156 scf.
  The flow rate of emissions is 0.0979 scfh.

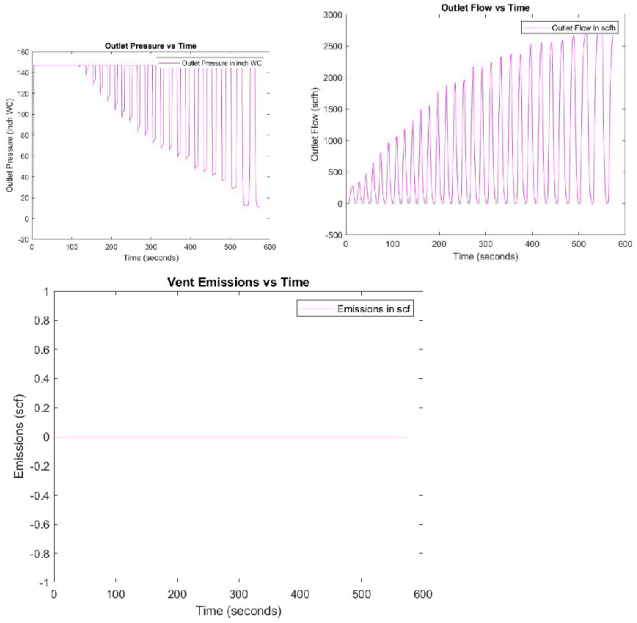






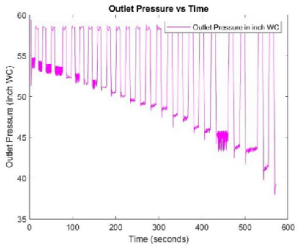
GTI ENERGY

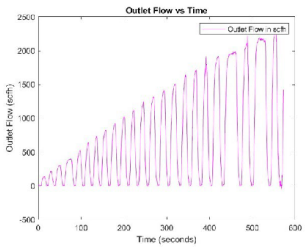
- 222489-035_BV
  The volume of total emissions in 573.98 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.

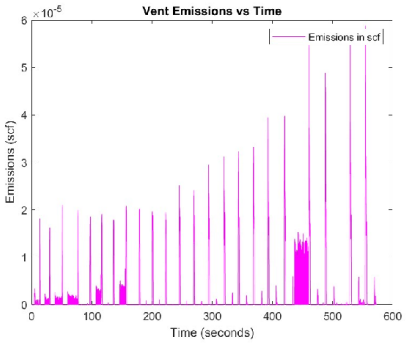


GTI ENERGY

- 222489-036
  The volume of total emissions in 572.92 seconds is 0.0096 scf.
  The flow rate of emissions is 0.0604 scfh.

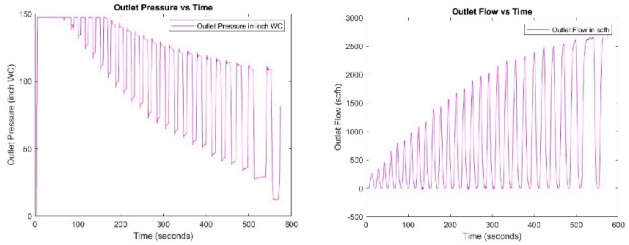


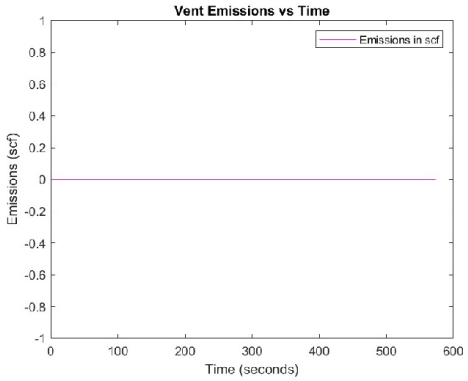




GTI ENERGY

- 222489-036_BV
  The volume of total emissions in 574.10 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.



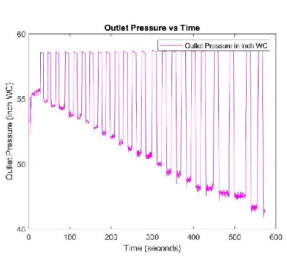


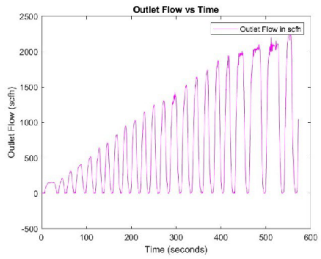
GTI ENERGY

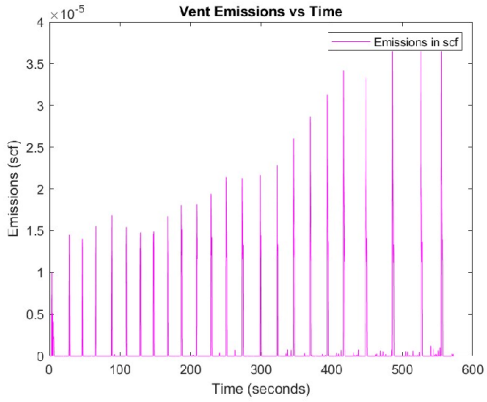
2-psig Outlet, 60-psig Inlet

- 222489-034

  The volume of total emissions in 572.75 seconds is 0.0059 scf.
  The flow rate of emissions is 0.0373 scfh.

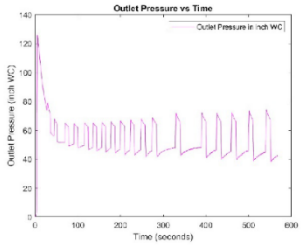


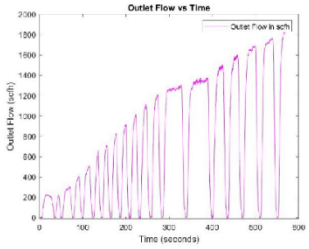


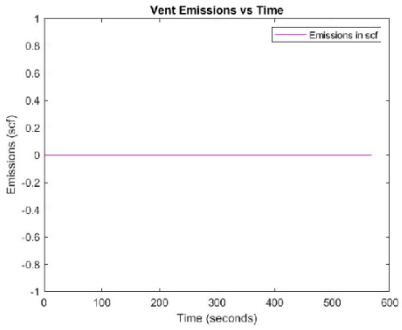


GTI ENERGY

- 222489-034_BV
  The volume of total emissions in 568.44 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.

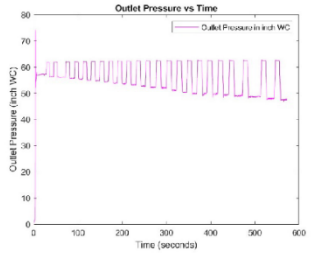


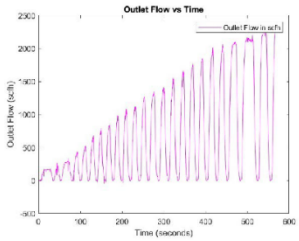


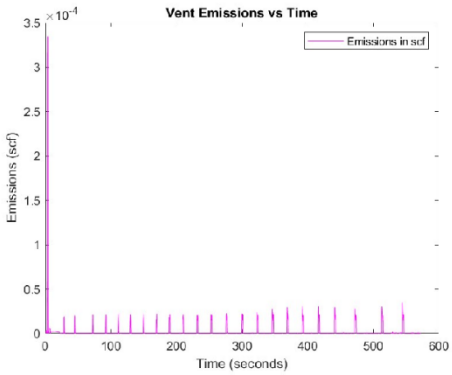


GTI ENERGY

- 222489-035
  The volume of total emissions in 572.76 seconds is 0.0094 scf.
  The flow rate of emissions is 0.0589 scfh.

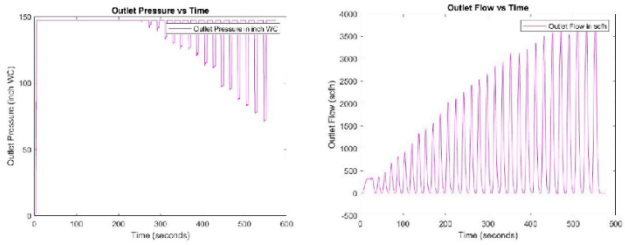


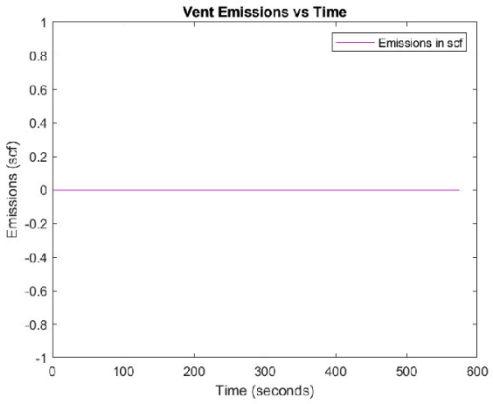




GTI ENERGY

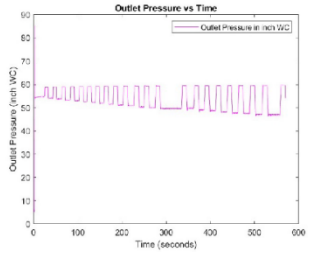
- 222489-035_BV
  The volume of total emissions in 575.10 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.

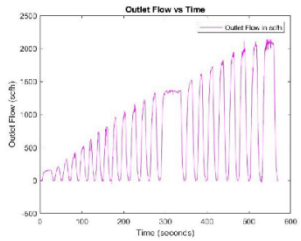


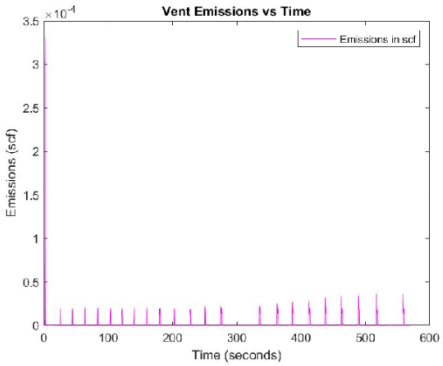


GTI ENERGY

- 222489-036
  The volume of total emissions in 570.73 seconds is 0.0083 scf.
  The flow rate of emissions is 0.0523 scfh.

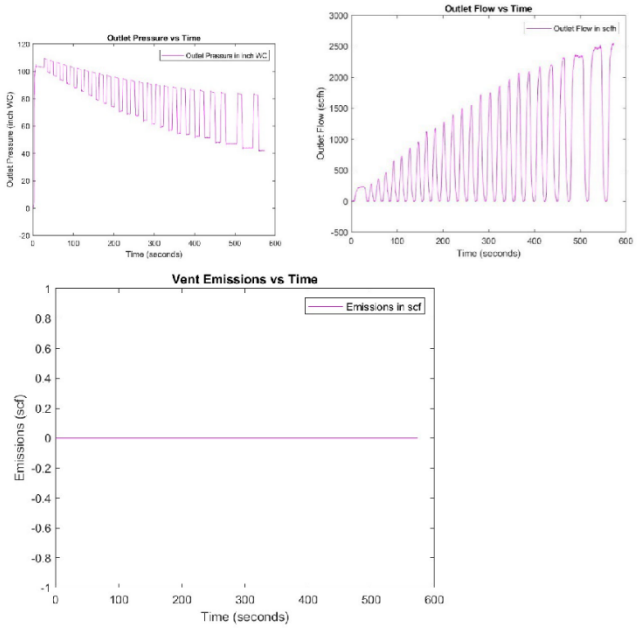






GTI ENERGY

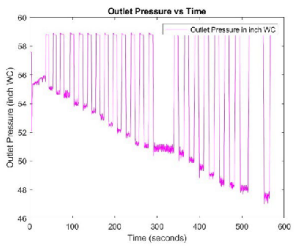
- 222489-036_BV
  The volume of total emissions in 573.58 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.

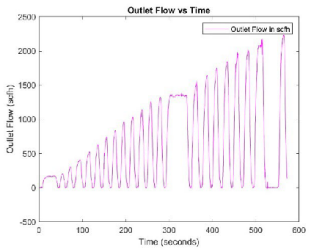


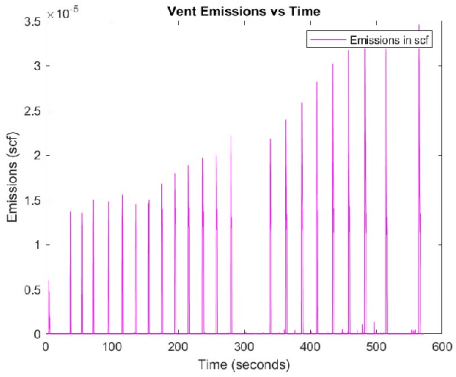
GTI ENERGY

2-psig Outlet, 100-psig Inlet

- 222489-034
  The volume of total emissions in 572.59 seconds is 0.0053 scf.
  The flow rate of emissions is 0.0334 scfh.

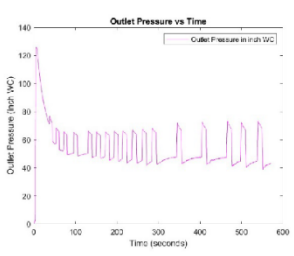


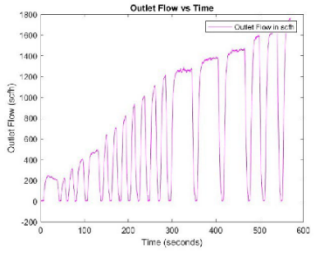


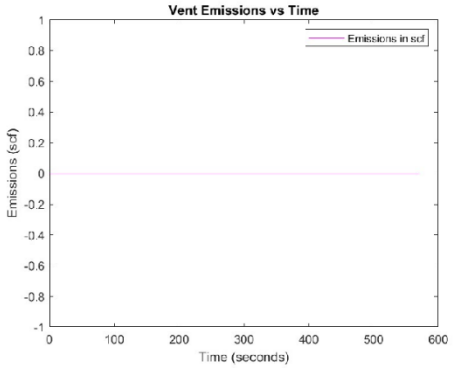


GTI ENERGY

- 222489-034_BV
  The volume of total emissions in 571.01 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.

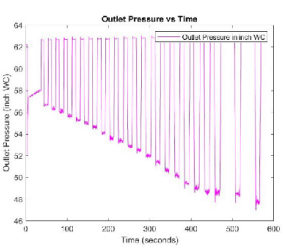


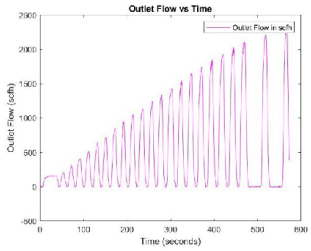


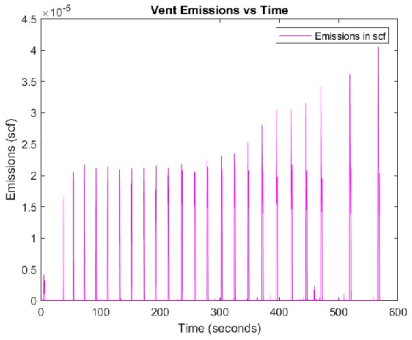


GTI ENERGY

- 222489-035
  The volume of total emissions in 573.03 seconds is 0.0069 scf.
  The flow rate of emissions is 0.0432 scfh.

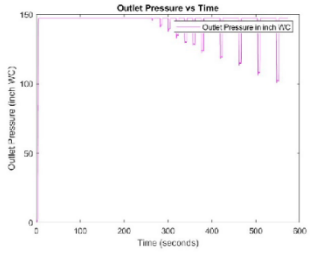


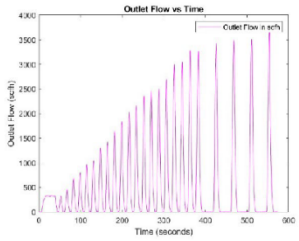


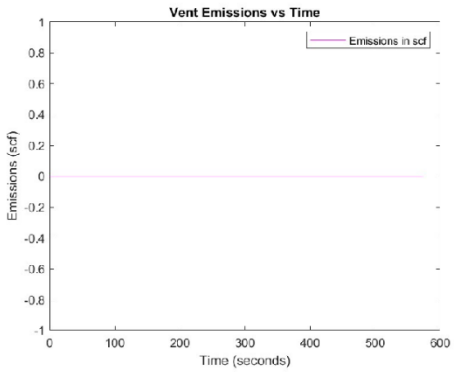


GTI ENERGY

- 222489-035_BV
  The volume of total emissions in 573.46 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.

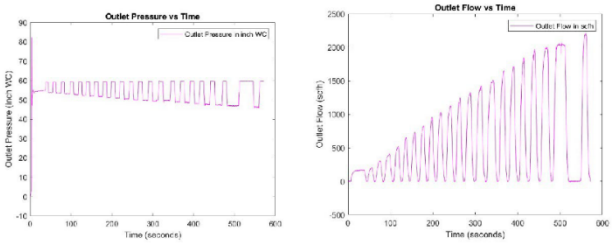


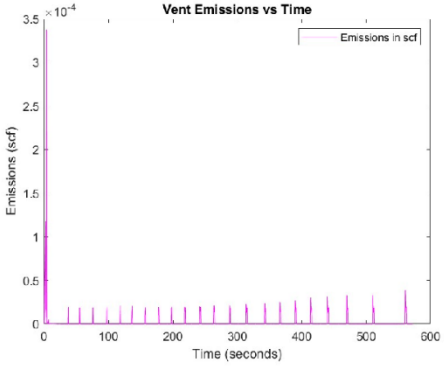




GTI ENERGY

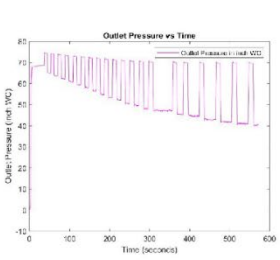
- 222489-036
  The volume of total emissions in 572.47 seconds is 0.0085 scf.
  The flow rate of emissions is 0.0531 scfh.

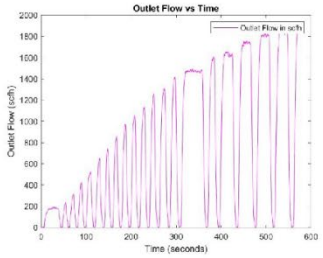


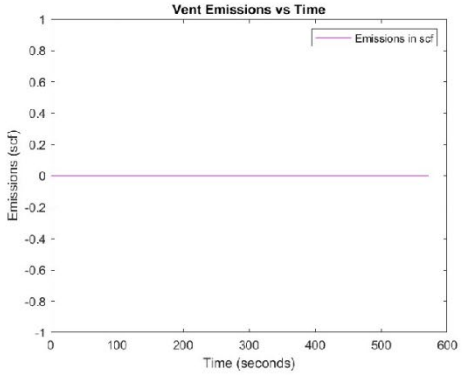


GTI ENERGY

- 222489-036_BV
  The volume of total emissions in 572.07 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.





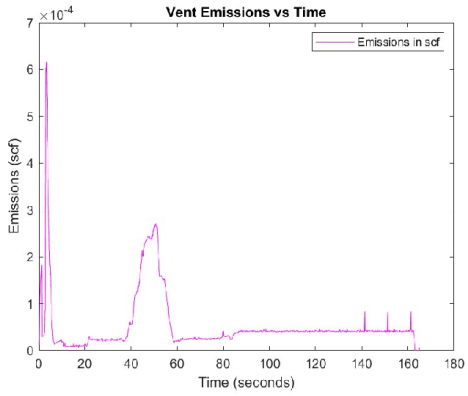


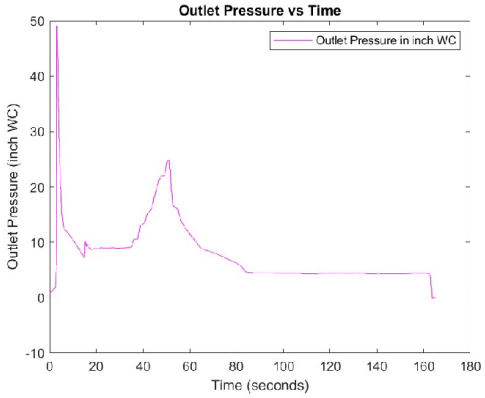
GTI ENERGY

Relief Tests

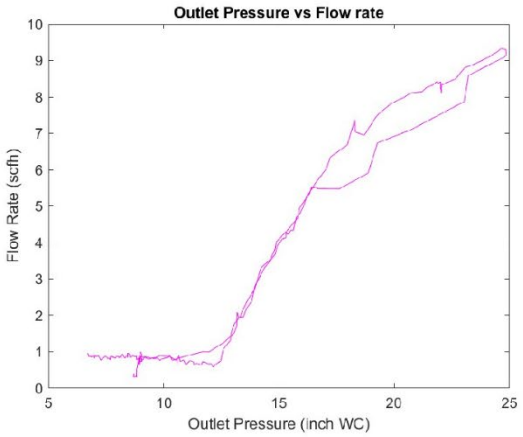
7" WC Outlet, 10-psig Inlet

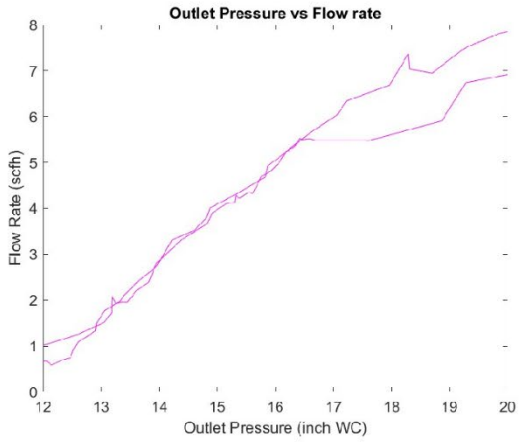
- **222489-031**
  The volume of total emissions in 165.14 seconds is 0.0823 scf.
  The average flow rate of emissions at 18 inches WC is 6.69 scfh.





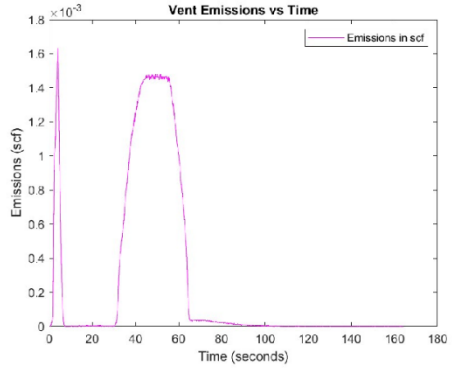
GTI ENERGY

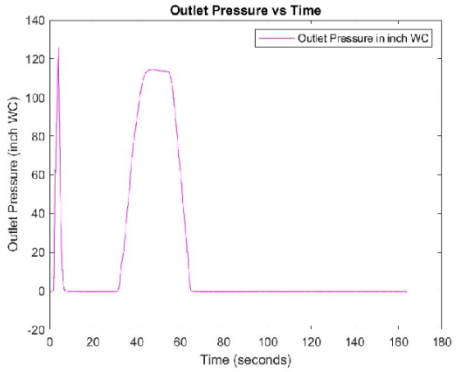

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
1
2
3
4
5
6
7
8
9
10
5
10
15
20
25


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
1
2
3
4
5
6
7
8
12
13
14
15
16
17
18
19
20

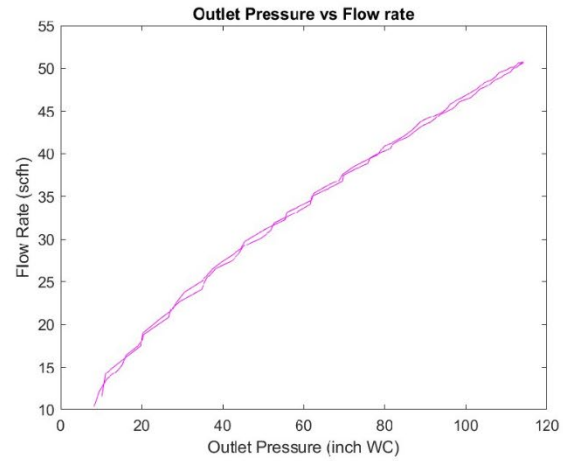
GTI ENERGY

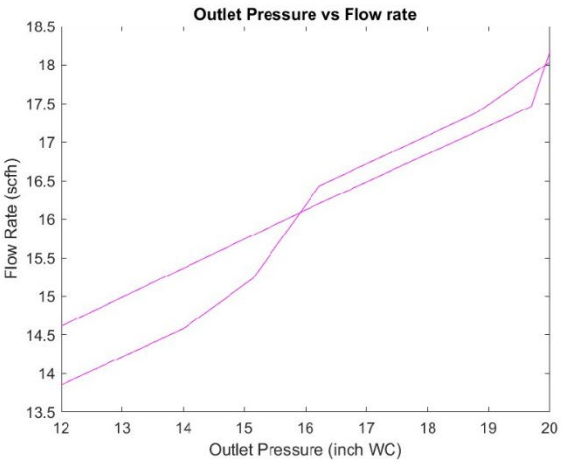
- **222489-031_DT1**
  The volume of total emissions in 164.24 seconds is 0.4080 scf.
  The average flow rate of emissions at 18 inches WC is 17.39 scfh.





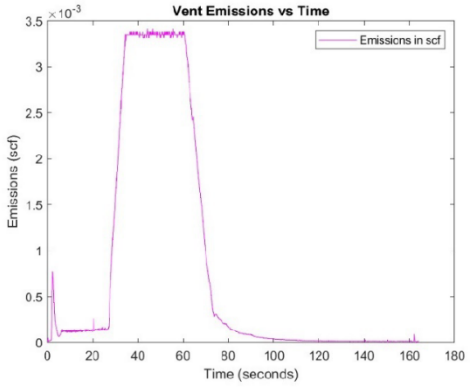
GTI ENERGY

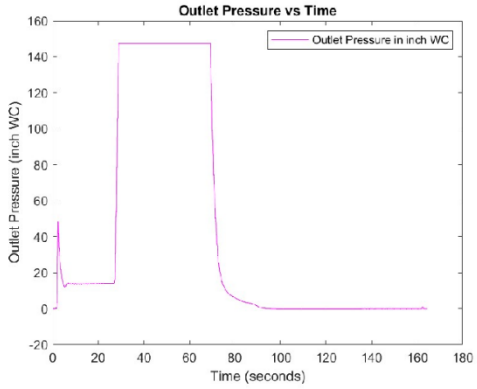

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
55
50
45
40
35
30
25
20
15
10
0
20
40
60
80
100
120


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
18.5
18
17.5
17
16.5
16
15.5
15
14.5
14
13.5
12
13
14
15
16
17
18
19
20

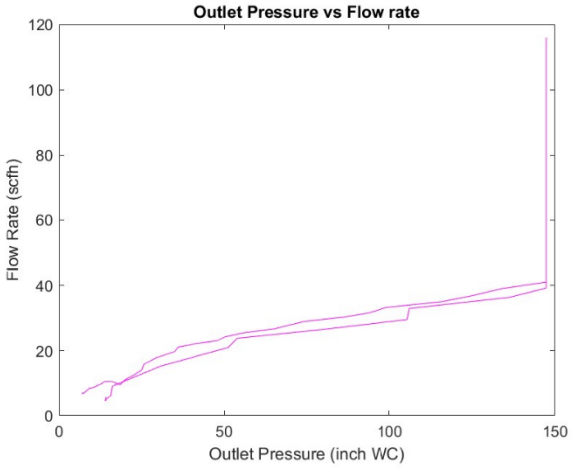
GTI ENERGY

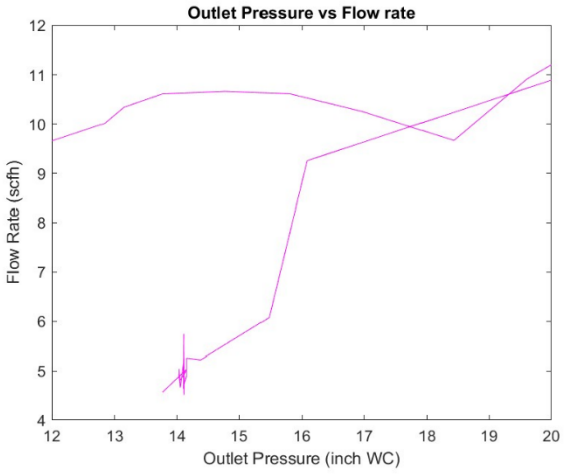
- **222489-031_DT2**
  The volume of total emissions in 164.33 seconds is 1.2730 scf.
  The average flow rate of emissions at 18 inches WC is 9.67 scfh.





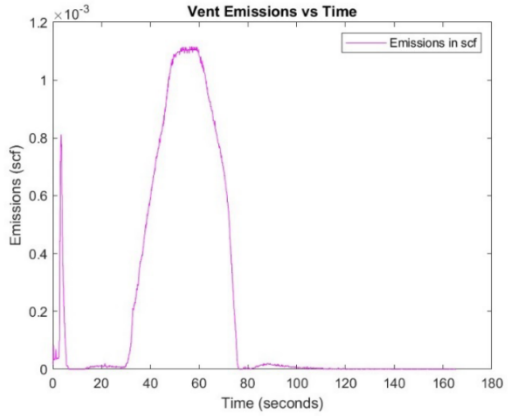
GTI ENERGY

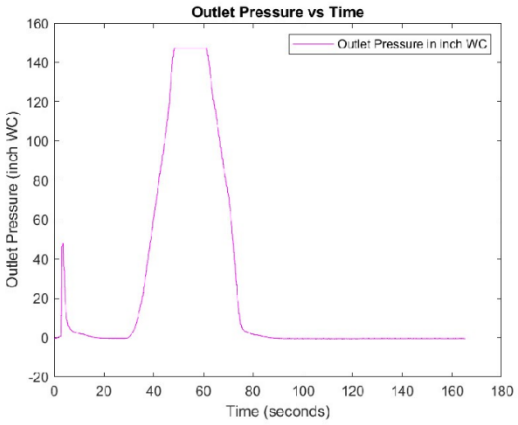

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
20
40
60
80
100
120
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
4
5
6
7
8
9
10
11
12
12
13
14
15
16
17
18
19
20

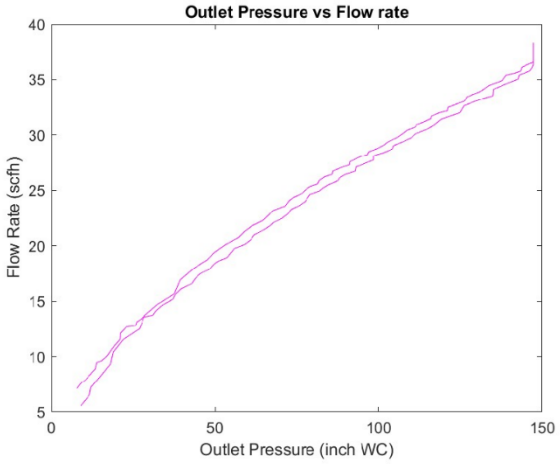
GTI ENERGY

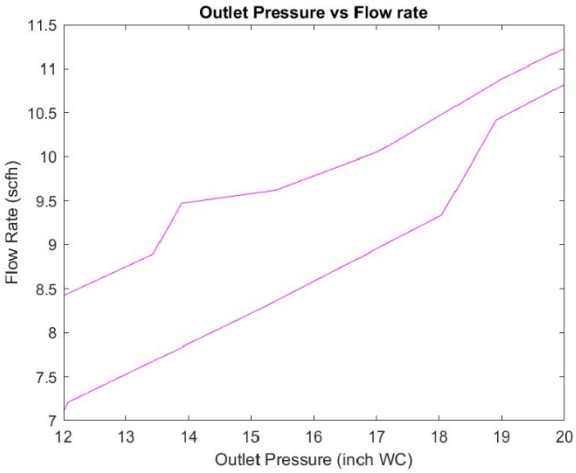
- **222489-031_LD**
  The volume of total emissions in 165.29 seconds is 0.3407 scf.
  The average flow rate of emissions at 18 inches WC is 9.97 scfh.





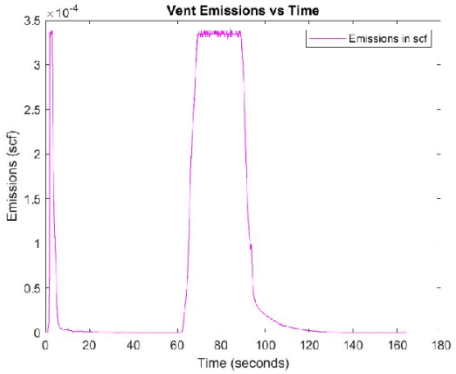
GTI ENERGY

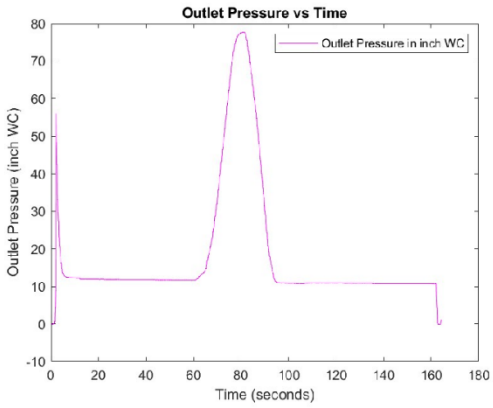

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
40
35
30
25
20
15
10
5
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
11.5
11
10.5
10
9.5
9
8.5
8
7.5
7
12
13
14
15
16
17
18
19
20

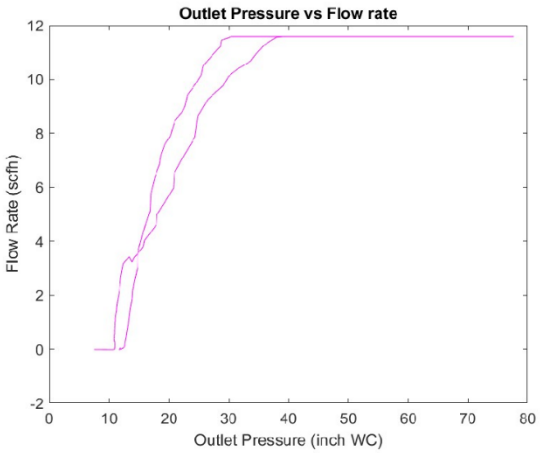
GTI ENERGY

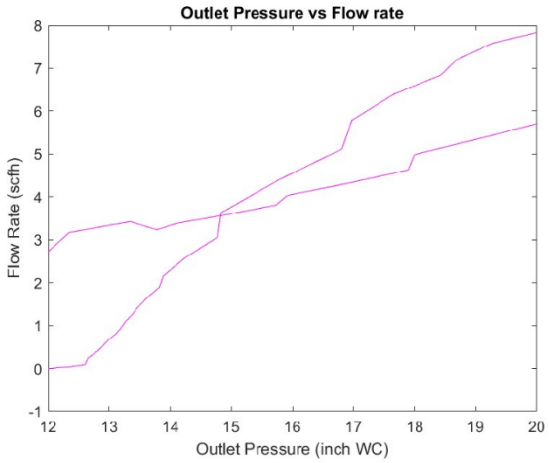
- **222489-032**
  The volume of total emissions in 164.35 seconds is 0.0939 scf.
  The average flow rate of emissions at 18 inches WC is 5.71 scfh.



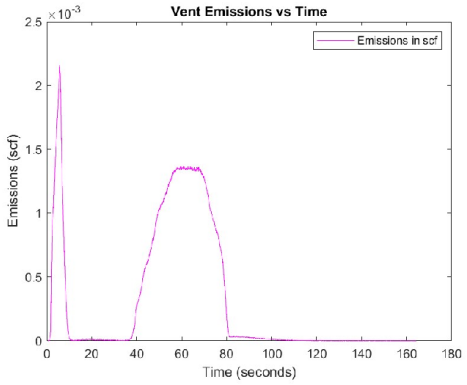


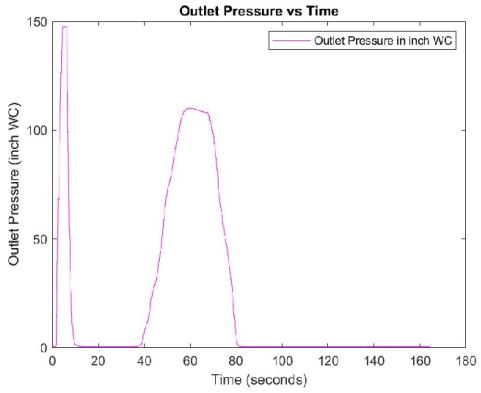
GTI ENERGY


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
12
10
8
6
4
2
0
-2
0
10
20
30
40
50
60
70
80

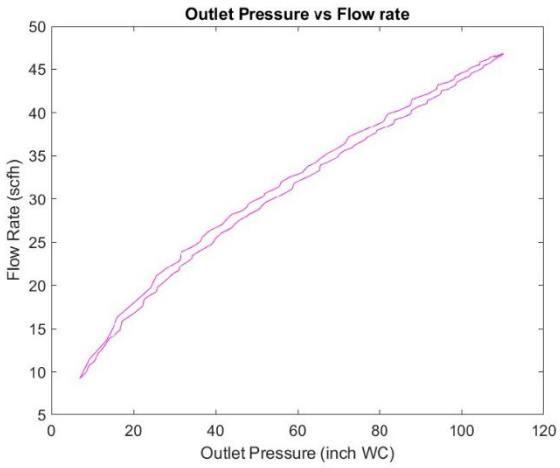

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
8
7
6
5
4
3
2
1
0
-1
12
13
14
15
16
17
18
19
20

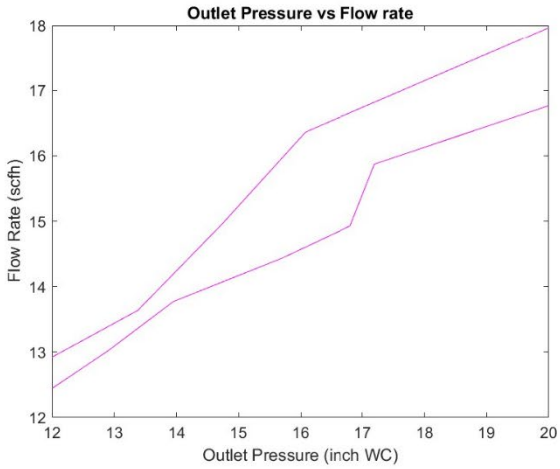
- **222489-032_DT1**
  The volume of total emissions in 164.34 seconds is 0.4878 scf.
  The average flow rate of emissions at 18 inches WC is 15.87 scfh.





GTI ENERGY


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
50
45
40
35
30
25
20
15
10
5
0
20
40
60
80
100
120

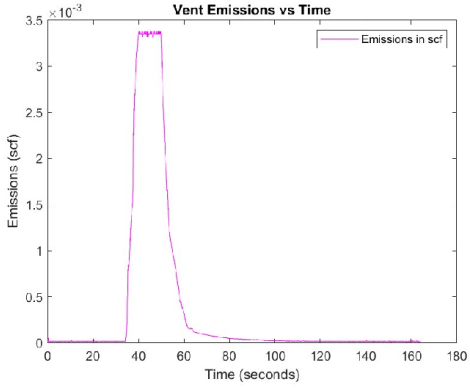

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
18
17
16
15
14
13
12
12
13
14
15
16
17
18
19
20

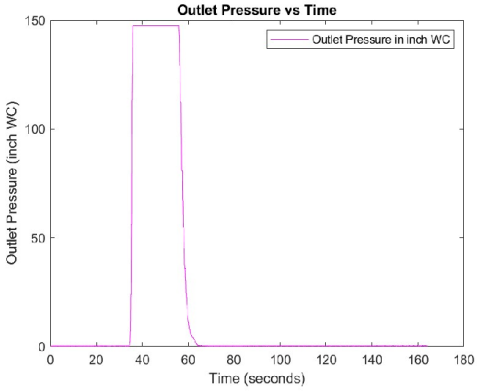
GTI ENERGY

- 222489-032_DT2

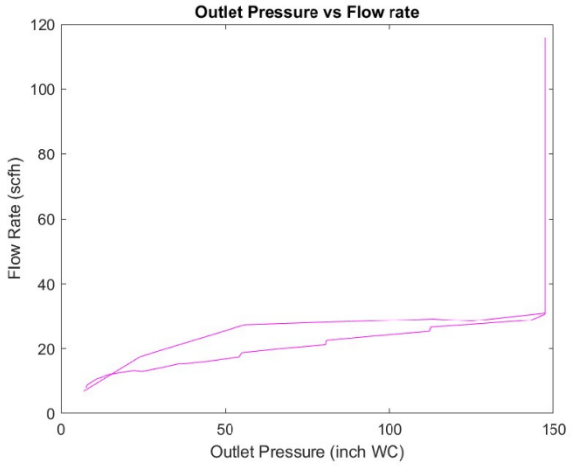
  The volume of total emissions in 164.25 seconds is 0.5744 scf.

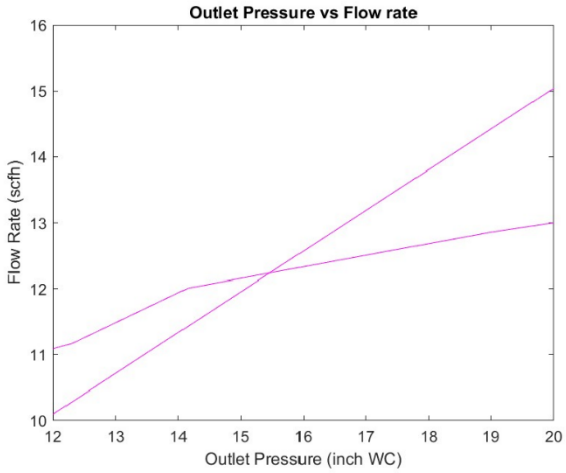
Commented [JW17]: No data points in range to calculate avg





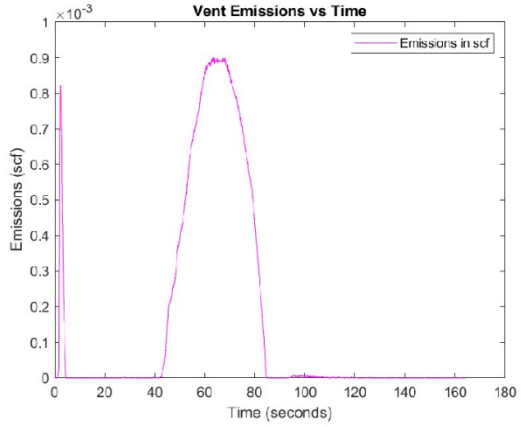
GTI ENERGY

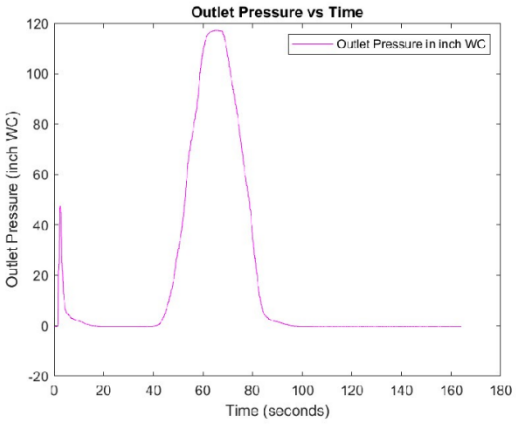

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
20
40
60
80
100
120
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
10
11
12
13
14
15
16
12
13
14
15
16
17
18
19
20

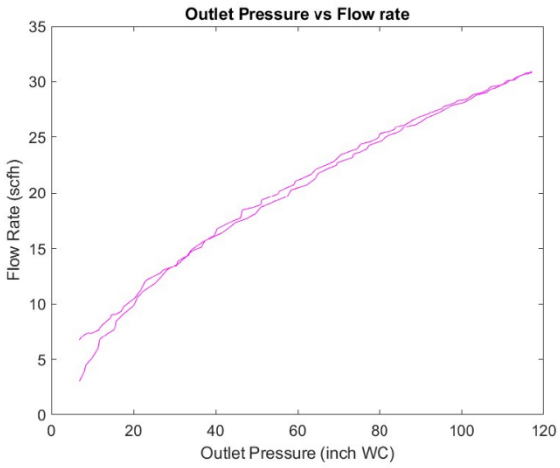
GTI ENERGY

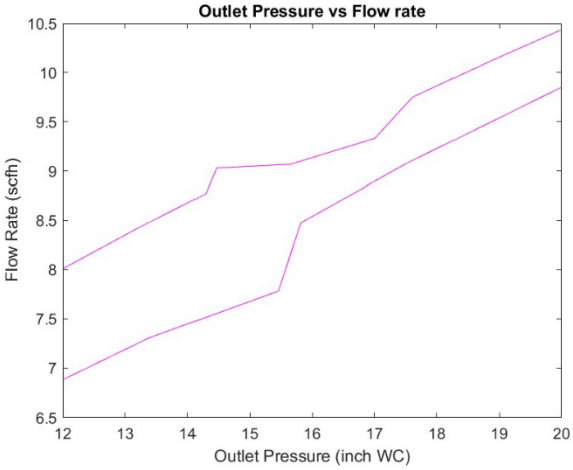
- **222489-032_LD**
  The volume of total emissions in 164.26 seconds is 0.2477 scf.
  The average flow rate of emissions at 18 inches WC is 9.17 scfh.





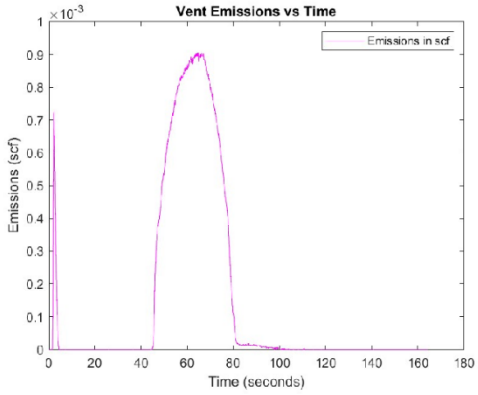
GTI ENERGY

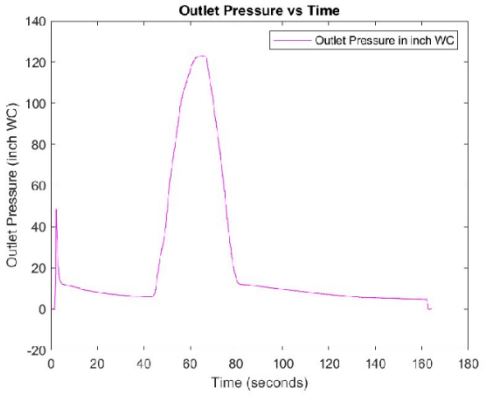

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
5
10
15
20
25
30
35
0
20
40
60
80
100
120


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
6.5
7
7.5
8
8.5
9
9.5
10
10.5
12
13
14
15
16
17
18
19
20

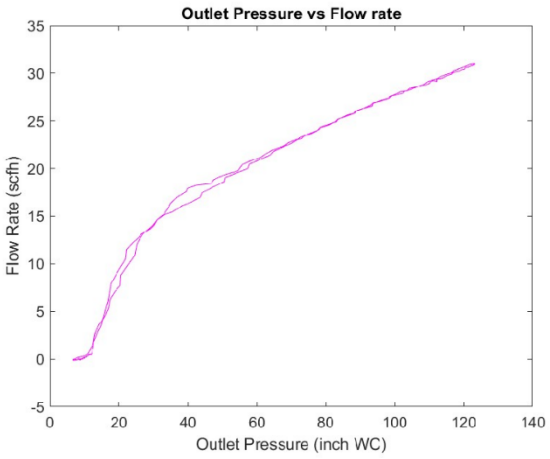
GTI ENERGY

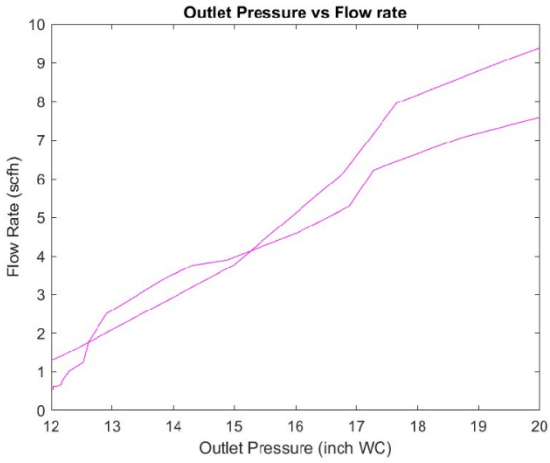
- **222489-033**
  The volume of total emissions in 164.37 seconds is 0.2338 scf.
  The average flow rate of emissions at 18 inches WC is 7.09 scfh.





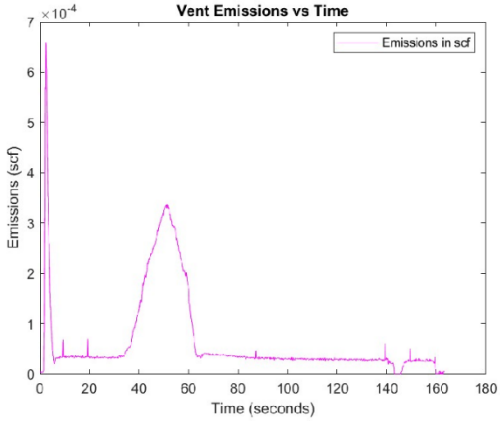
GTI ENERGY

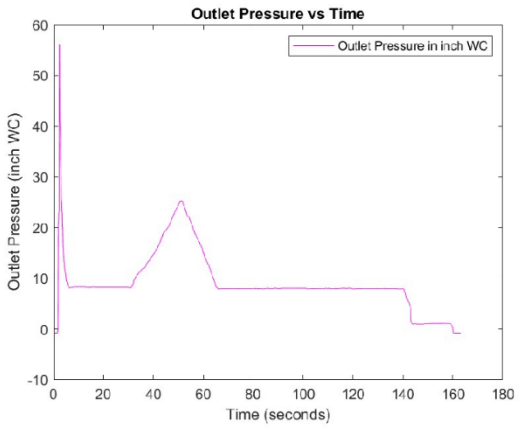

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
35
30
25
20
15
10
5
0
-5
0
20
40
60
80
100
120
140


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
10
9
8
7
6
5
4
3
2
1
0
12
13
14
15
16
17
18
19
20

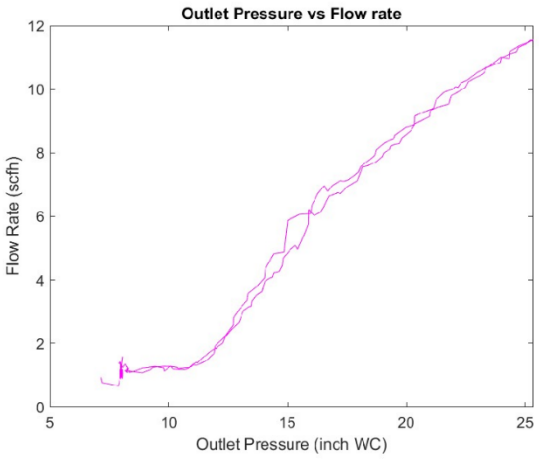
GTI ENERGY

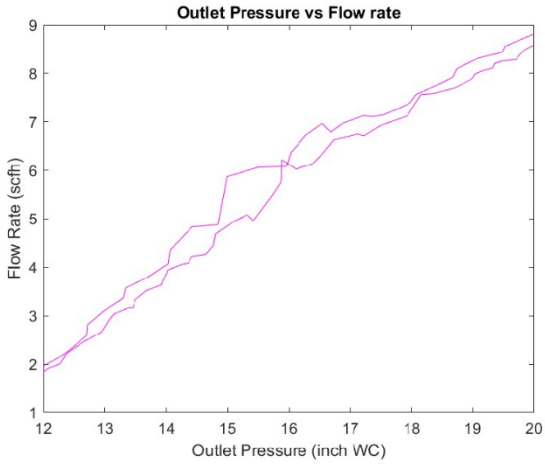
- **222489-033_DT1**
  The volume of total emissions in 163.24 seconds is 0.1021 scf.
  The average flow rate of emissions at 18 inches WC is 7.41 scfh.





GTI ENERGY

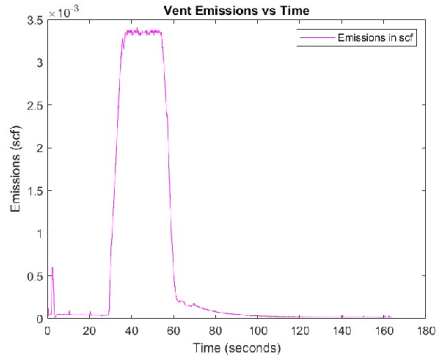

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
2
4
6
8
10
12
5
10
15
20
25

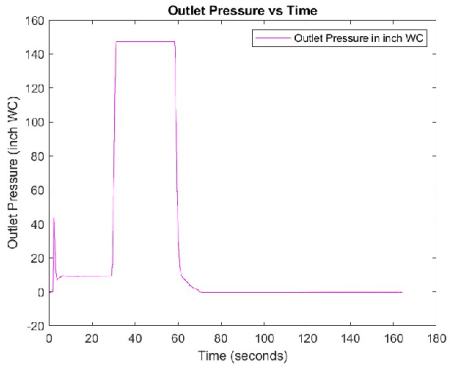

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
1
2
3
4
5
6
7
8
9
12
13
14
15
16
17
18
19
20

GTI ENERGY

- 222489-033_DT2

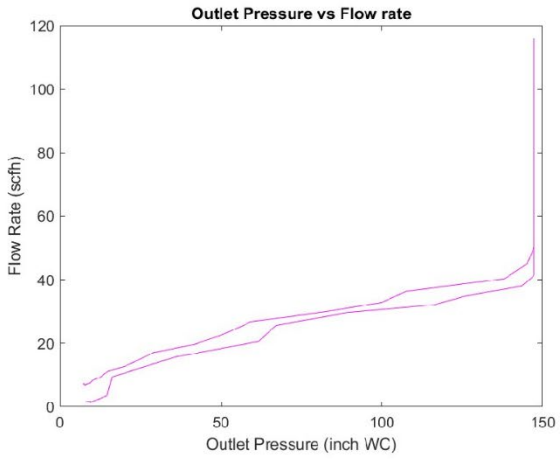
  The volume of total emissions in 164.25 seconds is 0.8920 scf.

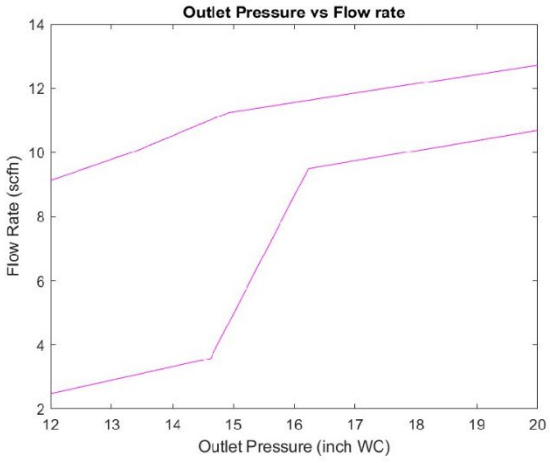




Commented [JW18]: No data points within range to calculate avg

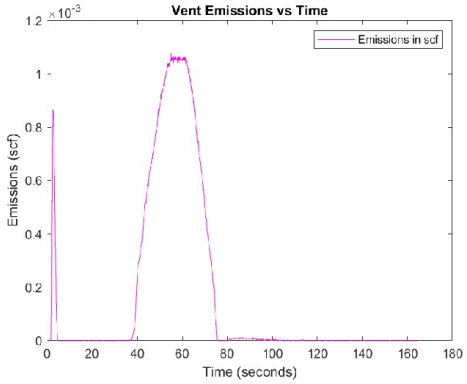
GTI ENERGY

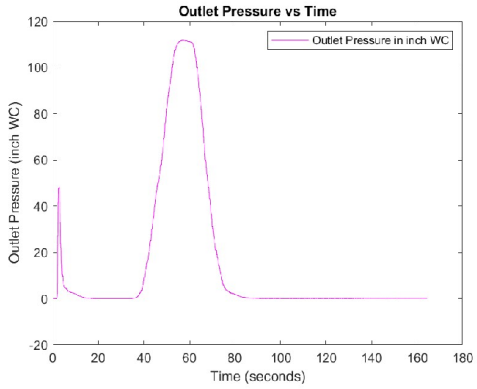

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
20
40
60
80
100
120
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
2
4
6
8
10
12
14
12
13
14
15
16
17
18
19
20

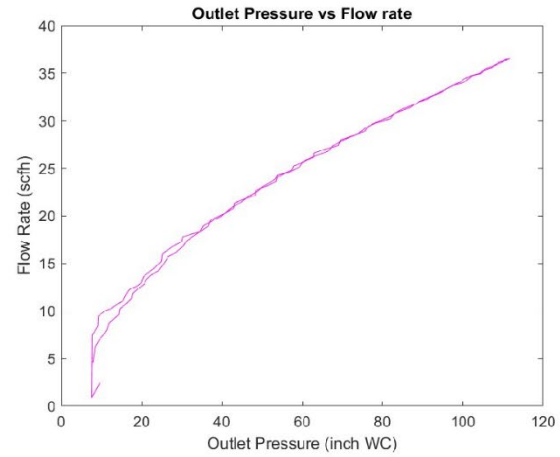
GTI ENERGY

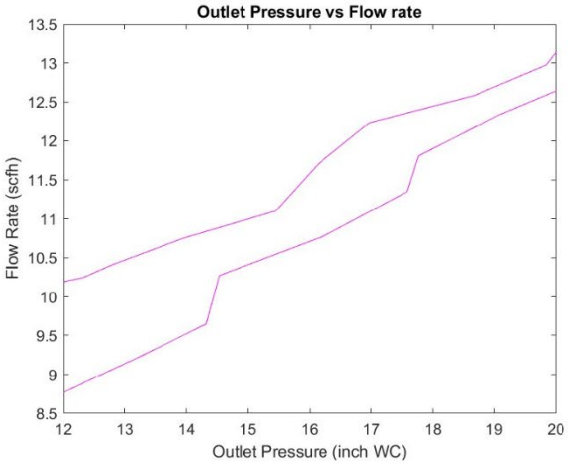
- **222489-033_LD**
  The volume of total emissions in 164.54 seconds is 0.2654 scf.
  The average flow rate of emissions at 18 inches WC is 11.58 scfh.





GTI ENERGY


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
5
10
15
20
25
30
35
40
0
20
40
60
80
100
120

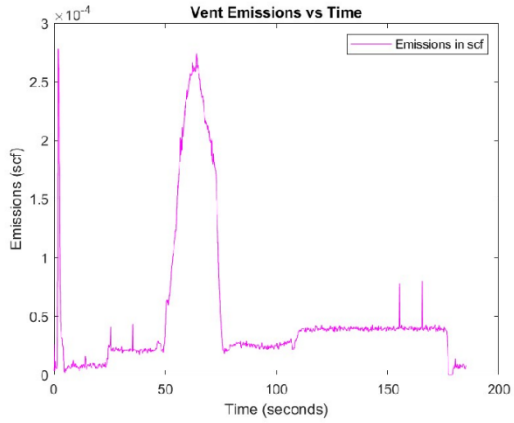

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
8.5
9
9.5
10
10.5
11
11.5
12
12.5
13
13.5
12
13
14
15
16
17
18
19
20

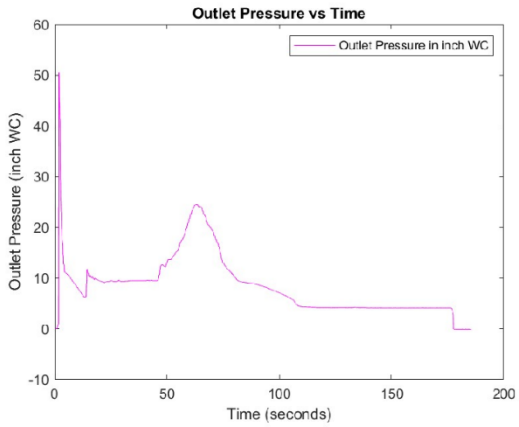
GTI ENERGY

7" WC Outlet, 60-psig Inlet

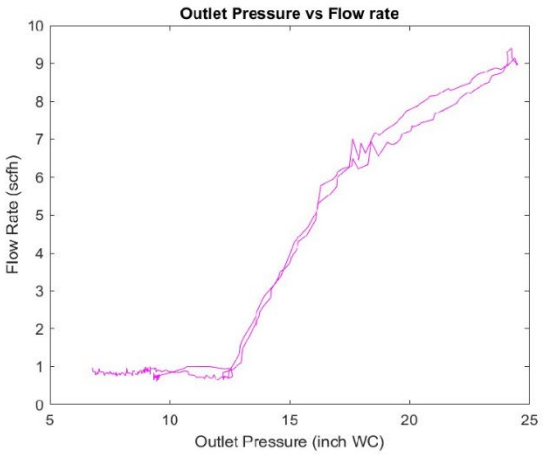
- **222489-031**

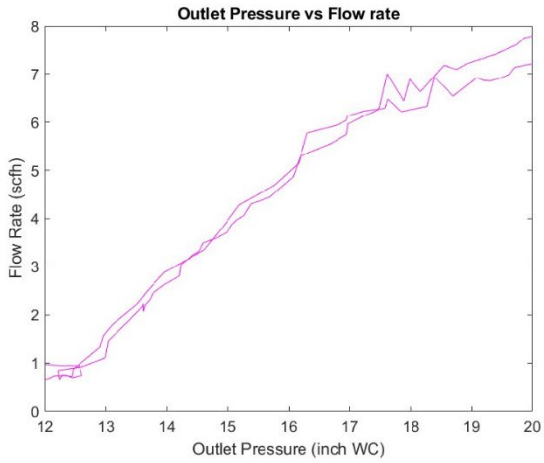
  The volume of total emissions in 185.37 seconds is 0.0880 scf.
  The average flow rate of emissions at 18 inches WC is 6.55 scfh.





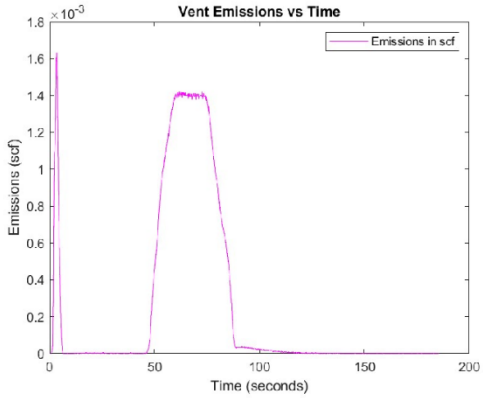
GTI ENERGY

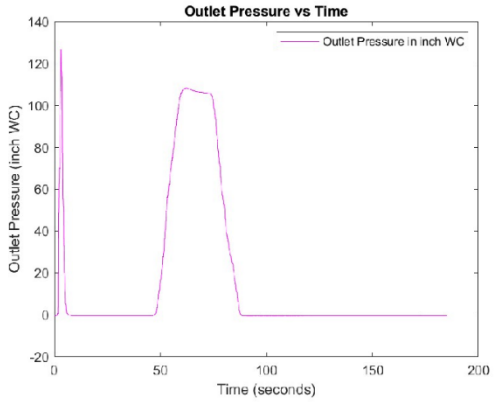

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
1
2
3
4
5
6
7
8
9
10
5
10
15
20
25


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
1
2
3
4
5
6
7
8
12
13
14
15
16
17
18
19
20

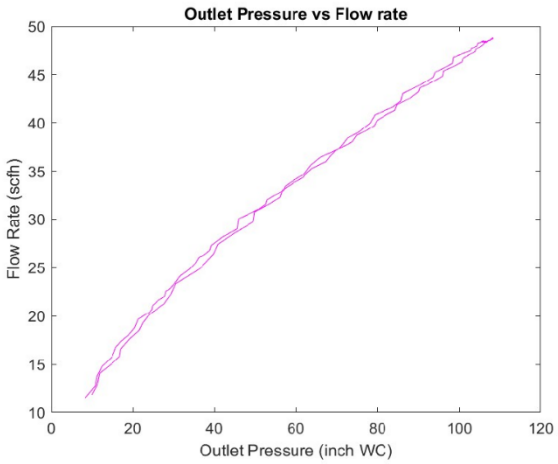
GTI ENERGY

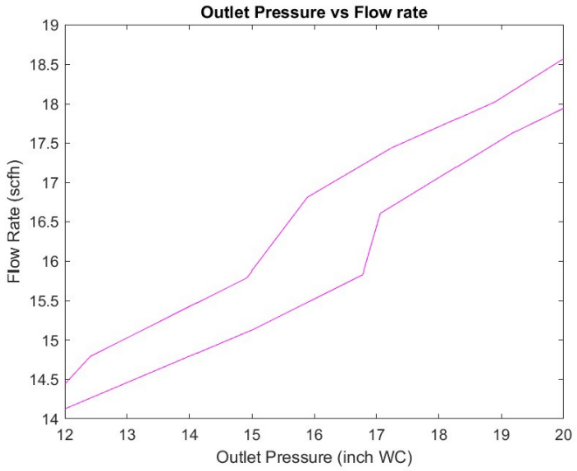
- **222489-031_DT1**
  The volume of total emissions in 185.49 seconds is 0.4439 scf.
  The average flow rate of emissions at 18 inches WC is 16.72 scfh.





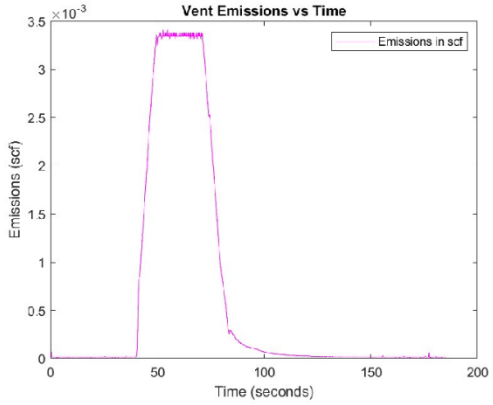
GTI ENERGY

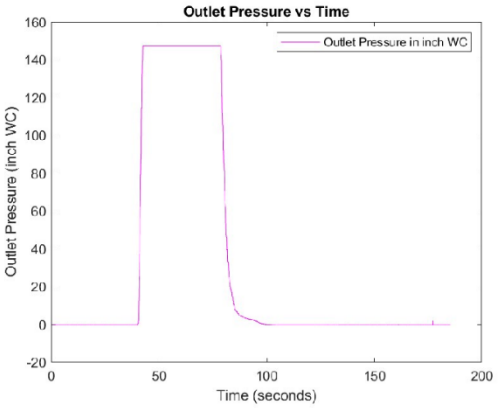

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
50
45
40
35
30
25
20
15
10
0
20
40
60
80
100
120


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
19
18.5
18
17.5
17
16.5
16
15.5
15
14.5
14
12
13
14
15
16
17
18
19
20

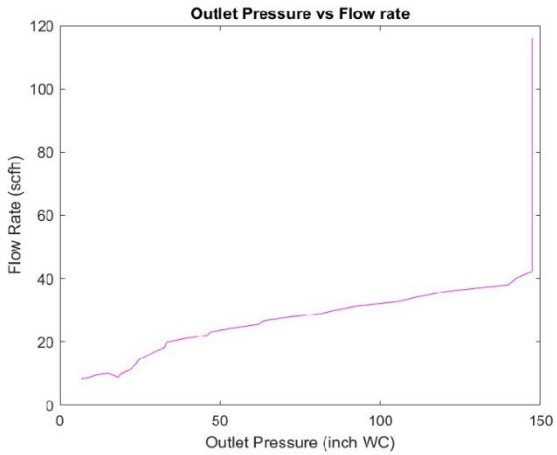
GTI ENERGY

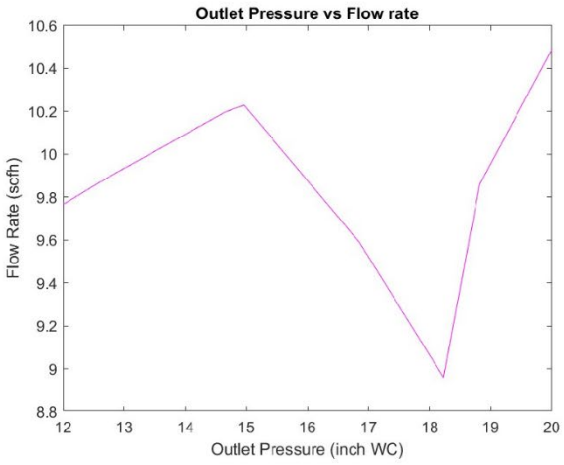
- **222489-031_DT2**
  The volume of total emissions in 185.37 seconds is 1.1141 scf.
  The average flow rate of emissions at 18 inches WC is 9.41 scfh.





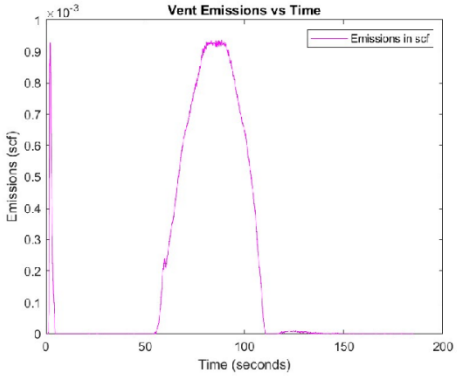
GTI ENERGY

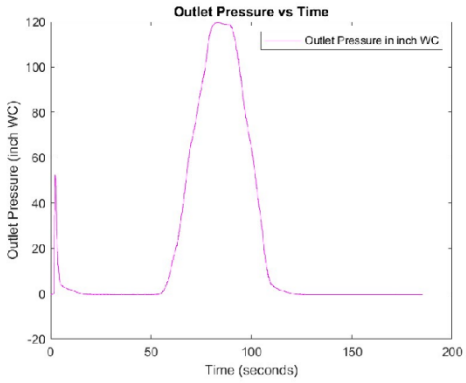

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
20
40
60
80
100
120
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
8.8
9
9.2
9.4
9.6
9.8
10
10.2
10.4
10.6
12
13
14
15
16
17
18
19
20

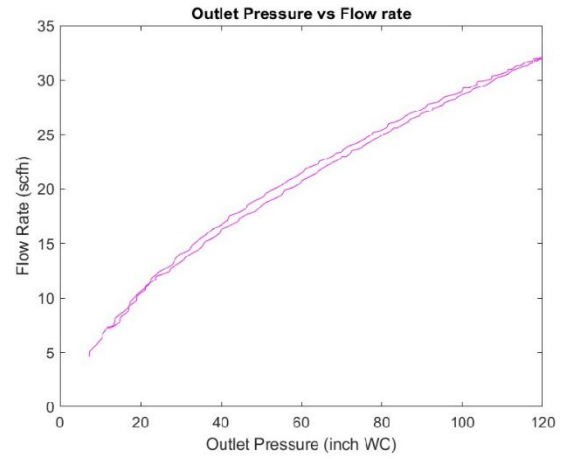
GTI ENERGY

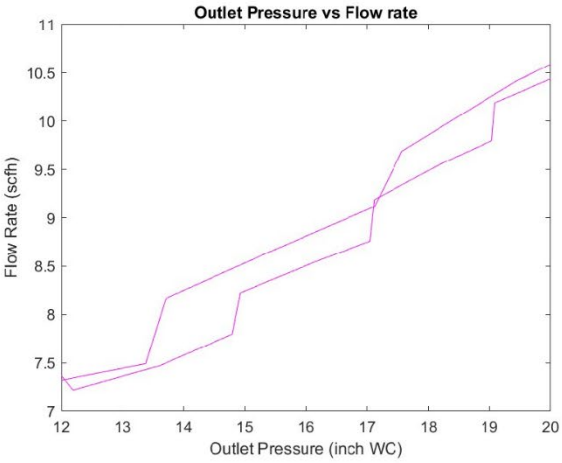
- **222489-031_LD**
  The volume of total emissions in 185.35 seconds is 0.3339 scf.
  The average flow rate of emissions at 18 inches WC is 9.02 scfh.



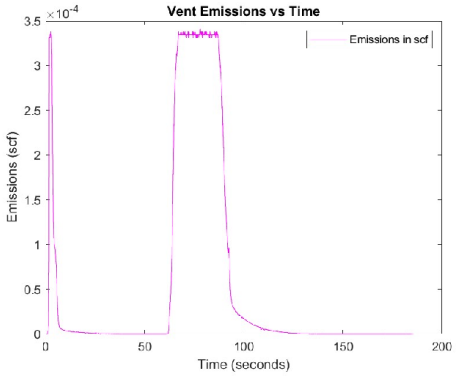


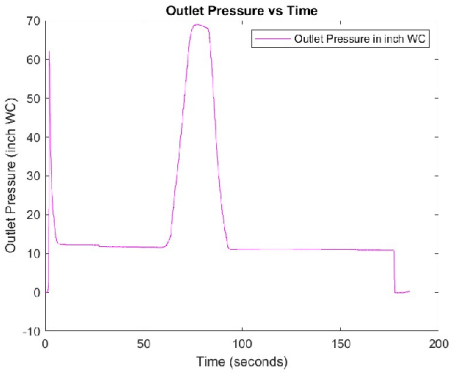
GTI ENERGY


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
5
10
15
20
25
30
35
0
20
40
60
80
100
120

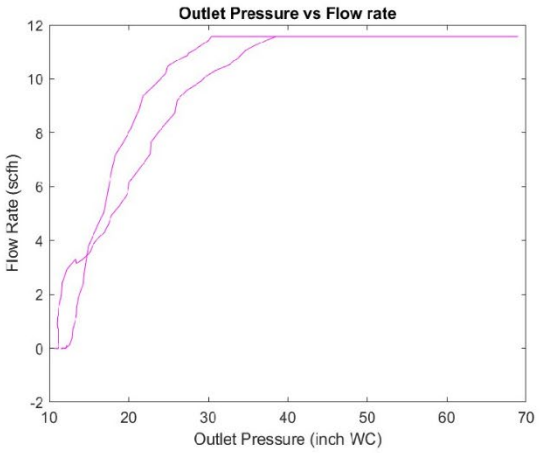

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
7
7.5
8
8.5
9
9.5
10
10.5
11
12
13
14
15
16
17
18
19
20

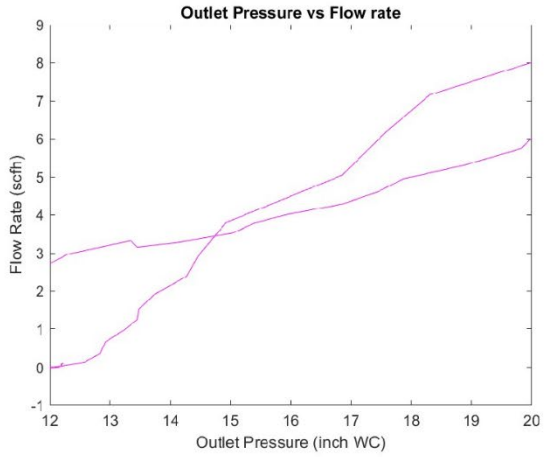
- **222489-032**
  The volume of total emissions in 185.37 seconds is 0.0960 scf.
  The average flow rate of emissions at 18 inches WC is 5.27 scfh.





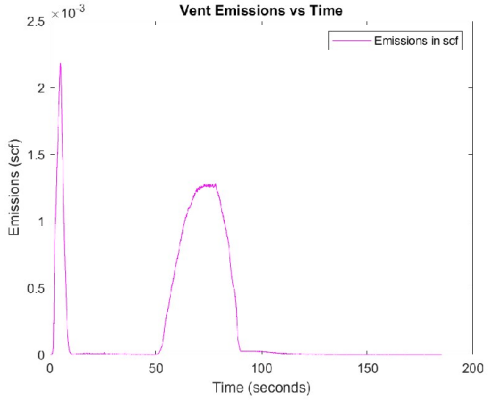
GTI ENERGY

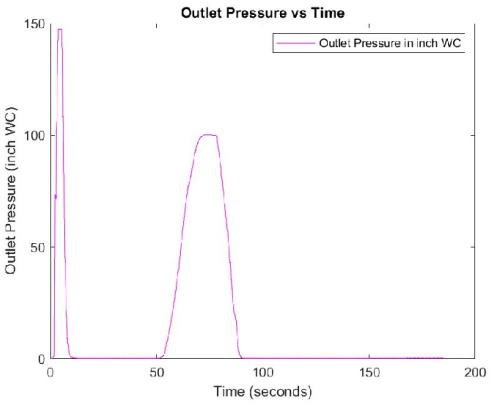

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
12
10
8
6
4
2
0
-2
10
20
30
40
50
60
70


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
9
8
7
6
5
4
3
2
1
0
-1
12
13
14
15
16
17
18
19
20

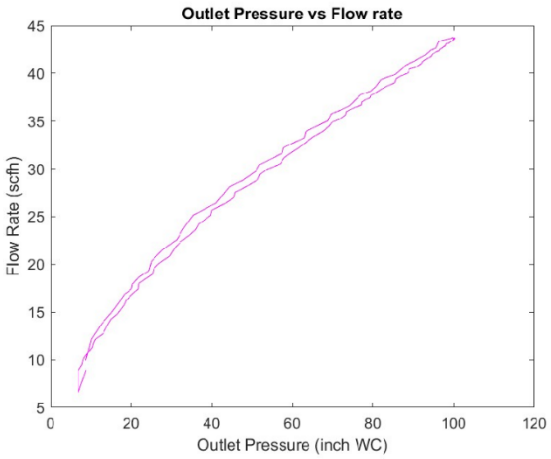
GTI ENERGY

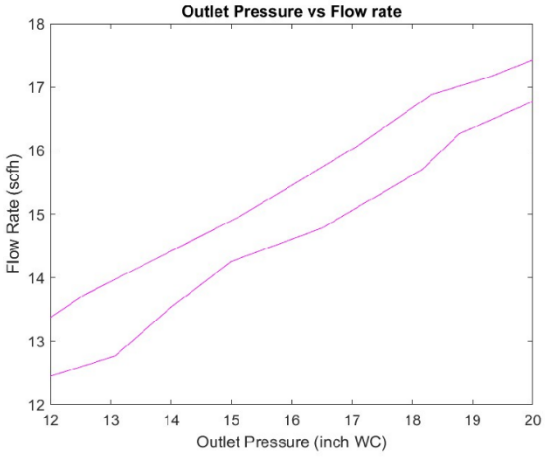
- **222489-032_DT1**
  The volume of total emissions in 185.37 seconds is 0.3973 scf.
  The average flow rate of emissions at 18 inches WC is 16.24 scfh.





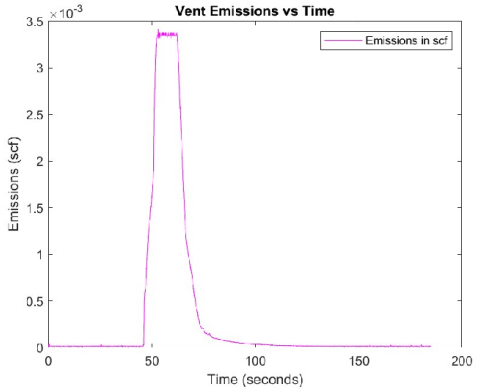
GTI ENERGY

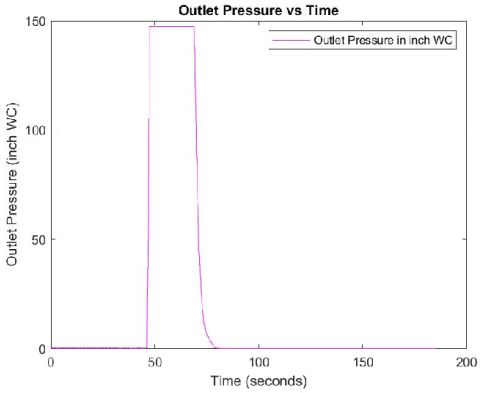

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
45
40
35
30
25
20
15
10
5
0
20
40
60
80
100
120


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
18
17
16
15
14
13
12
12
13
14
15
16
17
18
19
20

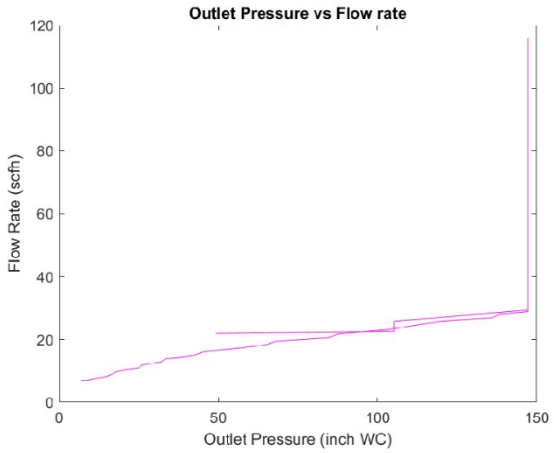
GTI ENERGY

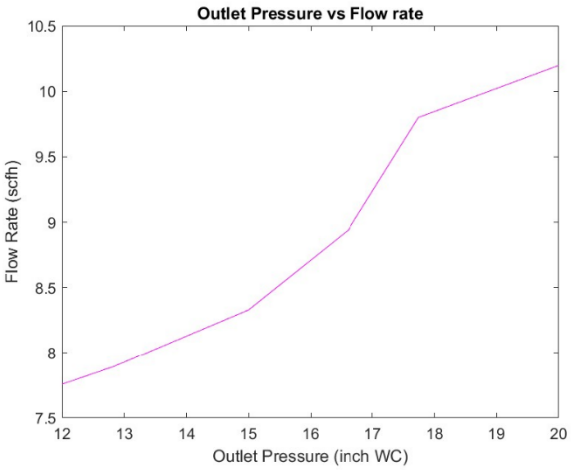
- **222489-032_DT2**
  The volume of total emissions in 185.37 seconds is 0.5920 scf.
  The average flow rate of emissions at 18 inches WC is 9.80 scfh.





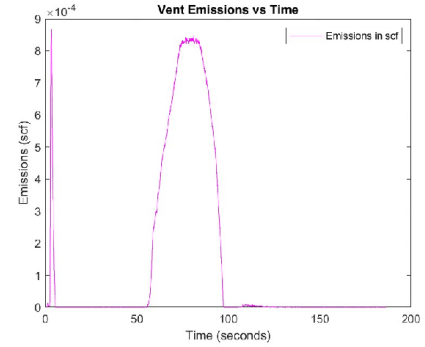
GTI ENERGY

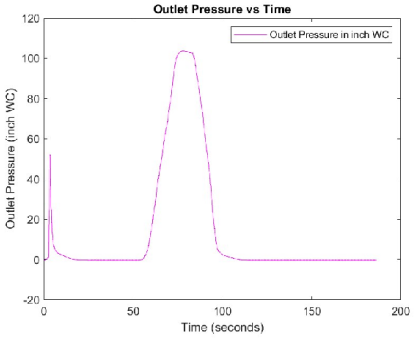

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
20
40
60
80
100
120
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
7.5
8
8.5
9
9.5
10
10.5
12
13
14
15
16
17
18
19
20

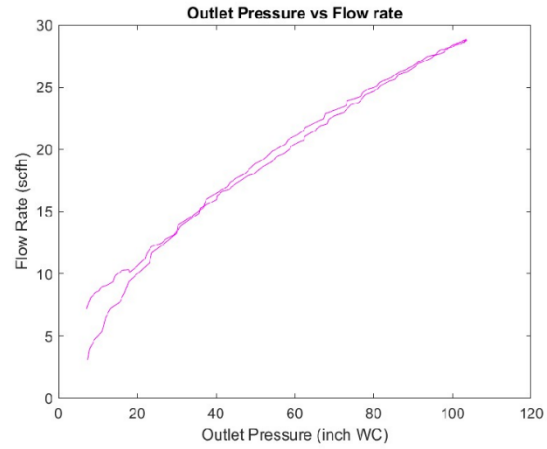
GTI ENERGY

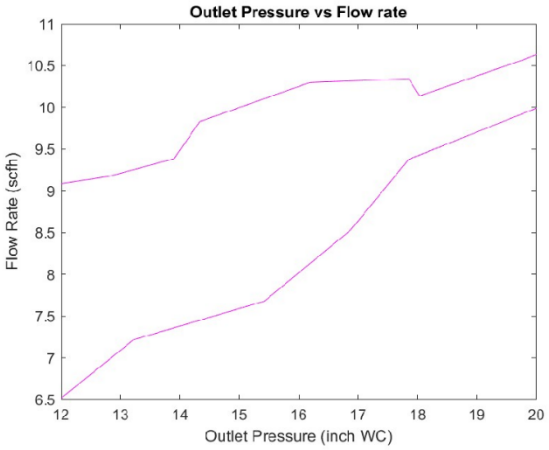
- **222489-032_LD**
  The volume of total emissions in 186.35 seconds is 0.2415 scf.
  The average flow rate of emissions at 18 inches WC is 9.38 scfh.





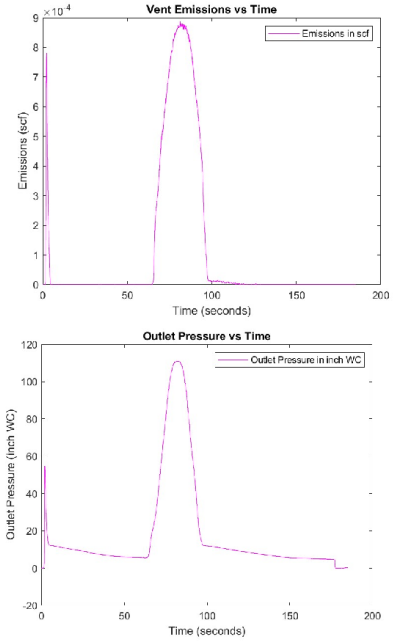
GTI ENERGY


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
5
10
15
20
25
30
0
20
40
60
80
100
120

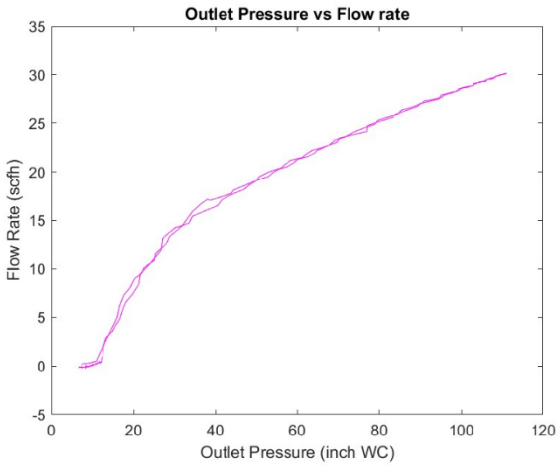

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
6.5
7
7.5
8
8.5
9
9.5
10
10.5
11
12
13
14
15
16
17
18
19
20

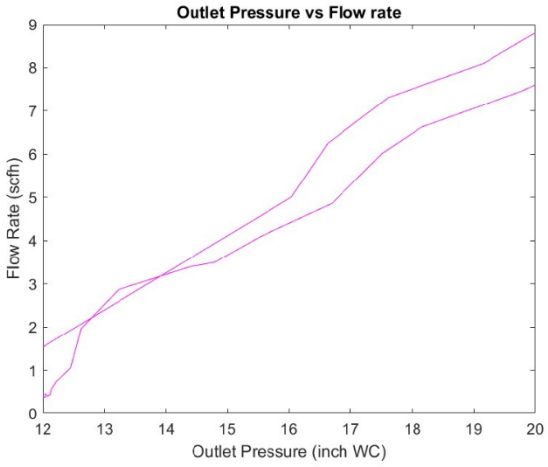
GTI ENERGY

- **222489-033**
  The volume of total emissions in 185.27 seconds is 0.1988 scf.
  The average flow rate of emissions at 18 inches WC is 6.57 scfh.



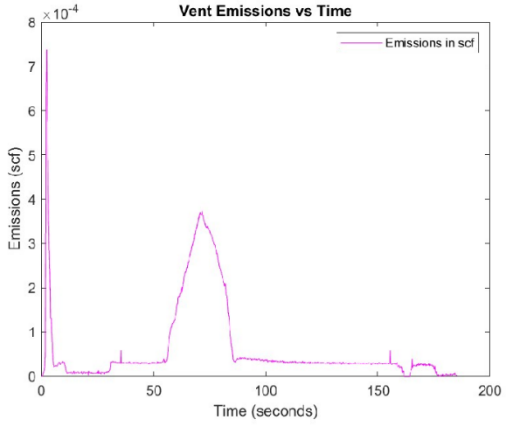
GTI ENERGY

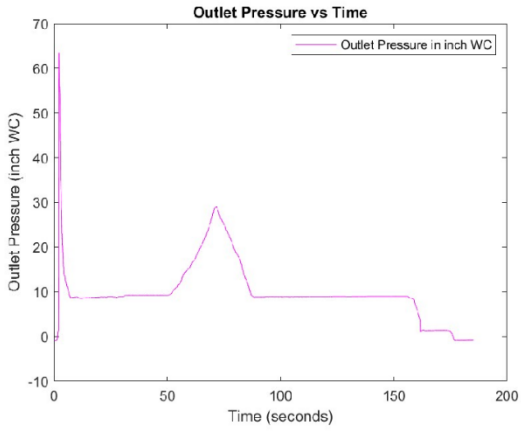

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
35
30
25
20
15
10
5
0
-5
0
20
40
60
80
100
120


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
9
8
7
6
5
4
3
2
1
0
12
13
14
15
16
17
18
19
20

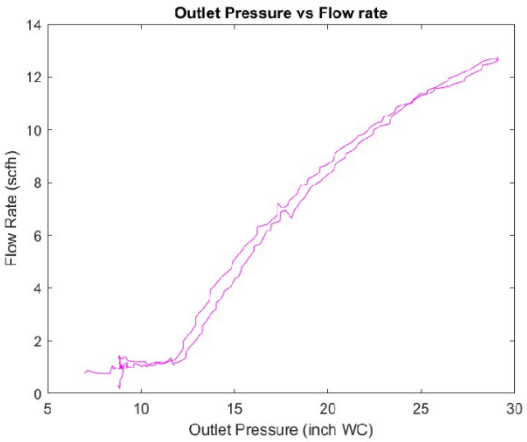
GTI ENERGY

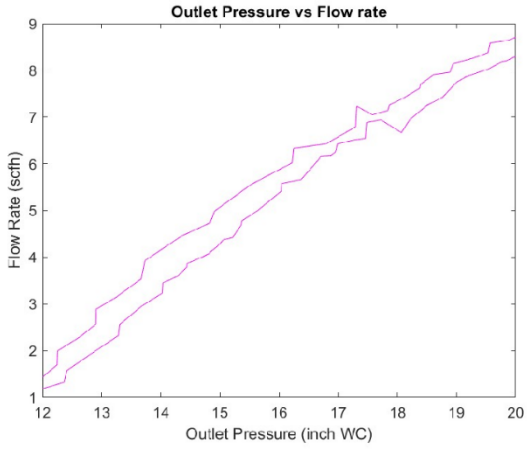
- **222489-033_DT1**
  The volume of total emissions in 185.31 seconds is 0.1140 scf.
  The average flow rate of emissions at 18 inches WC is 7.12 scfh.





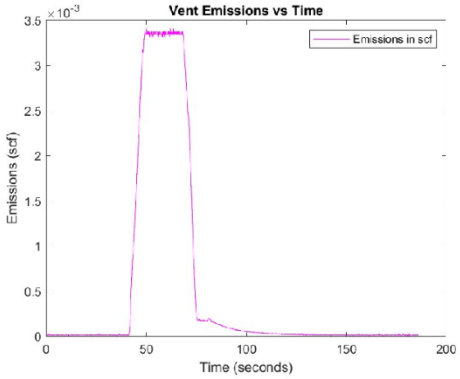
GTI ENERGY

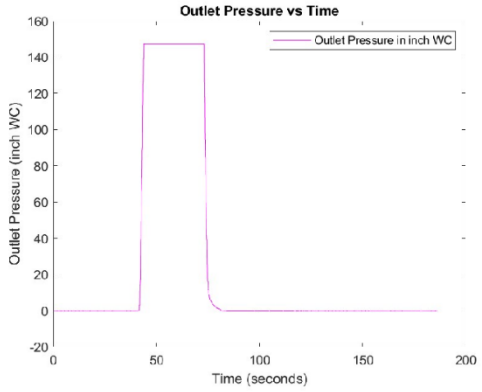

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
2
4
6
8
10
12
14
5
10
15
20
25
30


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
1
2
3
4
5
6
7
8
9
12
13
14
15
16
17
18
19
20

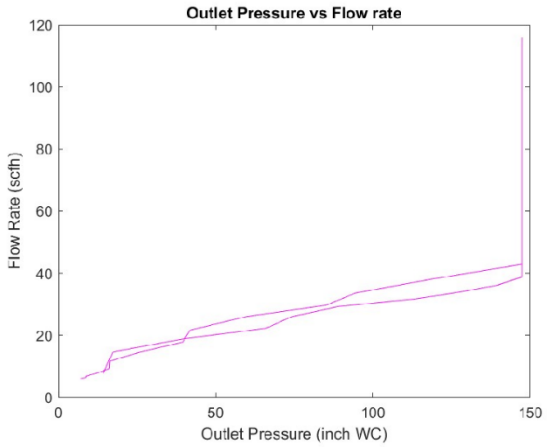
GTI ENERGY

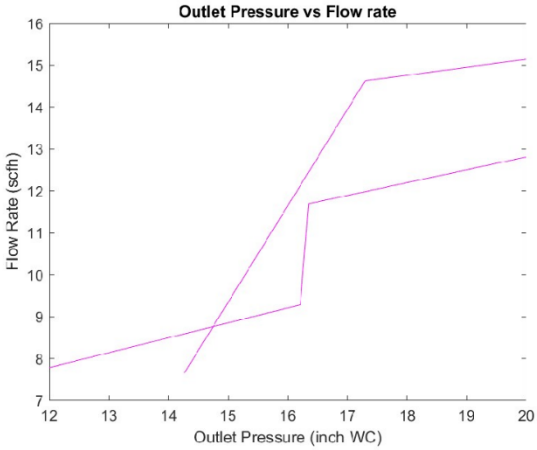
- **222489-033_DT2**
  The volume of total emissions in 186.36 seconds is 0.9294 scf.
  The average flow rate of emissions at 18 inches WC is 14.63 scfh.





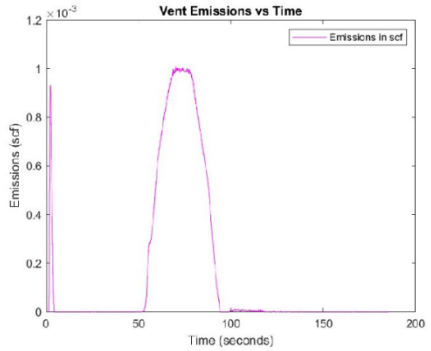
GTI ENERGY

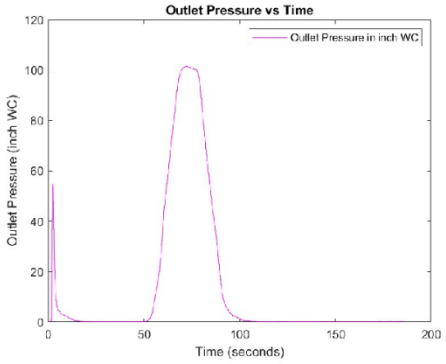

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
20
40
60
80
100
120
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
7
8
9
10
11
12
13
14
15
16
12
13
14
15
16
17
18
19
20

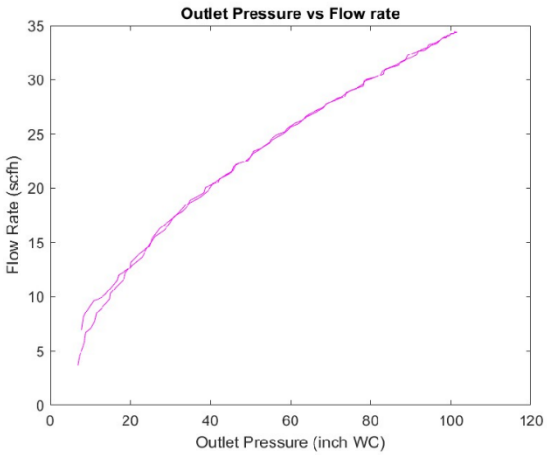
GTI ENERGY

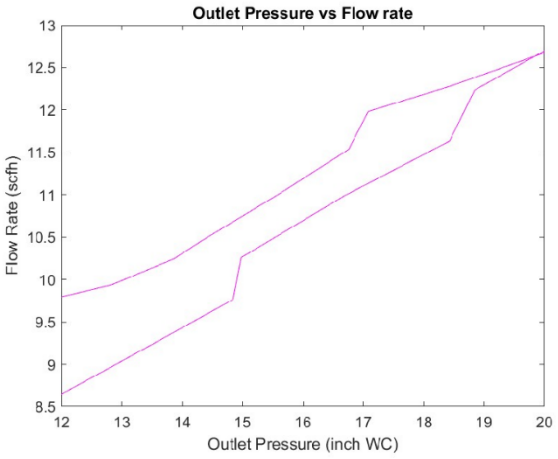
- **222489-033_LD**
  The volume of total emissions in 185.40 seconds is 0.2755 scf.
  The average flow rate of emissions at 18 inches WC is 12.03 scfh.





GTI ENERGY


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
5
10
15
20
25
30
35
0
20
40
60
80
100
120

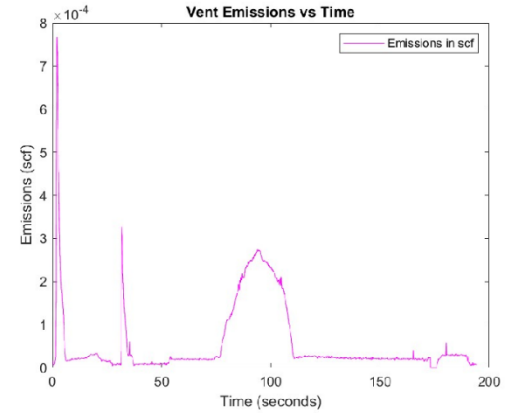

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
8.5
9
9.5
10
10.5
11
11.5
12
12.5
13
12
13
14
15
16
17
18
19
20

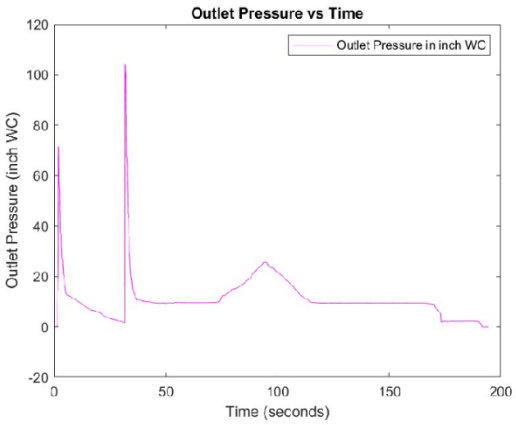
GTI ENERGY

7″ WC Outlet, 100-psig Inlet

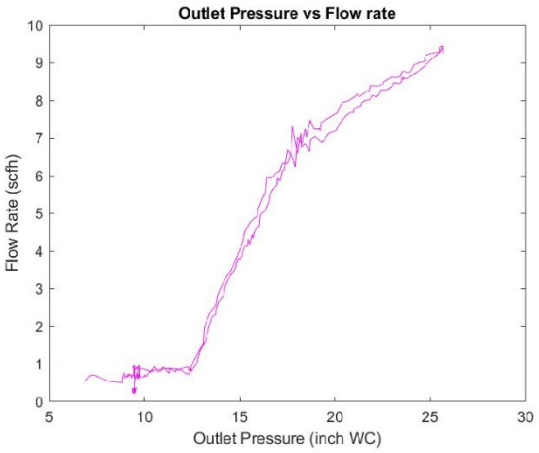
- **222489-031**

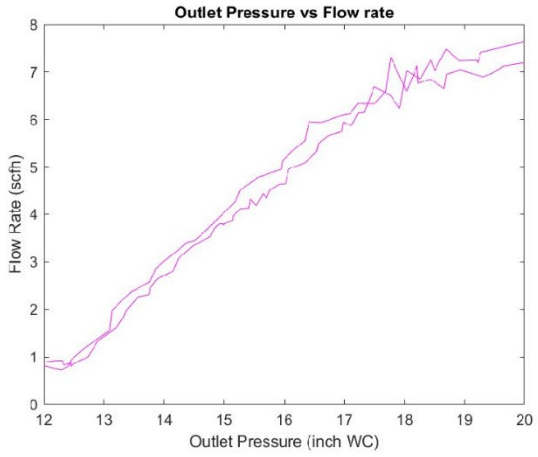
  The volume of total emissions in 194.43 seconds is 0.1050 scf.
  The average flow rate of emissions at 18 inches WC is 6.29 scfh.





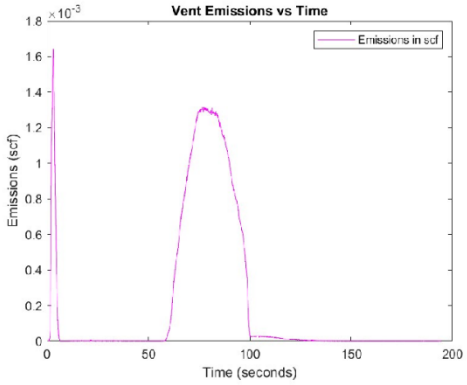
GTI ENERGY

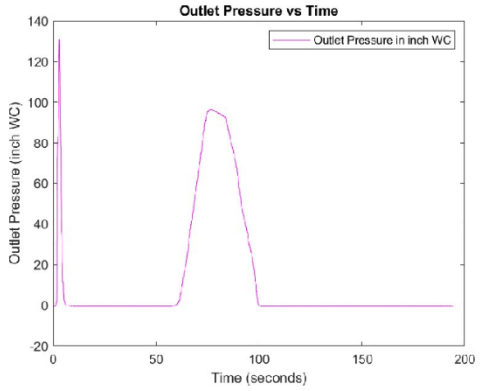

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
1
2
3
4
5
6
7
8
9
10
5
10
15
20
25
30


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
1
2
3
4
5
6
7
8
12
13
14
15
16
17
18
19
20

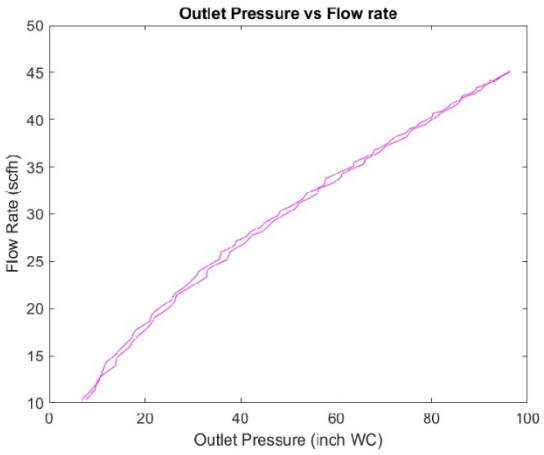
GTI ENERGY

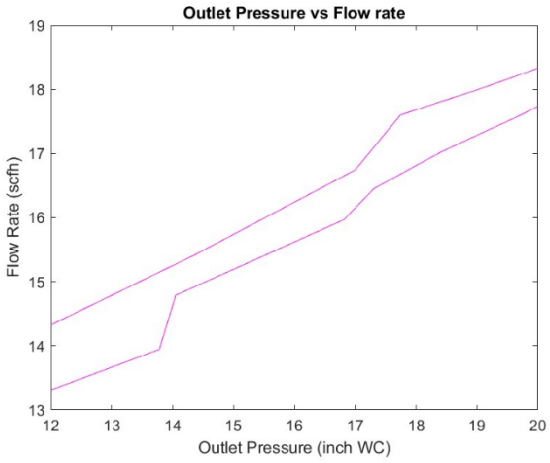
- **222489-031_DT1**
  The volume of total emissions in 194.42 seconds is 0.3861 scf.
  The average flow rate of emissions at 18 inches WC is 17.03 scfh.





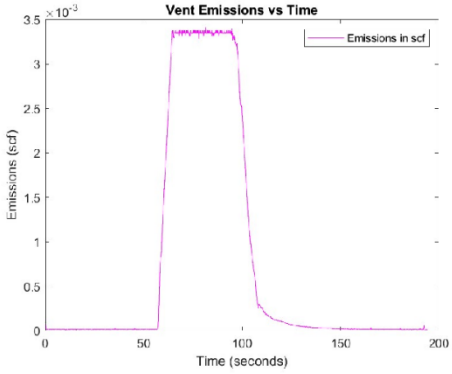
GTI ENERGY

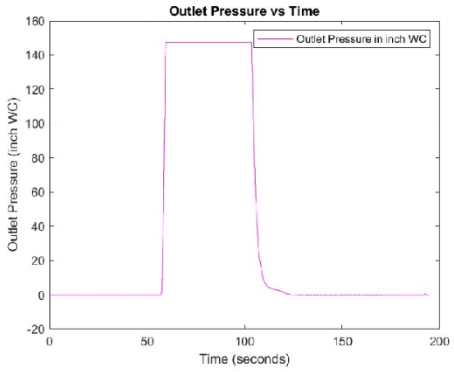

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
50
45
40
35
30
25
20
15
10
0
20
40
60
80
100


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
19
18
17
16
15
14
13
12
13
14
15
16
17
18
19
20

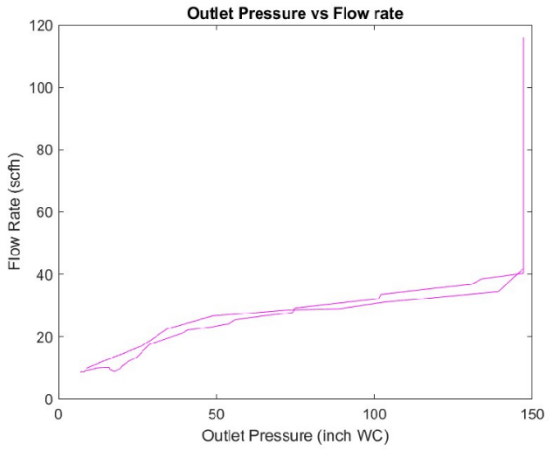
GTI ENERGY

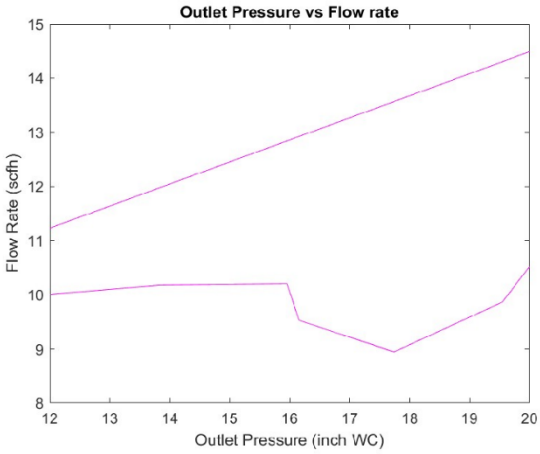
- **222489-031_DT2**
  The volume of total emissions in 194.44 seconds is 1.3893 scf.
  The average flow rate of emissions at 18 inches WC is 8.95 scfh.





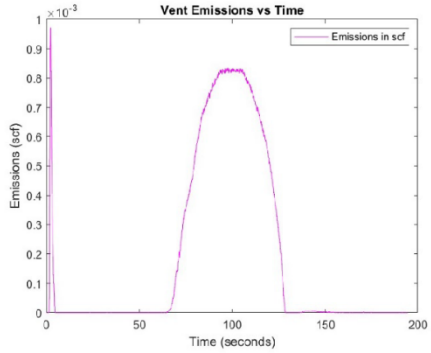
GTI ENERGY

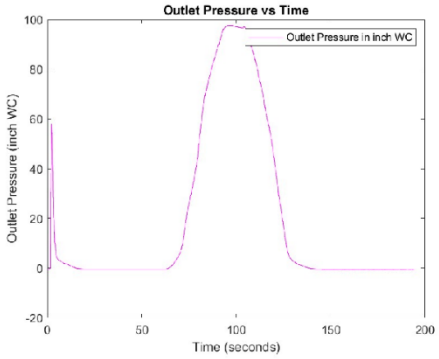

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
20
40
60
80
100
120
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
8
9
10
11
12
13
14
15
12
13
14
15
16
17
18
19
20

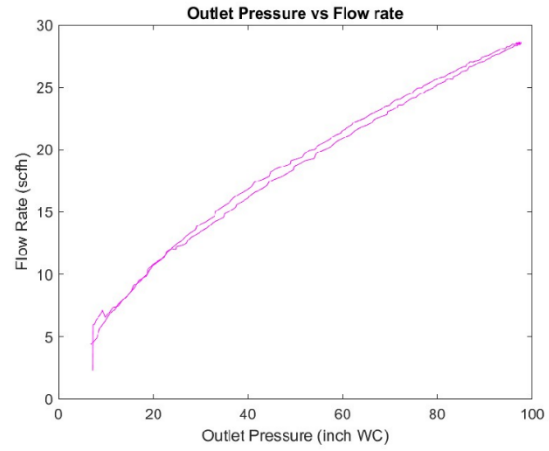
GTI ENERGY

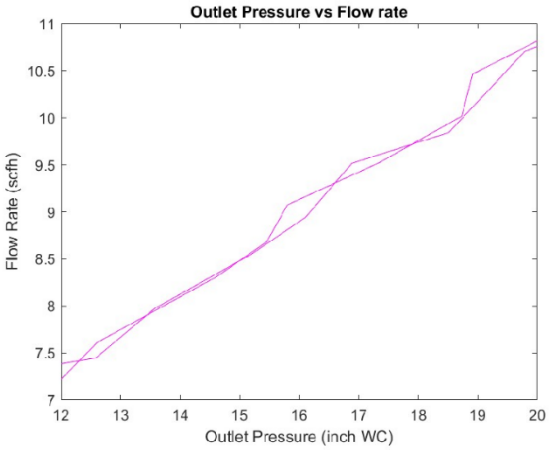
- **222489-031_LD**
  The volume of total emissions in 194.39 seconds is 0.3565 scf.
  The average flow rate of emissions at 18 inches WC is 9.96 scfh.





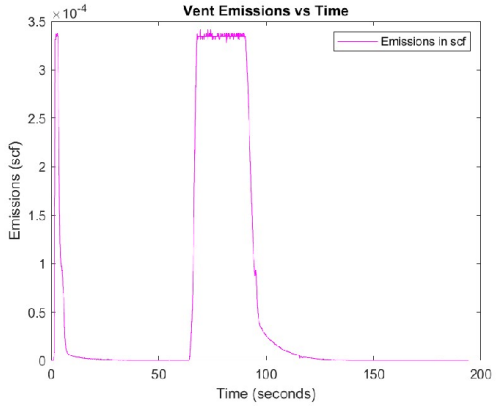
GTI ENERGY

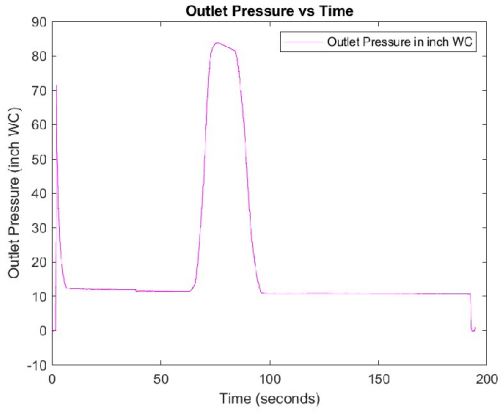

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
5
10
15
20
25
30
0
20
40
60
80
100


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
7
7.5
8
8.5
9
9.5
10
10.5
11
12
13
14
15
16
17
18
19
20

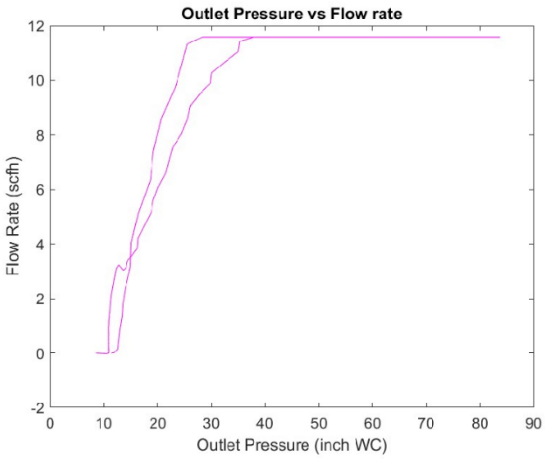
GTI ENERGY

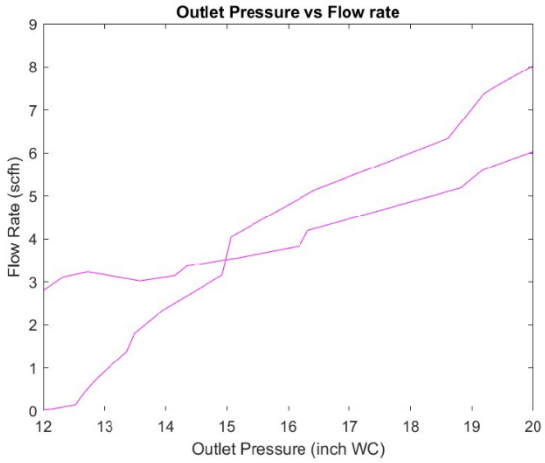
- **222489-032**
  The volume of total emissions in 194.49 seconds is 0.0997 scf.
  The average flow rate of emissions at 18 inches WC is 4.89 scfh.





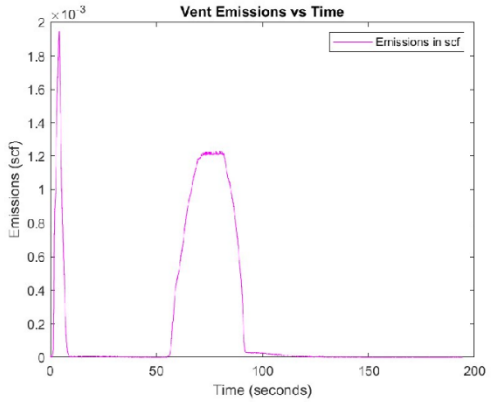
GTI ENERGY

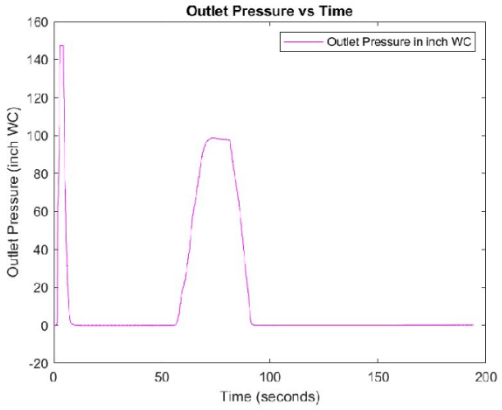

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
12
10
8
6
4
2
0
-2
0
10
20
30
40
50
60
70
80
90


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
9
8
7
6
5
4
3
2
1
0
12
13
14
15
16
17
18
19
20

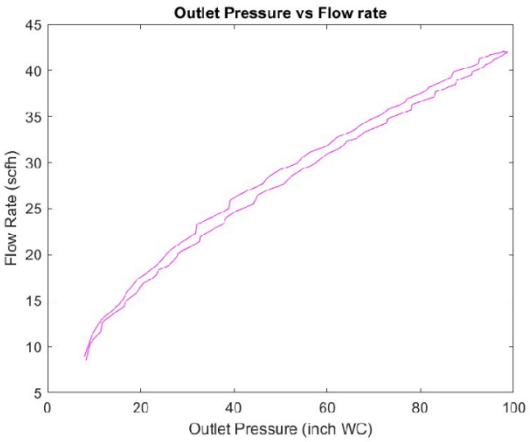
GTI ENERGY

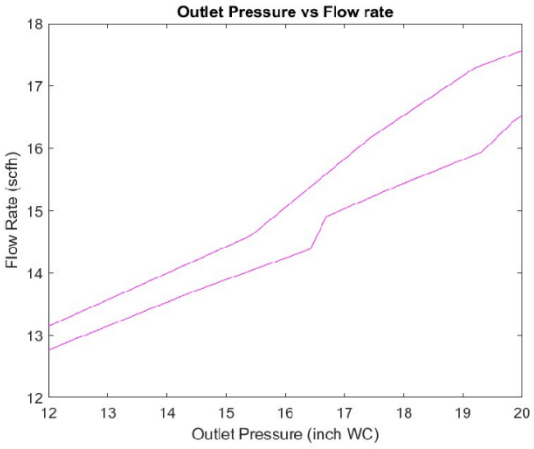
- **222489-032_DT1**
  The volume of total emissions in 194.43 seconds is 0.3717 scf.
  The average flow rate of emissions at 18 inches WC is 15.78 scfh.





GTI ENERGY


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
45
40
35
30
25
20
15
10
5
0
20
40
60
80
100

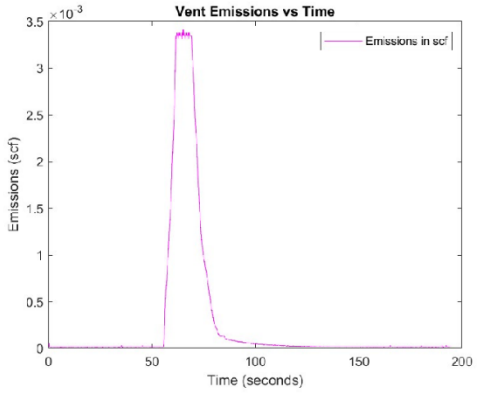

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
18
17
16
15
14
13
12
12
13
14
15
16
17
18
19
20

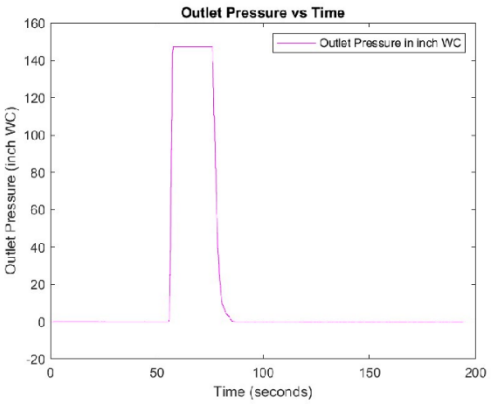
GTI ENERGY

- 222489-032_DT2

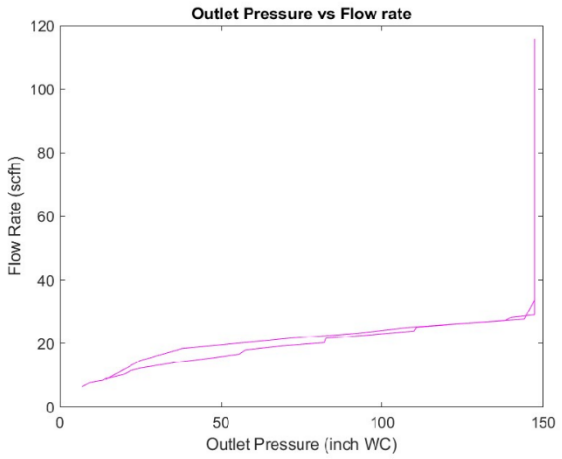
Commented [JW19]: Data outside range to calculate avg

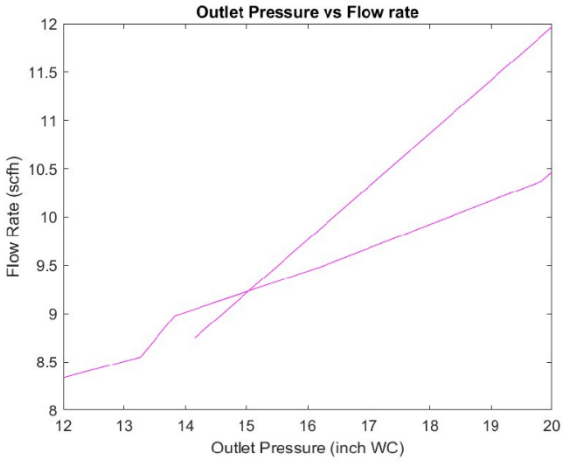
The volume of total emissions in 194.32 seconds is 0.5125 scf.





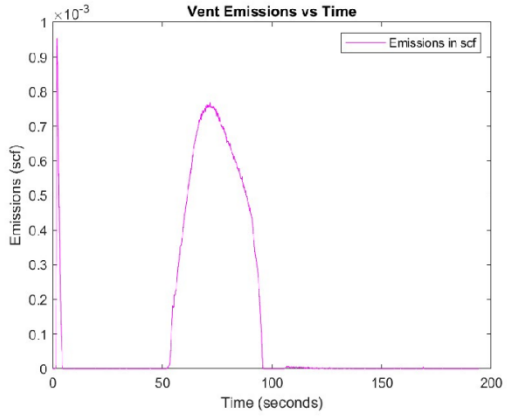
GTI ENERGY

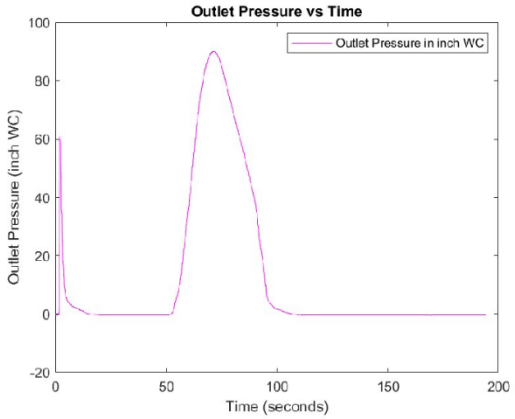

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
20
40
60
80
100
120
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
8
8.5
9
9.5
10
10.5
11
11.5
12
12
13
14
15
16
17
18
19
20

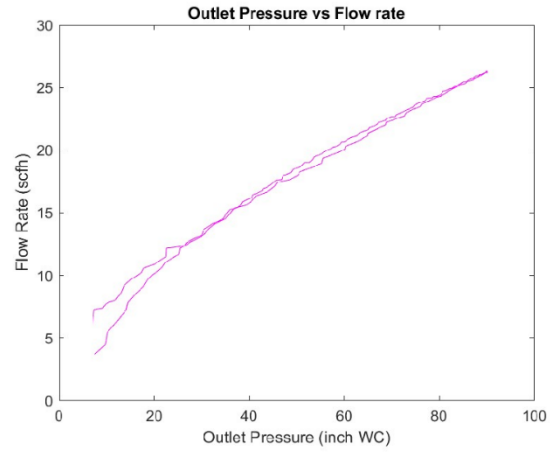
GTI ENERGY

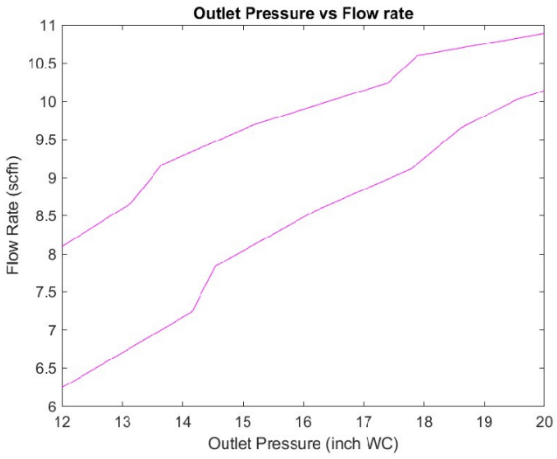
- **222489-032_LD**
  The volume of total emissions in 194.40 seconds is 0.2292 scf.
  The average flow rate of emissions at 18 inches WC is 9.81 scfh.





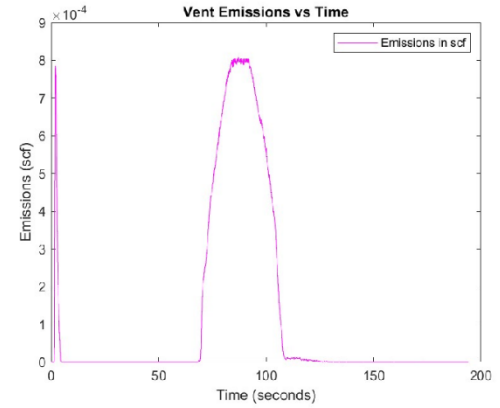
GTI ENERGY

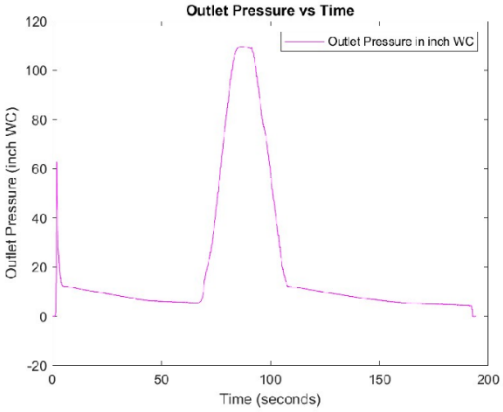

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
5
10
15
20
25
30
0
20
40
60
80
100


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
6
6.5
7
7.5
8
8.5
9
9.5
10
10.5
11
12
13
14
15
16
17
18
19
20

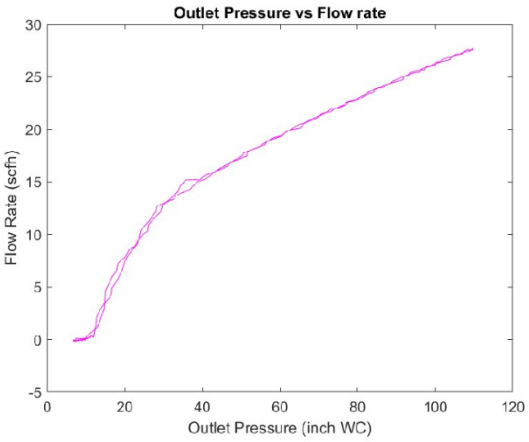
GTI ENERGY

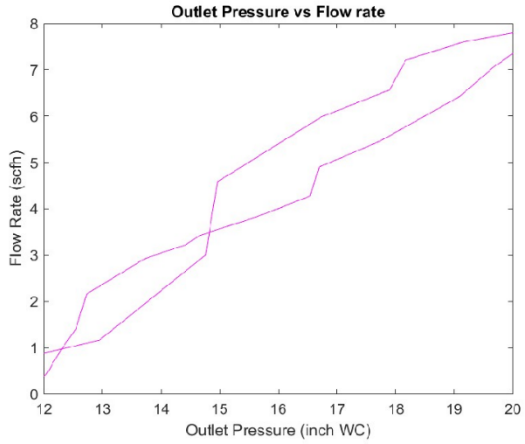
- **222489-033**
  The volume of total emissions in 194.42 seconds is 0.2202 scf.
  The average flow rate of emissions at 18 inches WC is 6.14 scfh.





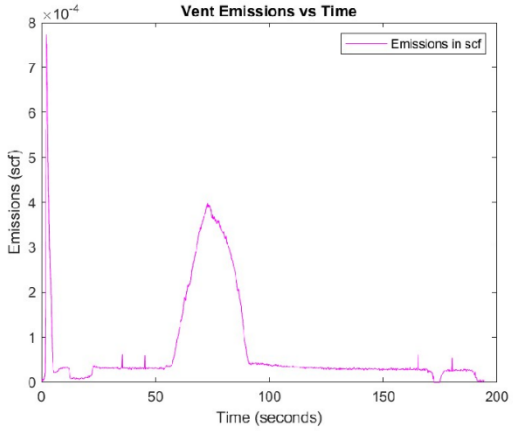
GTI ENERGY

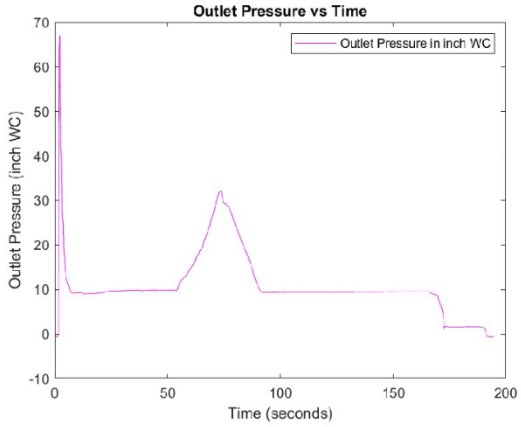

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
30
25
20
15
10
5
0
-5
0
20
40
60
80
100
120


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
8
7
6
5
4
3
2
1
0
12
13
14
15
16
17
18
19
20

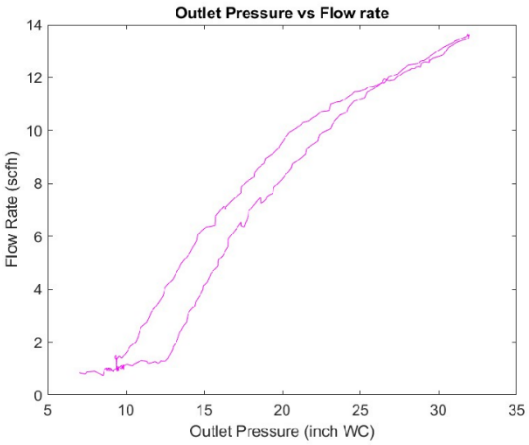
GTI ENERGY

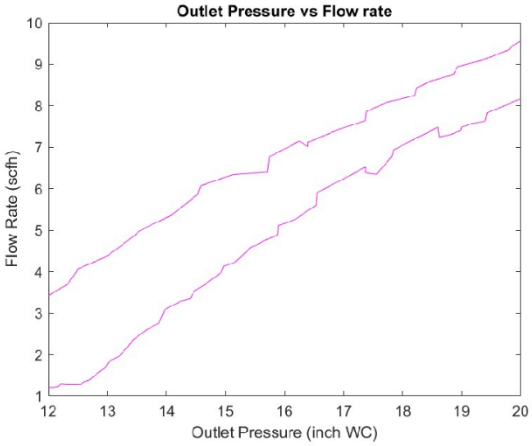
- **222489-033_DT1**
  The volume of total emissions in 194.42 seconds is 0.1348 scf.
  The average flow rate of emissions at 18 inches WC is 6.86 scfh.





GTI ENERGY


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
2
4
6
8
10
12
14
5
10
15
20
25
30
35

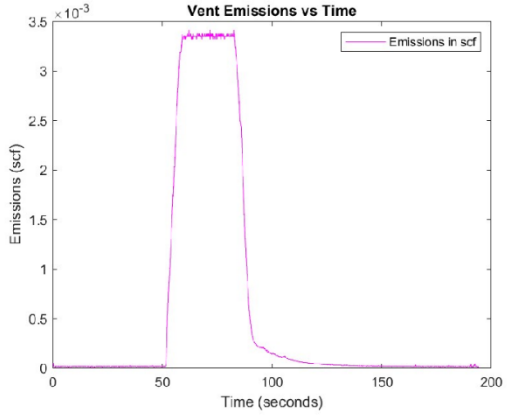

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
1
2
3
4
5
6
7
8
9
10
12
13
14
15
16
17
18
19
20

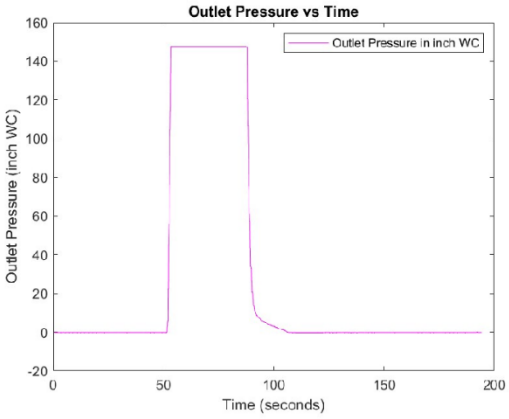
GTI ENERGY

- 222489-033_DT2

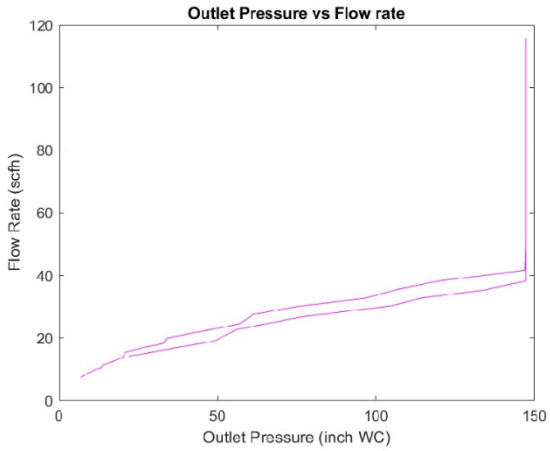
Commented [JW20]: No data in range to calculate avg

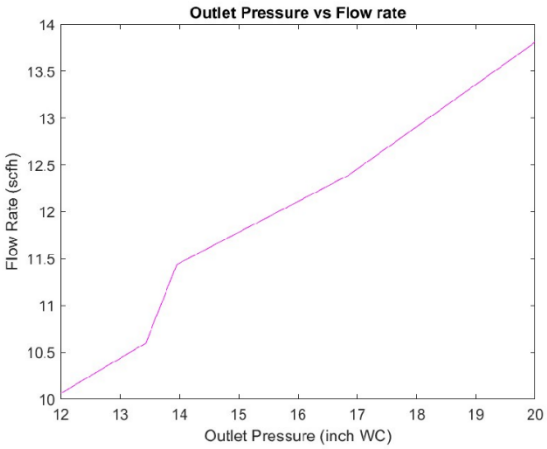
The volume of total emissions in 194.36 seconds is 1.0988 scf.





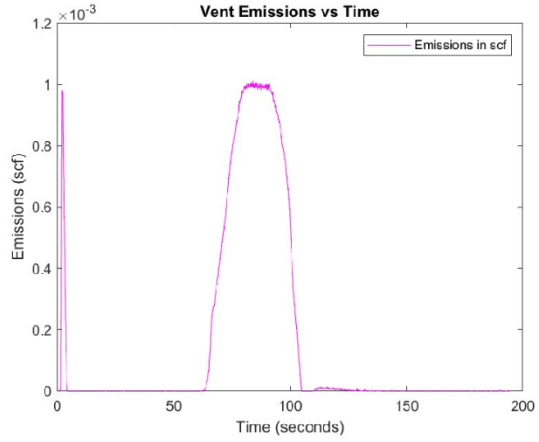
GTI ENERGY

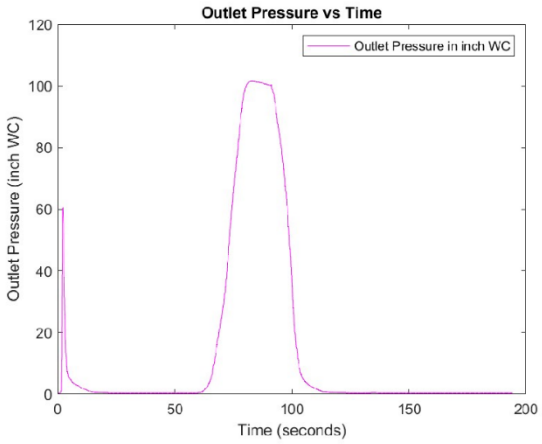

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
20
40
60
80
100
120
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
10
10.5
11
11.5
12
12.5
13
13.5
14
12
13
14
15
16
17
18
19
20

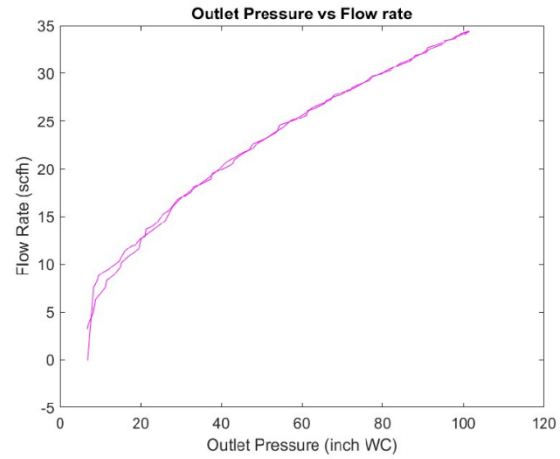
GTI ENERGY

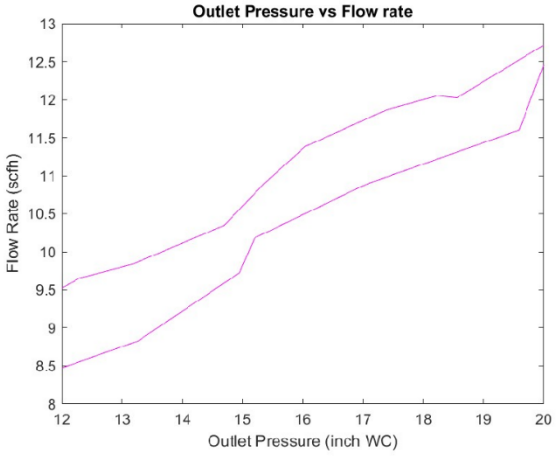
- **222489-033_LD**
  The volume of total emissions in 194.40 seconds is 0.2889 scf.
  The average flow rate of emissions at 18 inches WC is 11.72 scfh.





GTI ENERGY


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
35
30
25
20
15
10
5
0
-5
0
20
40
60
80
100
120

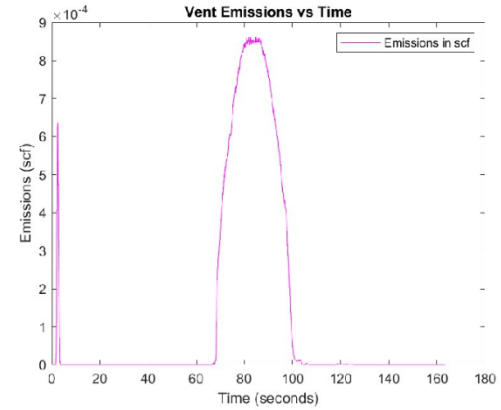

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
13
12.5
12
11.5
11
10.5
10
9.5
9
8.5
8
12
13
14
15
16
17
18
19
20

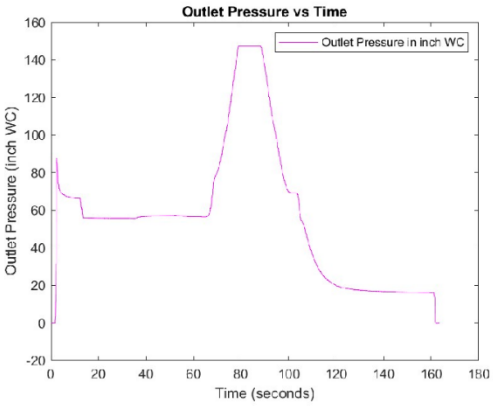
GTI ENERGY

2-psig Outlet, 10-psig Inlet

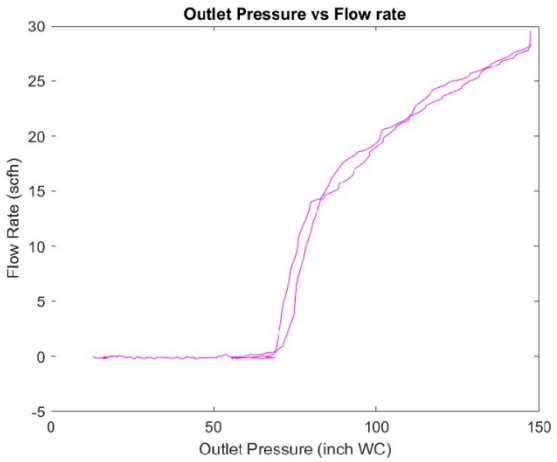
- **222489-034**

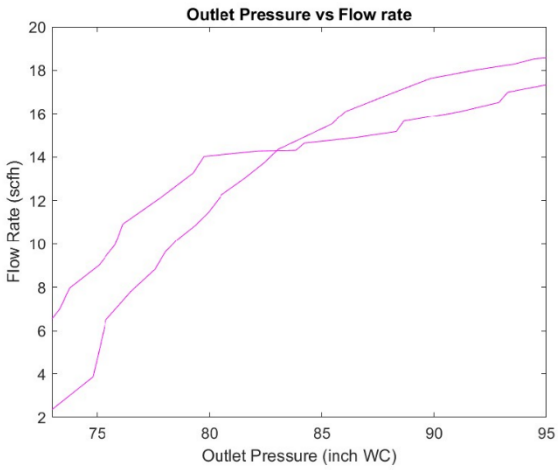
  The volume of total emissions in 163.40 seconds is 0.1986 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 16.83 scfh.





GTI ENERGY

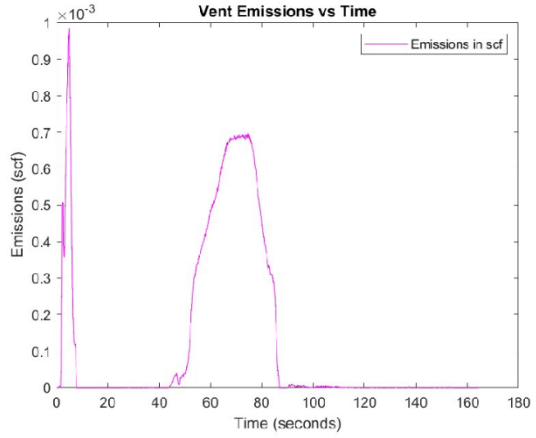

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
30
25
20
15
10
5
0
-5
0
50
100
150

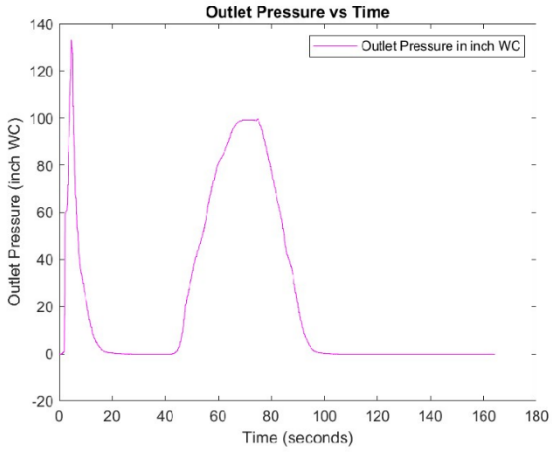

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
20
18
16
14
12
10
8
6
4
2
75
80
85
90
95

GTI ENERGY

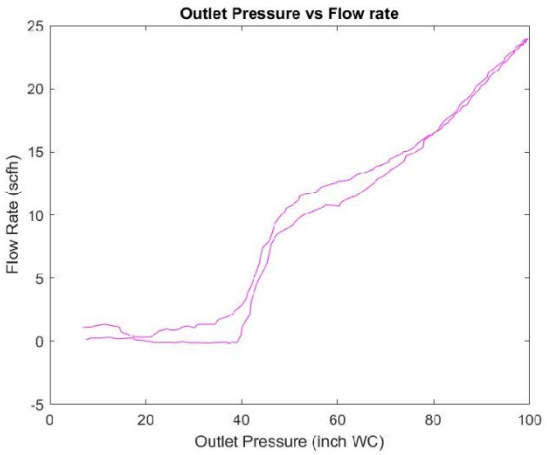
- **222489-034_LD**
  The volume of total emissions in 164.35 seconds is 0.1967 scf.

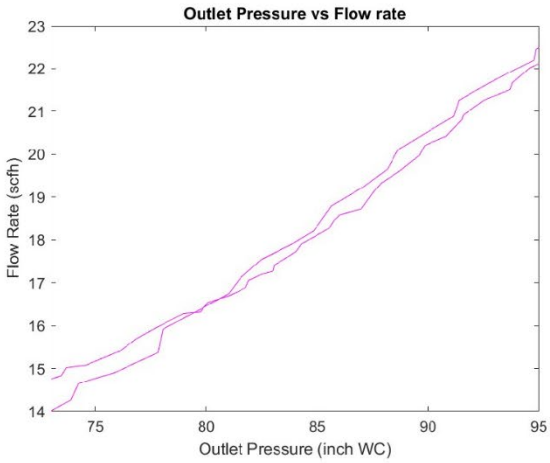
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 19.72 scfh.





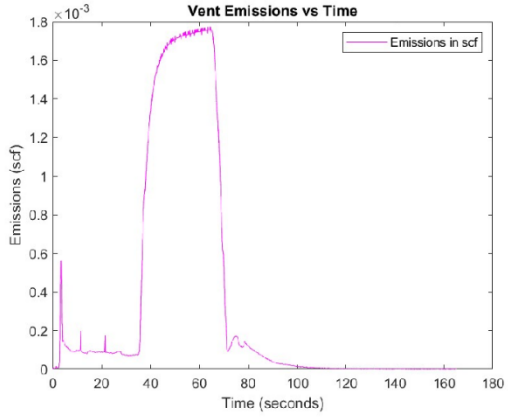
GTI ENERGY

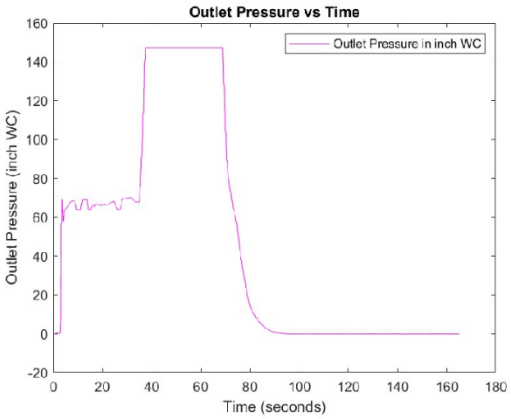

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
25
20
15
10
5
0
-5
0
20
40
60
80
100


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
23
22
21
20
19
18
17
16
15
14
75
80
85
90
95

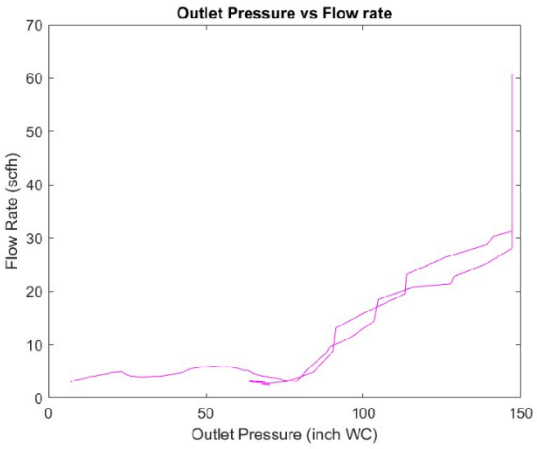
GTI ENERGY

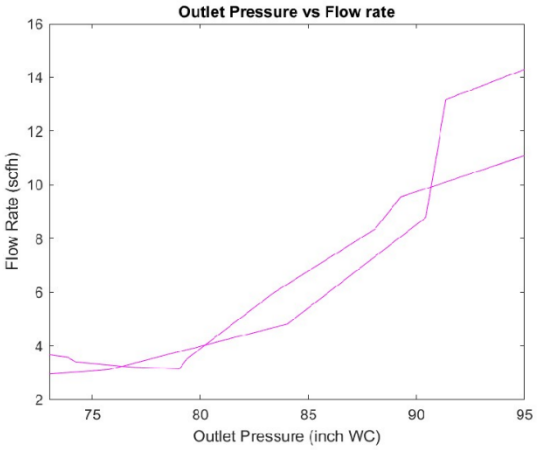
- **222489-034_DT1**
  The volume of total emissions in 165.24 seconds is 0.5597 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 9.97 scfh.





GTI ENERGY

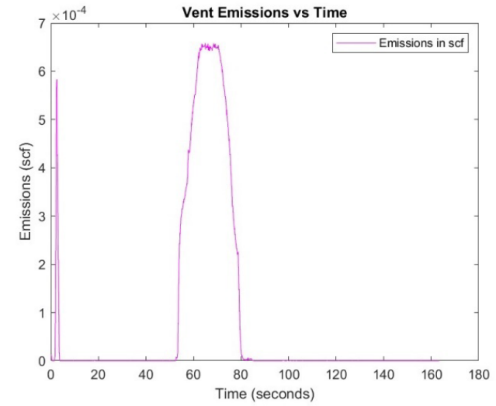

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
10
20
30
40
50
60
70
0
50
100
150

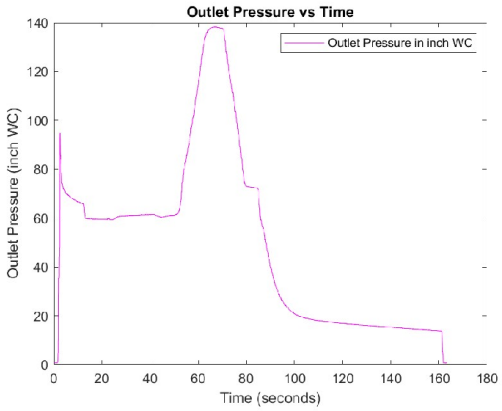

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
2
4
6
8
10
12
14
16
75
80
85
90
95

GTI ENERGY

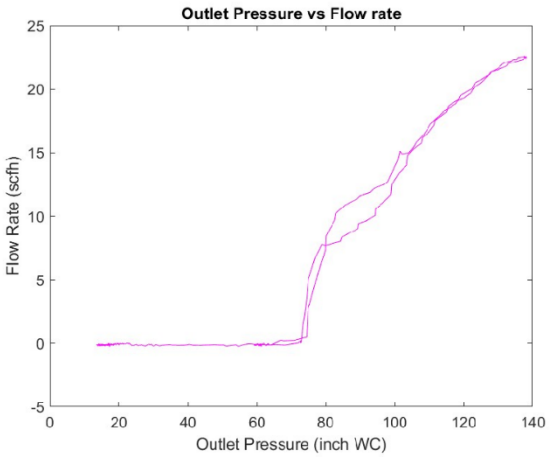
- **222489-035**
  The volume of total emissions in 163.42 seconds is 0.1290 scf.

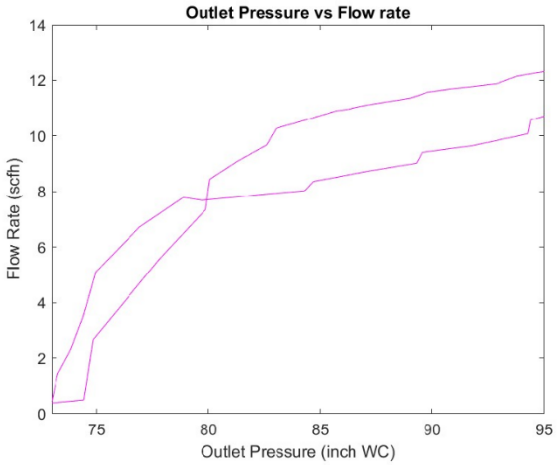
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 10.48 scfh.





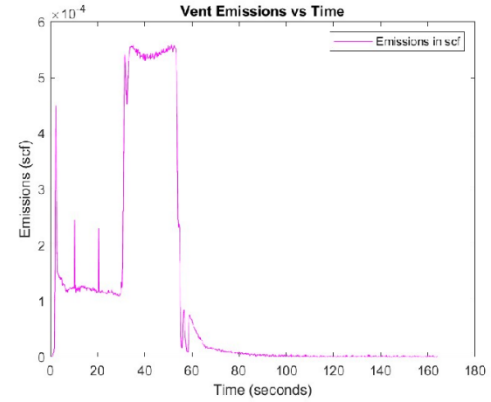
GTI ENERGY

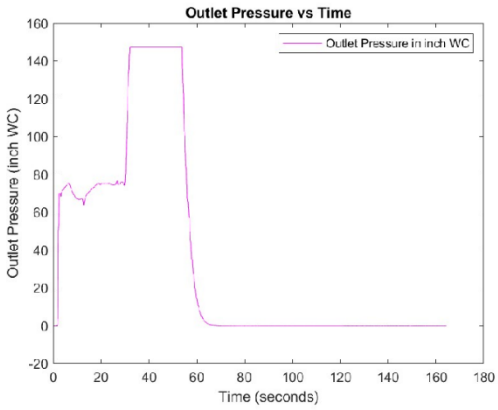

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
25
20
15
10
5
0
-5
0
20
40
60
80
100
120
140


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
14
12
10
8
6
4
2
0
75
80
85
90
95

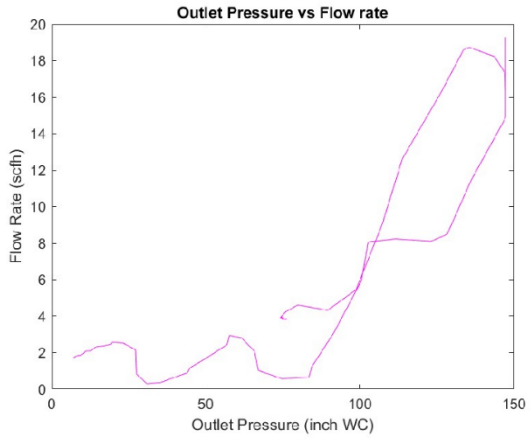
GTI ENERGY

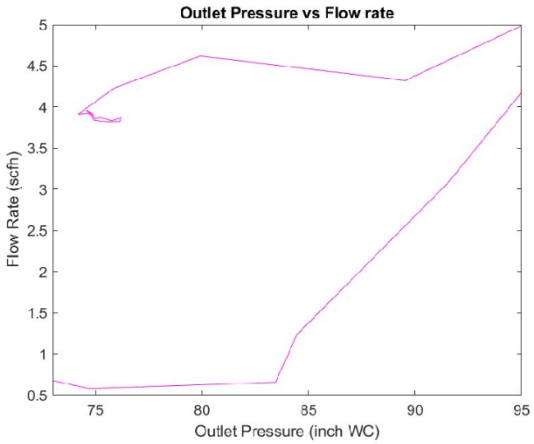
- **222489-035_DT1**
  The volume of total emissions in 164.33 seconds is 0.1651 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 4.32 scfh.





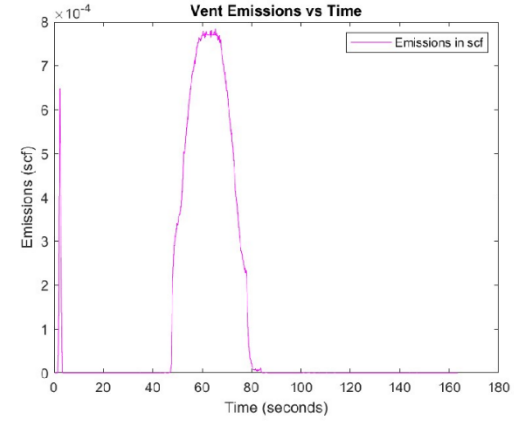
GTI ENERGY

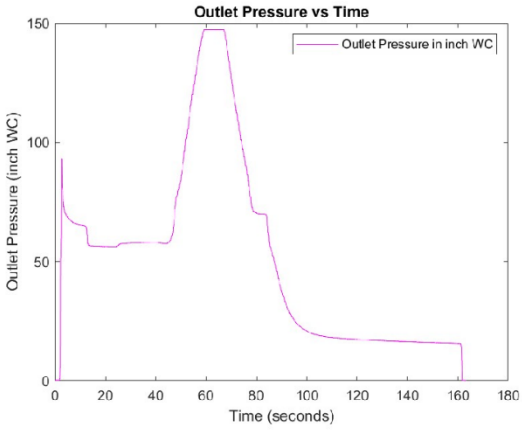

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
2
4
6
8
10
12
14
16
18
20
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
75
80
85
90
95

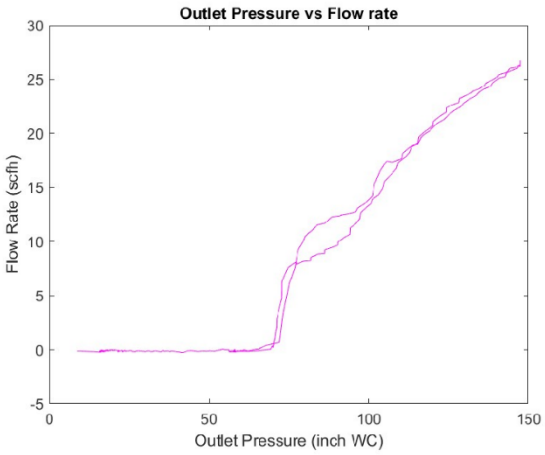
GTI ENERGY

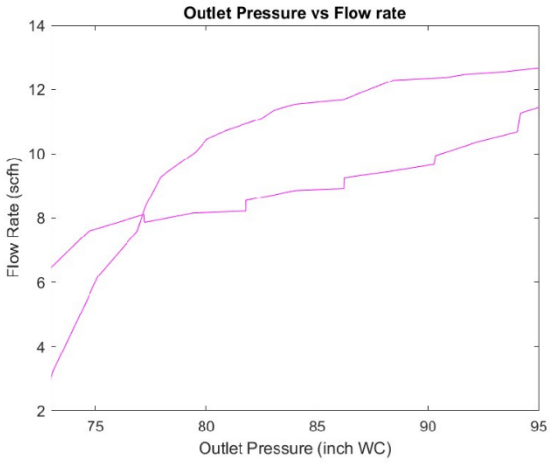
- **222489-036**
  The volume of total emissions in 163.40 seconds is 0.1737 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 10.61 scfh.





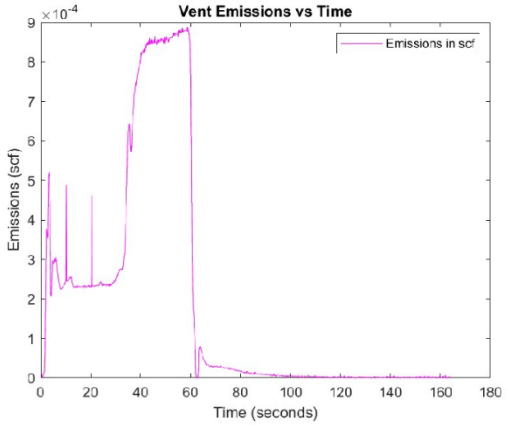
GTI ENERGY

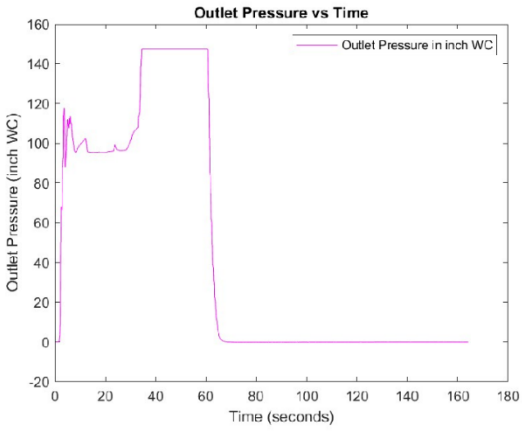

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
30
25
20
15
10
5
0
-5
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
14
12
10
8
6
4
2
75
80
85
90
95

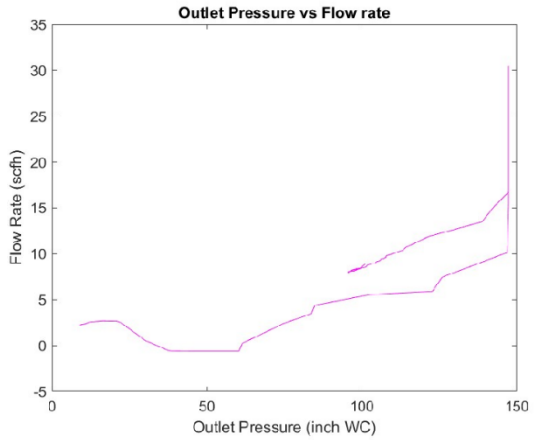
GTI ENERGY

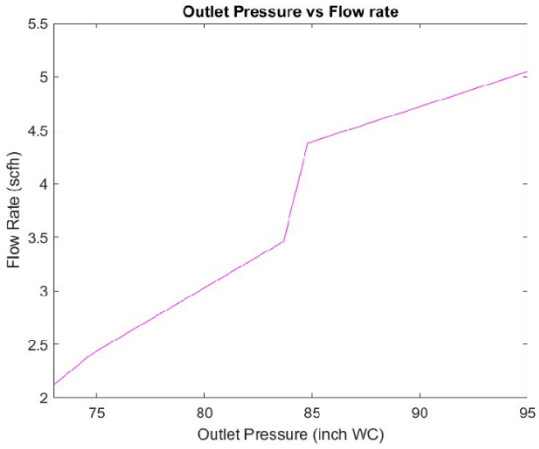
- **222489-036_DT1**
  The volume of total emissions in 164.25 seconds is 0.2952 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 11.12 scfh.





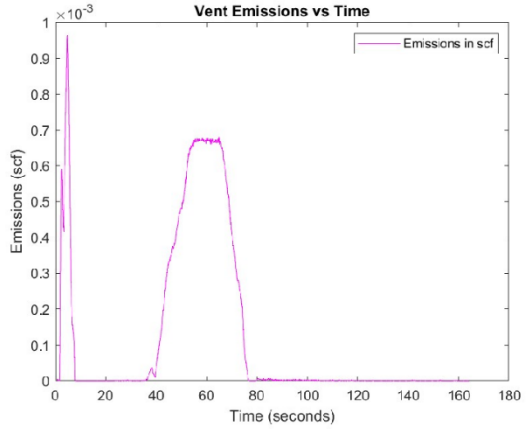
GTI ENERGY

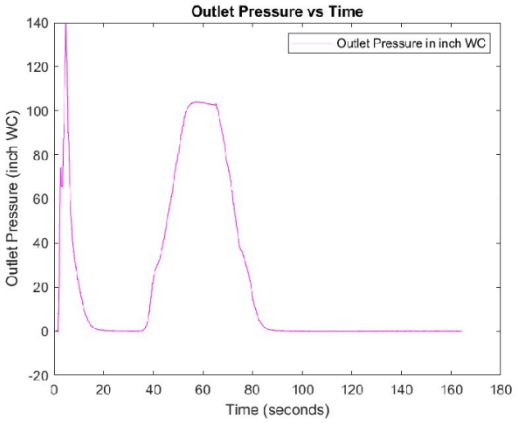

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
35
30
25
20
15
10
5
0
-5
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
5.5
5
4.5
4
3.5
3
2.5
2
75
80
85
90
95

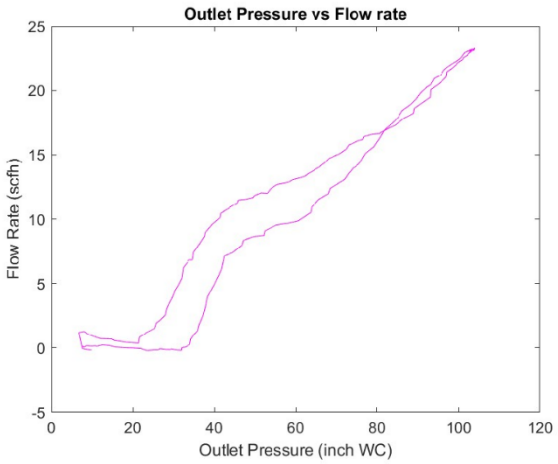
GTI ENERGY

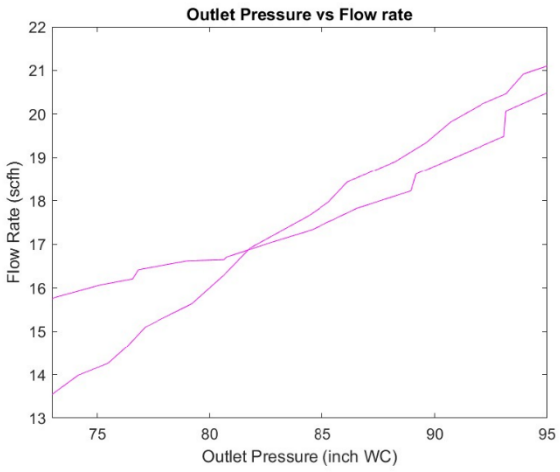
- **222489-036_LD**
  The volume of total emissions in 164.25 seconds is 0.1908 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 18.94 scfh.





GTI ENERGY

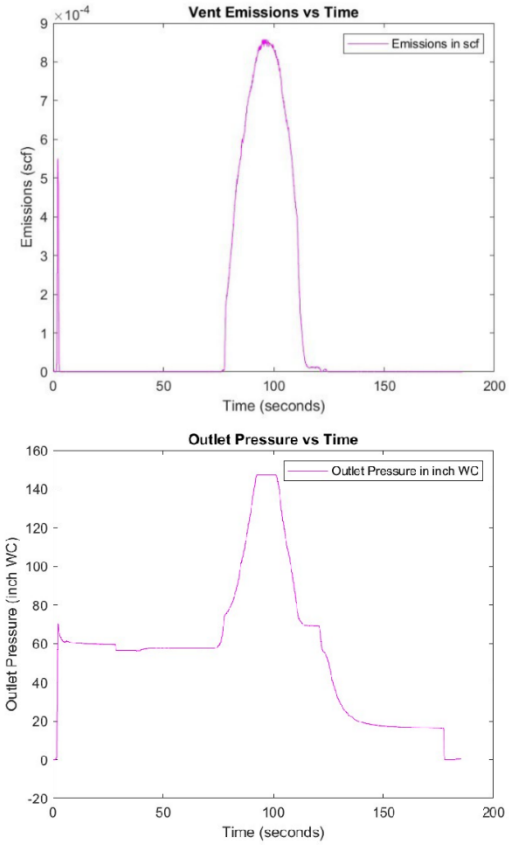

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
25
20
15
10
5
0
-5
0
20
40
60
80
100
120


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
22
21
20
19
18
17
16
15
14
13
75
80
85
90
95

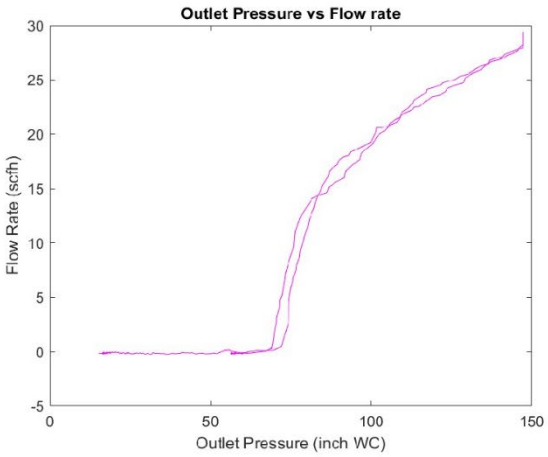
GTI ENERGY

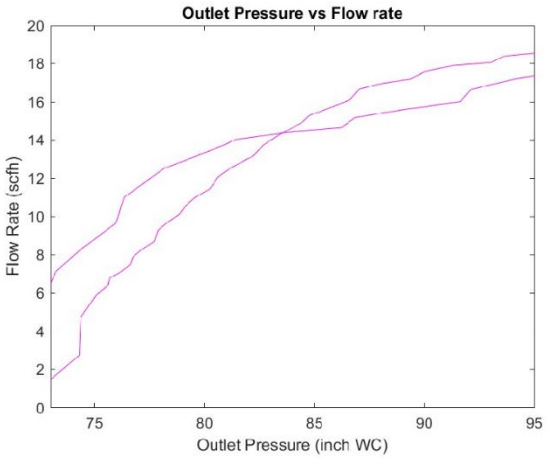
2-psig Outlet 60-psig Inlet

- **222489-034**
  The volume of total emissions in 185.41 seconds is 0.2118 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 16.42 scfh.



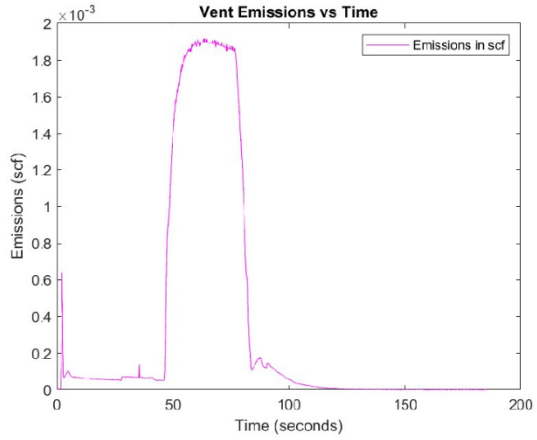
GTI ENERGY

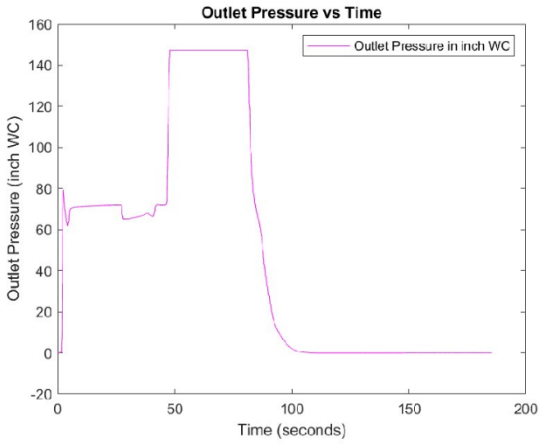

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
30
25
20
15
10
5
0
-5
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
20
18
16
14
12
10
8
6
4
2
0
75
80
85
90
95

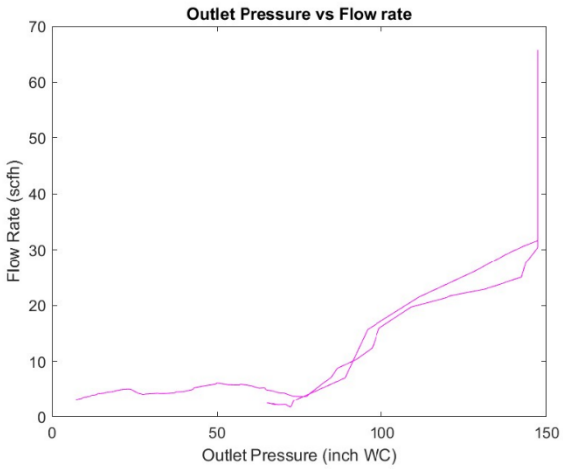
GTI ENERGY

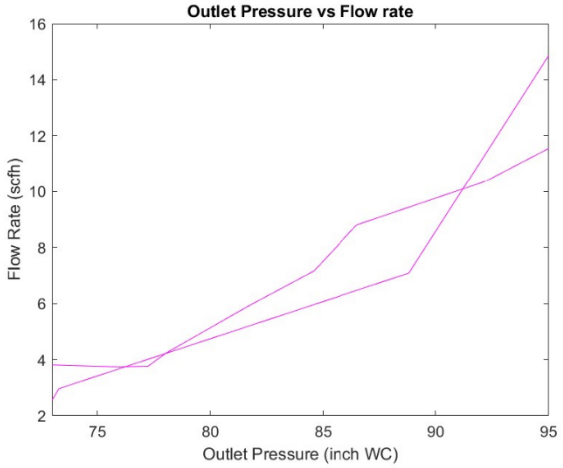
- **222489-034_DT1**
  The volume of total emissions in 185.39 seconds is 0.6273 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 7.94 scfh.





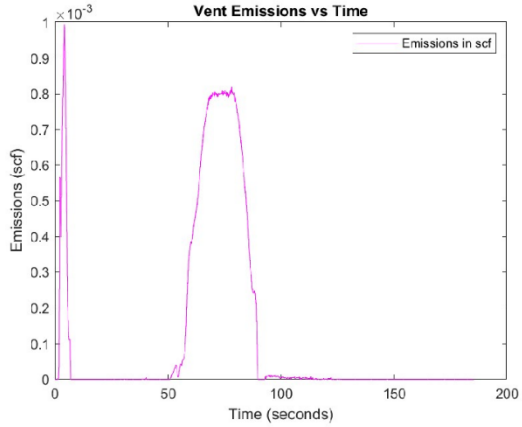
GTI ENERGY

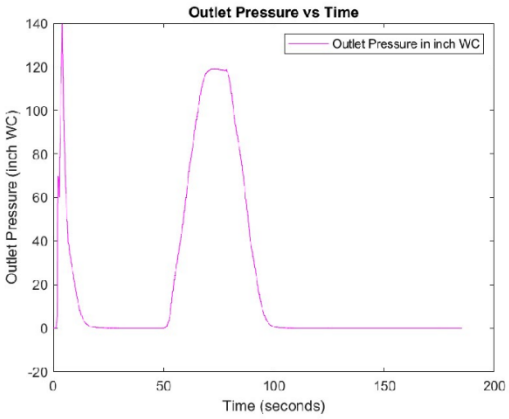

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
10
20
30
40
50
60
70
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
2
4
6
8
10
12
14
16
75
80
85
90
95

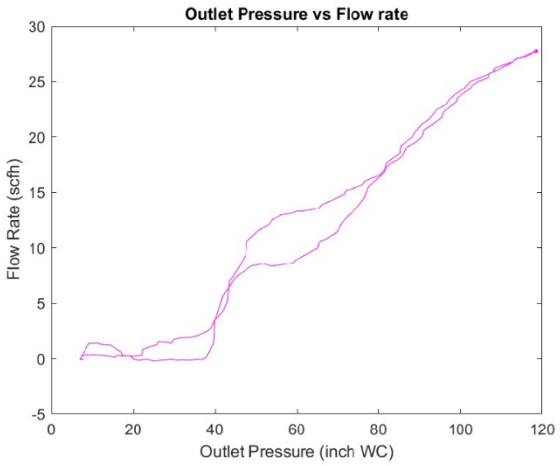
GTI ENERGY

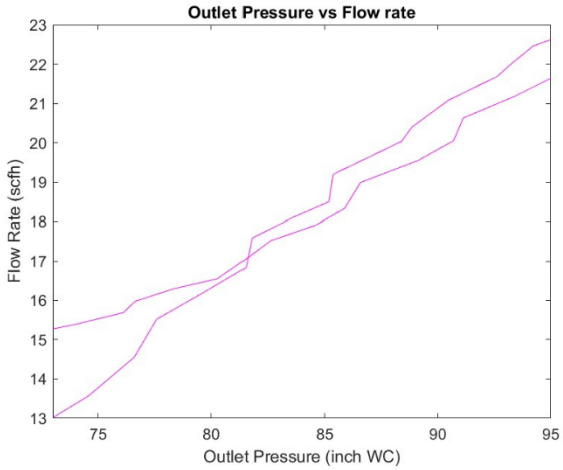
- **222489-034_LD**
  The volume of total emissions in 185.36 seconds is 0.2130 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 20.12 scfh.





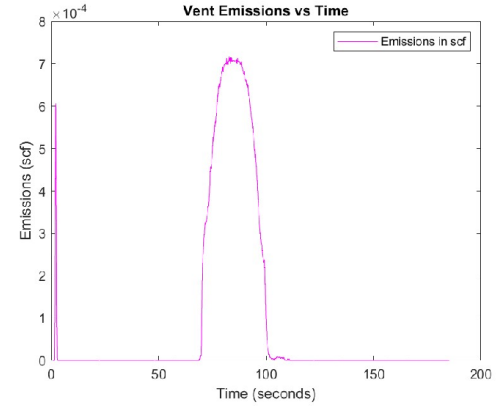
GTI ENERGY

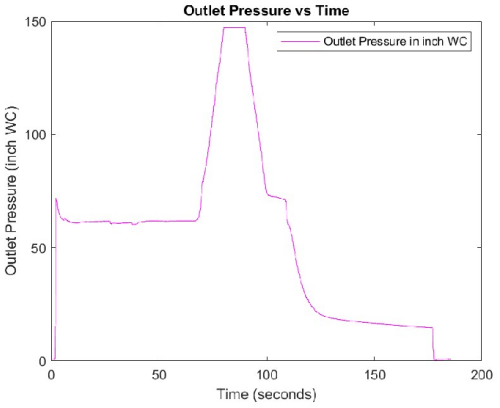

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
30
25
20
15
10
5
0
-5
0
20
40
60
80
100
120


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
23
22
21
20
19
18
17
16
15
14
13
75
80
85
90
95

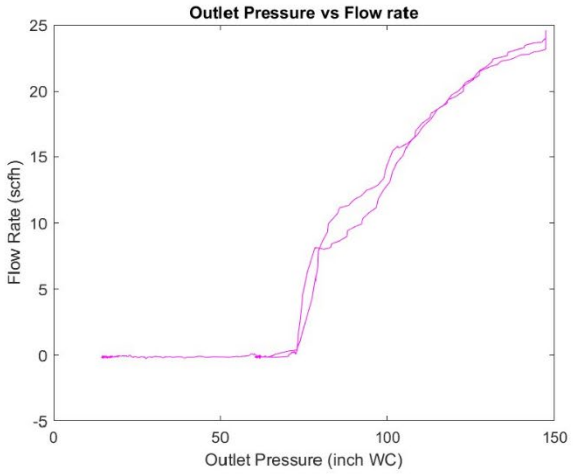
GTI ENERGY

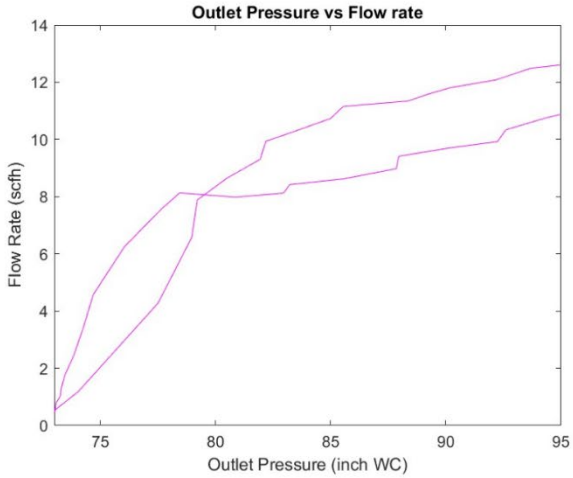
- **222489-035**
  The volume of total emissions in 185.47 seconds is 0.1610 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 10.58 scfh.





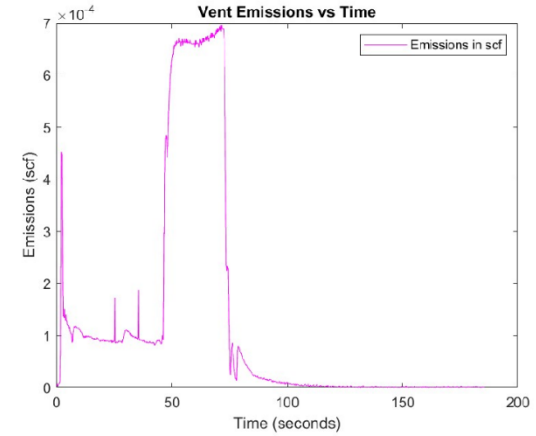
GTI ENERGY

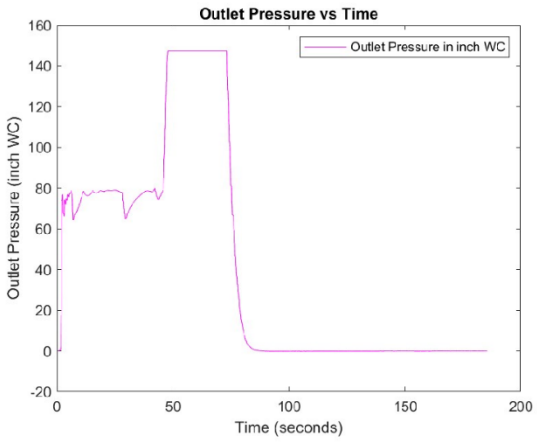

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
25
20
15
10
5
0
-5
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
14
12
10
8
6
4
2
0
75
80
85
90
95

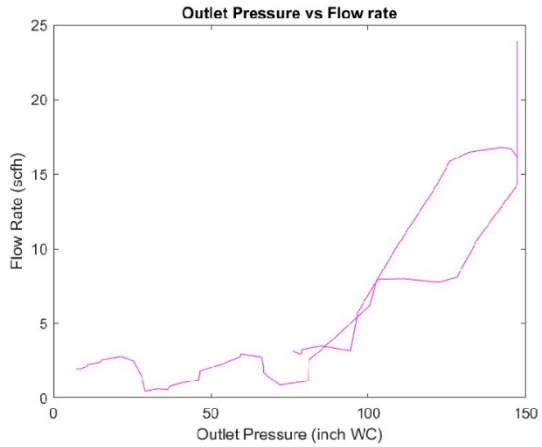
GTI ENERGY

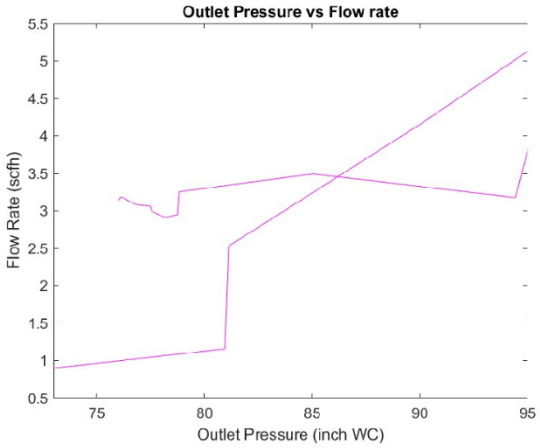
- **222489-035_DT1**
  The volume of total emissions in 185.40 seconds is 0.2219 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 4.15 scfh.



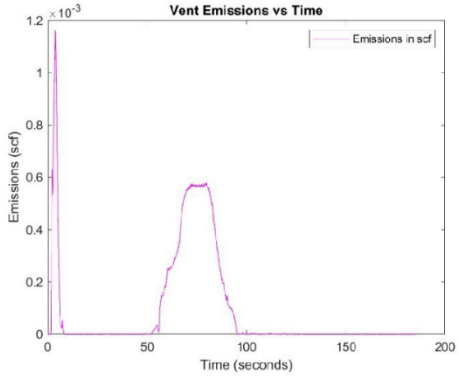


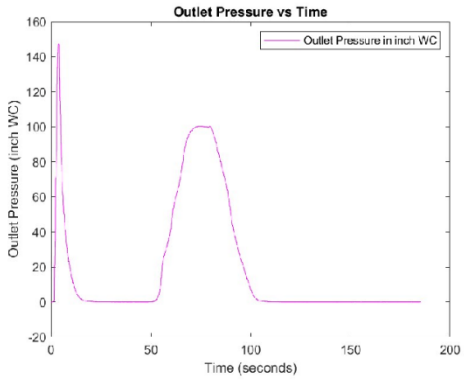
GTI ENERGY


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
5
10
15
20
25
0
50
100
150

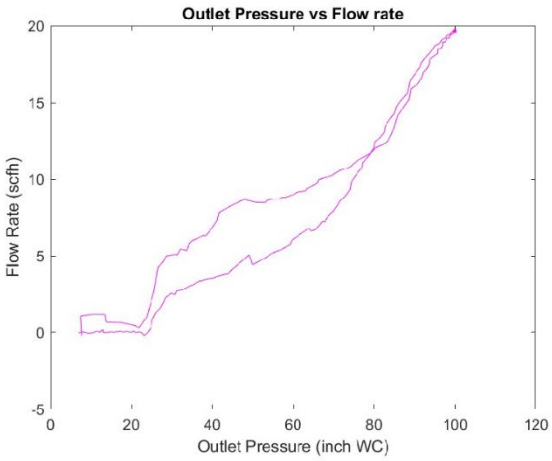

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
75
80
85
90
95

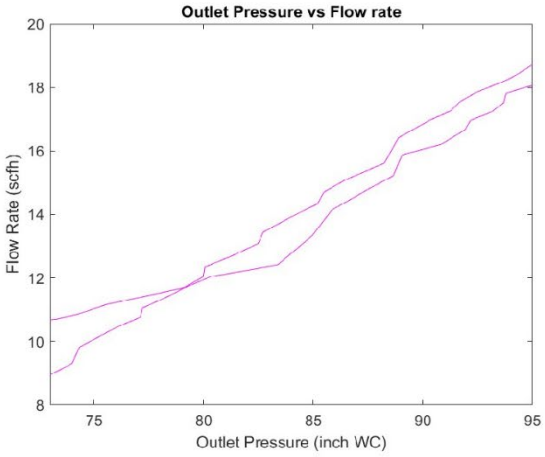
- **222489-035_LD**
  The volume of total emissions in 185.20 seconds is 0.1610 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 16.86 scfh.



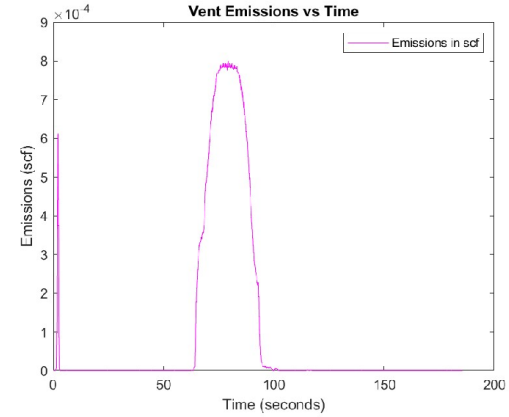


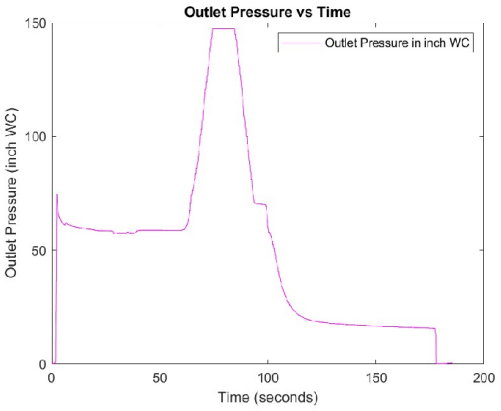
GTI ENERGY


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
20
15
10
5
0
-5
0
20
40
60
80
100
120

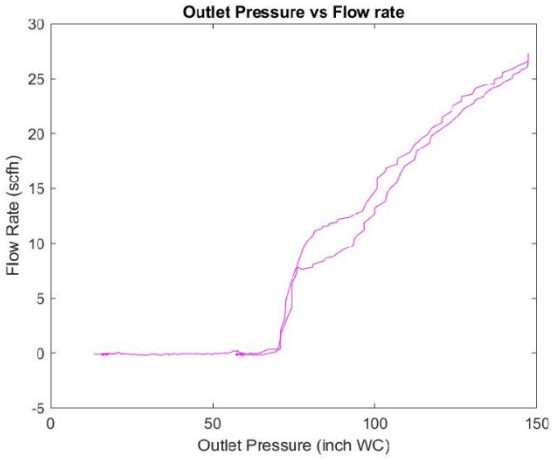

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
20
18
16
14
12
10
8
75
80
85
90
95

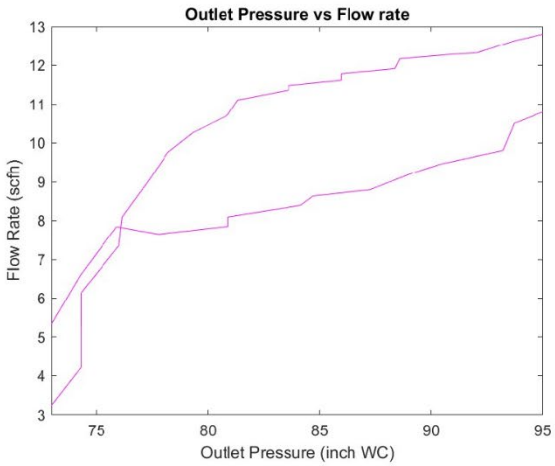
- **222489-036**
  The volume of total emissions in 185.48 seconds is 0.1678 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 10.90 scfh.





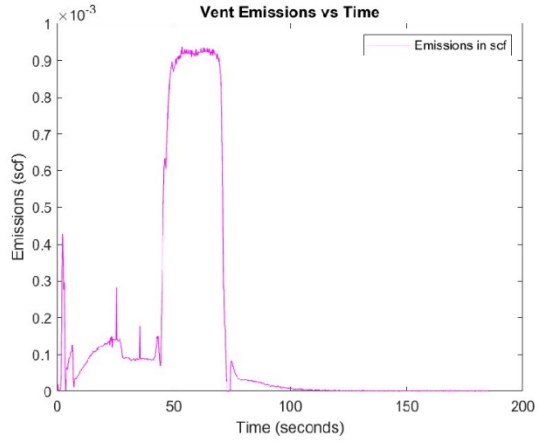
GTI ENERGY

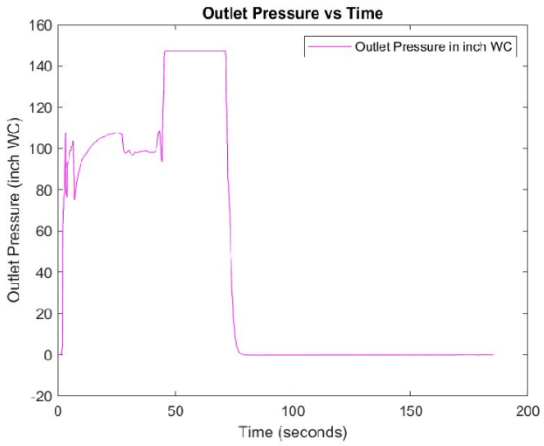

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
30
25
20
15
10
5
0
-5
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
13
12
11
10
9
8
7
6
5
4
3
75
80
85
90
95

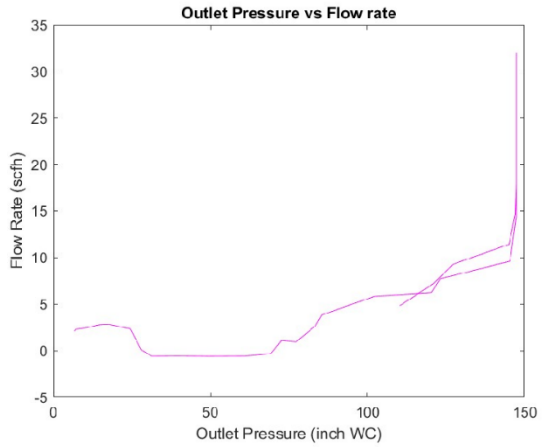
GTI ENERGY

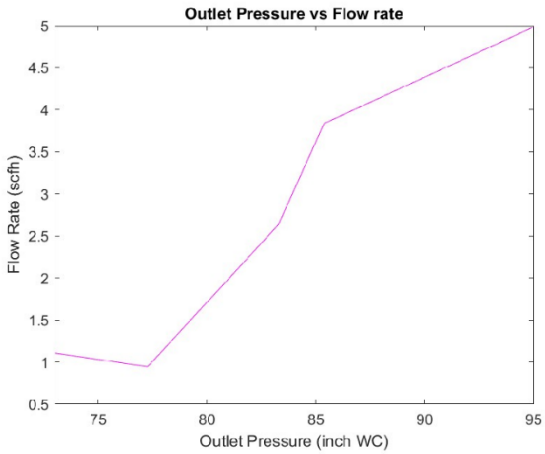
- **222489-036_DT1**
  The volume of total emissions in 185.37 seconds is 0.2724 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 1.36 scfh.





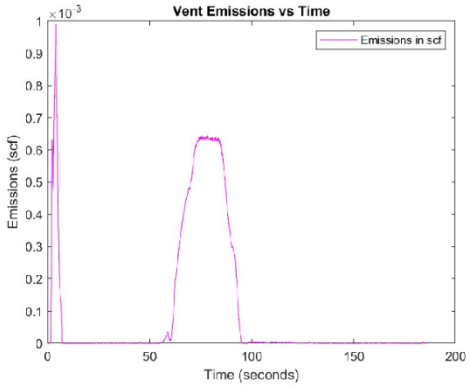
GTI ENERGY

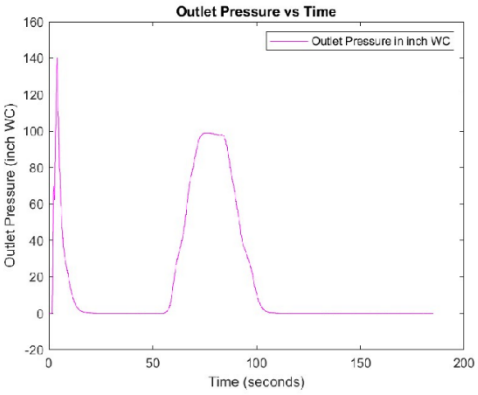

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
35
30
25
20
15
10
5
0
-5
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
75
80
85
90
95

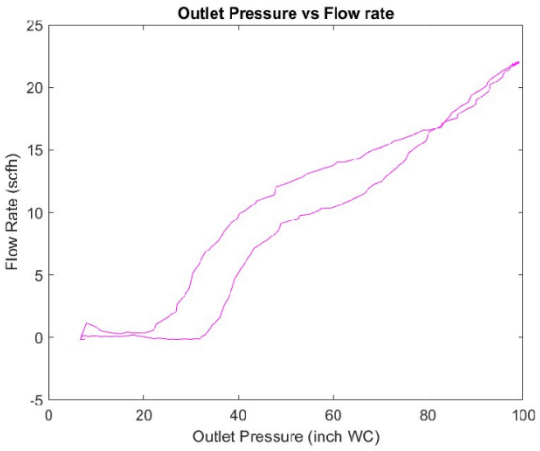
GTI ENERGY

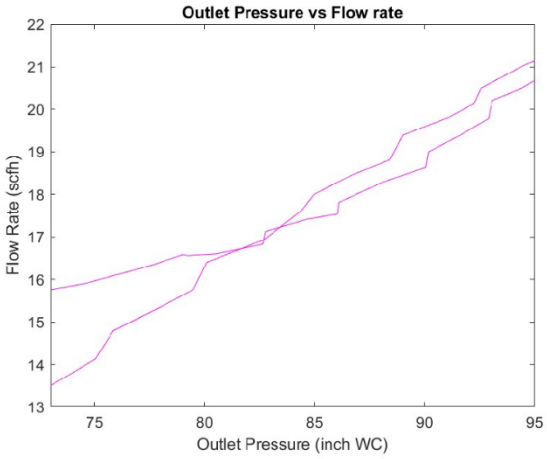
- **222489-036_LD**
  The volume of total emissions in 185.36 seconds is 0.1751 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 18.64 scfh.





GTI ENERGY


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
25
20
15
10
5
0
-5
0
20
40
60
80
100

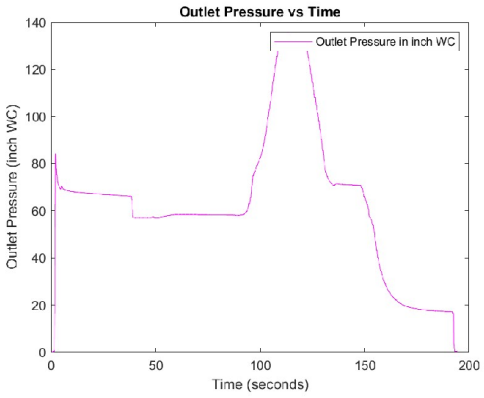

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
22
21
20
19
18
17
16
15
14
13
75
80
85
90
95

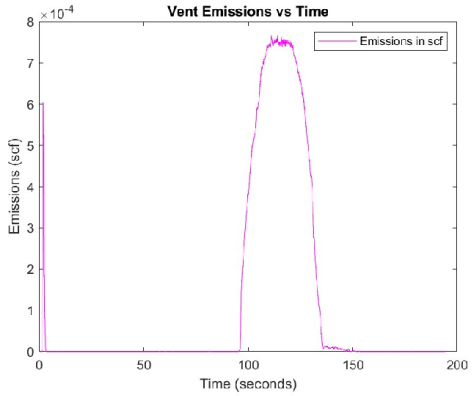
GTI ENERGY

2-psig Outlet, 100-psig Inlet

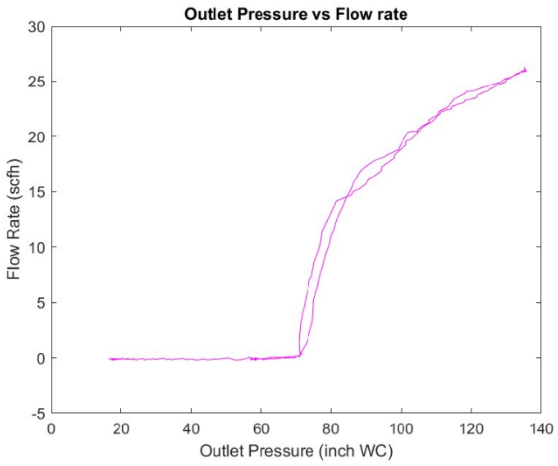
- **222489-034**

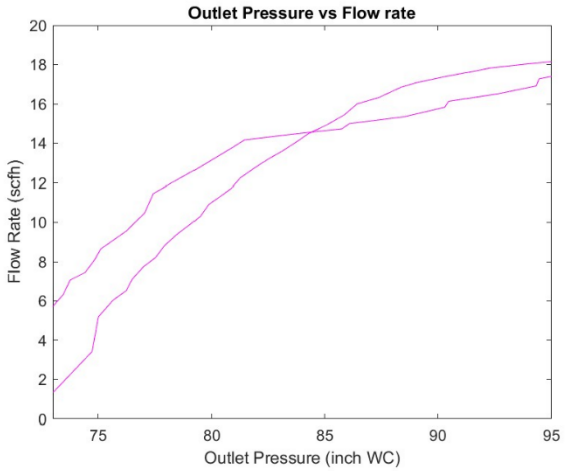
  The volume of total emissions in 194.45 seconds is 0.2145 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 16.22 scfh.





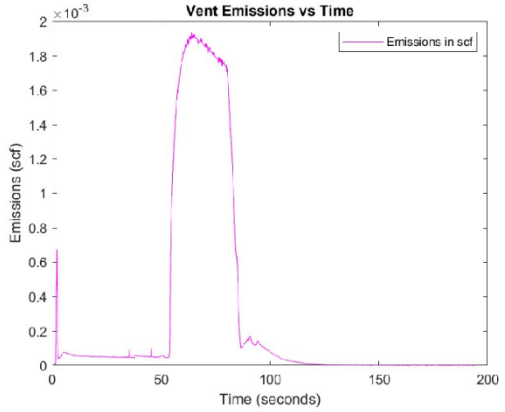
GTI ENERGY

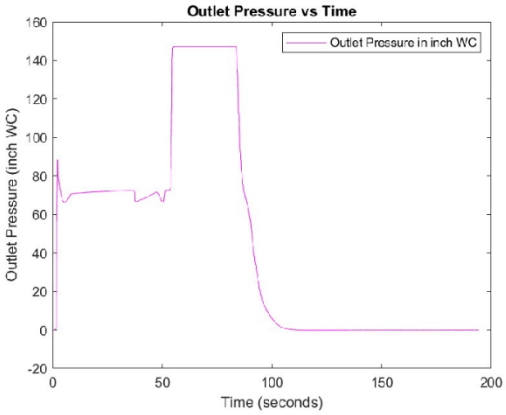

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
30
25
20
15
10
5
0
-5
0
20
40
60
80
100
120
140


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
20
18
16
14
12
10
8
6
4
2
0
75
80
85
90
95

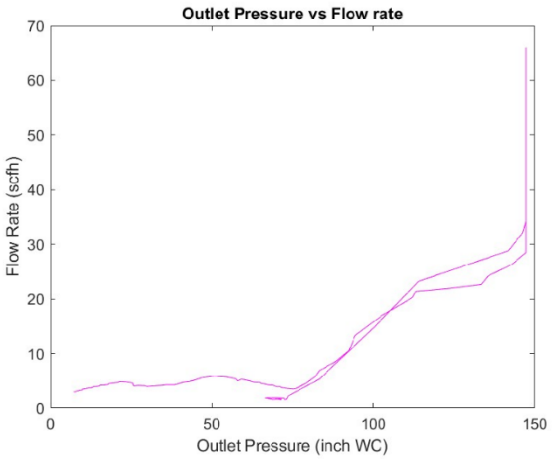
GTI ENERGY

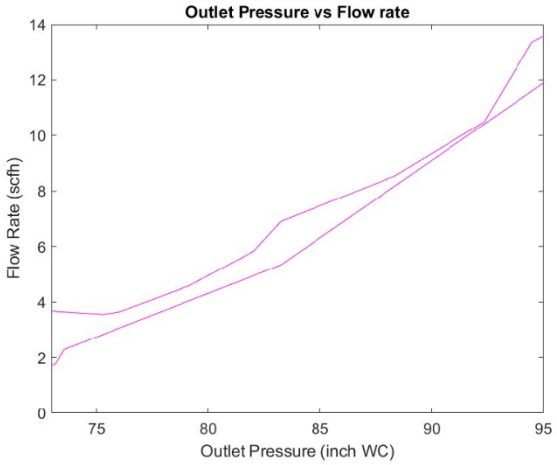
- **222489-034_DT1**
  The volume of total emissions in 194.45 seconds is 0.5480 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 11.93 scfh.





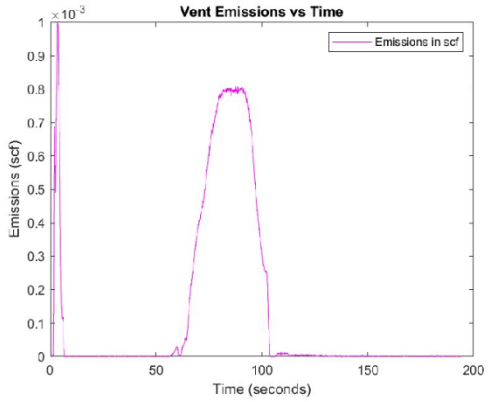
GTI ENERGY

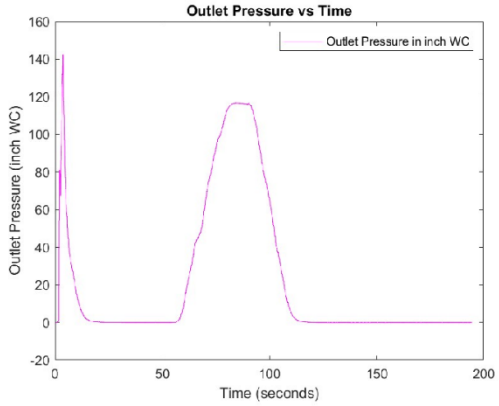

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
10
20
30
40
50
60
70
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
2
4
6
8
10
12
14
75
80
85
90
95

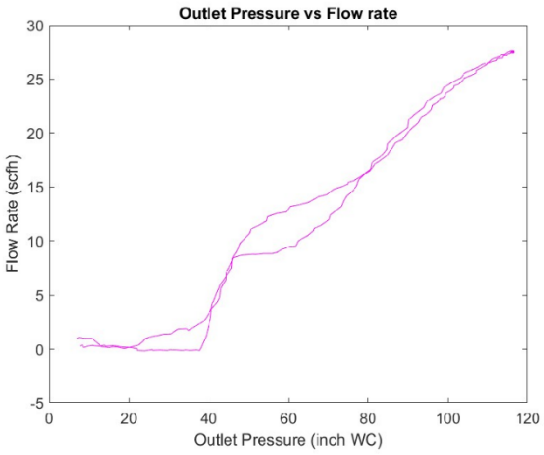
GTI ENERGY

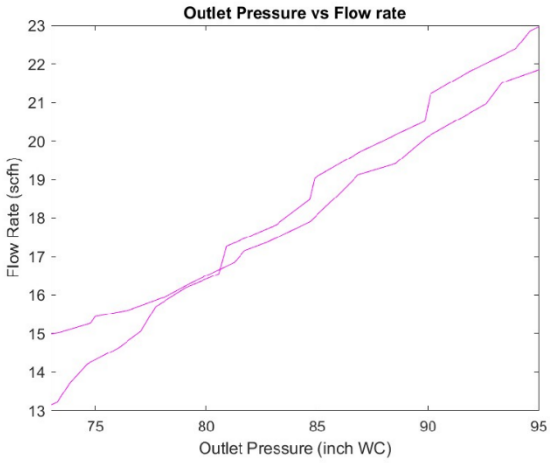
- **222489-034_LD**
  The volume of total emissions in 194.46 seconds is 0.2394 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 20.01 scfh.





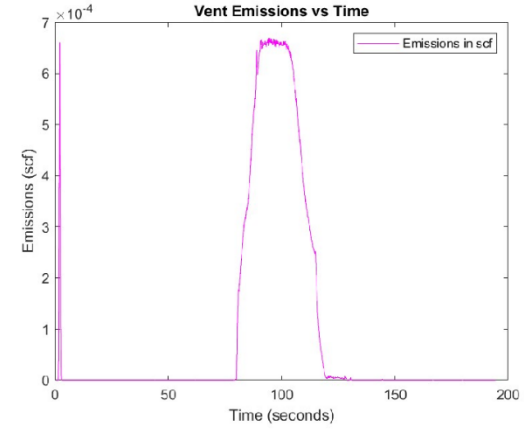
GTI ENERGY

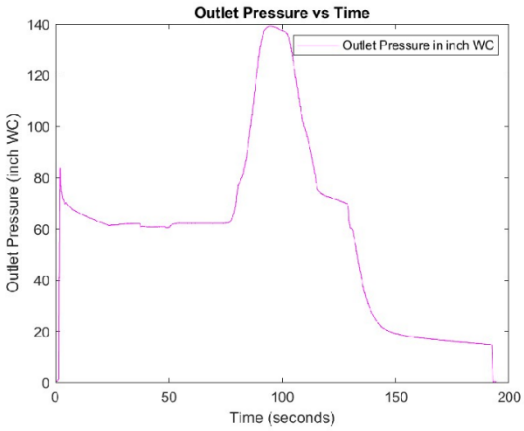

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
30
25
20
15
10
5
0
-5
0
20
40
60
80
100
120


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
23
22
21
20
19
18
17
16
15
14
13
75
80
85
90
95

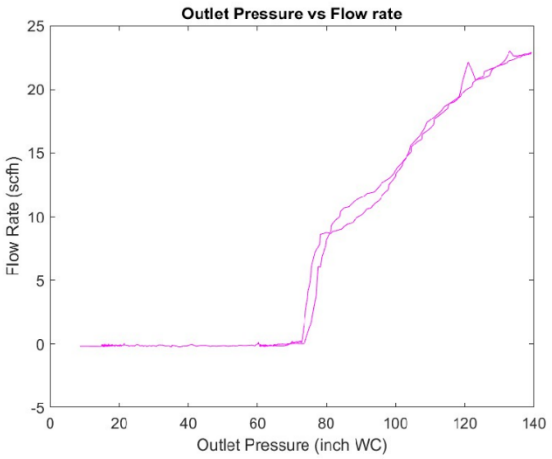
GTI ENERGY

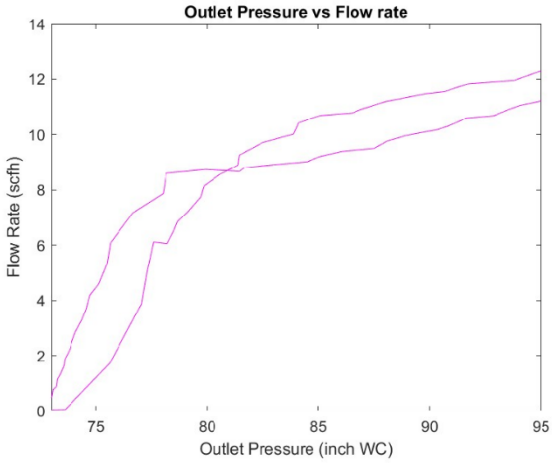
- **222489-035**
  The volume of total emissions in 194.34 seconds is 0.1747 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 10.47 scfh.





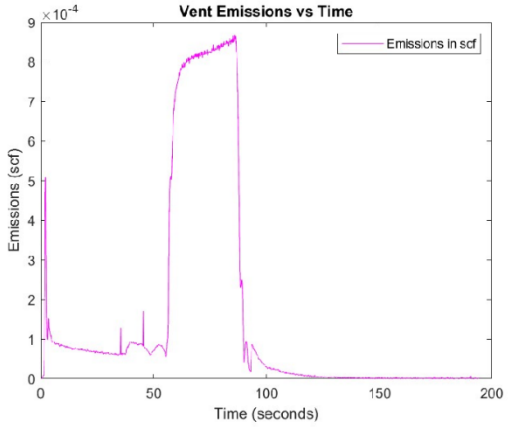
GTI ENERGY

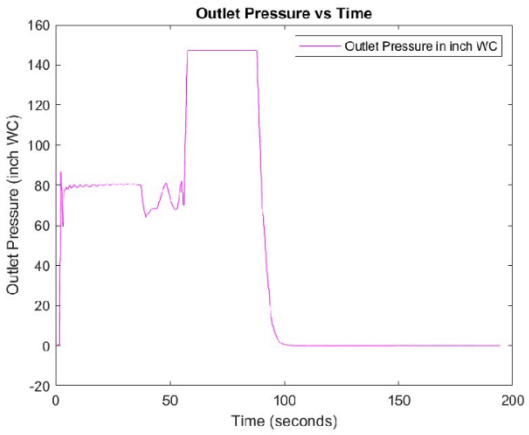

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
25
20
15
10
5
0
-5
0
20
40
60
80
100
120
140


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
14
12
10
8
6
4
2
0
75
80
85
90
95

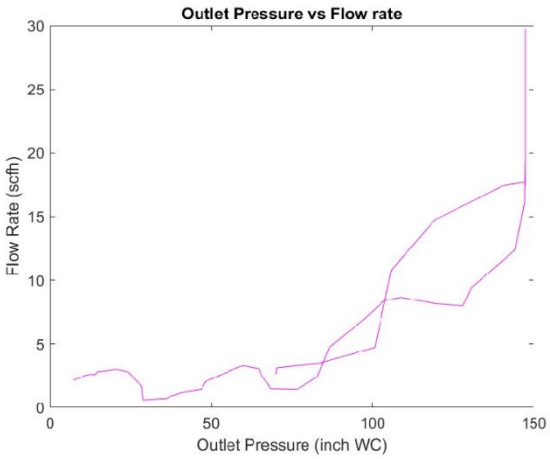
GTI ENERGY

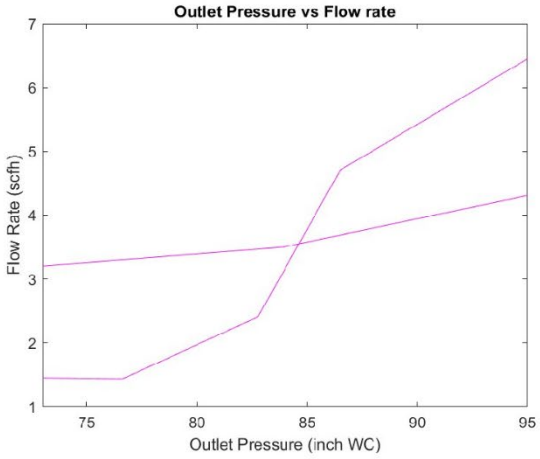
- **222489-035_DT1**
  The volume of total emissions in 194.43 seconds is 0.2953 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 11.15 scfh.





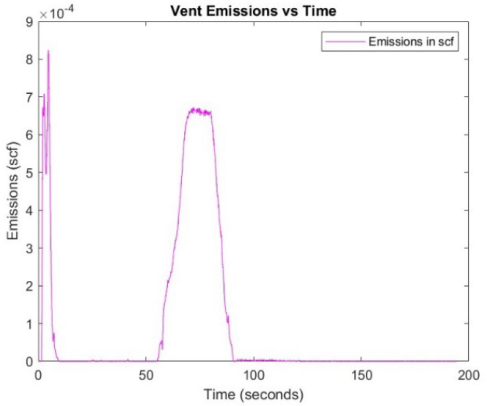
GTI ENERGY

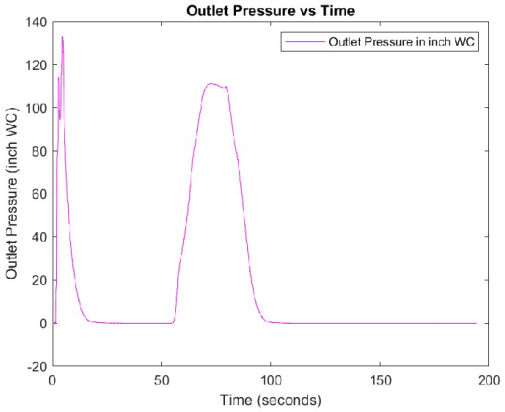

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
5
10
15
20
25
30
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
1
2
3
4
5
6
7
75
80
85
90
95

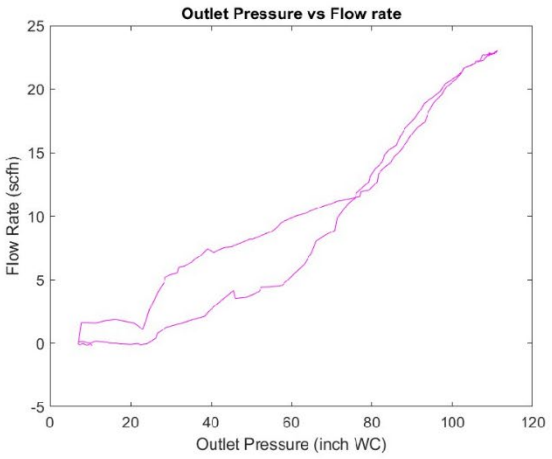
GTI ENERGY

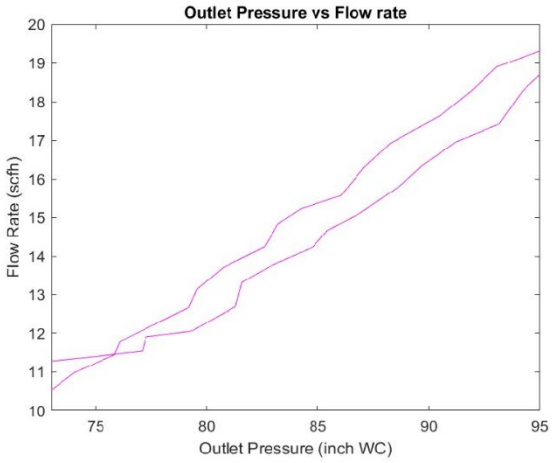
- **222489-035_LD**
  The volume of total emissions in 194.42 seconds is 0.1642 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 16.05 scfh.





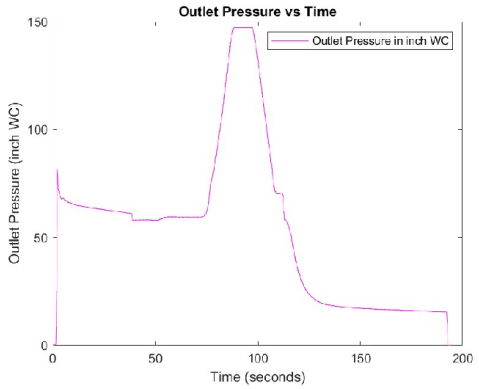
GTI ENERGY

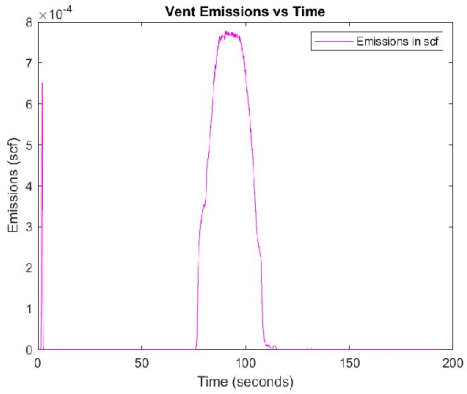

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
25
20
15
10
5
0
-5
0
20
40
60
80
100
120


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
20
19
18
17
16
15
14
13
12
11
10
75
80
85
90
95

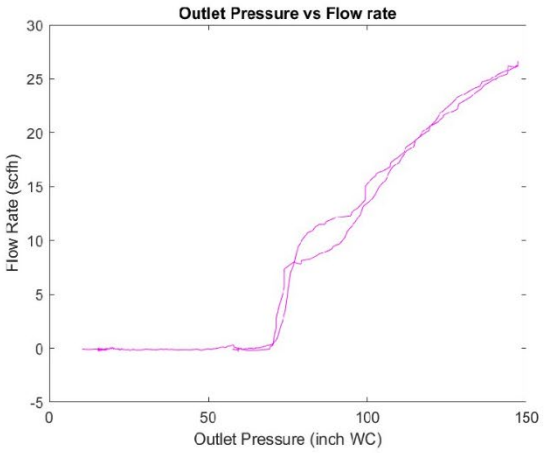
GTI ENERGY

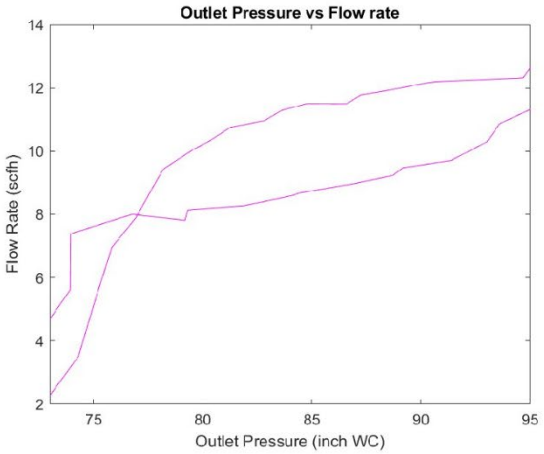
- **222489-036**
  The volume of total emissions in 194.33 seconds is 0.1774 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 10.77 scfh.





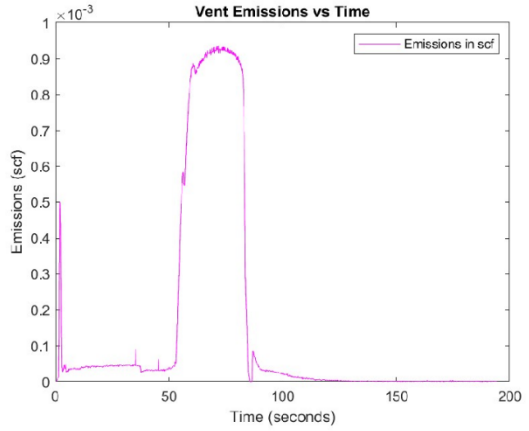
GTI ENERGY

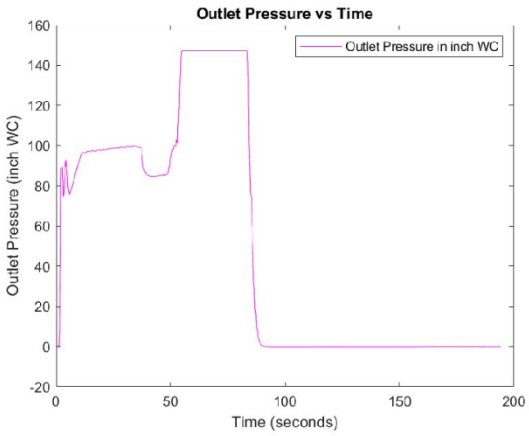

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
30
25
20
15
10
5
0
-5
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
14
12
10
8
6
4
2
75
80
85
90
95

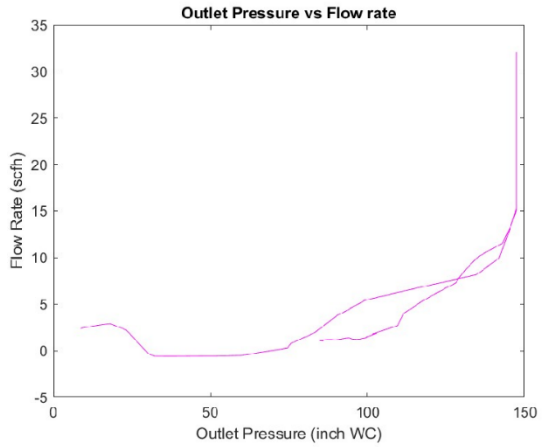
GTI ENERGY

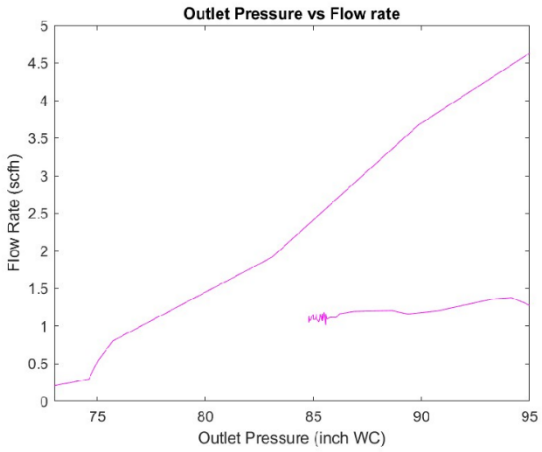
- **222489-036_DT1**
  The volume of total emissions in 194.32 seconds is 0.2716 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 2.63 scfh.





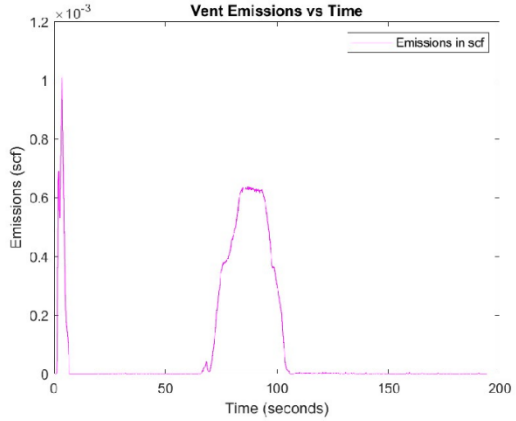
GTI ENERGY

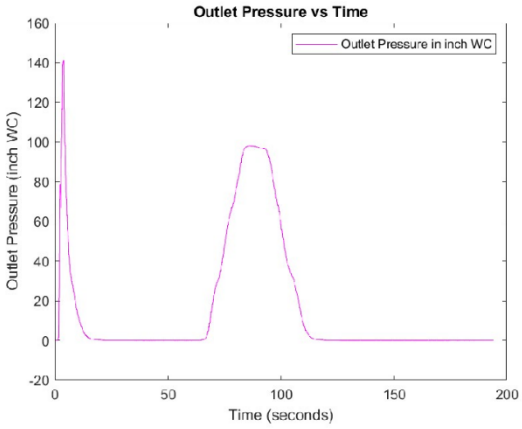

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
35
30
25
20
15
10
5
0
-5
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
75
80
85
90
95

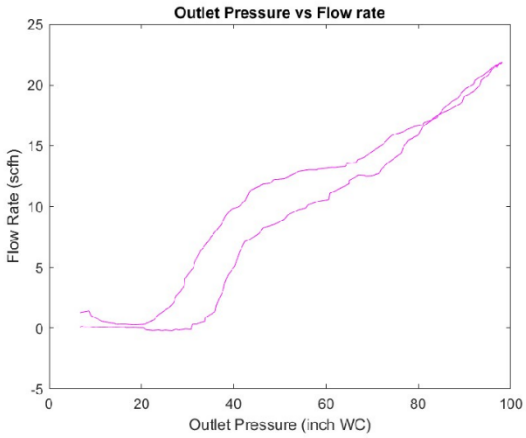
GTI ENERGY

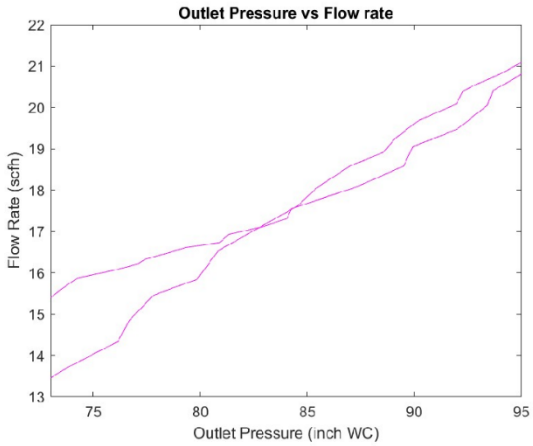
- **222489-036_LD**
  The volume of total emissions in 194.31 seconds is 0.1669 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 18.88 scfh.





GTI ENERGY


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
25
20
15
10
5
0
-5
0
20
40
60
80
100

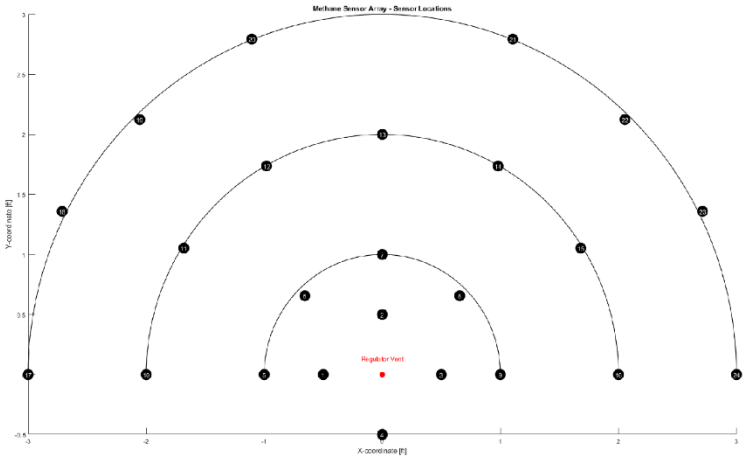

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
22
21
20
19
18
17
16
15
14
13
75
80
85
90
95

GTI ENERGY

Methane Concentration Maps

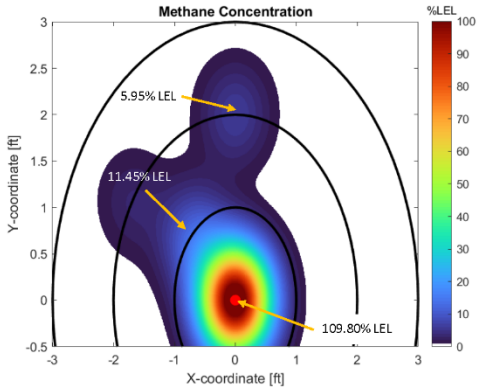
Sensor Locations

Commented [JW21]: Added sensor locations

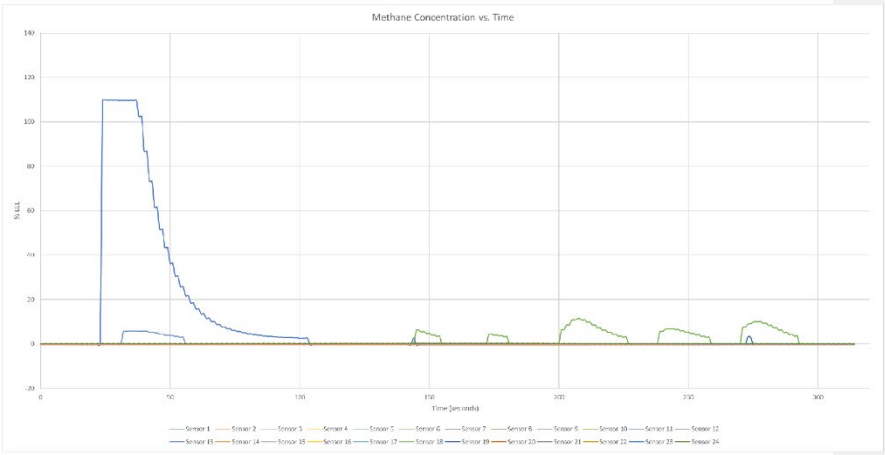


7" WC Outlet

	7 In-WC	222489-033_DT1_1_sensor1 next to vent	Sigma = .38
VL5	Primary Diaphragm Tear	Standard Array Configuration	1 in from vent

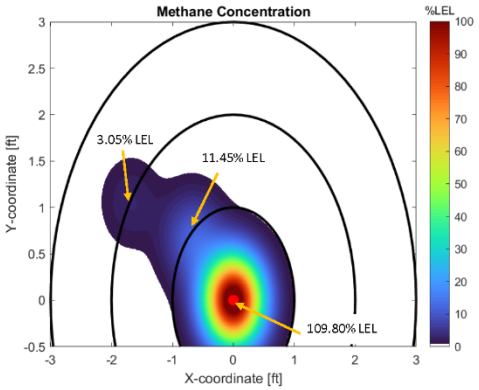


GTI ENERGY

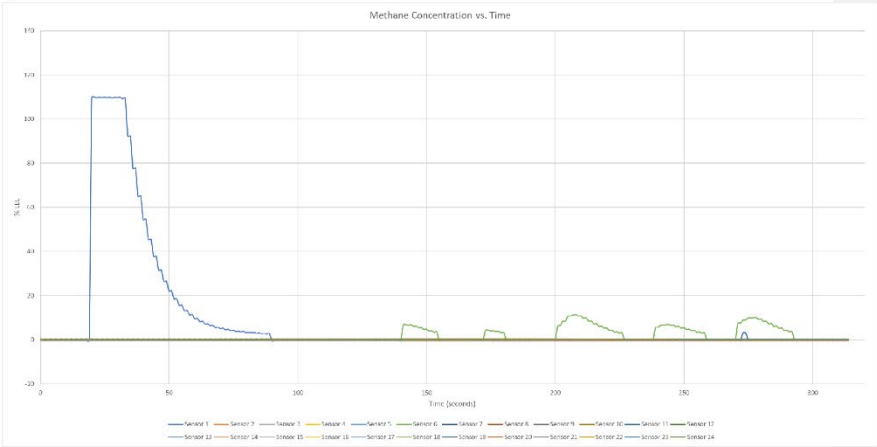

Methane Concentration vs. Time
% LEL
Time [seconds]
Sensor 1
Sensor 2
Sensor 3
Sensor 4
Sensor 5
Sensor 6
Sensor 7
Sensor 8
Sensor 9
Sensor 10
Sensor 11
Sensor 12
Sensor 13
Sensor 14
Sensor 15
Sensor 16
Sensor 17
Sensor 18
Sensor 19
Sensor 20
Sensor 21
Sensor 22
Sensor 23
Sensor 24

GTI ENERGY

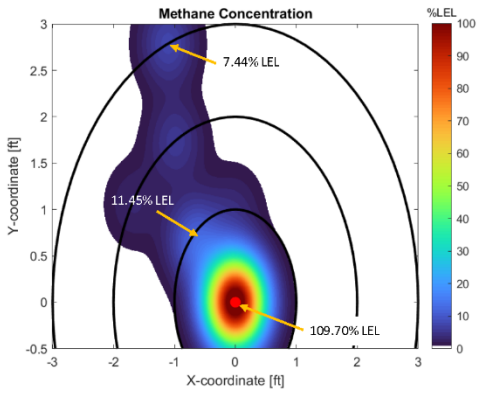
	7 In-WC	222489-033_DT1_2_sensor1 next to vent	Sigma = .32
VL5	Primary Diaphragm Tear	Standard Array Configuration	1 in from vent



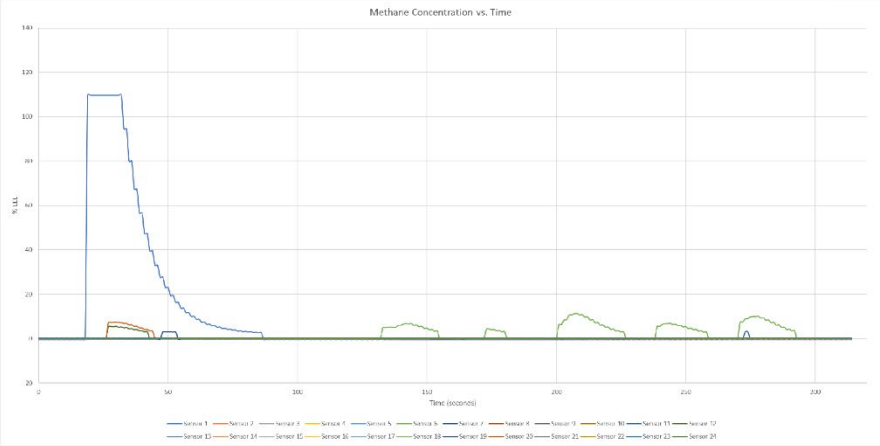
GTI ENERGY


Methane Concentration vs. Time
Time (seconds)

	7 In-WC	222489-033_DT1_3_sensor1 next to vent	Sigma = .32
VL5	Primary Diaphragm Tear	Standard Array Configuration	1 in from vent

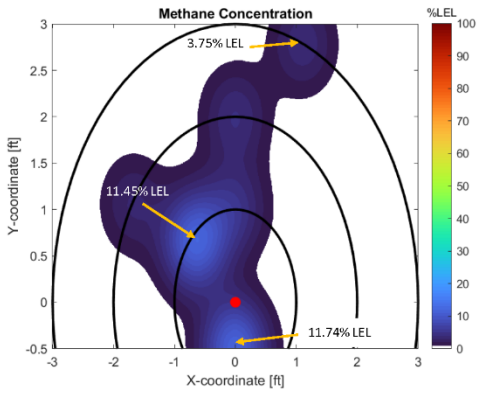


GTI ENERGY



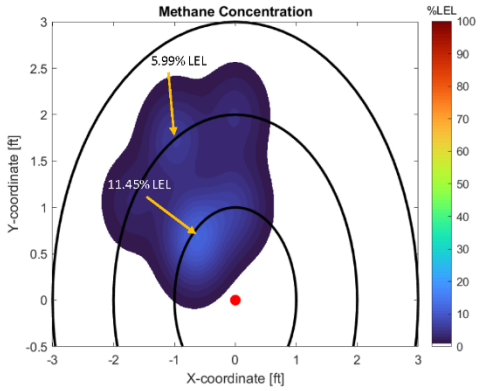
GTI ENERGY

	7 In-WC	222489-033_DT1_4_sensor1 6 in	Sigma = .36
VL5	Primary Diaphragm Tear	Standard Array Configuration	6 in from vent

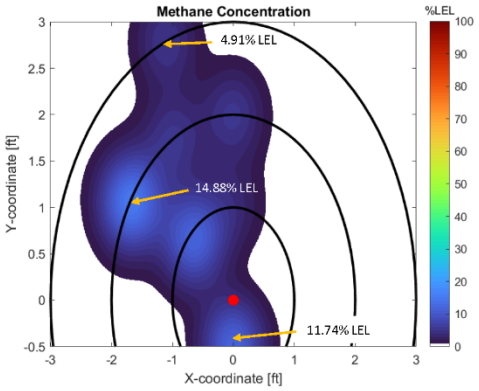


GTI ENERGY

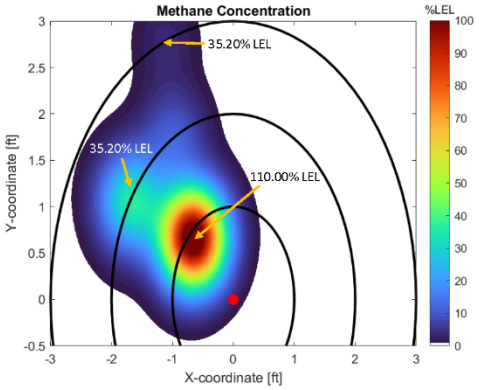
	7 In-WC	222489-033_DT1_5_sensor1 6 in	Sigma = .34
VL5	Primary Diaphragm Tear	Standard Array Configuration	6 in from vent



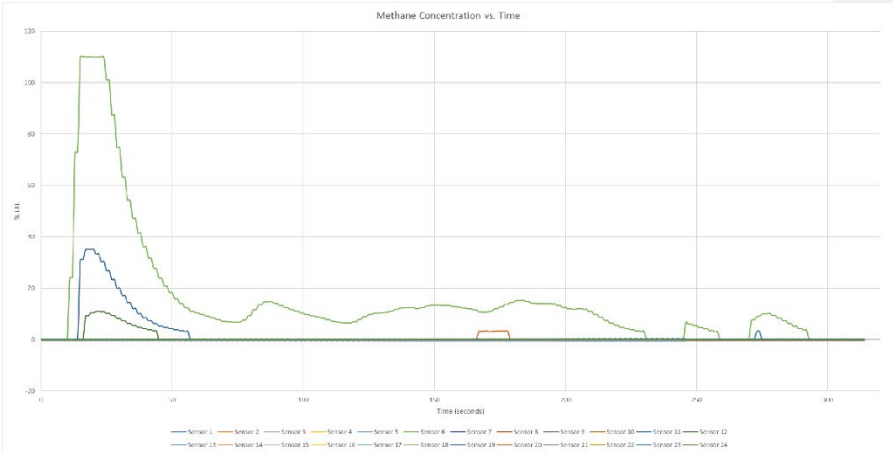
	7 In-WC	222489-033_DT1_6_sensor1 6 in	Sigma = .35
VL5	Primary Diaphragm Tear	Standard Array Configuration	6 in from vent



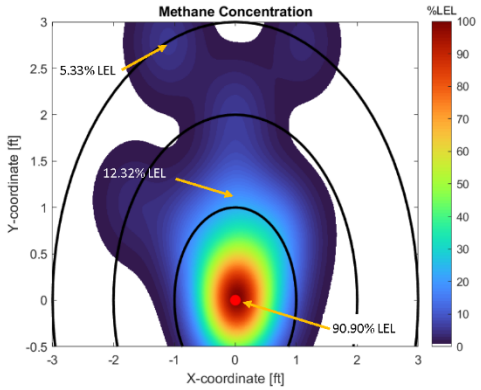
	7 In-WC	222489-033_DT2	Sigma = .36
VL5	Primary and Secondary Diaphragm Tear	Standard Array Configuration	6 in from vent



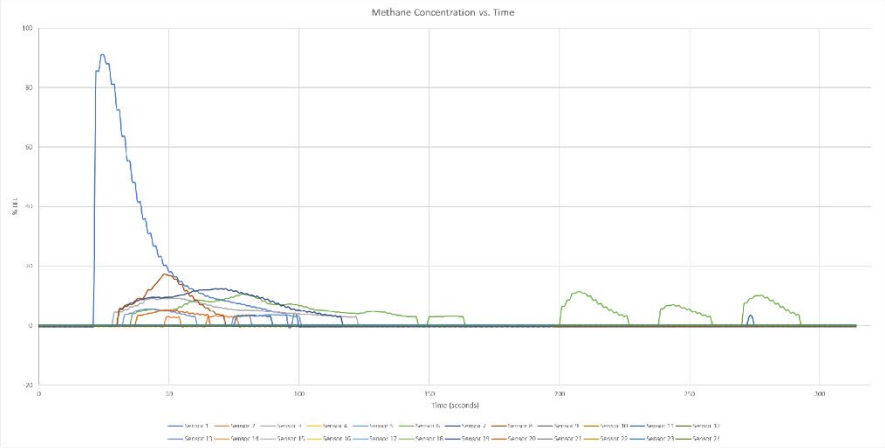
GTI ENERGY


Methane Concentration vs. Time
120
100
80
60
40
20
0
-20
% LEL
Time (seconds)
Sensor 1
Sensor 2
Sensor 3
Sensor 4
Sensor 5
Sensor 6
Sensor 7
Sensor 8
Sensor 9
Sensor 10
Sensor 11
Sensor 12
Sensor 13
Sensor 14
Sensor 15
Sensor 16
Sensor 17
Sensor 18
Sensor 19
Sensor 20
Sensor 21
Sensor 22
Sensor 23
Sensor 24

	7 In-WC	222489-032_LD_1_sensor1 next to vent	Sigma = .4
VL5	Lever Disconnect	Standard Array Configuration	1 in from vent

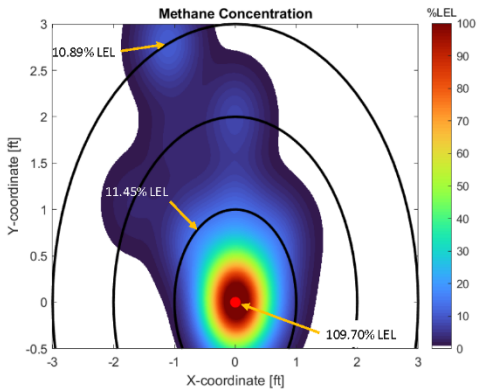


GTI ENERGY

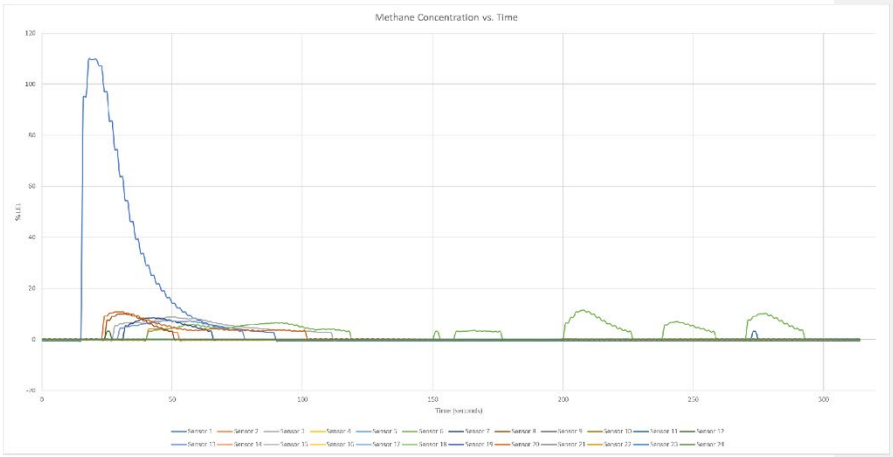

Methane Concentration vs. Time
100
80
60
0
-20
0
50
100
150
200
250
300
Time (seconds)

GTI ENERGY

	7 In-WC	222489-032_LD_2_sensor1 next to vent	Sigma = .35
VL5	Lever Disconnect	Standard Array Configuration	1 in from vent

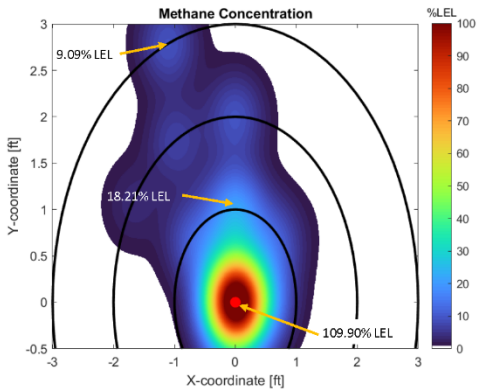


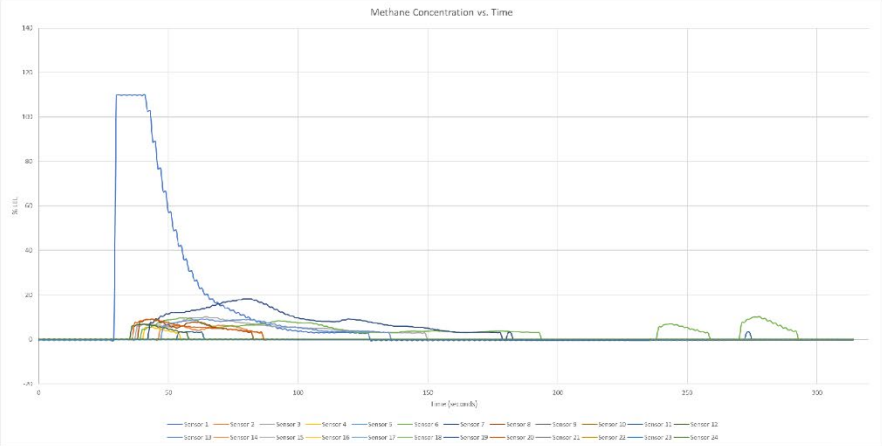
GTI ENERGY


Methane Concentration vs. Time
120
100
80
60
40
20
0
%LEL
0
50
100
150
200
250
300
Time (seconds)

GTI ENERGY

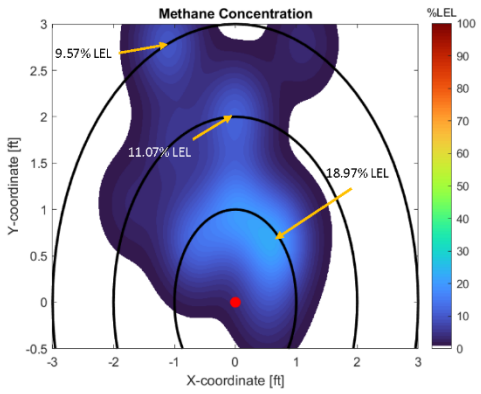
	7 In-WC	222489-032_LD_3_sensor1 next to vent	Sigma = .33
VL5	Lever Disconnect	Standard Array Configuration	1 in from vent




Methane Concentration vs. Time
140
120
100
80
60
40
20
0
0
50
100
150
200
250
300
Sensor 1
Sensor 2
Sensor 3
Sensor 4
Sensor 5
Sensor 6
Sensor 7
Sensor 8
Sensor 9
Sensor 10
Sensor 11
Sensor 12
Sensor 13
Sensor 14
Sensor 15
Sensor 16
Sensor 17
Sensor 18
Sensor 19
Sensor 20
Sensor 21
Sensor 22
Sensor 23
Sensor 24

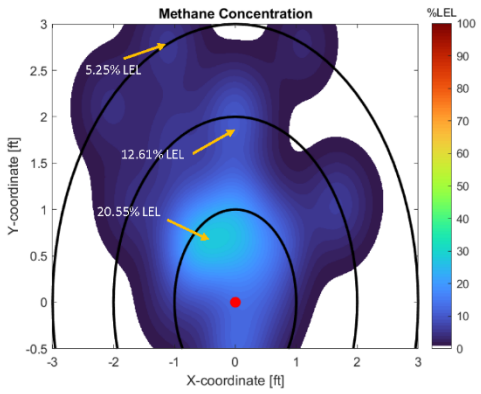
GTI ENERGY

	7 In-WC	222489-032_LD_4_sensor1 6in	Sigma = .37
VL5	Lever Disconnect	Standard Array Configuration	6 in from vent



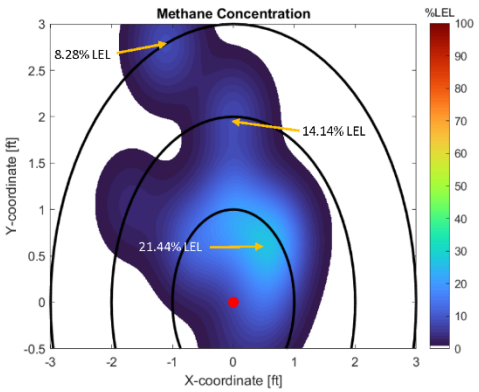
GTI ENERGY

	7 In-WC	222489-032_LD_5_sensor1 6in	Sigma = .38
VL5	Lever Disconnect	Standard Array Configuration	6 in from vent

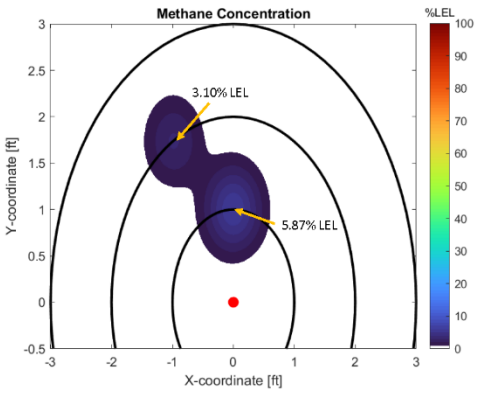


GTI ENERGY

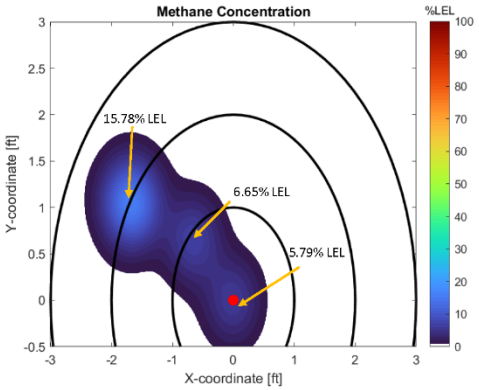
	7 In-WC	222489-032_LD_6_sensor1 6in	Sigma = .375
VL5	Lever Disconnect	Standard Array Configuration	6 in from vent



	7 In-WC	222489-031_multi lockup_sensor1 6in	Sigma = .32
VL5	Normal Condition – Multi Lockup	Standard Array Configuration	6 in from vent

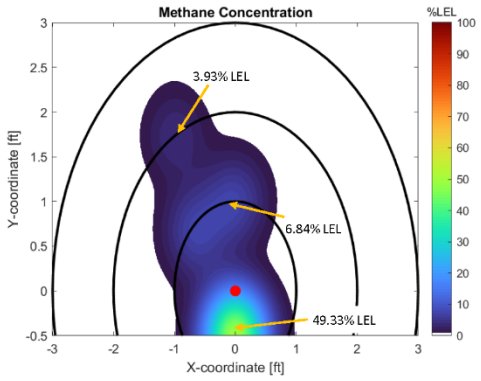


	7 In-WC	222489-031_multi lockup_sensor1 next to vent	Sigma = .32
VL5	Normal Condition – Multi Lockup	Standard Array Configuration	1 in from vent



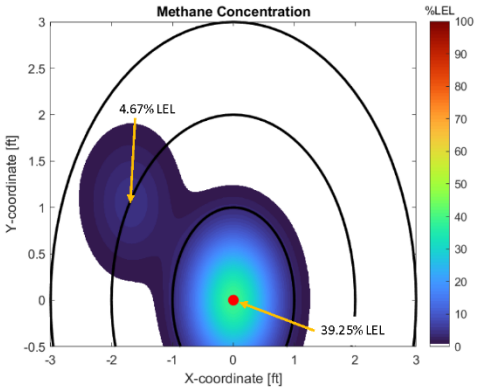
GTI ENERGY

	7 In-WC	222489-031_multi lockup_sensor1 next to vent_trial2	Sigma = .35
VL5	Normal Condition – Multi Lockup	Standard Array Configuration	1 in from vent



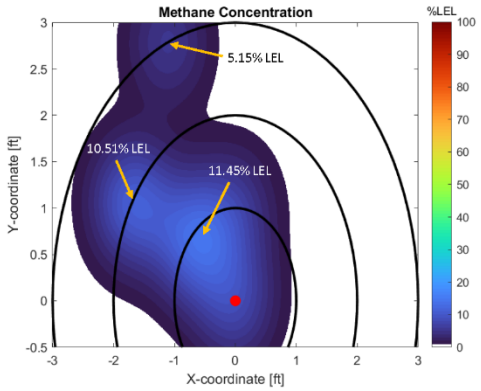
GTI ENERGY

	7 In-WC	222489-031_single lockup_sensor1 next to vent	Sigma = .46
VL5	Normal Condition – Single Lockup	Standard Array Configuration	1 in from vent

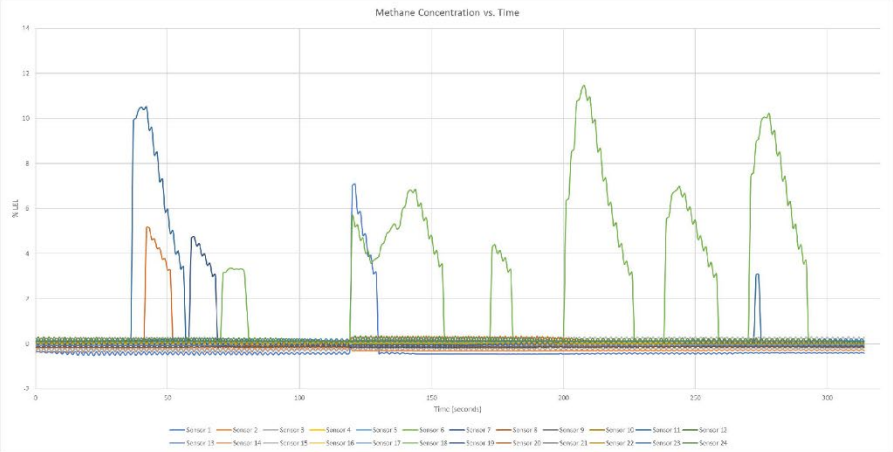


2-psig Outlet

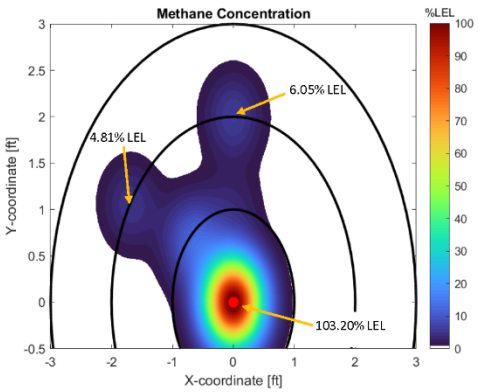
	2 PSI	222489-035_DT1_1_sensor1 next to vent	Sigma = .46
VL5	Primary Diaphragm Tear	Standard Array Configuration	1 in from vent



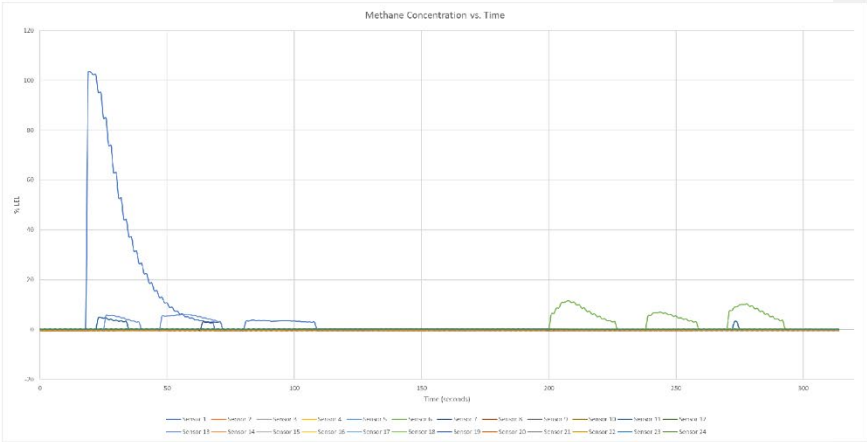
GTI ENERGY


Methane Concentration vs. Time
14
12
10
8
6
4
2
0
-2
N.U.
0
50
100
150
200
250
300
Time [seconds]
Sensor 1
Sensor 2
Sensor 3
Sensor 4
Sensor 5
Sensor 6
Sensor 7
Sensor 8
Sensor 9
Sensor 10
Sensor 11
Sensor 12
Sensor 13
Sensor 14
Sensor 15
Sensor 16
Sensor 17
Sensor 18
Sensor 19
Sensor 20
Sensor 21
Sensor 22
Sensor 23
Sensor 24

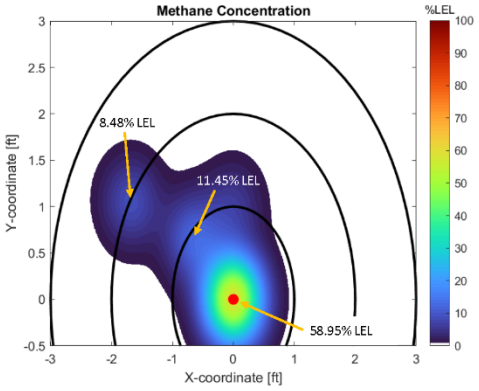
	2 PSI	222489-035_DT1_2_sensor1 next to vent	Sigma = .32
VL5	Primary Diaphragm Tear	Standard Array Configuration	1 in from vent



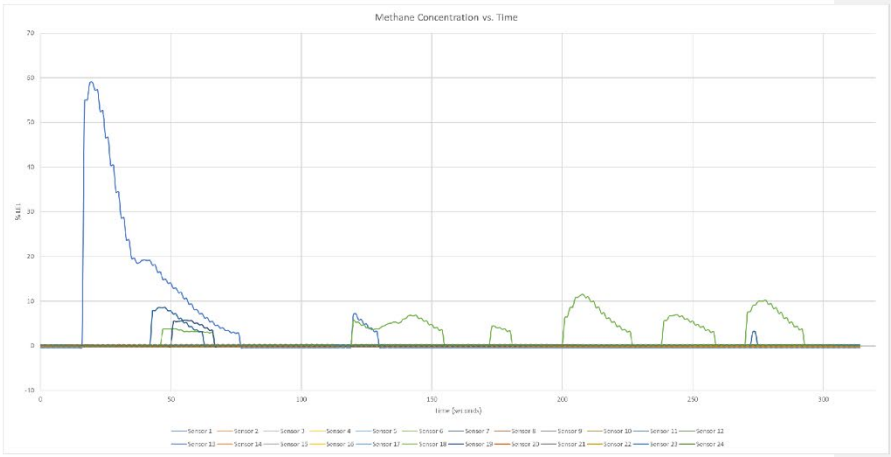
GTI ENERGY


Methane Concentration vs. Time
% LEL
Time (seconds)

	2 PSI	222489-035_DT1_3_sensor1 next to vent	Sigma = .32
VL5	Primary Diaphragm Tear	Standard Array Configuration	1 in from vent

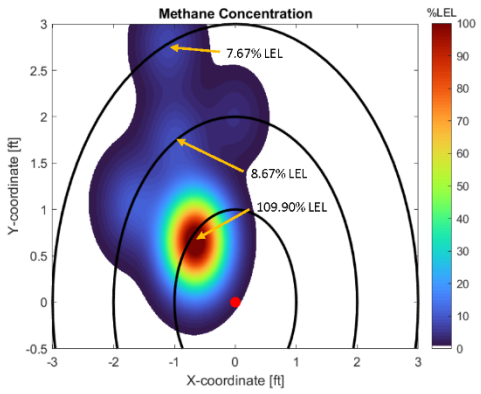


GTI ENERGY

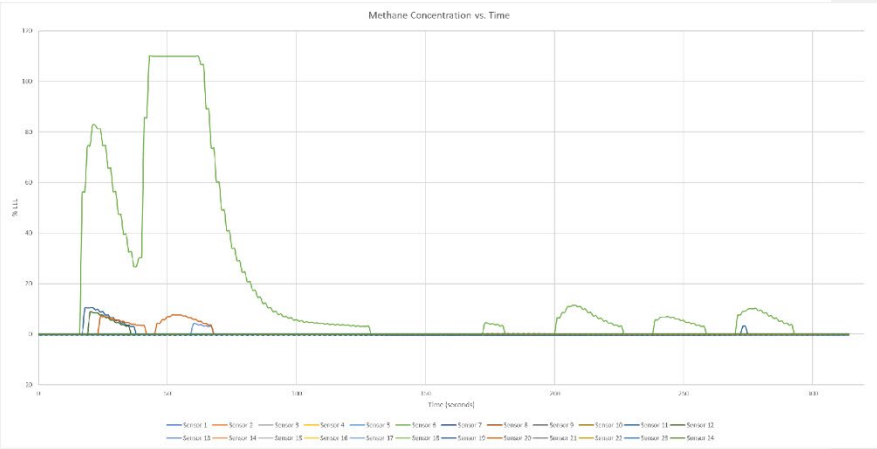

Methane Concentration vs. Time
70
60
50
40
30
20
10
0
-10
0
50
100
150
200
250
300
Sensor 1
Sensor 2
Sensor 3
Sensor 4
Sensor 5
Sensor 6
Sensor 7
Sensor 8
Sensor 9
Sensor 10
Sensor 11
Sensor 12
Sensor 13
Sensor 14
Sensor 15
Sensor 16
Sensor 17
Sensor 18
Sensor 19
Sensor 20
Sensor 21
Sensor 22
Sensor 23
Sensor 24

GTI ENERGY

	2 PSI	222489-035_DT1_4_sensor1 6in	Sigma = .33
VL5	Primary Diaphragm Tear	Standard Array Configuration	6 in from vent

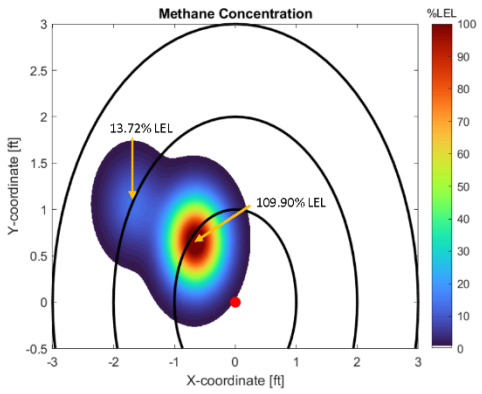


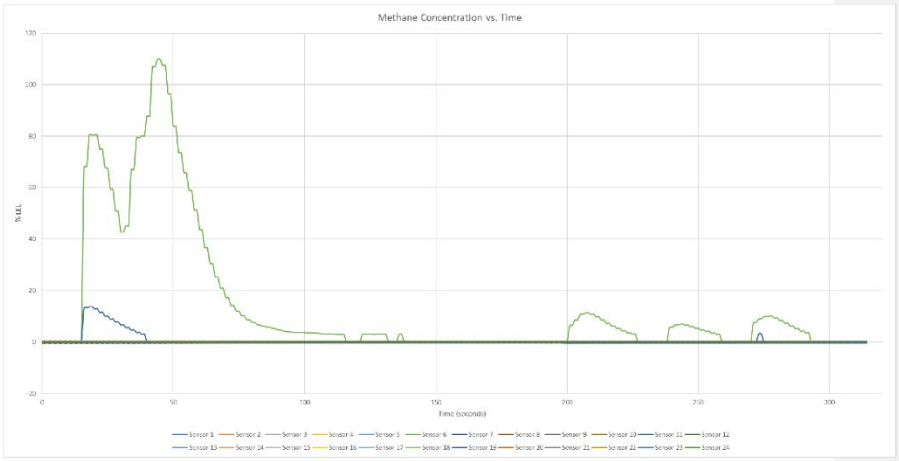
GTI ENERGY


Methane Concentration vs. Time
% LEL
Time [seconds]
Sensor 1
Sensor 2
Sensor 3
Sensor 4
Sensor 5
Sensor 6
Sensor 7
Sensor 8
Sensor 9
Sensor 10
Sensor 11
Sensor 12
Sensor 13
Sensor 14
Sensor 15
Sensor 16
Sensor 17
Sensor 18
Sensor 19
Sensor 20
Sensor 21
Sensor 22
Sensor 23
Sensor 24

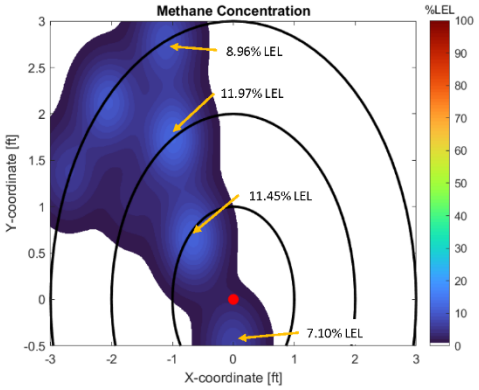
GTI ENERGY

	2 PSI	222489-035_DT1_5_sensor1 6in	Sigma = .3
VL5	Primary Diaphragm Tear	Standard Array Configuration	6 in from vent



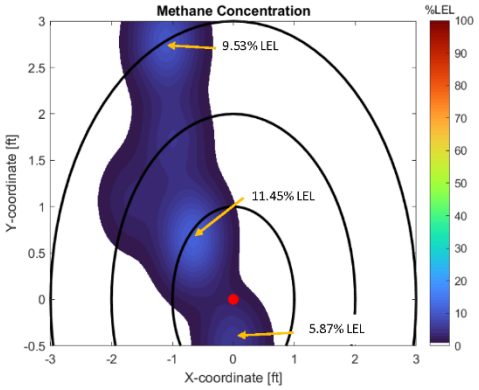

Methane Concentration vs. Time
%LEL
Time (seconds)
Sensor 1
Sensor 2
Sensor 3
Sensor 4
Sensor 5
Sensor 6
Sensor 7
Sensor 8
Sensor 9
Sensor 10
Sensor 11
Sensor 12
Sensor 13
Sensor 14
Sensor 15
Sensor 16
Sensor 17
Sensor 18
Sensor 19
Sensor 20
Sensor 21
Sensor 22
Sensor 23
Sensor 24

	2 PSI	222489-035_DT2_trial1	Sigma = .34
VL5	Primary and Secondary Diaphragm Tear	Standard Array Configuration	6 in from vent



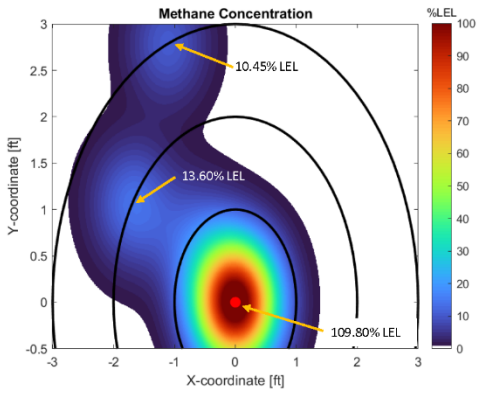
GTI ENERGY

	2 PSI	222489-035_DT2_trial2	Sigma = .36
VL5	Primary and Secondary Diaphragm Tear	Standard Array Configuration	6 in from vent

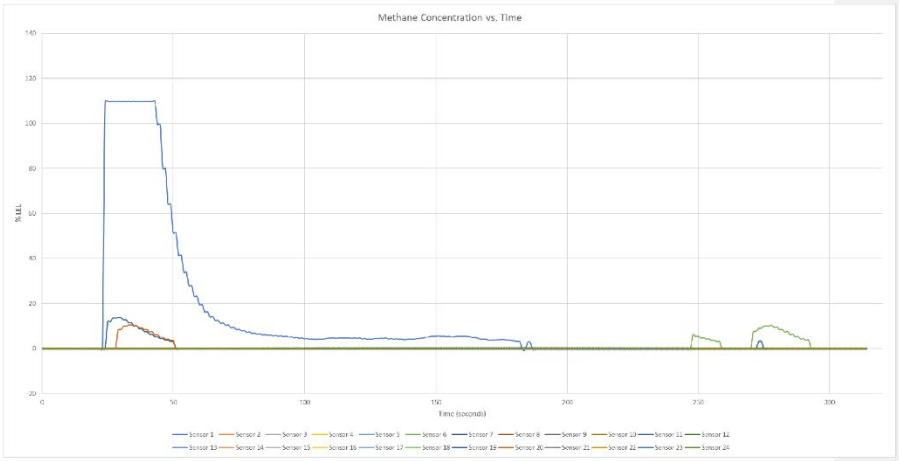


GTI ENERGY

	2 PSI	222489-036_LD_1_sensor1 next to vent	Sigma = .45
VL5	Lever Disconnect	Standard Array Configuration	1 in from vent

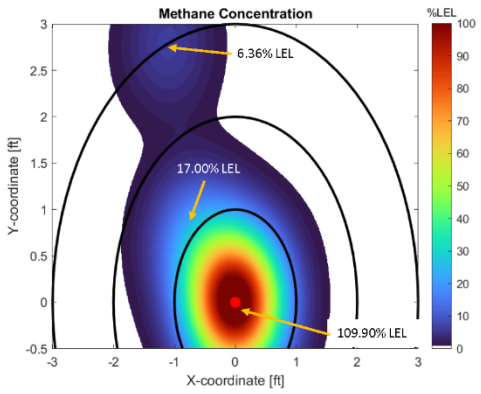


GTI ENERGY

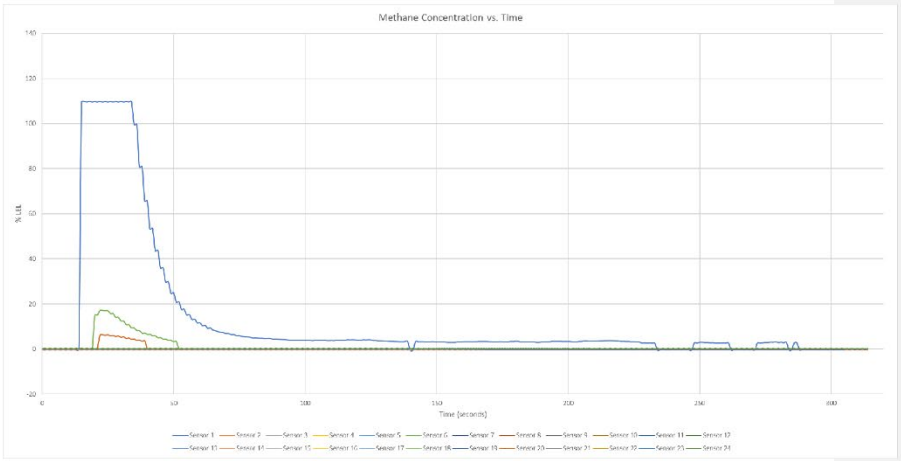

Methane Concentration vs. Time
% LEL
Time (seconds)
Sensor 1
Sensor 2
Sensor 3
Sensor 4
Sensor 5
Sensor 6
Sensor 7
Sensor 8
Sensor 9
Sensor 10
Sensor 11
Sensor 12
Sensor 13
Sensor 14
Sensor 15
Sensor 16
Sensor 17
Sensor 18
Sensor 19
Sensor 20
Sensor 21
Sensor 22
Sensor 23
Sensor 24

GTI ENERGY

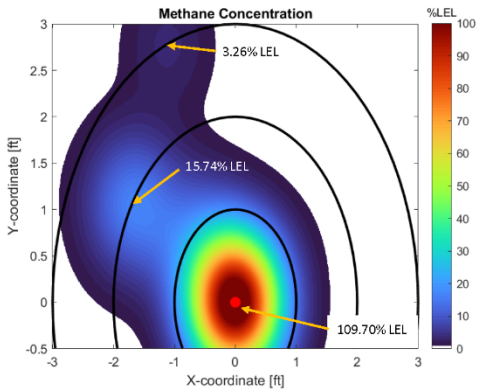
	2 PSI	222489-036_LD_2_sensor1 next to vent	Sigma = .5
VL5	Lever Disconnect	Standard Array Configuration	1 in from vent



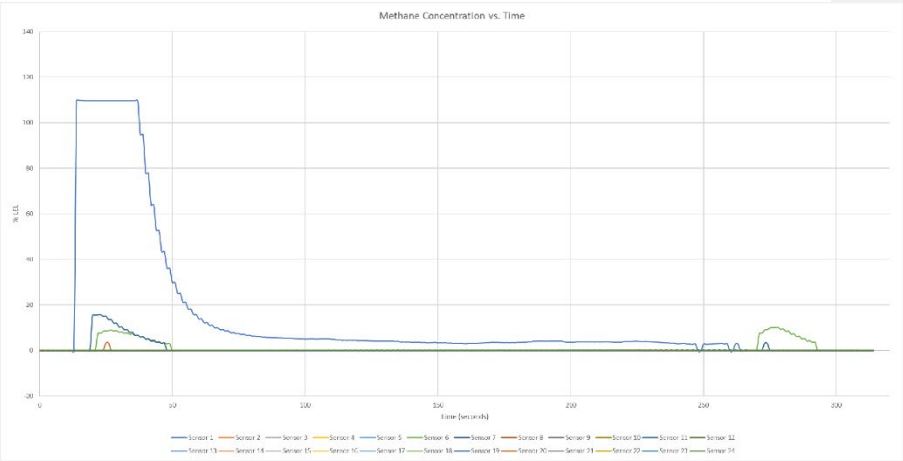
GTI ENERGY


Methane Concentration vs. Time
140
120
100
80
60
40
20
0
-20
% LEL
Time (seconds)
Sensor 1
Sensor 2
Sensor 3
Sensor 4
Sensor 5
Sensor 6
Sensor 7
Sensor 8
Sensor 9
Sensor 10
Sensor 11
Sensor 12
Sensor 13
Sensor 14
Sensor 15
Sensor 16
Sensor 17
Sensor 18
Sensor 19
Sensor 20
Sensor 21
Sensor 22
Sensor 23
Sensor 24

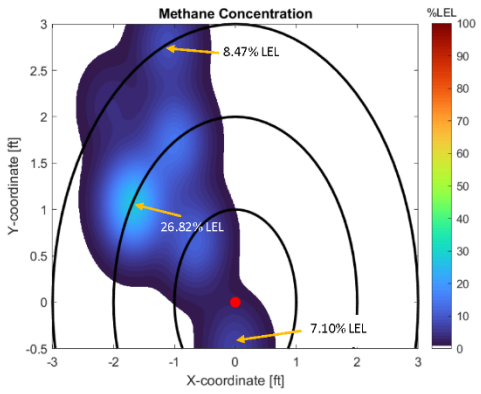
	2 PSI	222489-036_LD_3_sensor1 next to vent	Sigma = .5
VL5	Lever Disconnect	Standard Array Configuration	1 in from vent



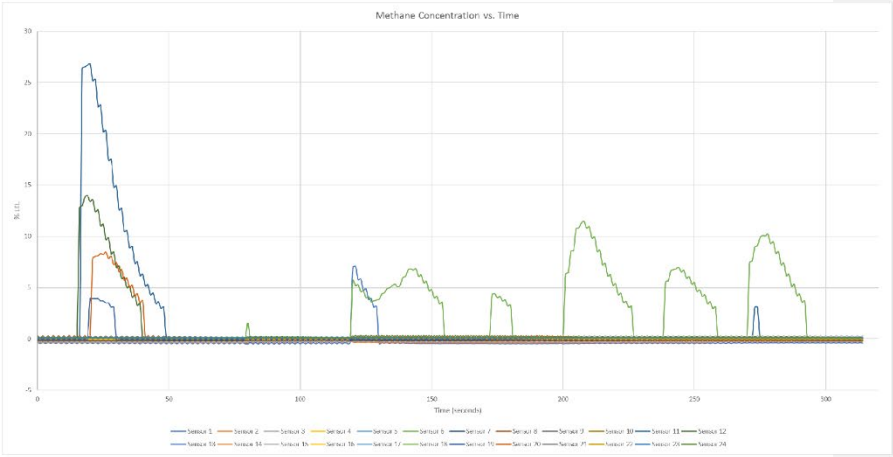
GTI ENERGY


Methane Concentration vs. Time
% LEL
Time (seconds)
Sensor 1
Sensor 2
Sensor 3
Sensor 4
Sensor 5
Sensor 6
Sensor 7
Sensor 8
Sensor 9
Sensor 10
Sensor 11
Sensor 12
Sensor 13
Sensor 14
Sensor 15
Sensor 16
Sensor 17
Sensor 18
Sensor 19
Sensor 20
Sensor 21
Sensor 22
Sensor 23
Sensor 24

	2 PSI	222489-036_LD_4_sensor1 next to vent	Sigma = .34
VL5	Lever Disconnect	Standard Array Configuration	1 in from vent

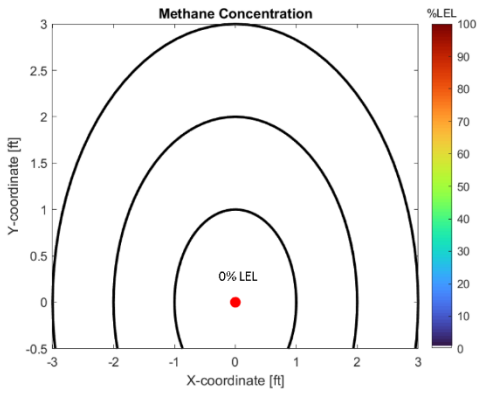


GTI ENERGY


Methane Concentration vs. Time
30
25
20
15
10
5
0
-5
0
50
100
150
200
250
300
Time (seconds)

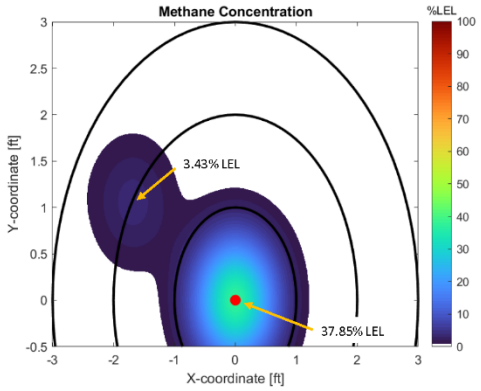
GTI ENERGY

	2 PSI	222489-034_multi lockup_sensor1 6in	Sigma = .3
VL5	Normal Condition – Multi Lockup	Standard Array Configuration	6 in from vent



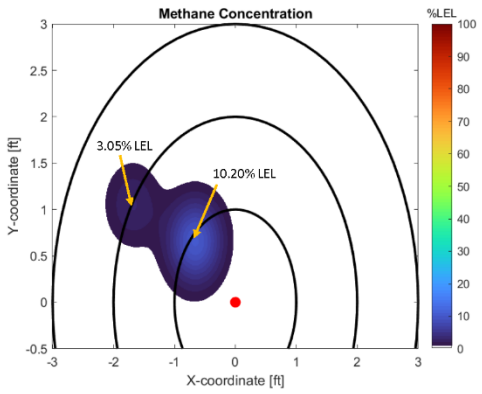
GTI ENERGY

	2 PSI	222489-034_multi lockup_sensor1 next to vent	Sigma = .45
VL5	Normal Condition – Multi Lockup	Standard Array Configuration	1 in from vent

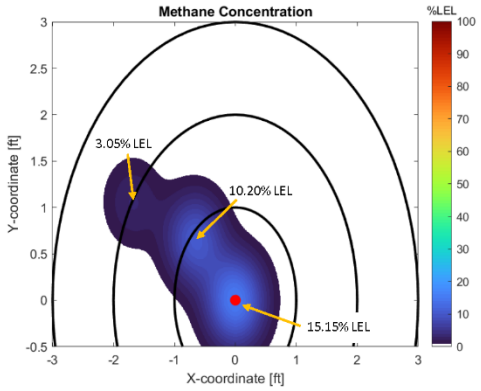


GTI ENERGY

	2 PSI	222489-034_single lockup_sensor1 6in	Sigma = .3
VL5	Normal Condition – Single Lockup	Standard Array Configuration	6 in from vent



	2 PSI	222489-034_single lockup_sensor1 next to vent	Sigma = .32
VL5	Normal Condition – Single Lockup	Standard Array Configuration	1 in from vent



GTI ENERGY

Appendix E – IRV1 Manufacturer Test Data

GTI ENERGY
solutions that transform

REPORT
GTI ENERGY PROJECT NUMBER 23059

Comparison of Compact Service Regulators – Results of Testing

IRV1 Summary

GTI Energy Technical Contact:
Joe Carlstrom
Joseph Irwin, PE
Tom Bates
Jake Witecha

1700 S. Mount Prospect Rd.
Des Plaines, Illinois 60018
www.gti.energy

Introduction

This report was created to review data obtained during PHMSA project 693JK32110001 and OTD project 5.22.j - Design and Placement of Compact Service Regulators with subject matter experts from the manufacturer. The following Part 1 and Part 2 matrix outlines the test methodology used to obtain data for analysis purposes for safe clearance distances.

Part 1 Test methodology

All testing was performed on the rig with air and software formula coefficients for natural gas.

Test	Standard/Procedure reference	Conditions	Test Criteria	Parameters
Modified Lock-Up Test	ANSI B109.4 -[5.3.5]	Temperature: Ambient; Inlet pressure: 10, 60, 100 psig; Flow: 100, 200, 300, until maximum manufacturer specifications [SCFH Air]	Outlet pressure Max 9"±0.5 iwc 2.15±0.15 psig (2psig reg.)	Lock up [iwc]
			Flow rate at vent 2.5 SCFH (vent limited) 100 SCFH (IRV)	Vent flow rate [SCFH]
Modified Relief Point Test	ANSI B109.4 -[5.3.8]	Temperature: Ambient; Inlet pressure: 10, 60, 100 psig; Outlet pressure: slowly increase until slam shut closes or maximum allowable pressure reached	Outlet pressure MAX 17"±0.5 iwc; 3.3±0.15iwc psig (2psig reg.)	Relief point [iwc]
			Flow rate at vent 2.5 SCFH (vent limited) 100 SCFH (IRV)	Vent flow rate [SCFH]

Part 2 Test Methodology

Testing was performed in an enclosed and controlled environment with natural gas. Safety rules were implemented to monitor and limit the amounts of natural gas. When an accumulation of natural gas greater than 100% LEL was detected by multiple sensors the natural gas source was terminated and the test concluded.

Single Lock-Up Test	ANSI B109.4 - [5.3.5]	**Temperature**: Ambient; **Inlet pressure**: 60 psig; **Flow Rate**: 390 SCFH (7 iwc reg.) 1260 SCFH (2 psig reg.) **Lockup condition**: One lock up induced, wait 30 seconds for gas concentration dissipate to 0% LEL, repeat 10 times.	Outlet pressure Max 9"±0.5 iwc (7 iwc reg.) 2.15±0.15 psig (2psig reg.)	Lock up pressure [iwc]
			Methane concentration at vent 0%LEL (vent limited) 3%LEL (IRV)	Methane Concentration [% LEL]
Multi Lock-Up Test	ANSI B109.4 - [5.3.5]	**Temperature**: Ambient; **Inlet pressure**: 60 psig; **Flow Rate**: 390 SCFH (7 iwc reg.) 1260 SCFH (2 psig reg.) **Lockup condition**: Two lock ups induced in quick succession, wait 30 seconds for gas concentration dissipate to 0%LEL, repeat 3 times, after 3 repetitions increase the number of lockups by 1 to a maximum of 4.	Outlet pressure Max 9"±0.5 iwc (7 inW/C reg.) 2.15±0.15 psig (2psig reg.)	Lock up pressure [inW/C]
			Methane concentration at vent 0%LEL (vent limited) 3%LEL (IRV)	Methane Concentration [% LEL]

GTI ENERGY

Summary

Modified Lockup Tests

Average Emission Rate [SCFH], Normal Conditions, 7" WC

Model	10-psig inlet	60-psig inlet	100-psig inlet
IRV1	0.8980	0.5458	0.6065

Average Emission Rate [SCFH], Primary Diaphragm Tear, 7" WC

Model	10-psig inlet	60-psig inlet	100-psig inlet
IRV1	54.1002	79.7787	75.1434

Average Emission Rate [SCFH], Lever Disconnect, 7" WC

Model	10-psig inlet	60-psig inlet	100-psig inlet
IRV1	59.1212	87.3591	80.6878

Average Emission Rate [SCFH], Normal Conditions, 2-psig

Model	10-psig inlet	60-psig inlet	100-psig inlet
IRV1	0.6493	0.6285	0.6170

Average Emission Rate [SCFH], Primary Diaphragm Tear, 2-psig

Model	10-psig inlet	60-psig inlet	100-psig inlet
IRV1	66.4184	85.9781	83.6789

Average Emission Rate [SCFH], Lever Disconnect, 2-psig

Model	10-psig inlet	60-psig inlet	100-psig inlet
IRV1	43.5564	81.1017	79.4632

Relief Tests

Average Emission Rate [SCFH], Normal Conditions, 7" WC

Model	10-psig inlet	60-psig inlet	100-psig inlet
IRV1	10.8833	8.5367	8.8500

Average Emission Rate [SCFH], Primary Diaphragm Tear, 7" WC

Model	10-psig inlet	60-psig inlet	100-psig inlet
IRV1	NA*	NA*	NA*

*Flow rate exceeded flow meter range

Average Emission Rate [SCFH], Lever Disconnect, 7" WC

Model	10-psig inlet	60-psig inlet	100-psig inlet
IRV1	32.8600	27.7500	NA*

*Flow rate exceeded flow meter range

Average Emission Rate [SCFH], Normal Conditions, 2-psig

Model	10-psig inlet	60-psig inlet	100-psig inlet
IRV1	6.3567	6.4400	6.3567

Average Emission Rate [SCFH], Primary Diaphragm Tear, 2-psig

Model	10-psig inlet	60-psig inlet	100-psig inlet
IRV1	69.3000	71.6900	54.3800

Average Emission Rate [SCFH], Lever Disconnect, 2-psig

Model	10-psig inlet	60-psig inlet	100-psig inlet
IRV1	29.4500	NA*	42.1300

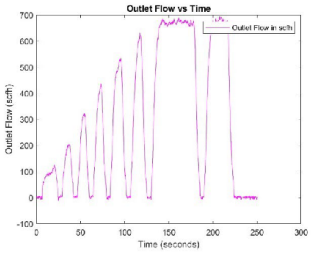
*Flow rate exceeded flow meter range

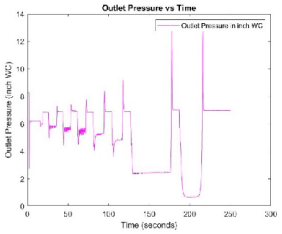
Modified Lockup Tests

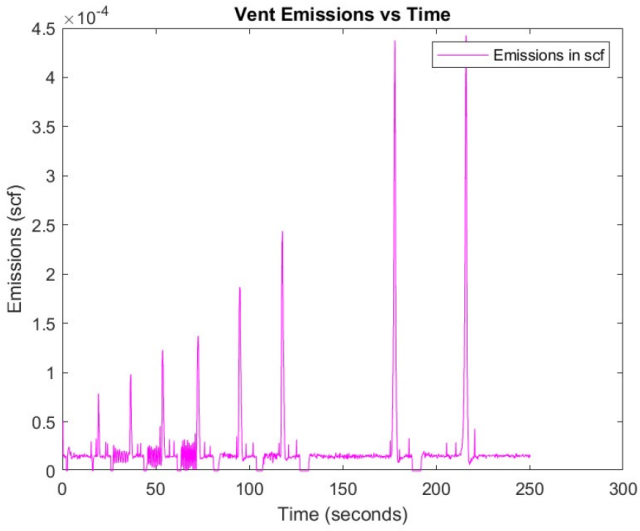
7" WC Outlet, 3/16" Orifice, 10-psig Inlet

- 222489-19

  The volume of total emissions in 250.46 seconds is 0.0493 scf.
  The flow rate of emissions is 0.7088 scfh.



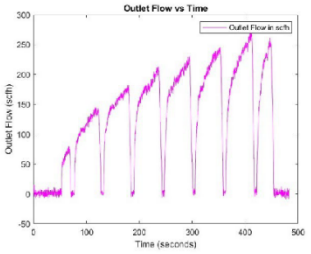


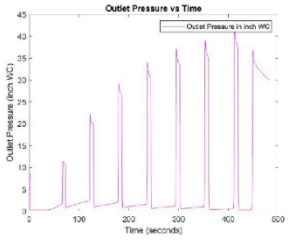


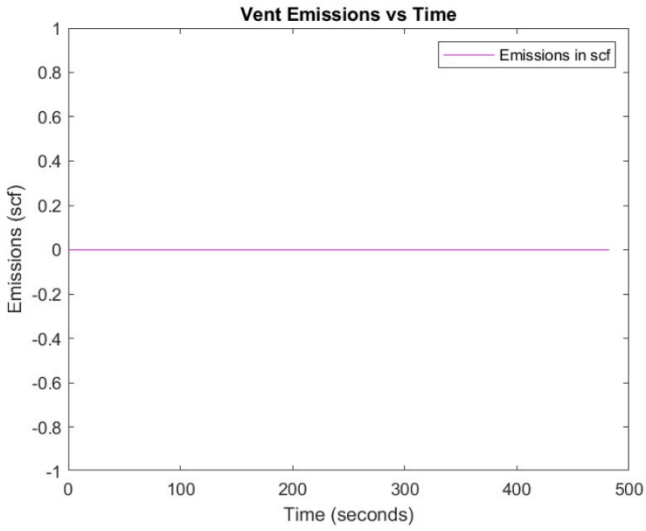
7

GTI ENERGY

- 222489-19_BV
  The volume of total emissions in 482.40 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.

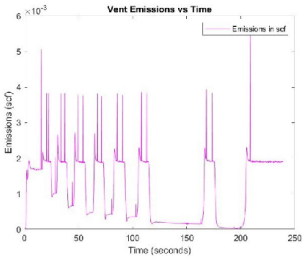


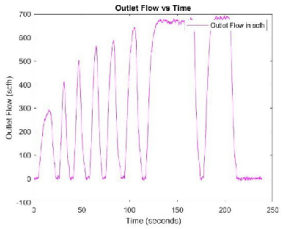


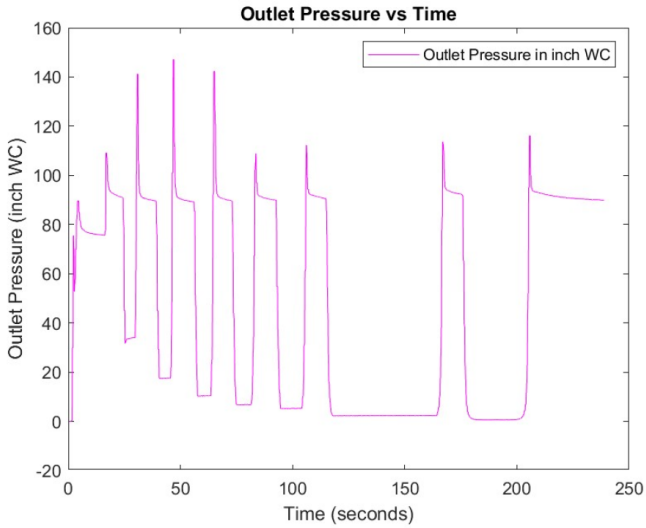


8

- 222489-19_DT
  The volume of total emissions in 238.82 seconds is 2.4848 scf.
  The flow rate of emissions is 37.4566 scfh.



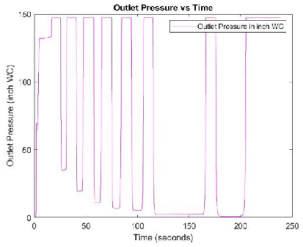


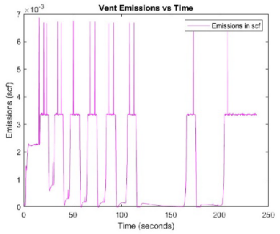


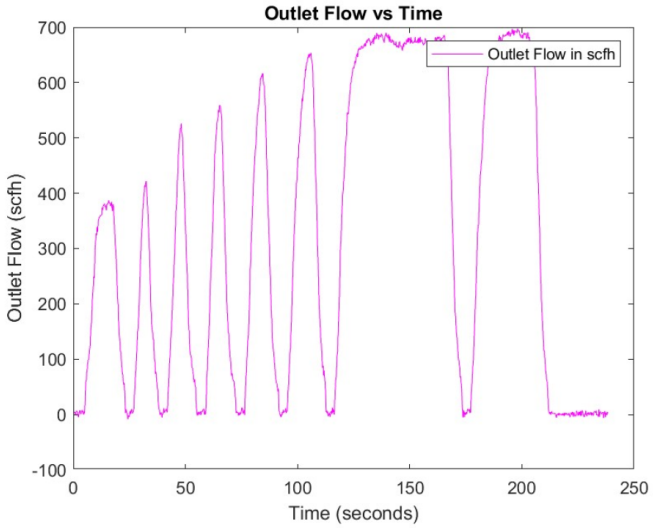
9

GTI ENERGY

- 222489-19_LD
  The volume of total emissions in 238.35 seconds is 3.7658 scf.
  The flow rate of emissions is 56.8769 scfh.



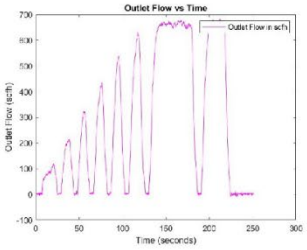


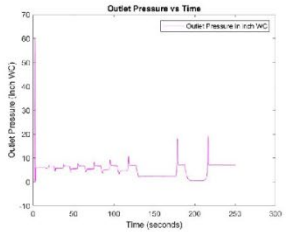


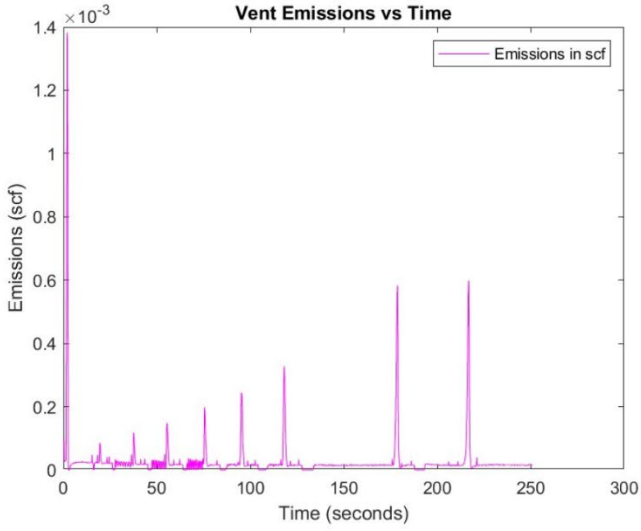
10

GTI ENERGY

- 222489-20
  The volume of total emissions in 251.06 seconds is 0.0656 scf.
  The flow rate of emissions is 0.9407 scfh.

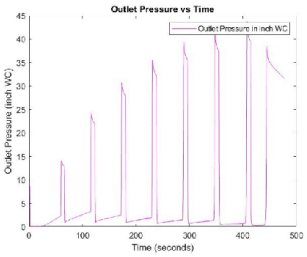


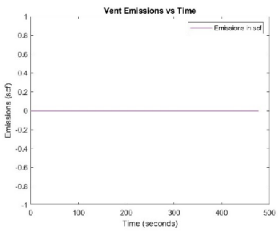


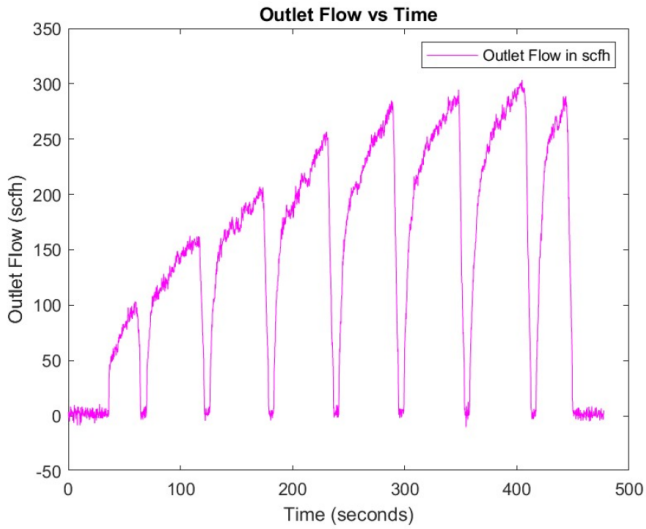


GTI ENERGY

- 222489-20_BV
  The volume of total emissions in 477.50 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.



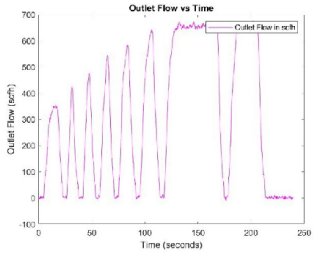


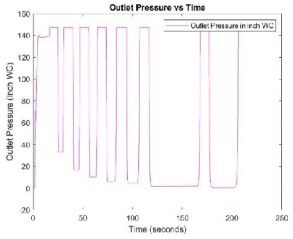


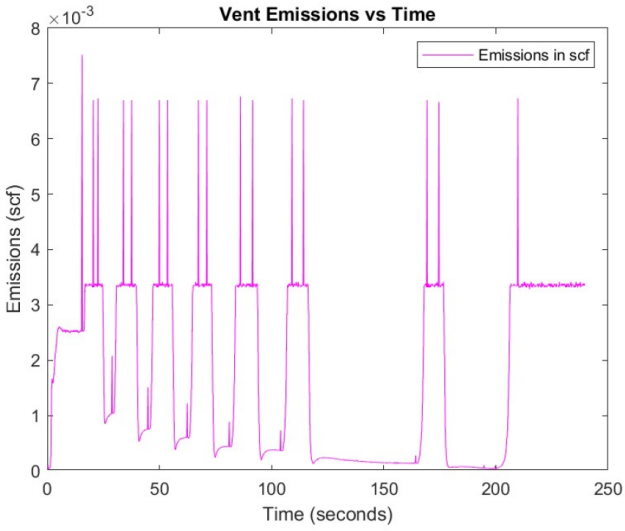
12

GTI ENERGY

- 222489-20_DT
  The volume of total emissions in 239.58 seconds is 3.9532 scf.
  The flow rate of emissions is 59.4022 scfh.



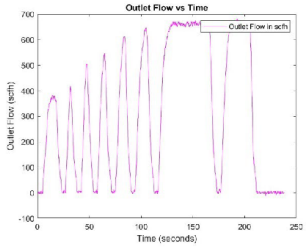


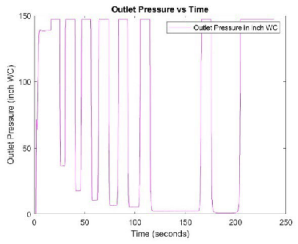


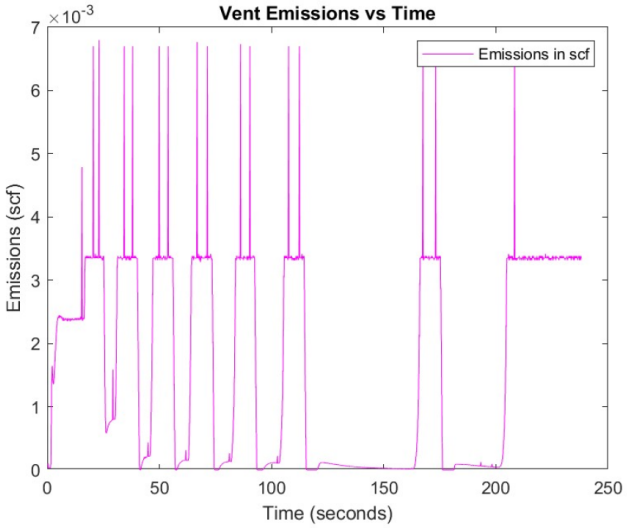
13

GTI ENERGY

- 222489-20_LD
  The volume of total emissions in 238.23 seconds is 3.7273 scf.
  The flow rate of emissions is 56.3254 scfh.



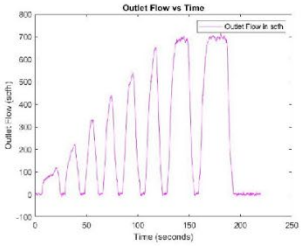


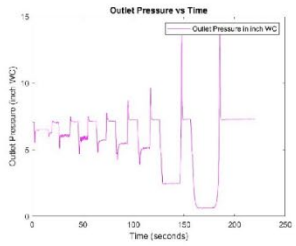


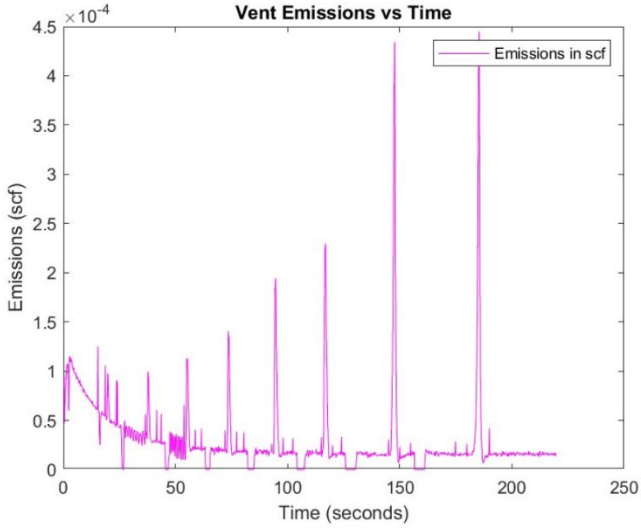
14

GTI ENERGY

- 222489-21
  The volume of total emissions in 219.77 seconds is 0.0638 scf.
  The flow rate of emissions is 1.0446 scfh.



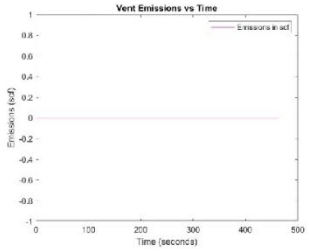


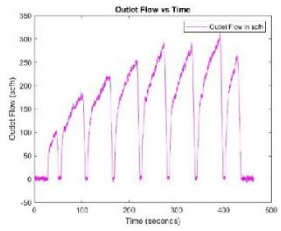


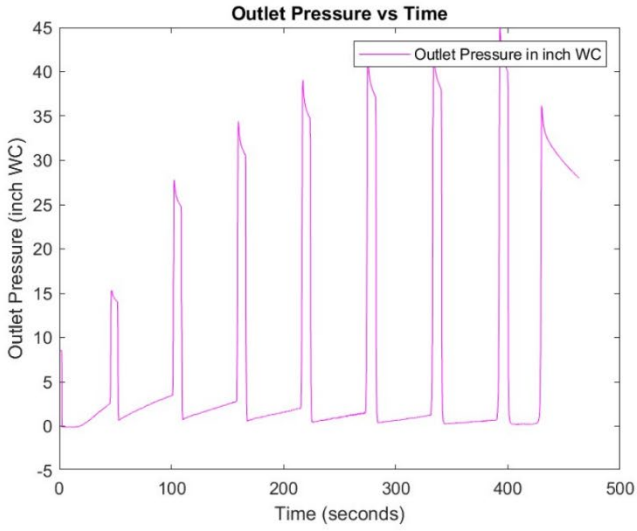
15

GTI ENERGY

- 222489-21_BV
  The volume of total emissions in 463.09 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.



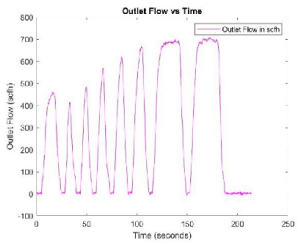


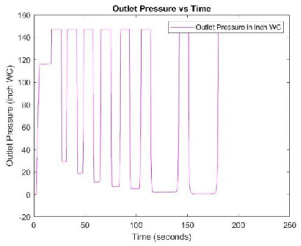


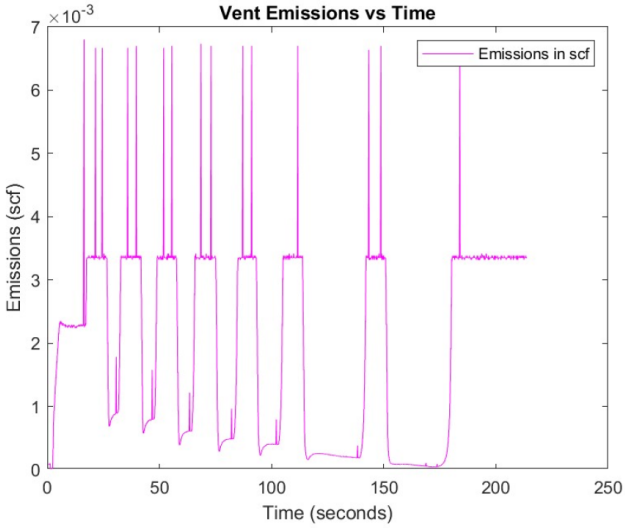
16

GTI ENERGY

- 222489-21_DT
  The volume of total emissions in 213.80 seconds is 3.8865 scf.
  The flow rate of emissions is 65.4417 scfh.

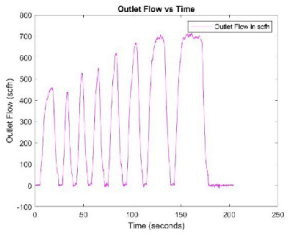


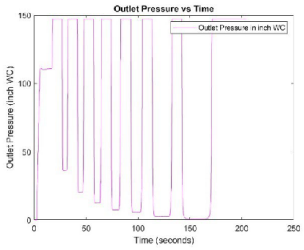


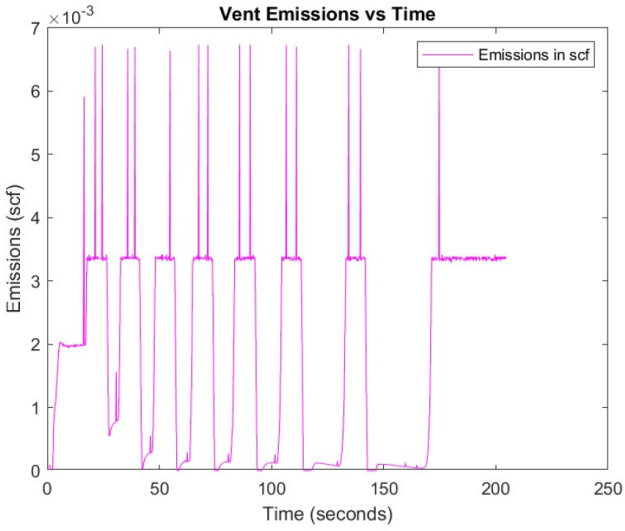


17

- 222489-21_LD
  The volume of total emissions in 204.60 seconds is 3.6465 scf.
  The flow rate of emissions is 64.1612 scfh.





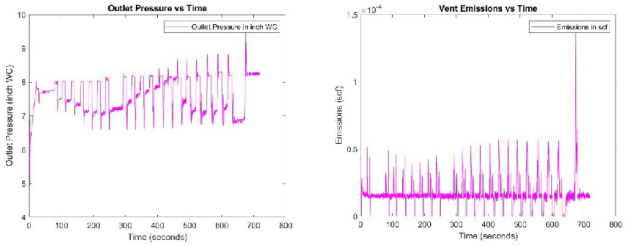


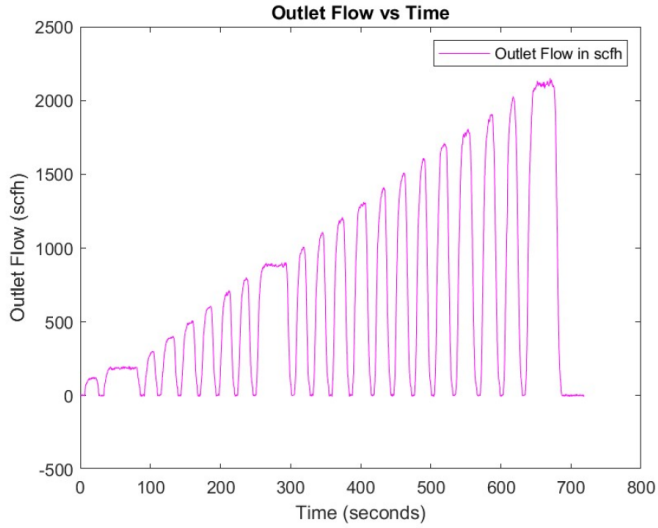
GTI ENERGY

7” WC Outlet, 3/16” Orifice, 60-psig Inlet

- 222489-19

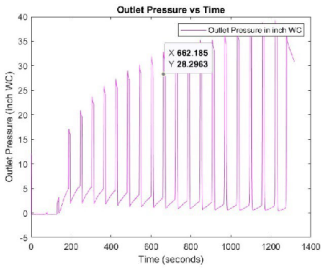
The volume of total emissions in 718.42 seconds is 0.1111 scf.
The flow rate of emissions is 0.5569 scfh.

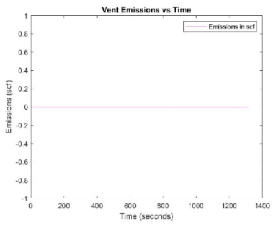


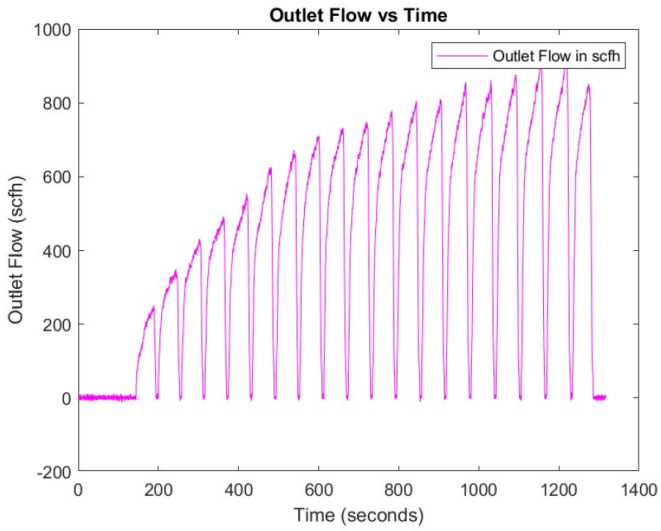


GTI ENERGY

- 222489-19_BV
  The volume of total emissions in 1317.12 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.

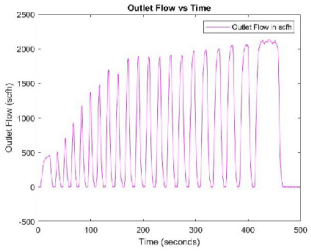


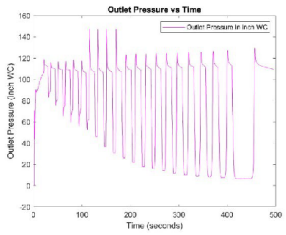


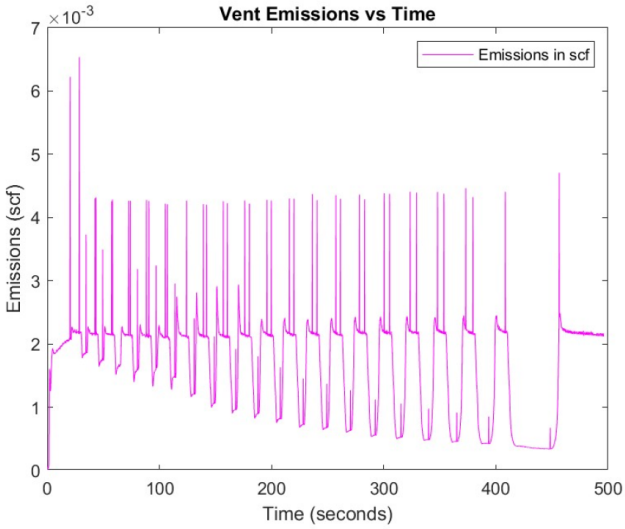


20

- 222489-19_DT
  The volume of total emissions in 496.29 seconds is 7.8046 scf.
  The flow rate of emissions is 56.6132 scfh.



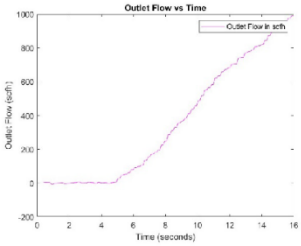


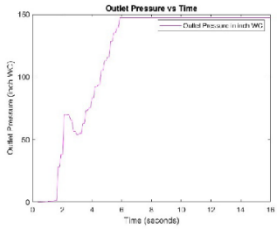


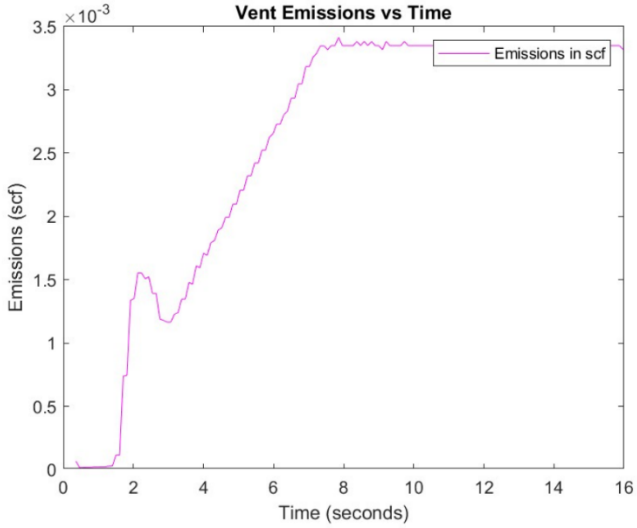
21

GTI ENERGY

- 222489-19_LD
  The volume of total emissions in 15.97 seconds is 0.3904 scf.
  The flow rate of emissions is 87.9719 scfh.

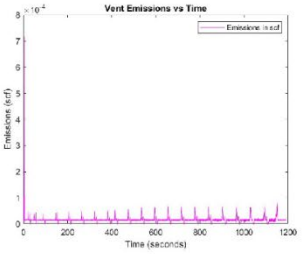


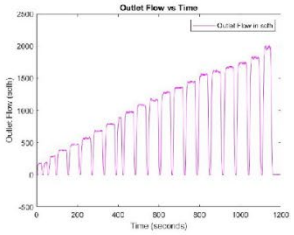


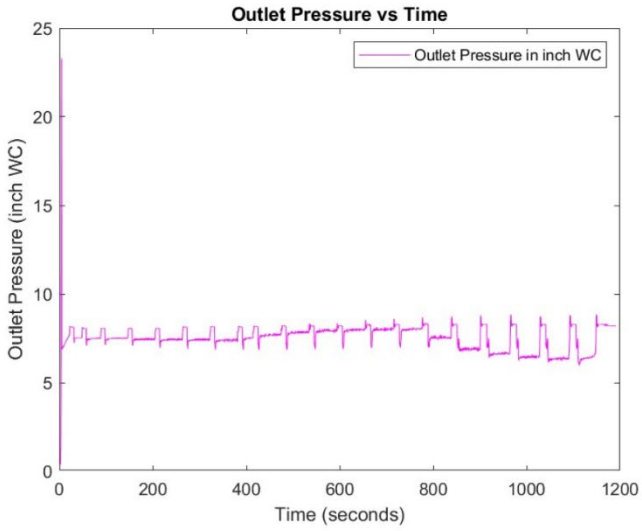


GTI ENERGY

- 222489-20
  The volume of total emissions in 1191.62 seconds is 0.1824 scf.
  The flow rate of emissions is 0.5509 scfh.



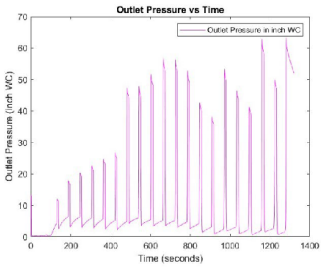


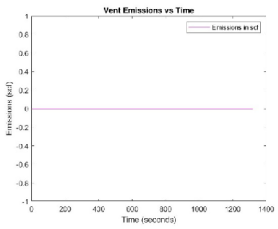


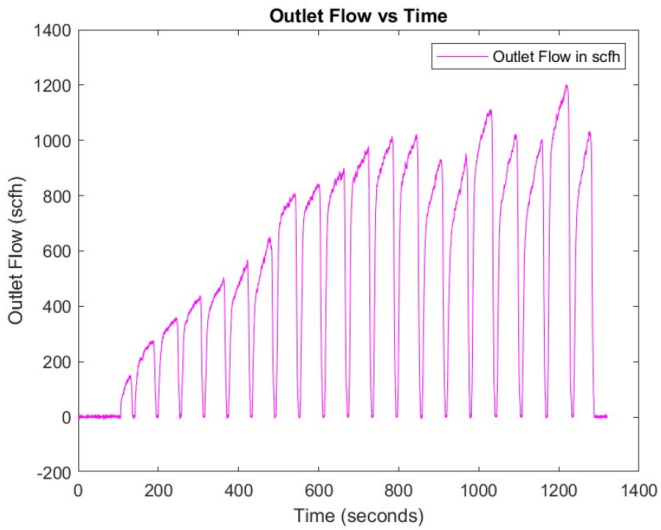
23

GTI ENERGY

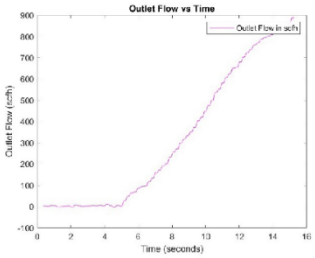
- 222489-20_BV
  The volume of total emissions in 1320.00 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.

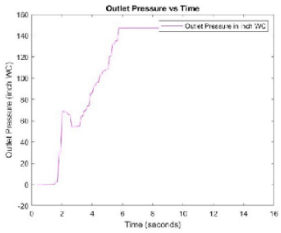


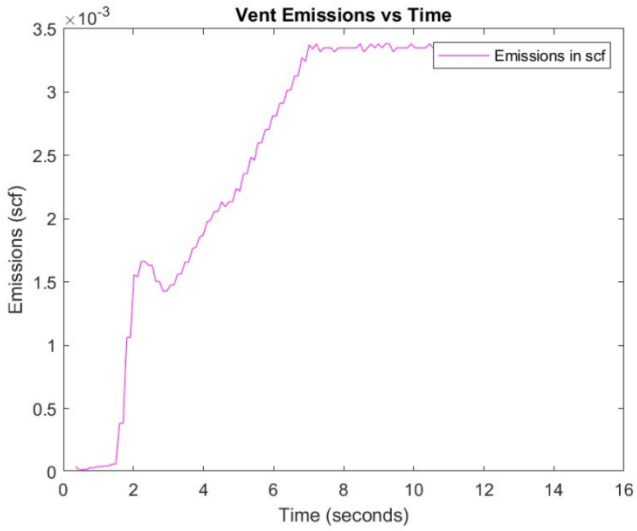




- 222489-20_DT
  The volume of total emissions in 15.24 seconds is 0.3752 scf.
  The flow rate of emissions is 88.6635 scfh.



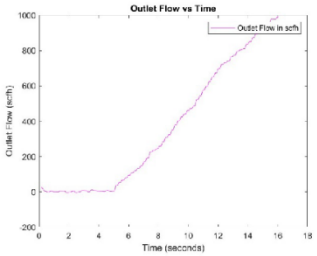


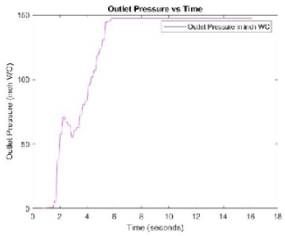


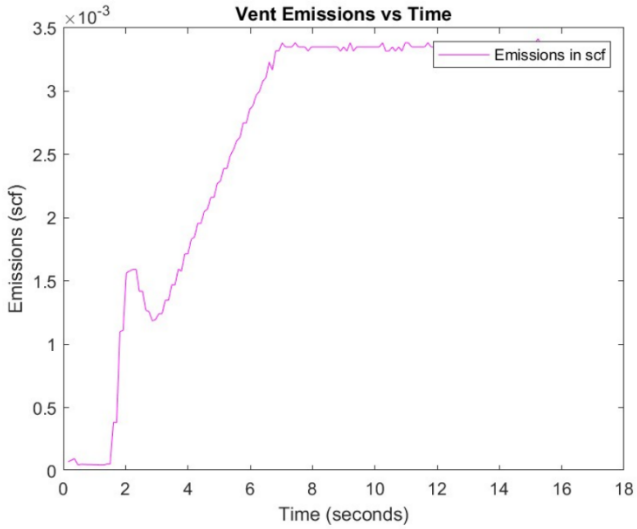
25

GTI ENERGY

- 222489-20_LD
  The volume of total emissions in 16.08 seconds is 0.3996 scf.
  The flow rate of emissions is 89.4572 scfh.

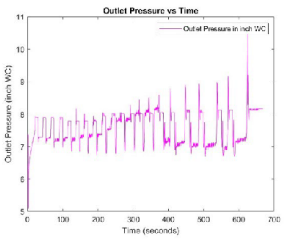


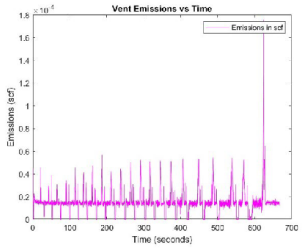


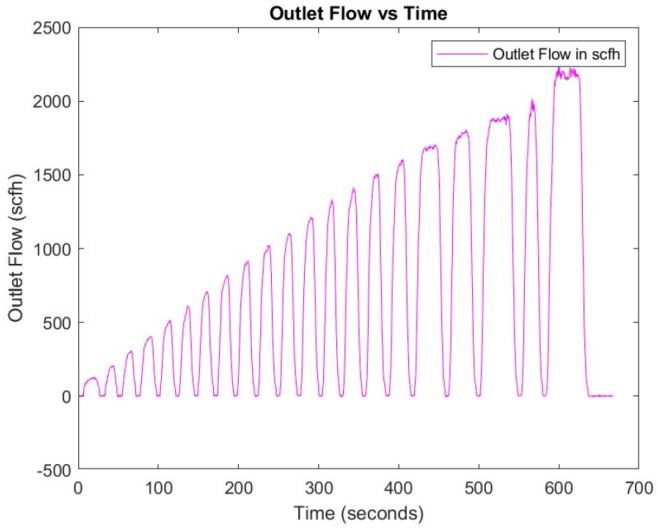


GTI ENERGY

- 222489-21
  The volume of total emissions in 667.85 seconds is 0.0983 scf.
  The flow rate of emissions is 0.5297 scfh.

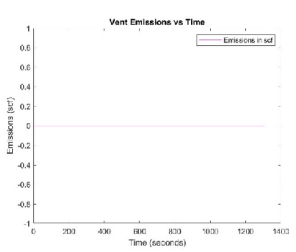


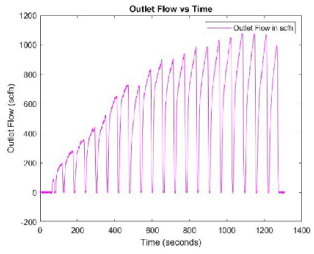


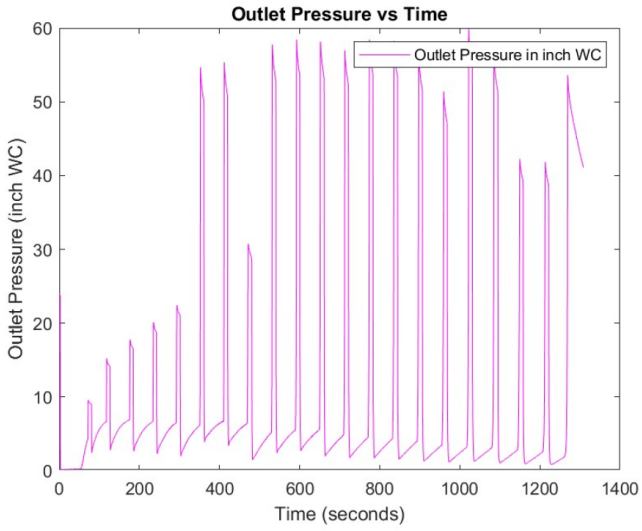


27

- 222489-21_BV
  The volume of total emissions in 1308.07 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.



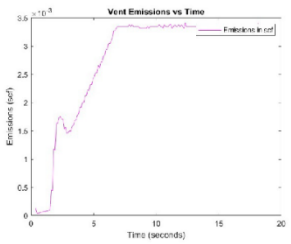


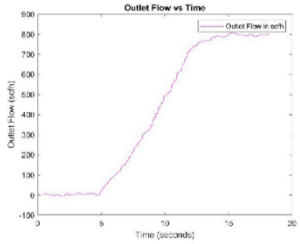


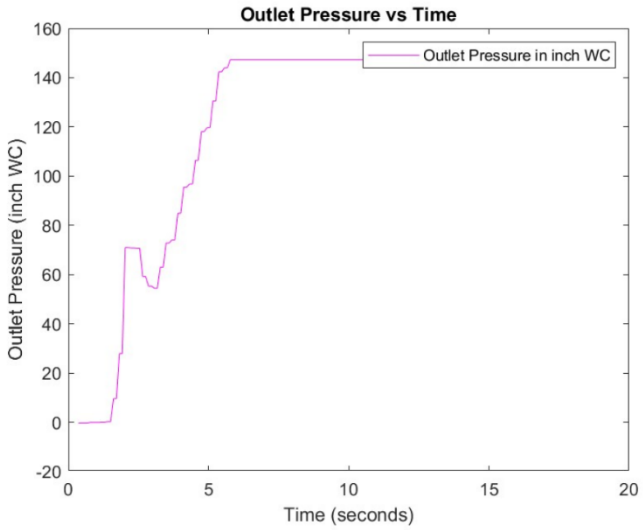
28

GTI ENERGY

- 222489-21_DT
  The volume of total emissions in 18.17 seconds is 0.4747 scf.
  The flow rate of emissions is 94.0593 scfh.



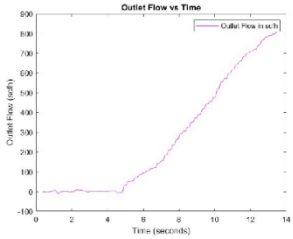


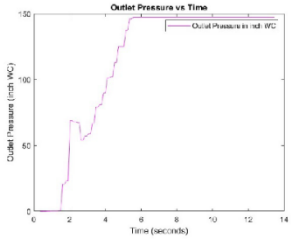


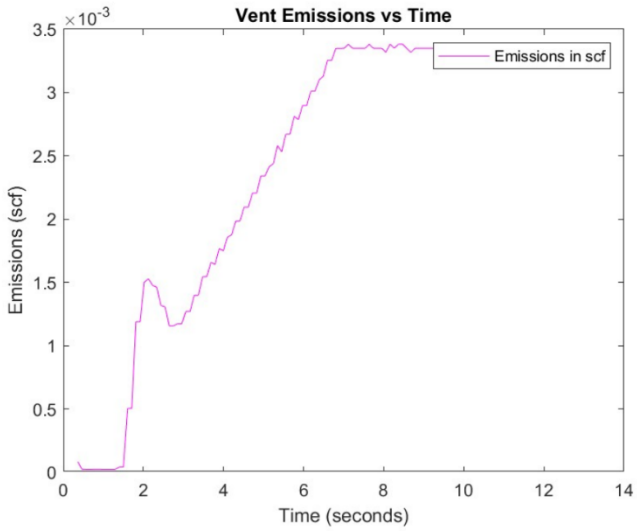
29

GTI ENERGY

- 222489-21_LD
  The volume of total emissions in 13.46 seconds is 0.3166 scf.
  The flow rate of emissions is 84.6483 scfh.







30

GTI ENERGY

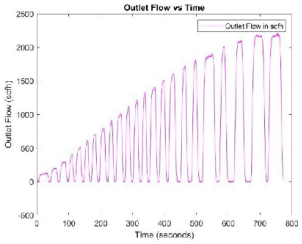
7" WC Outlet, 3/16" Orifice, 100-psig Inlet

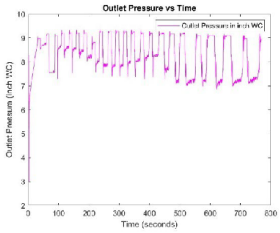
Commented [JW1]: Need to finish Fisher Emerson

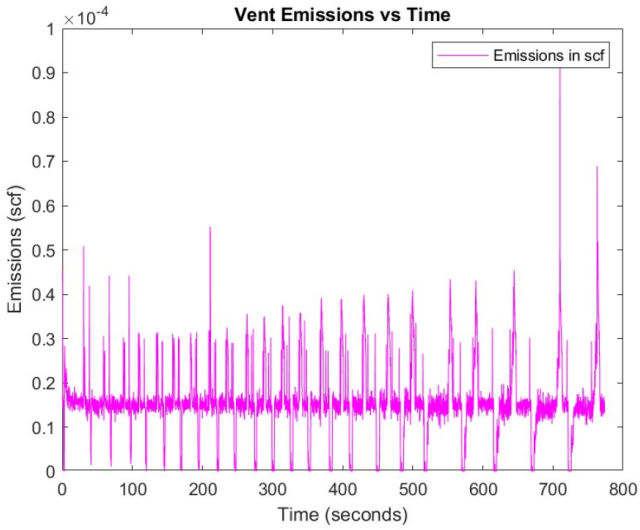
- 222489-19

  The volume of total emissions in 773.81 seconds is 0.1134 scf.

  The flow rate of emissions is 0.5275 scfh.

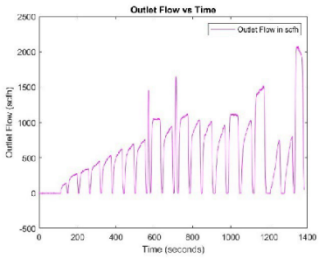


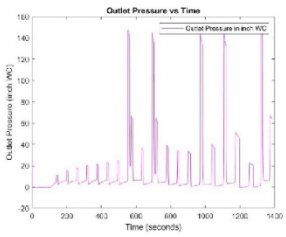


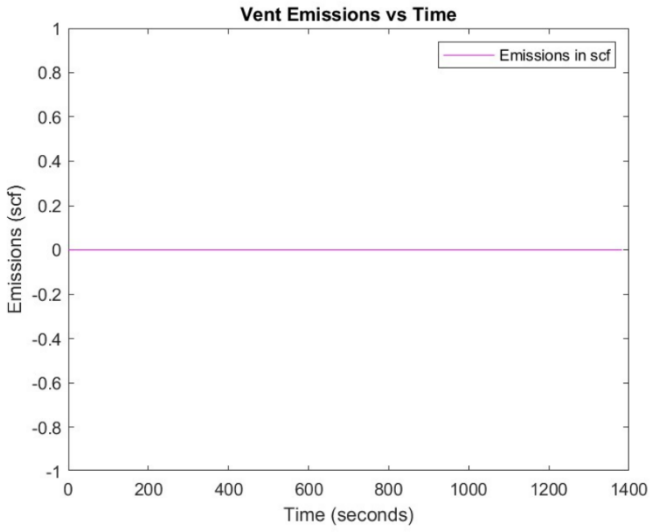


31

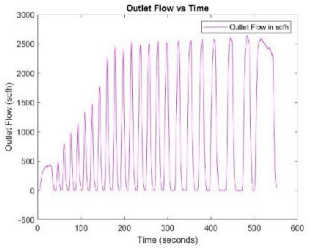
- 222489-19_BV
  The volume of total emissions in 1382.48 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.

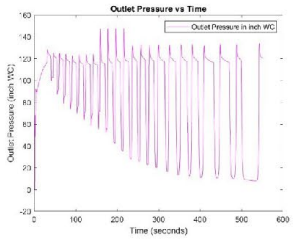


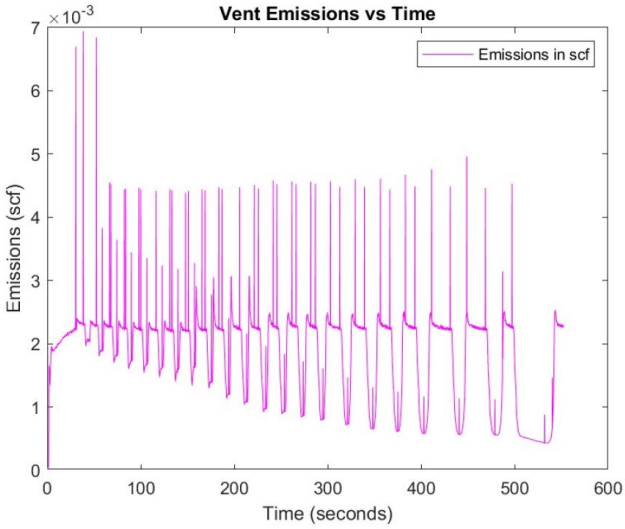




- 222489-19_DT
  The volume of total emissions in 552.39 seconds is 9.5534 scf.
  The flow rate of emissions is 62.2611 scfh.



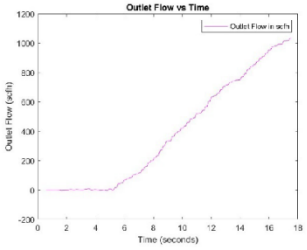


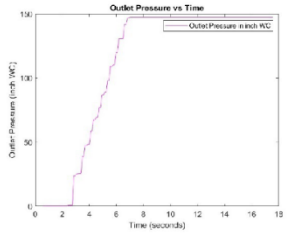


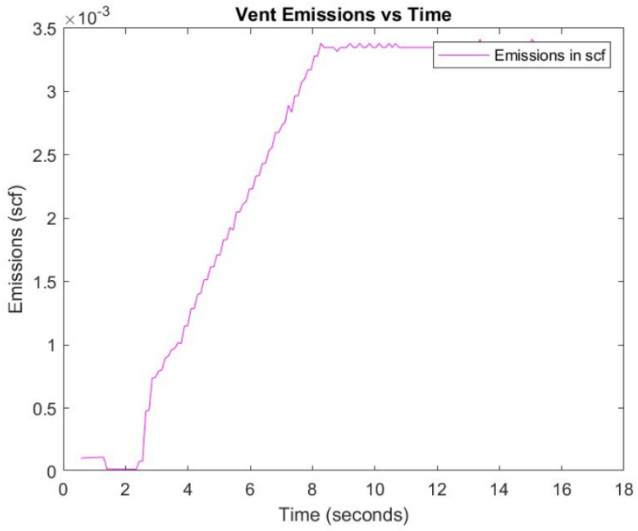
33

GTI ENERGY

- 222489-19_LD
  The volume of total emissions in 17.55 seconds is 0.4064 scf.
  The flow rate of emissions is 83.3963 scfh.



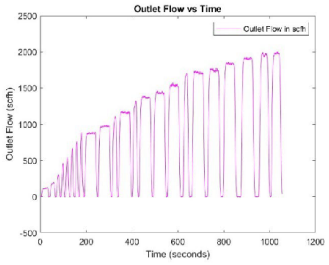


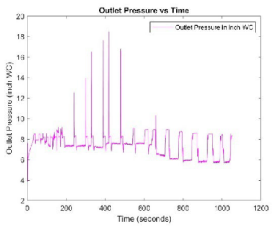


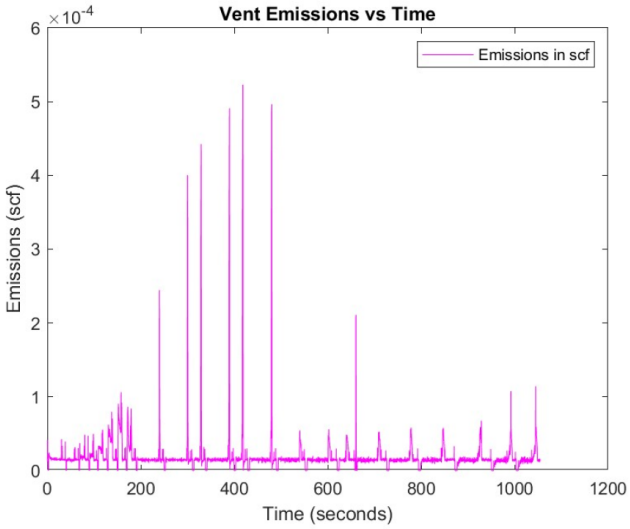
34

GTI ENERGY

- 222489-20
  The volume of total emissions in 1055.19 seconds is 0.1870 scf.
  The flow rate of emissions is 0.6380 scfh.



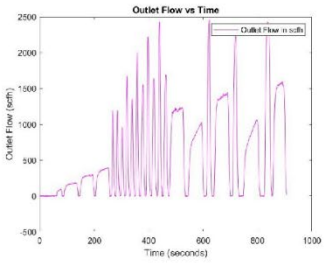


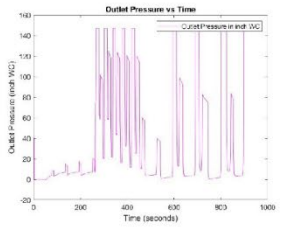


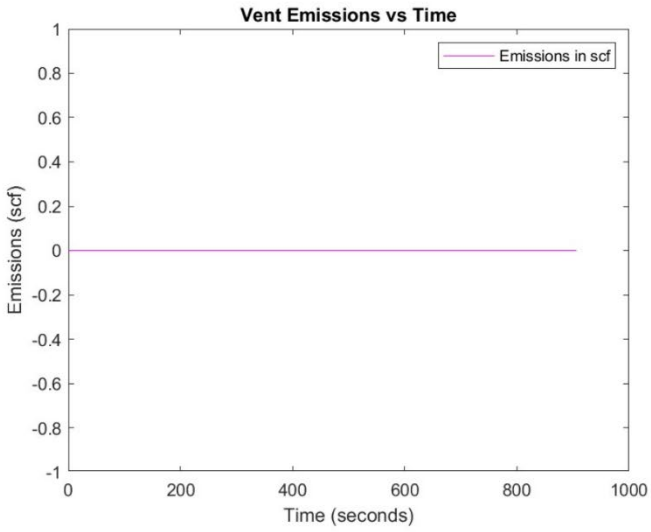
35

GTI ENERGY

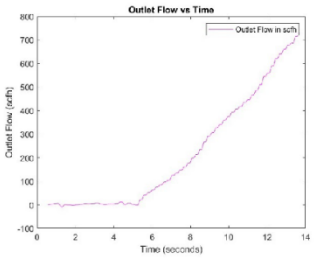
- 222489-20_BV
  The volume of total emissions in 906.22 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.

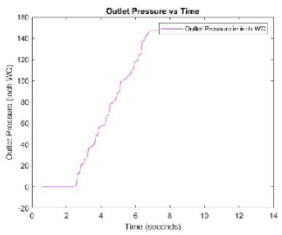


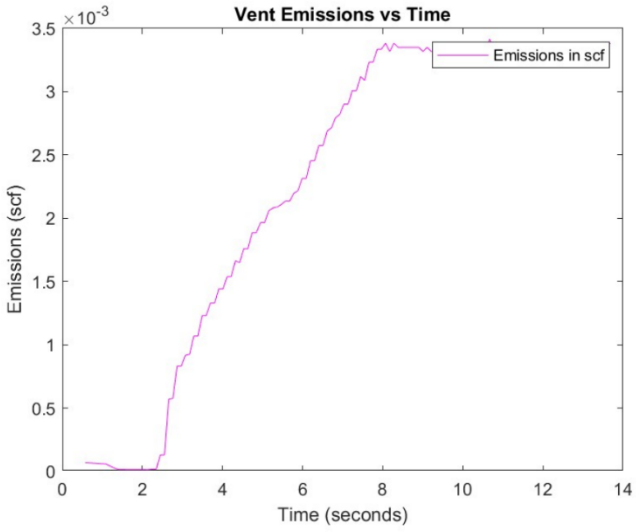




- 222489-20_DT
  The volume of total emissions in 13.68 seconds is 0.2910 scf.
  The flow rate of emissions is 76.5541 scfh.



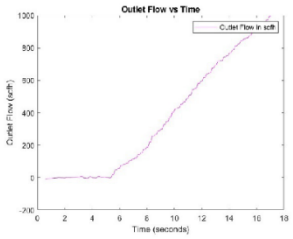


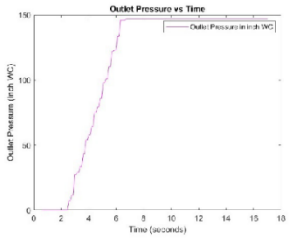


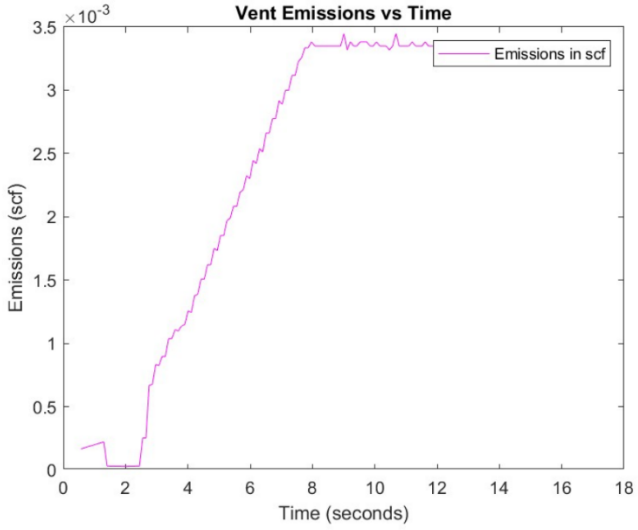
37

GTI ENERGY

- 222489-20_LD
  The volume of total emissions in 17.04 seconds is 0.3960 scf.
  The flow rate of emissions is 83.6718 scfh.

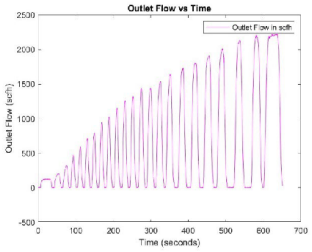


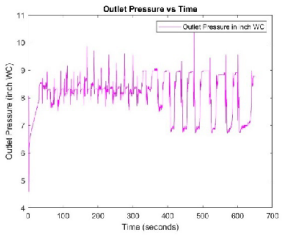


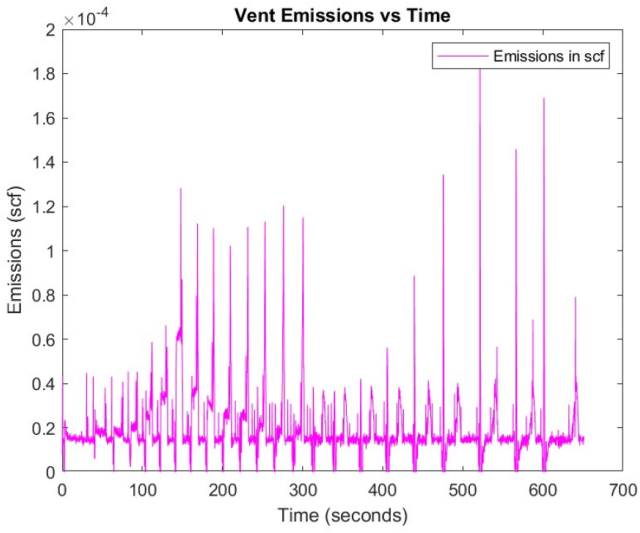


GTI ENERGY

- 222489-21
  The volume of total emissions in 651.11 seconds is 0.1183 scf.
  The flow rate of emissions is 0.6540 scfh.



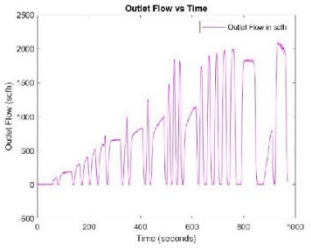


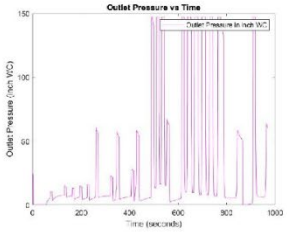


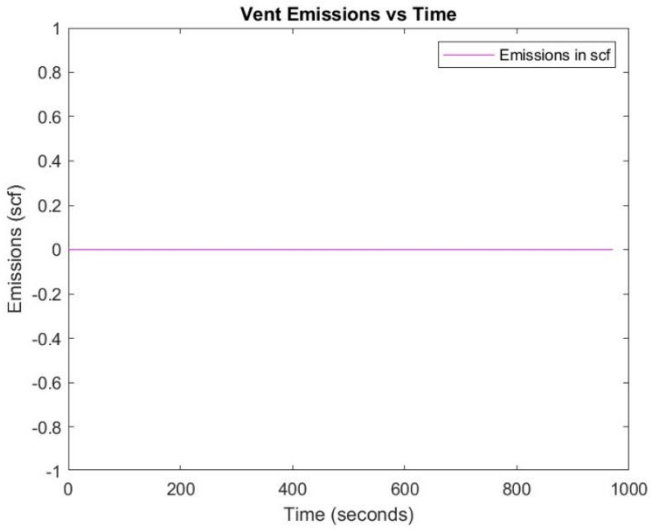
39

GTI ENERGY

- 222489-21_BV
  The volume of total emissions in 971.32 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.

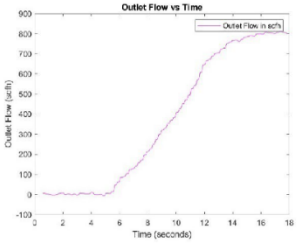


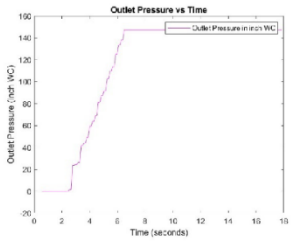


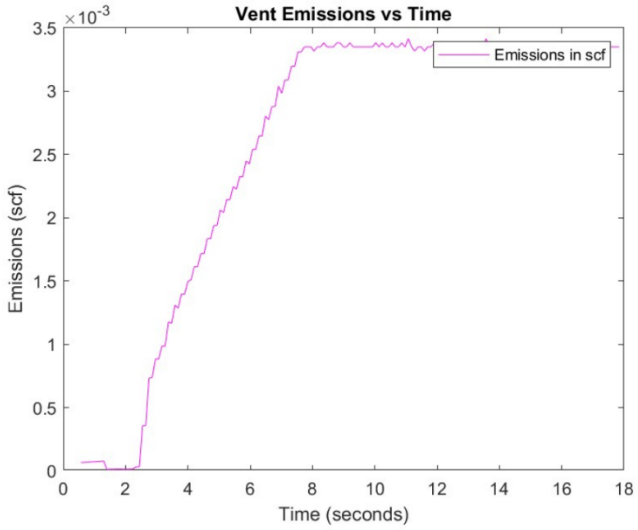


40

- 222489-21_DT
  The volume of total emissions in 17.84 seconds is 0.4293 scf.
  The flow rate of emissions is 86.6150 scfh.



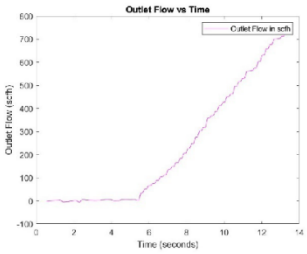


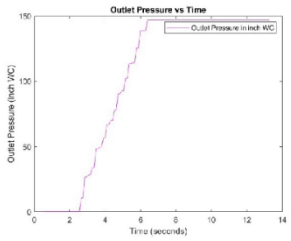


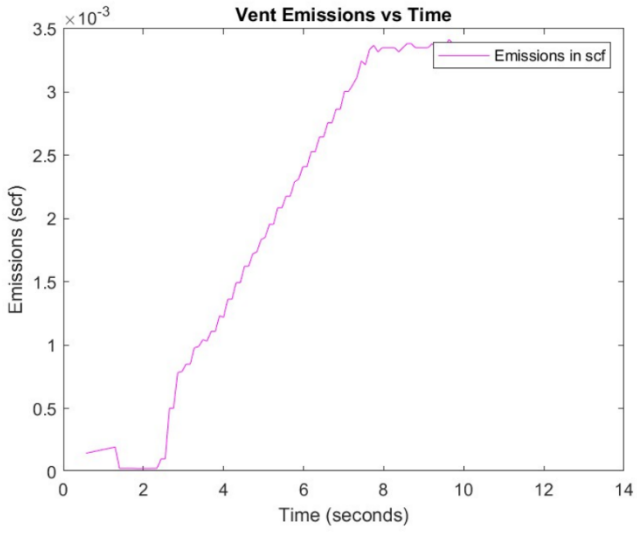
41

GTI ENERGY

- 222489-21_LD
  The volume of total emissions in 13.27 seconds is 0.2765 scf.
  The flow rate of emissions is 74.9952 scfh.





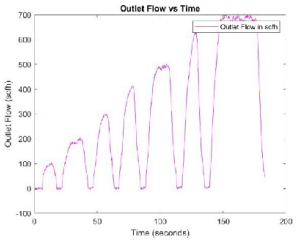


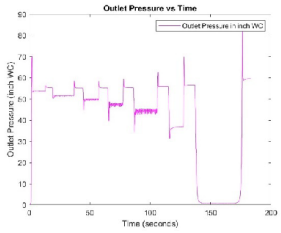
42

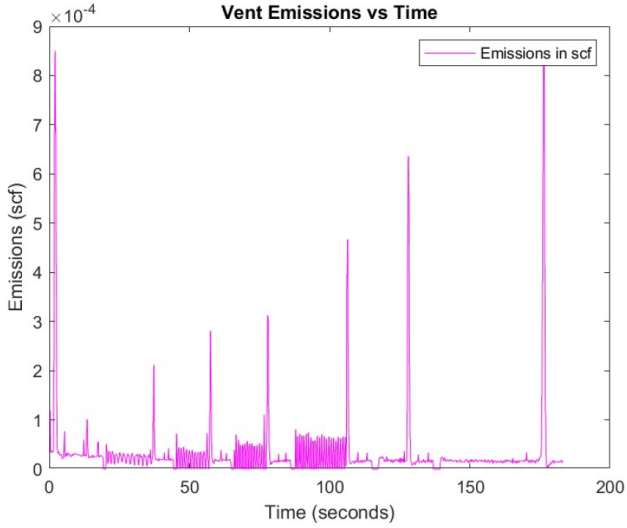
GTI ENERGY

2-psig Outlet, 3/16" Orifice, 10-psig Inlet

- 222489-22
  The volume of total emissions in 183.25 seconds is 0.0563 scf.
  The flow rate of emissions is 1.1059 scfh.



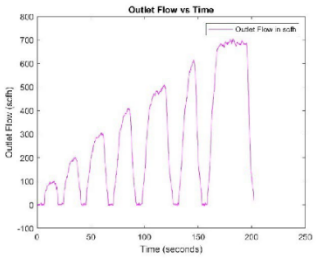


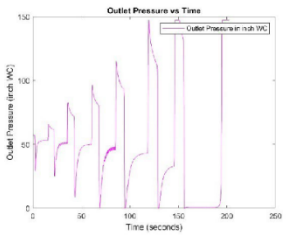


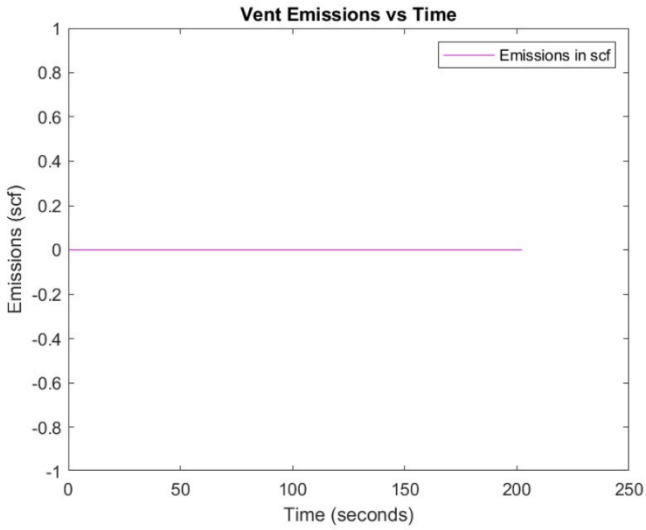
43

GTI ENERGY

- 222489-22_BV
  The volume of total emissions in 202.27 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.



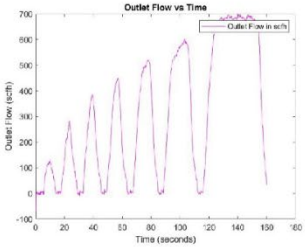


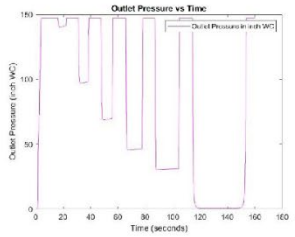


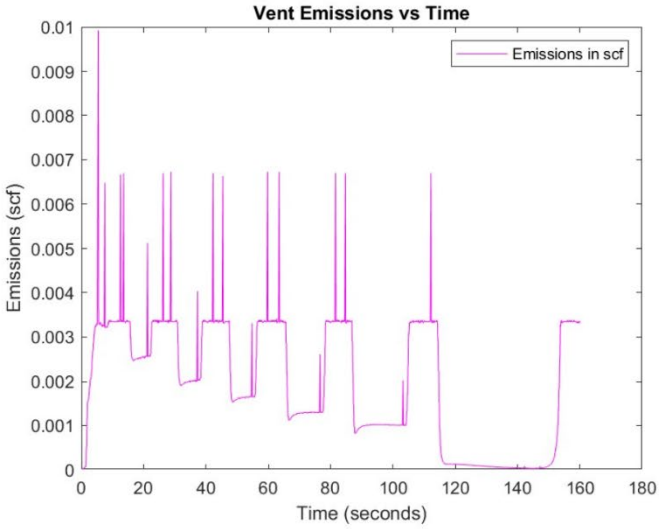
44

GTI ENERGY

- 222489-22_DT
  The volume of total emissions in 160.11 seconds is 2.9391 scf.
  The flow rate of emissions is 66.0863 scfh.



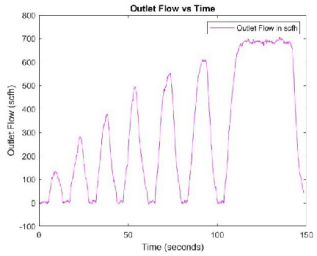


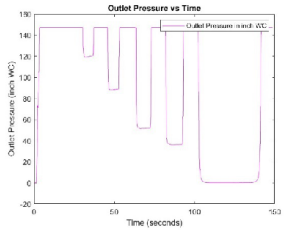


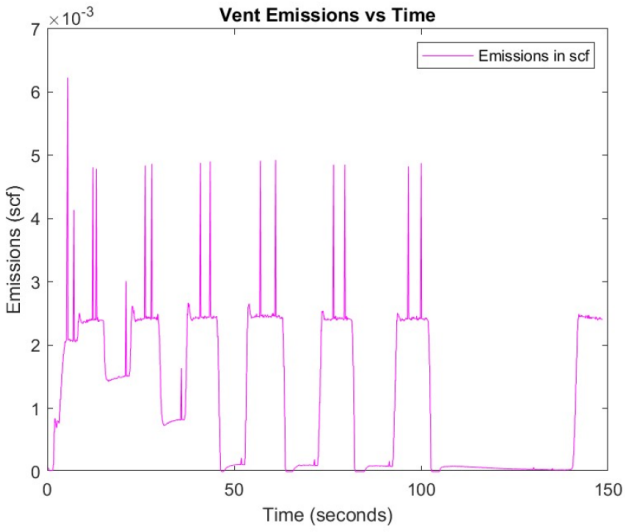
45

GTI ENERGY

- 222489-22_LD
  The volume of total emissions in 148.54 seconds is 1.6823 scf.
  The flow rate of emissions is 40.7735 scfh.



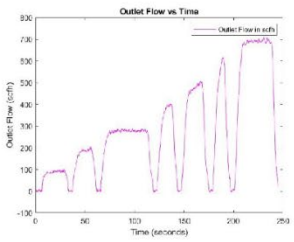


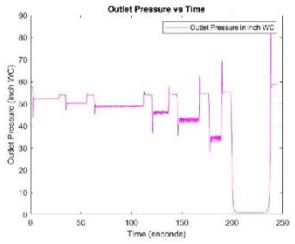


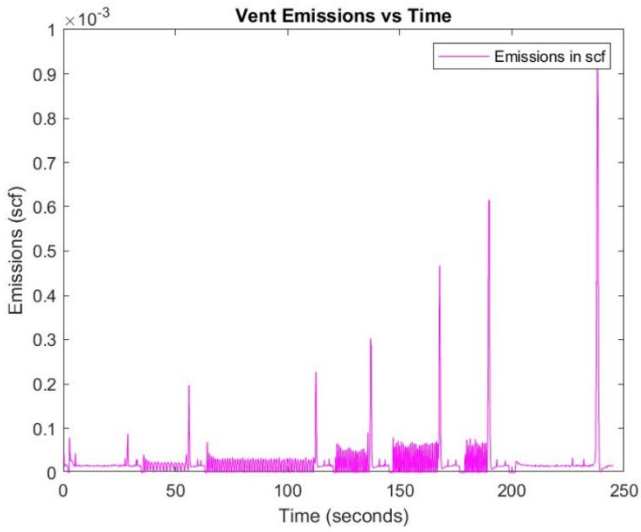
46

GTI ENERGY

- 222489-23
  The volume of total emissions in 245.09 seconds is 0.0573 scf.
  The flow rate of emissions is 0.8421 scfh.



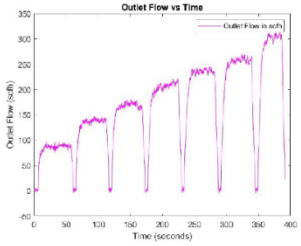


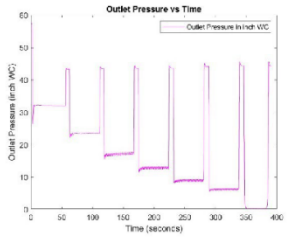


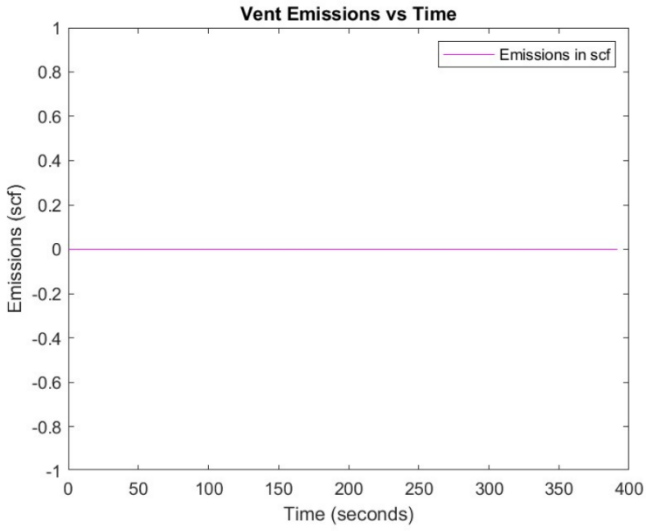
47

GTI ENERGY

- 222489-23_BV
  The volume of total emissions in 391.66 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.

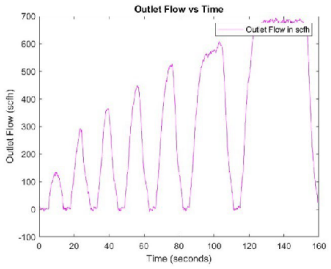


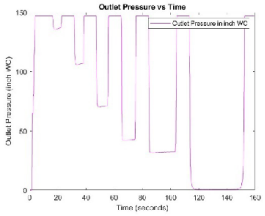


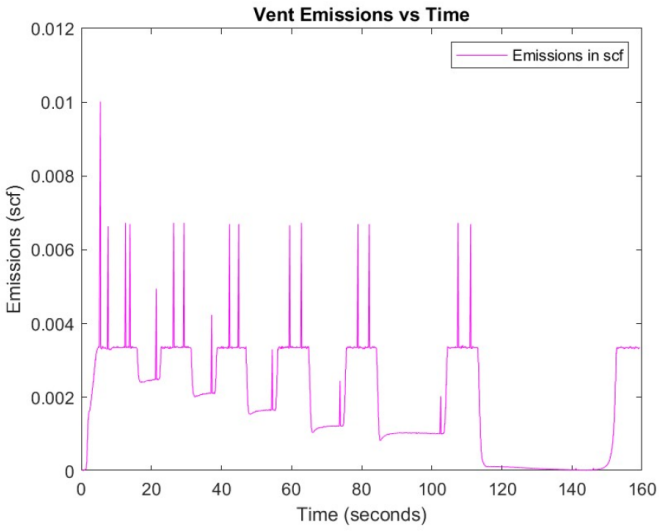


48

- 222489-23_DT
  The volume of total emissions in 159.35 seconds is 2.9184 scf.
  The flow rate of emissions is 65.9317 scfh.

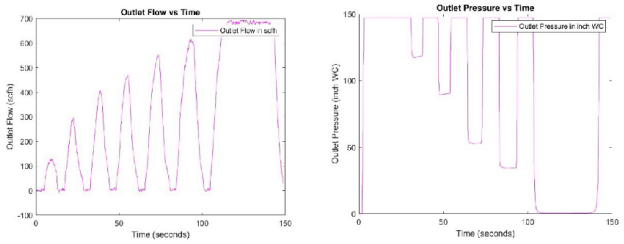


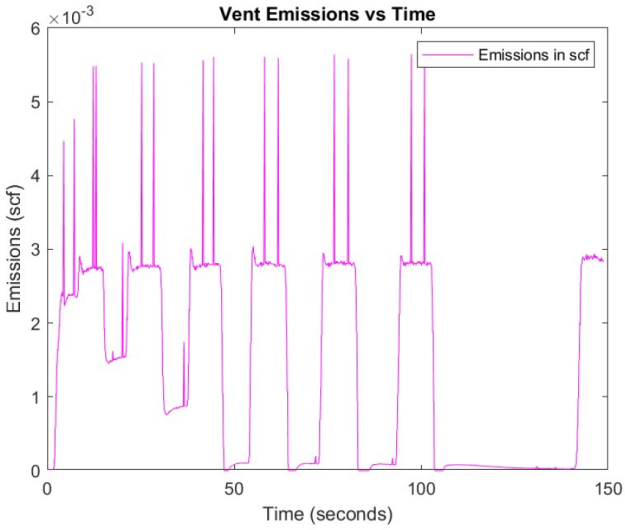




49

- 222489-23_LD
  The volume of total emissions in 148.79 seconds is 1.9387 scf.
  The flow rate of emissions is 46.9061 scfh.

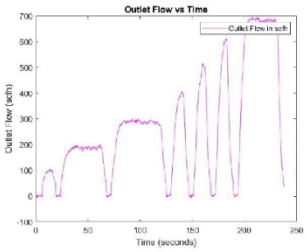


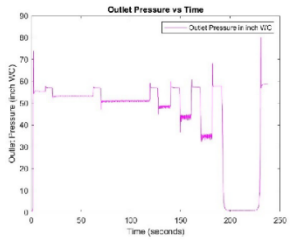


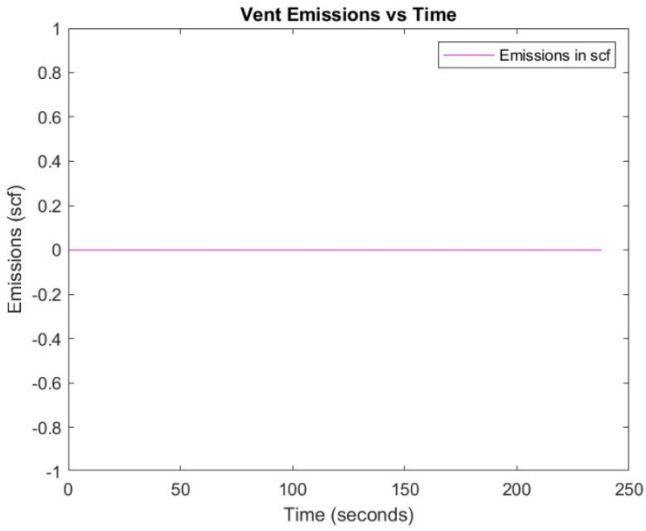
50

GTI ENERGY

- 222489-24
  The volume of total emissions in 237.76 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.

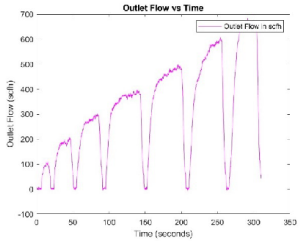


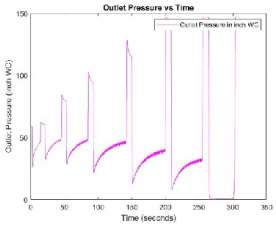


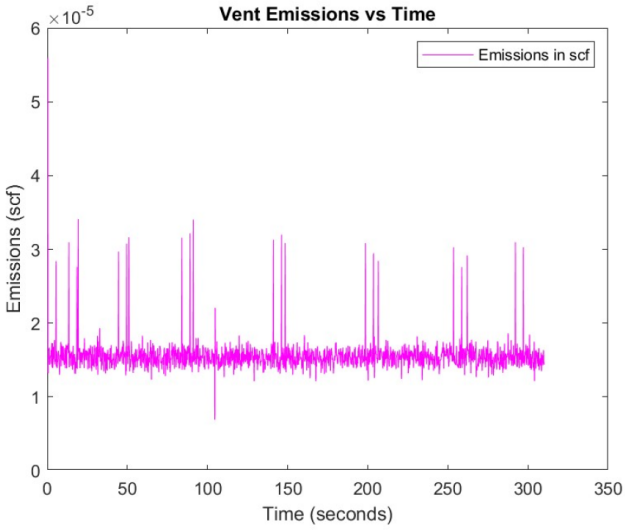


51

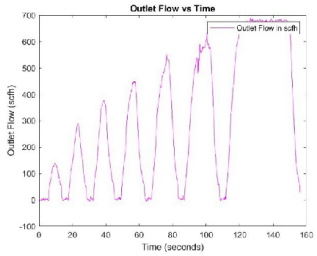
- 222489-24_BV
  The volume of total emissions in 310.19 seconds is 0.0458 scf.
  The flow rate of emissions is 0.5311 scfh.

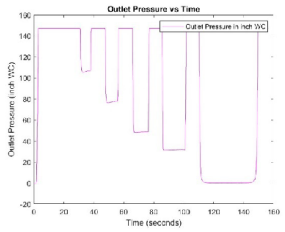


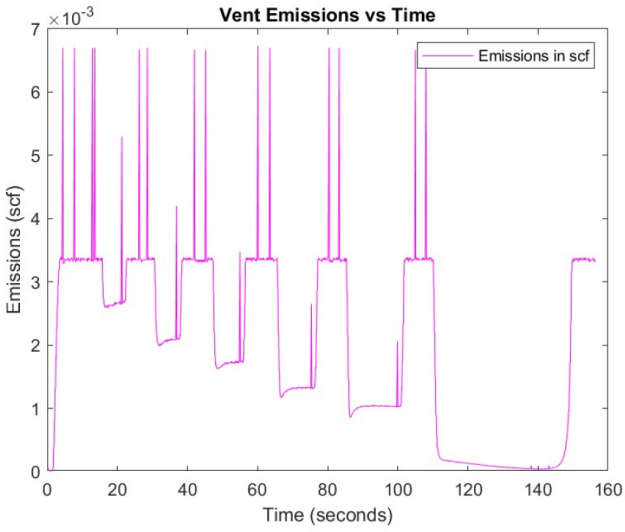




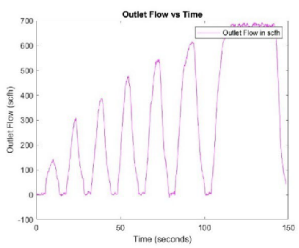
- 222489-24_DT
  The volume of total emissions in 156.32 seconds is 2.9197 scf.
  The flow rate of emissions is 67.2371 scfh.

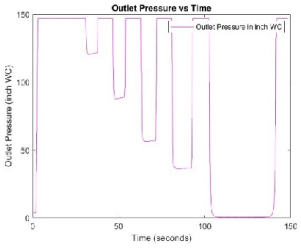


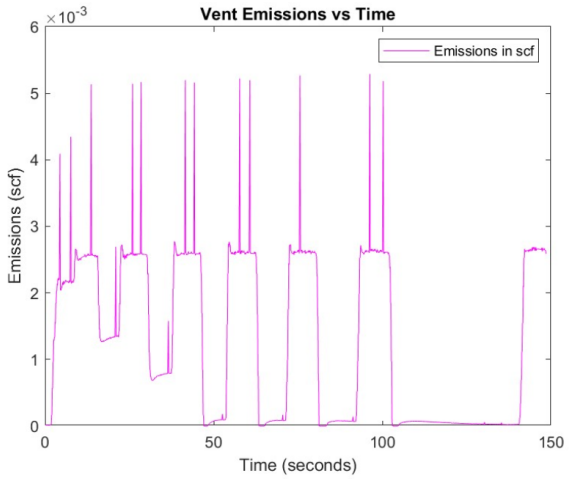




- 222489-24_LD
  The volume of total emissions in 148.54 seconds is 1.7738 scf.
  The flow rate of emissions is 42.9895 scfh.



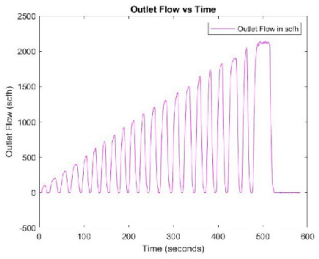


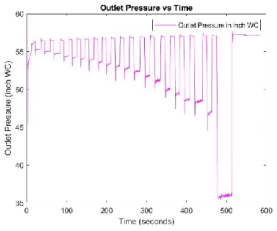


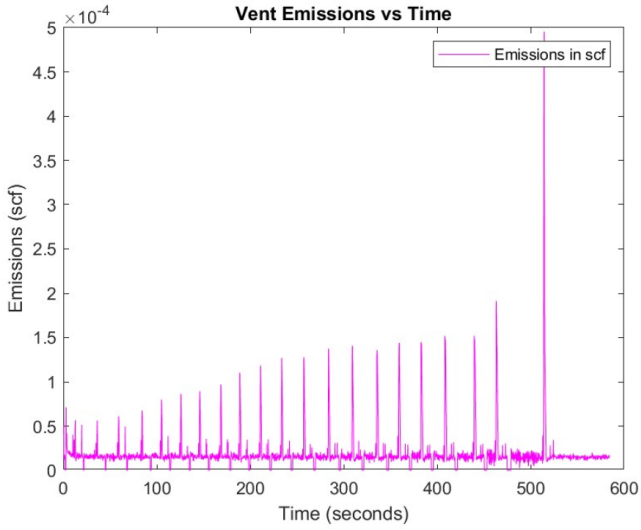
54

2-psig Outlet, 3/16" Orifice, 60-psig Inlet

- 222489-22
  The volume of total emissions in 584.21 seconds is 0.1043 scf.
  The flow rate of emissions is 0.6424 scfh.

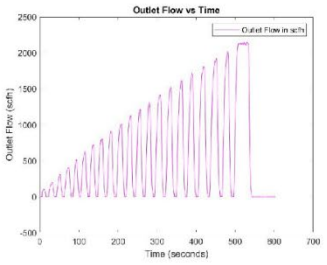


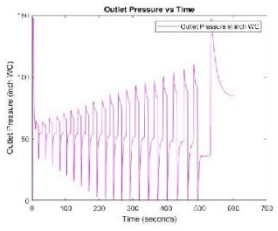


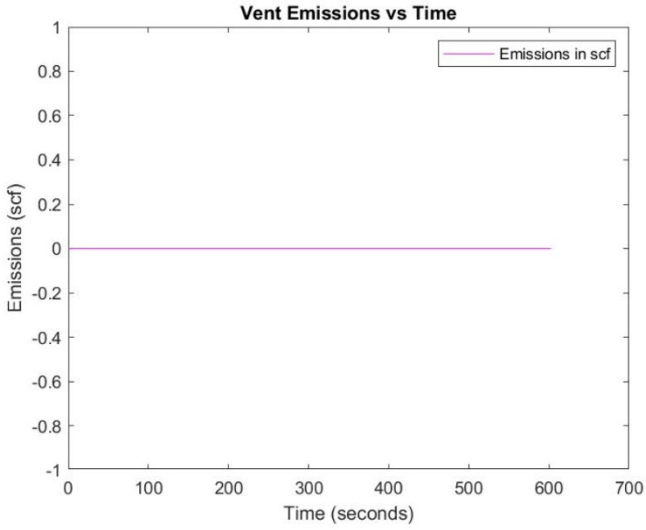


55

- 222489-22_BV
  The volume of total emissions in 602.60 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.

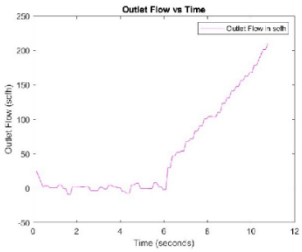


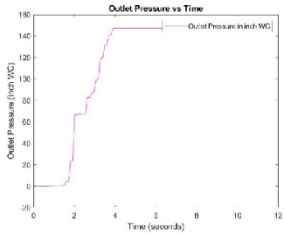


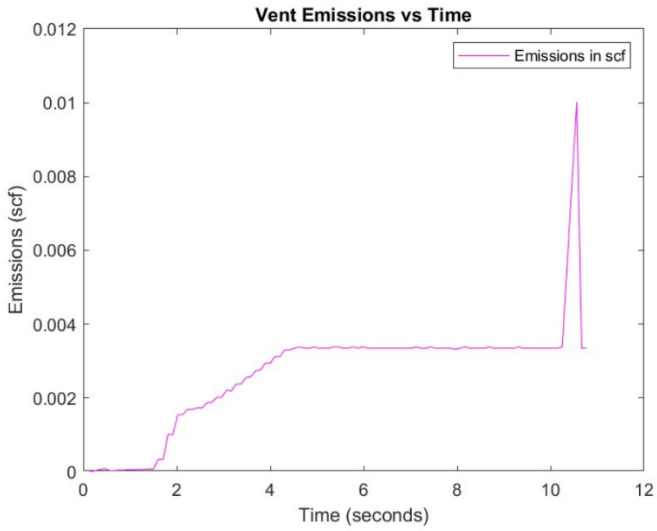


56

- 222489-22_DT
  The volume of total emissions in 10.77 seconds is 0.2643 scf.
  The flow rate of emissions is 88.3526 scfh.



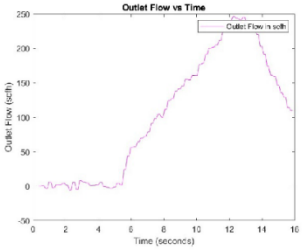


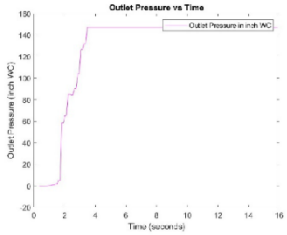


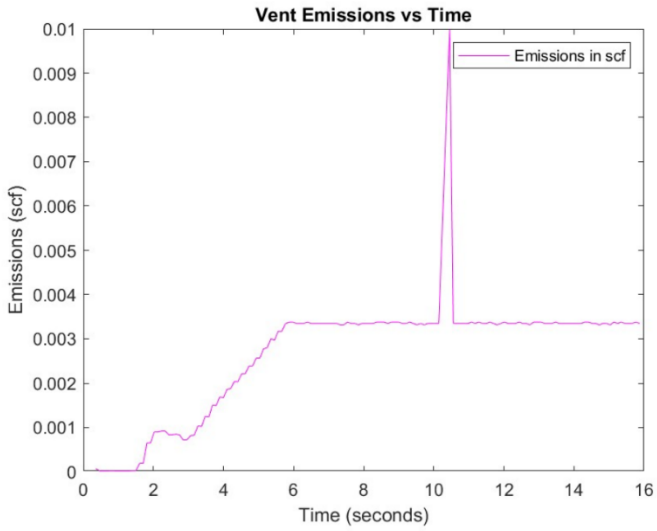
57

GTI ENERGY

- 222489-22_LD
  The volume of total emissions in 15.87 seconds is 0.3918 scf.
  The flow rate of emissions is 88.8687 scfh.



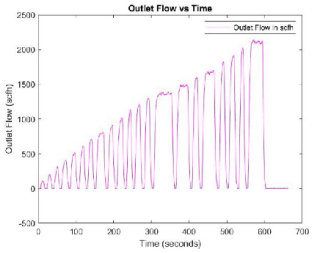


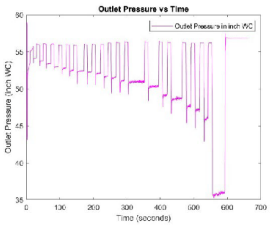


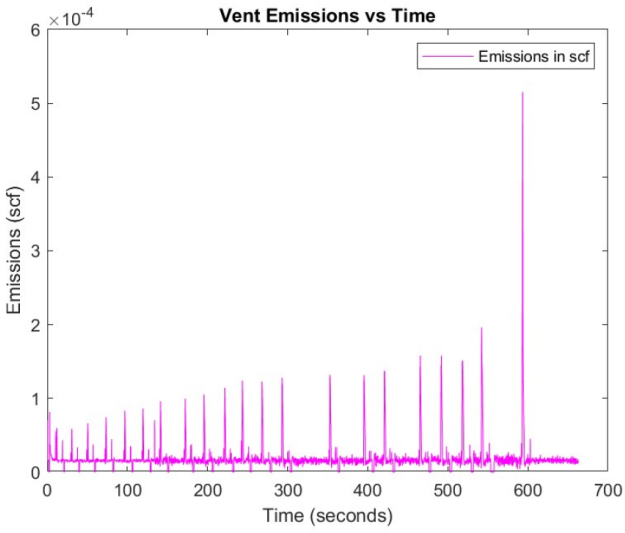
58

GTI ENERGY

- 222489-23
  The volume of total emissions in 662.82 seconds is 0.1188 scf.
  The flow rate of emissions is 0.6451 scfh.

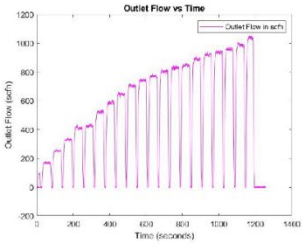


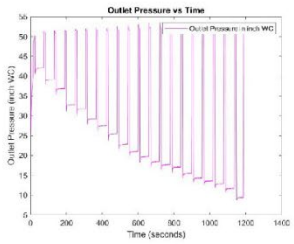


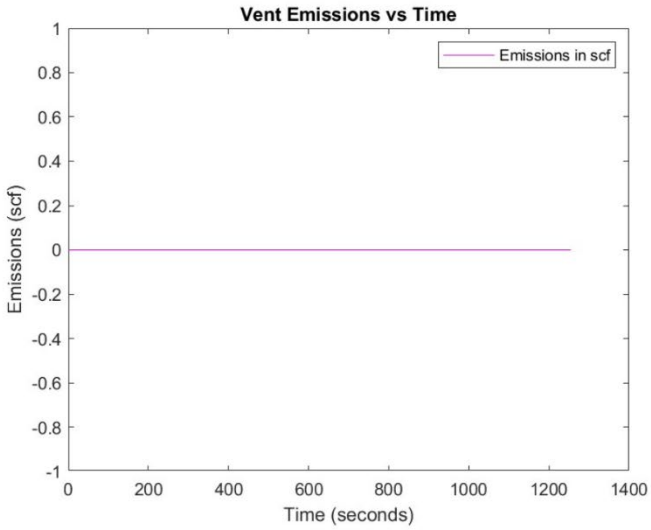


59

- 222489-23_BV
  The volume of total emissions in 1254.74 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.



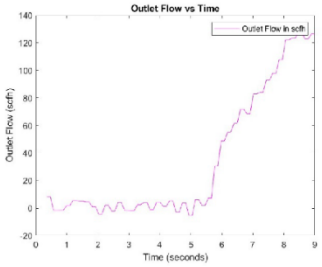


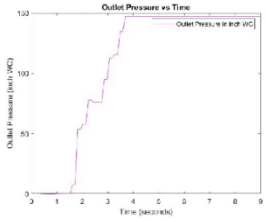


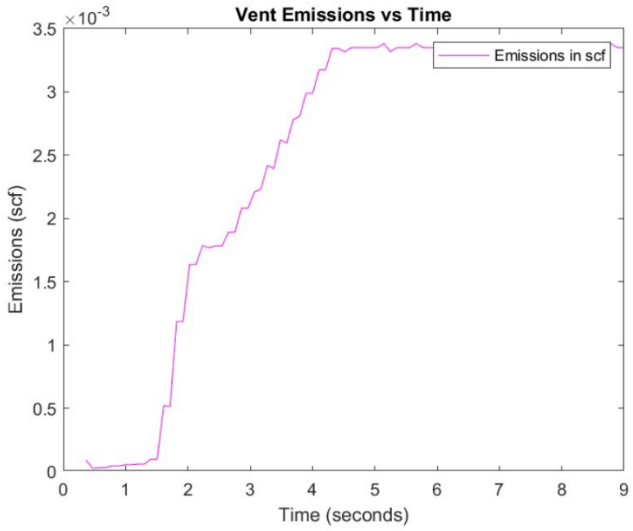
60

GTI ENERGY

- 222489-23_DT
  The volume of total emissions in 8.99 seconds is 0.2088 scf.
  The flow rate of emissions is 83.6036 scfh.



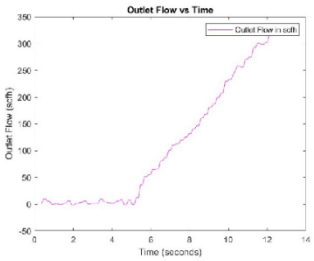


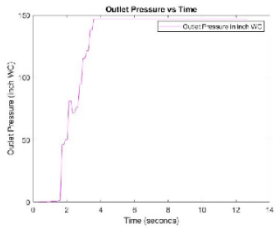


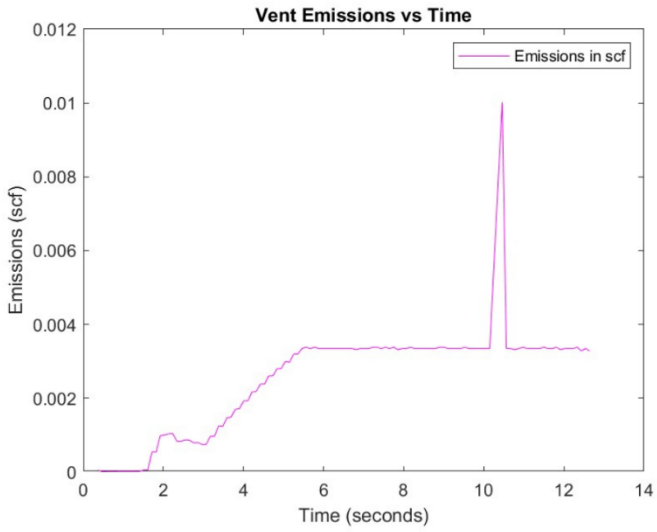
61

GTI ENERGY

- 222489-23_LD
  The volume of total emissions in 12.64 seconds is 0.2936 scf.
  The flow rate of emissions is 83.6184 scfh.



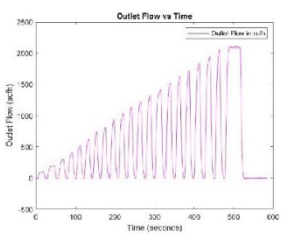


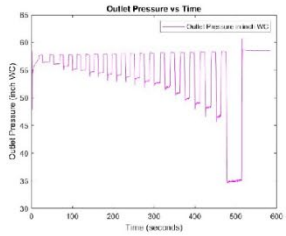


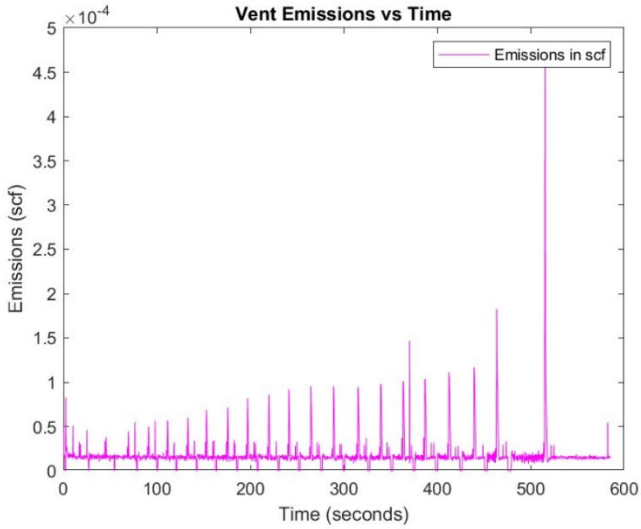
62

GTI ENERGY

- 222489-24
  The volume of total emissions in 585.17 seconds is 0.0972 scf.
  The flow rate of emissions is 0.5979 scfh.



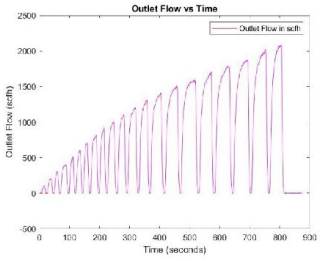


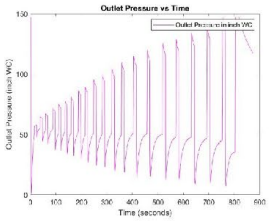


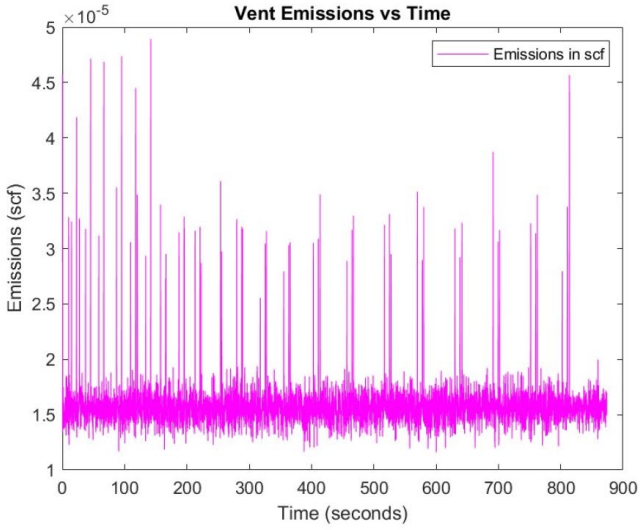
63

GTI ENERGY

- 222489-24_BV
  The volume of total emissions in 873.79 seconds is 0.1309 scf.
  The flow rate of emissions is 0.5393 scfh.

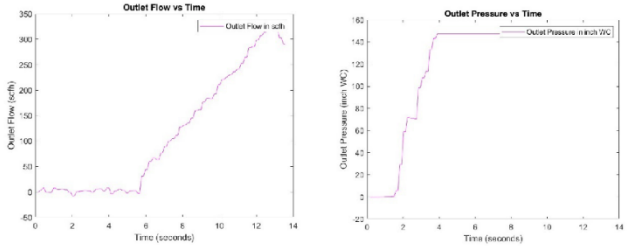


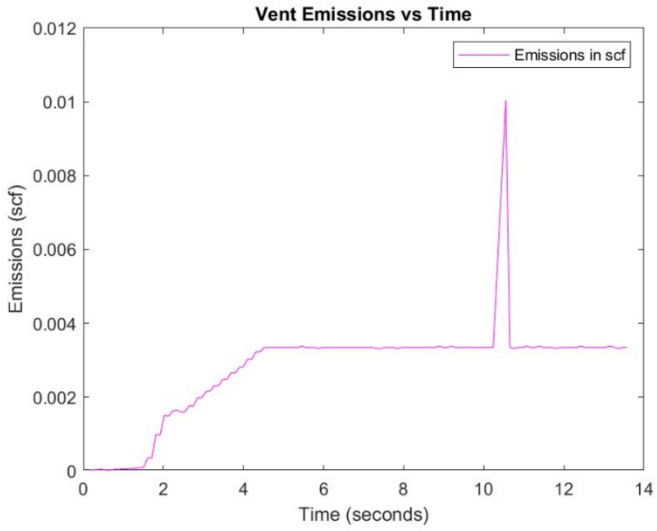




64

- 222489-24_DT
  The volume of total emissions in 13.56 seconds is 0.3525 scf.
  The flow rate of emissions is 93.5409 scfh.

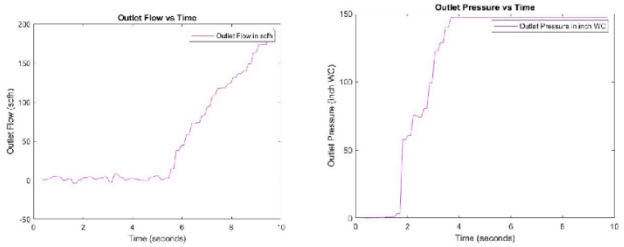


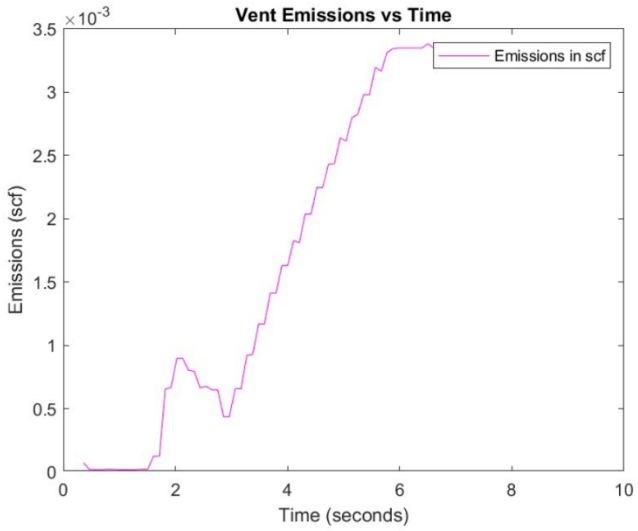


65

GTI ENERGY

- 222489-24_LD
  The volume of total emissions in 9.73 seconds is 0.1914 scf.
  The flow rate of emissions is 70.8180 scfh.





66

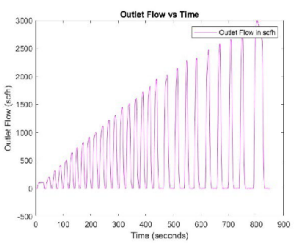
GTI ENERGY

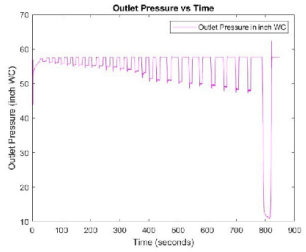
2-psig Outlet, 3/16" Orifice, 100-psig Inlet

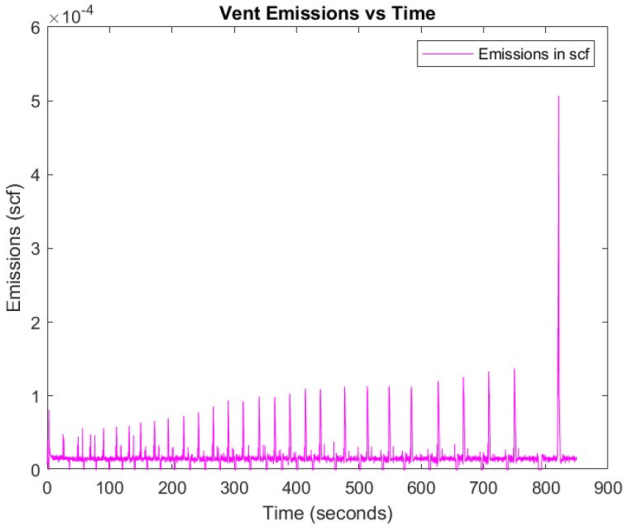
- 222489-22

  The volume of total emissions in 849.41 seconds is 0.1460 scf.

  The flow rate of emissions is 0.6189 scfh.



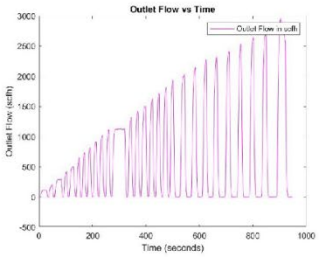


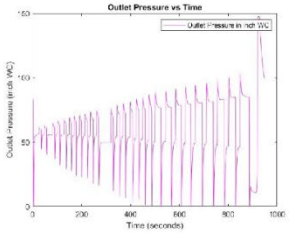


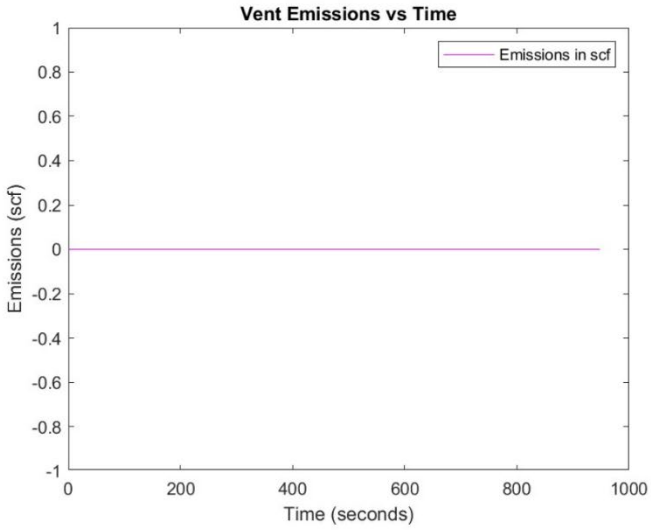
67

GTI ENERGY

- 222489-22_BV
  The volume of total emissions in 947.95 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.

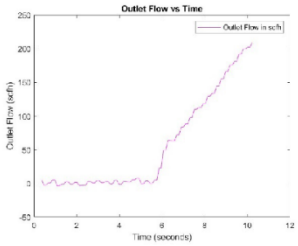


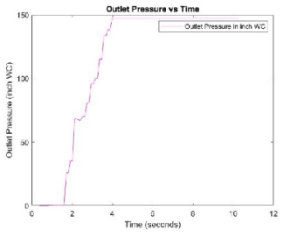


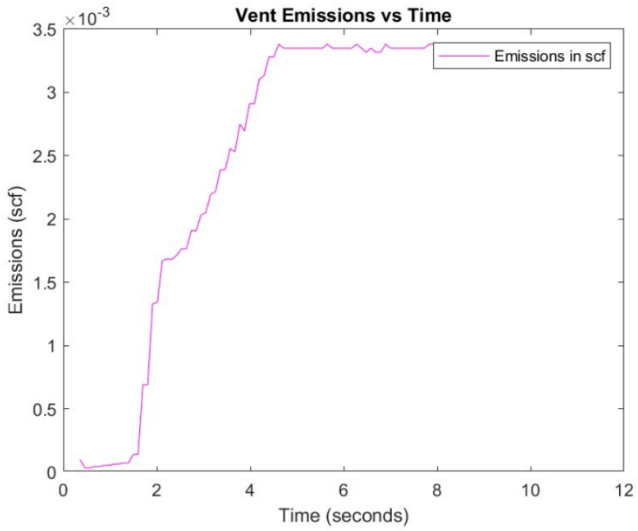


68

- 222489-22_DT
  The volume of total emissions in 10.23 seconds is 0.2460 scf.
  The flow rate of emissions is 86.5266 scfh.



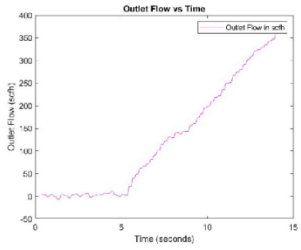


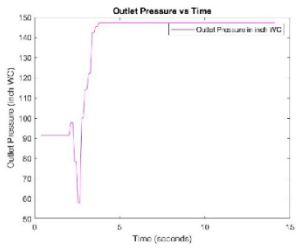


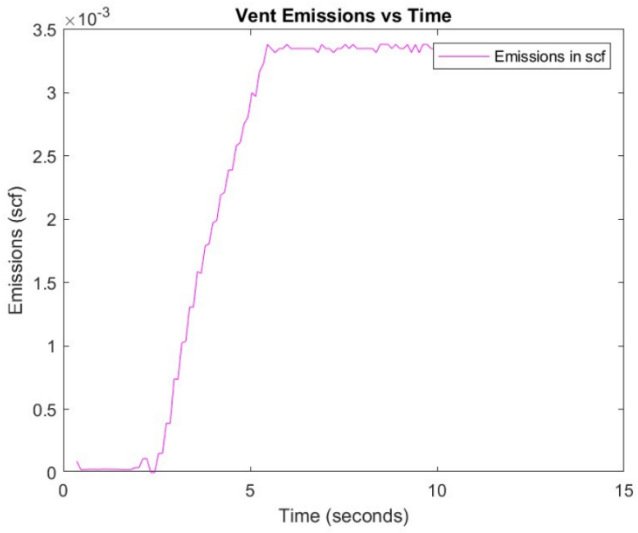
69

GTI ENERGY

- 222489-22_LD
  The volume of total emissions in 14.10 seconds is 0.3328 scf.
  The flow rate of emissions is 84.9387 scfh.



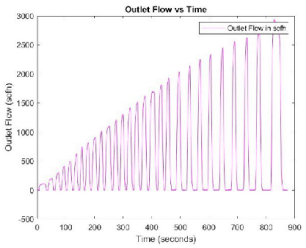


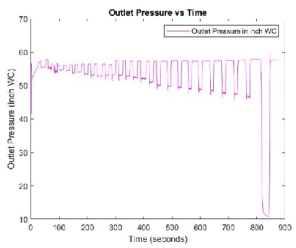


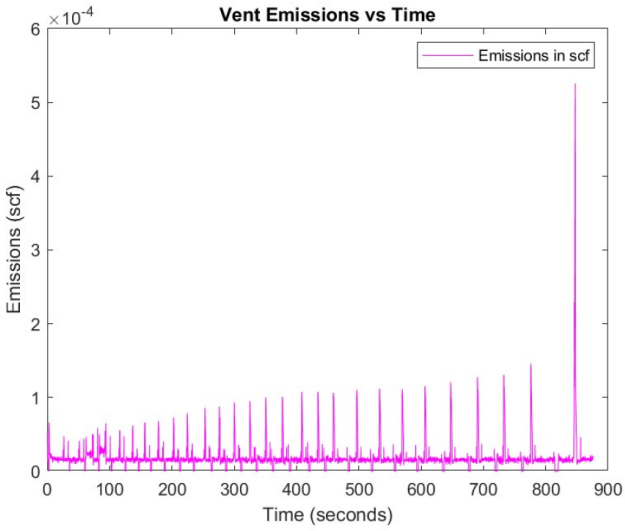
70

GTI ENERGY

- 222489-23
  The volume of total emissions in 875.92 seconds is 0.1573 scf.
  The flow rate of emissions is 0.6467 scfh.



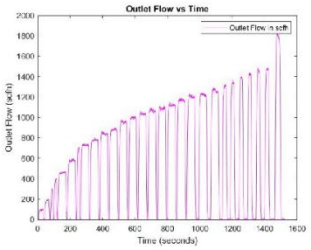


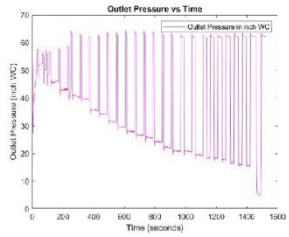


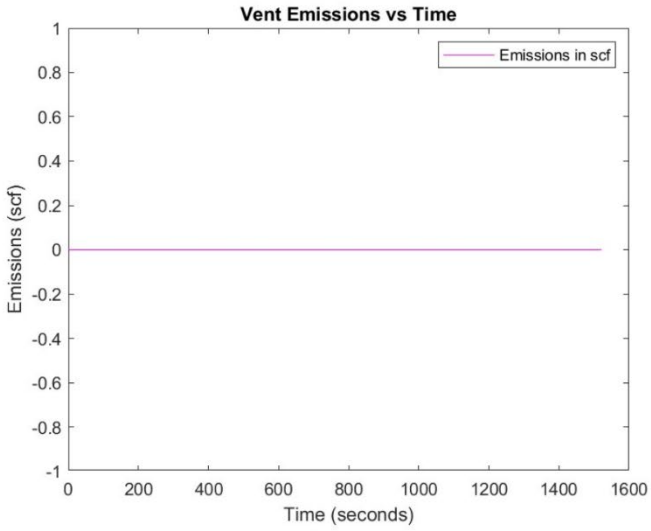
71

GTI ENERGY

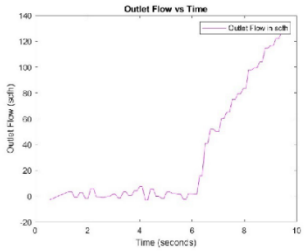
- 222489-23_BV
  The volume of total emissions in 1521.24 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.

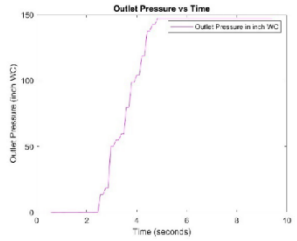


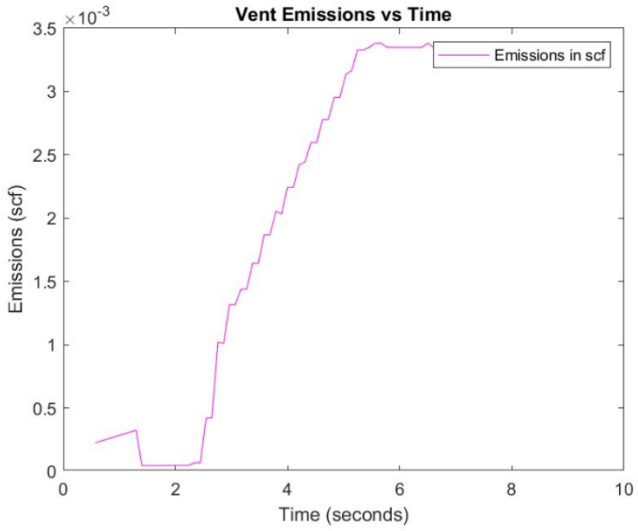




- 222489-23_DT
  The volume of total emissions in 9.42 seconds is 0.1905 scf.
  The flow rate of emissions is 72.8267 scfh.

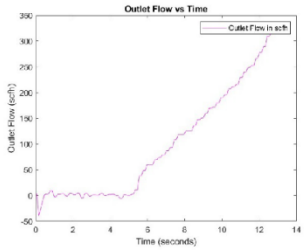


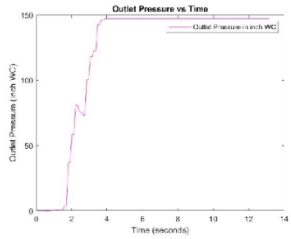


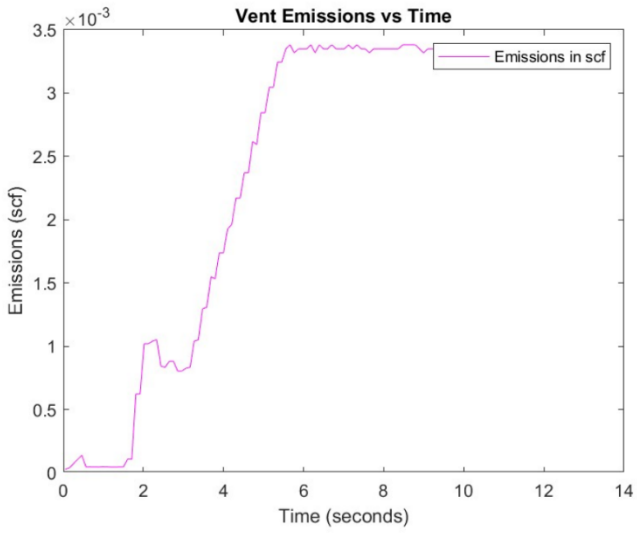


73

- 222489-23_LD
  The volume of total emissions in 13.16 seconds is 0.3090 scf.
  The flow rate of emissions is 84.5028 scfh.

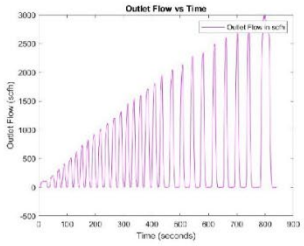


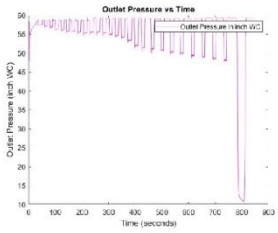


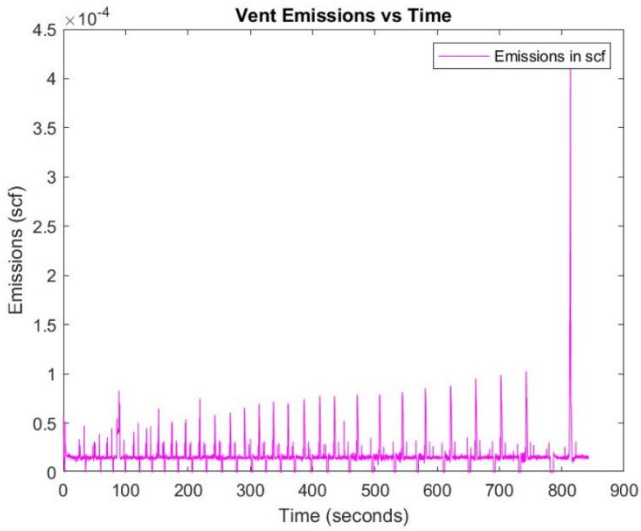


74

- 222489-24
  The volume of total emissions in 842.73 seconds is 0.1371 scf.
  The flow rate of emissions is 0.5855 scfh.

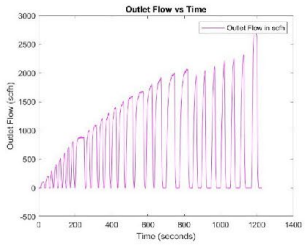


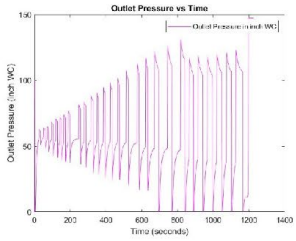


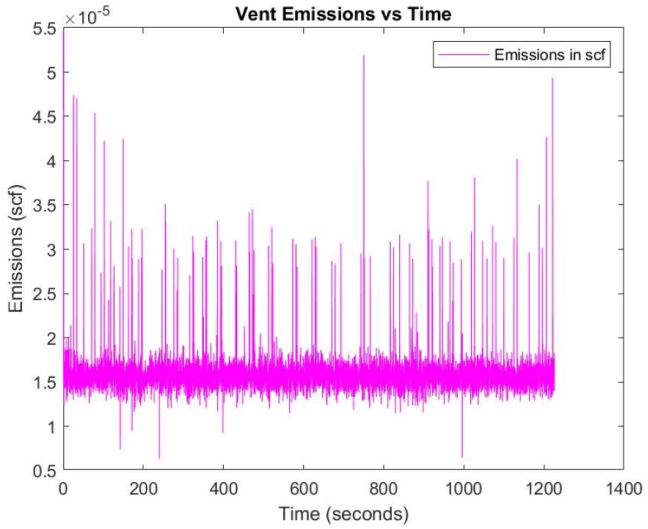


75

- 222489-24_BV
  The volume of total emissions in 1226.12 seconds is 0.1849 scf.
  The flow rate of emissions is 0.5429 scfh.

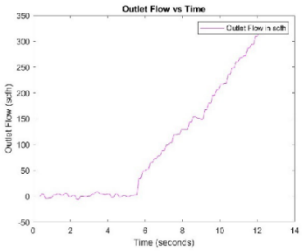


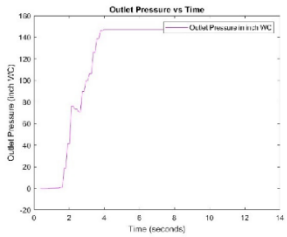


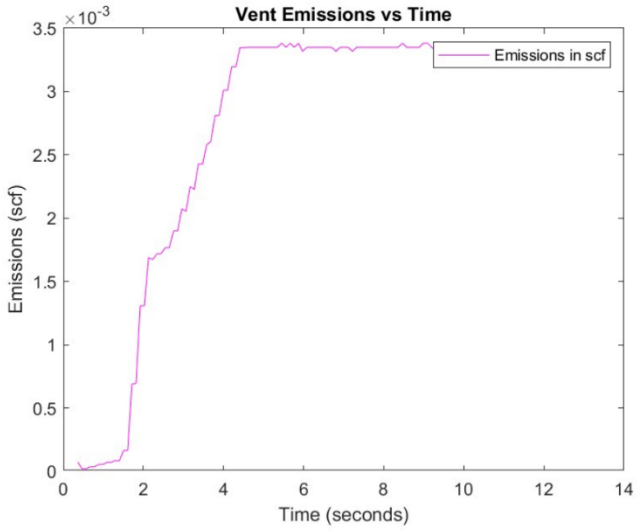


76

- 222489-24_DT
  The volume of total emissions in 12.32 seconds is 0.3138 scf.
  The flow rate of emissions is 91.6833 scfh.



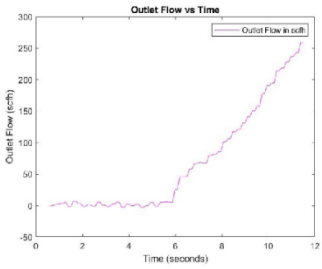


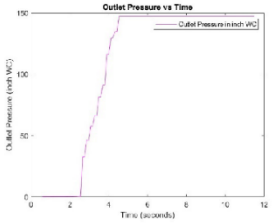


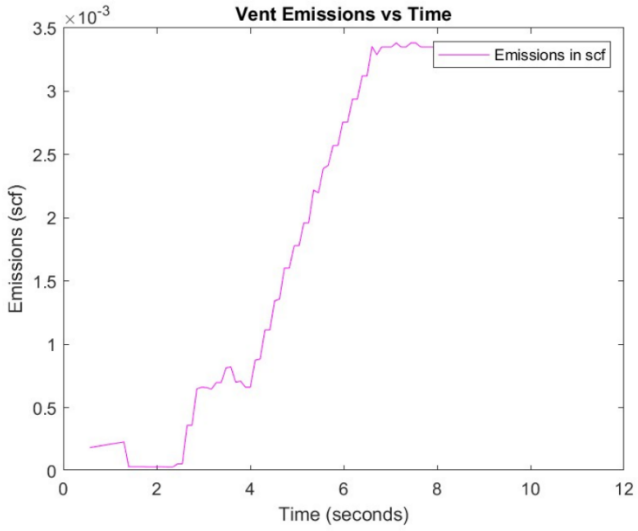
77

GTI ENERGY

- 222489-24_LD
  The volume of total emissions in 11.50 seconds is 0.2202 scf.
  The flow rate of emissions is 68.9480 scfh.







78

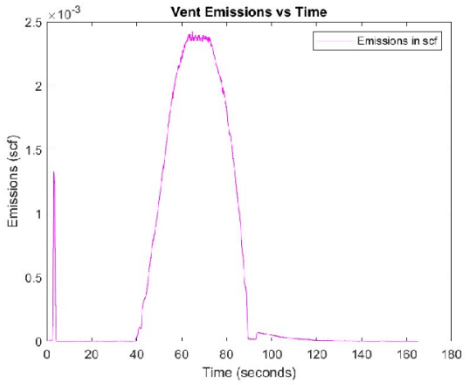
GTI ENERGY

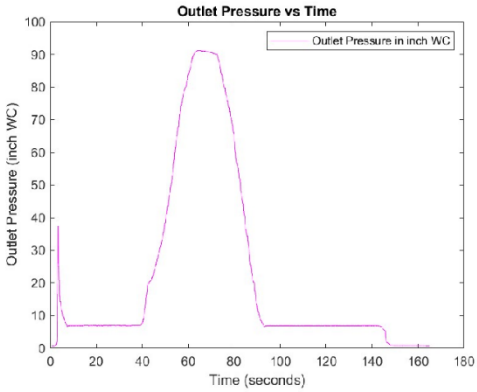
Relief Tests

7" WC Outlet, 3/16" Orifice, 10-psig Inlet

- **222489-019**
  The volume of total emissions in 165.22 seconds is 0.7716 scf.
  The average flow rate of emissions at 18 inches WC is 9.66 scfh.

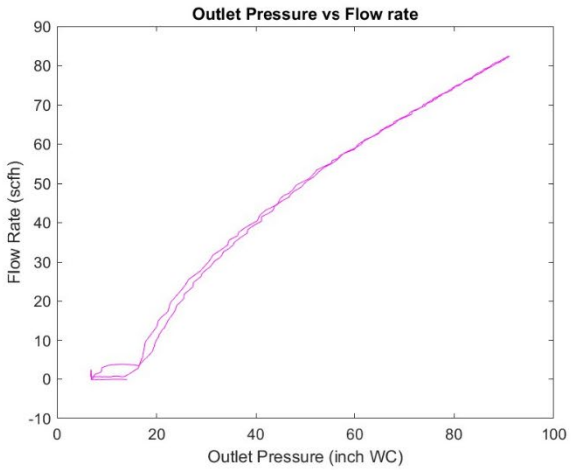
GTI ENERGY

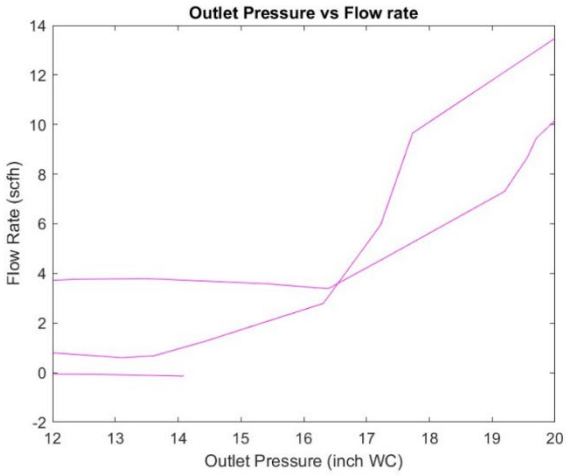




80

GTI ENERGY

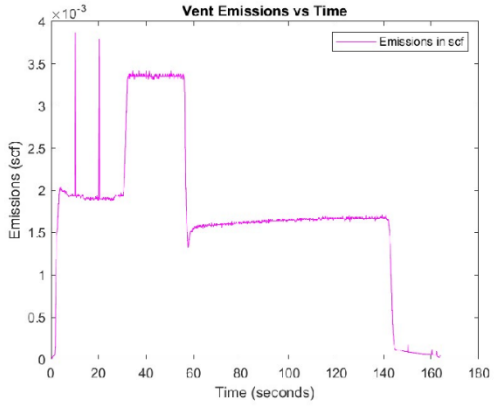


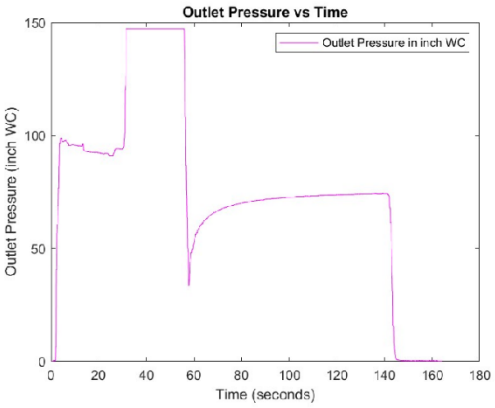


81

GTI ENERGY

- **222489-019_DT**
  The volume of total emissions in 164.19 seconds is 2.7292 scf.

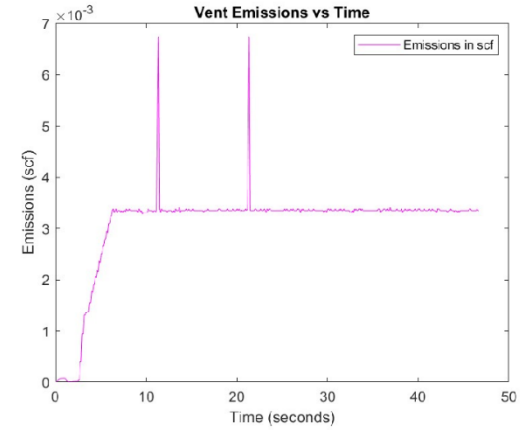


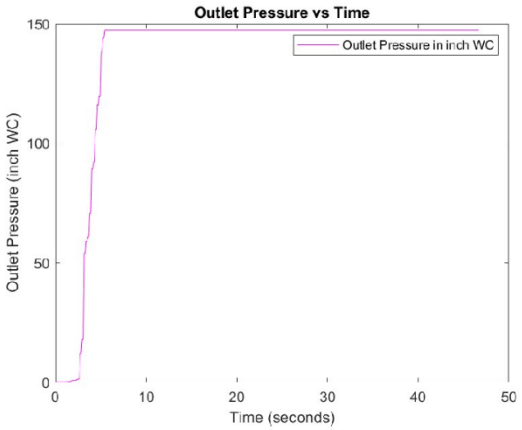


82

GTI ENERGY

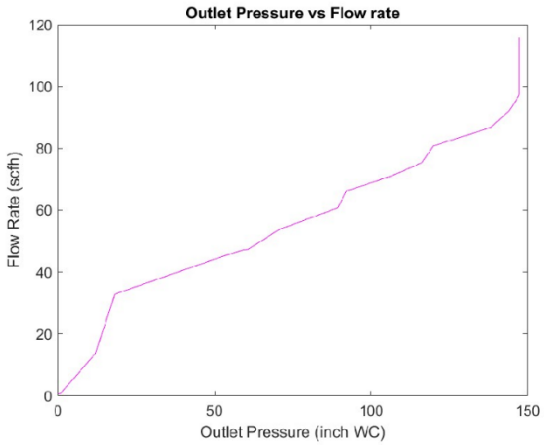
- **222489-019_LD**
  The volume of total emissions in 46.69 seconds is 1.3738 scf.
  The average flow rate of emissions at 18 inches WC is 32.86 scfh.

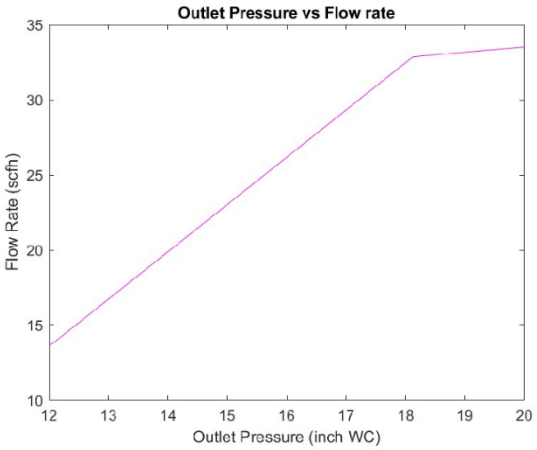




83

GTI ENERGY

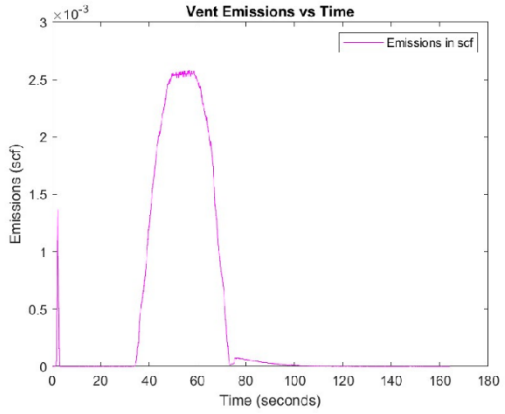


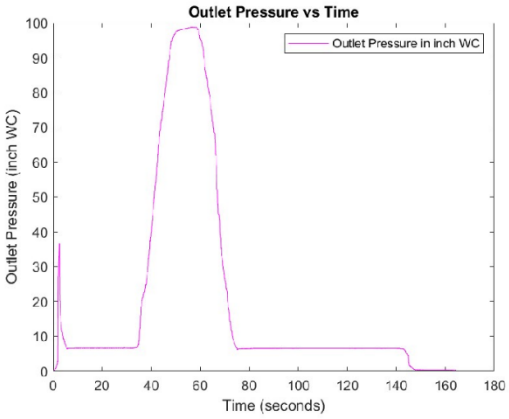


84

GTI ENERGY

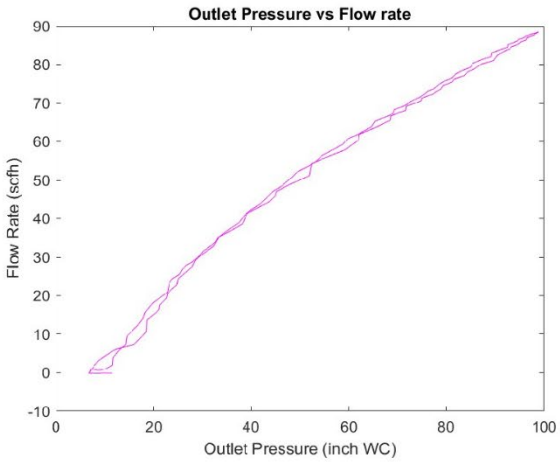
- **222489-020**
  The volume of total emissions in 164.29 seconds is 0.6830 scf.
  The average flow rate of emissions at 18 inches WC is 14.92 scfh.

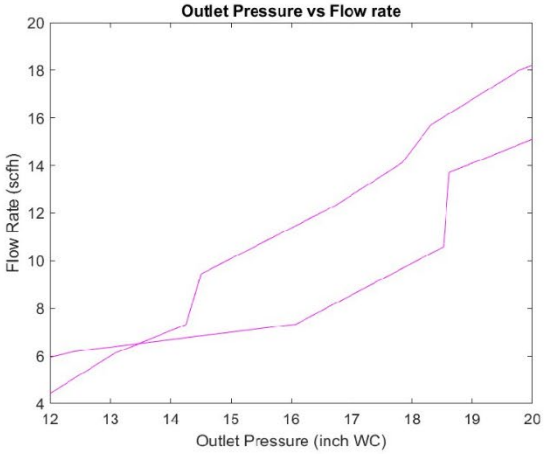




85

GTI ENERGY

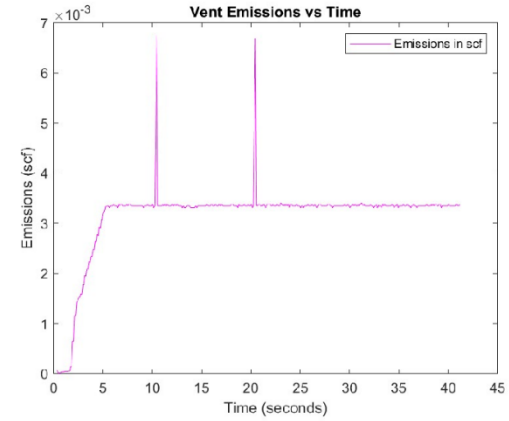


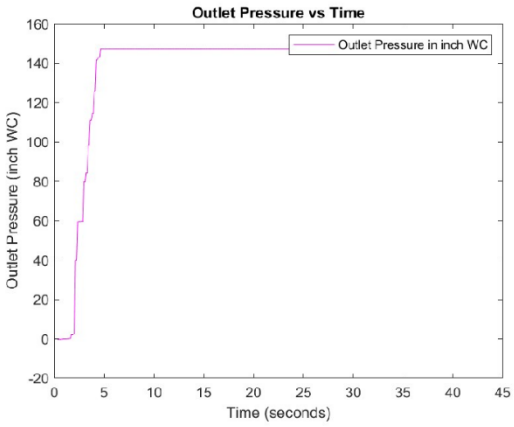


86

GTI ENERGY

- **222489-020_DT**
  The volume of total emissions in 41.18 seconds is 1.2291 scf.

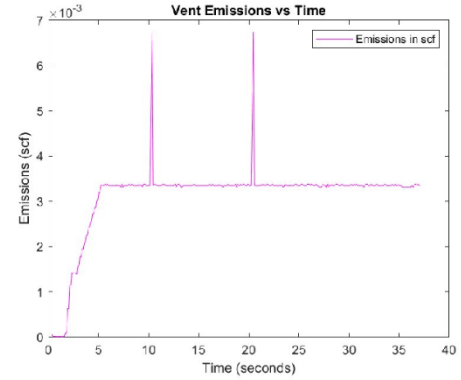


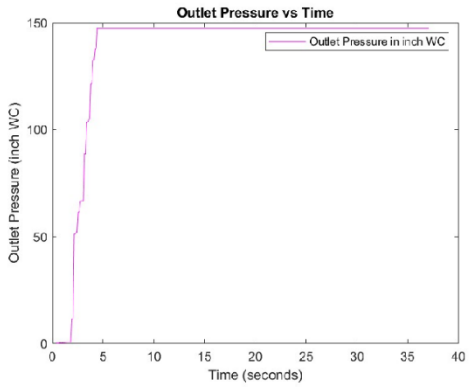


87

GTI ENERGY

- **222489-020_LD**
  The volume of total emissions in 37.11 seconds is 1.0949 scf.

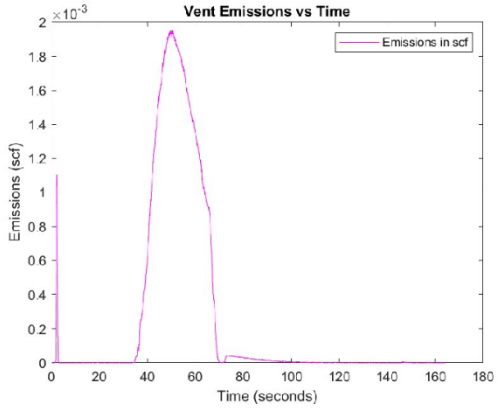


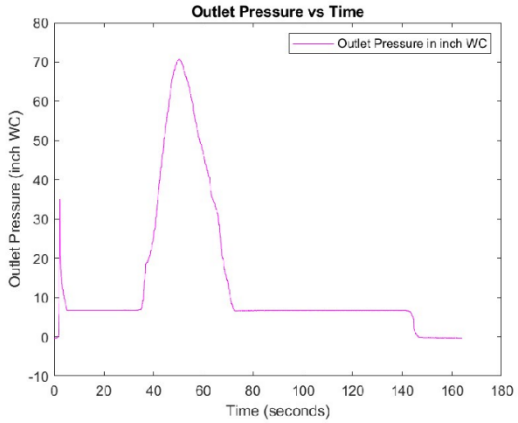


88

GTI ENERGY

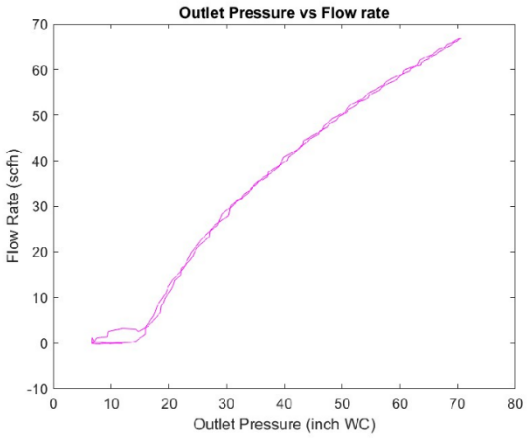
- **222489-021**
  The volume of total emissions in 164.29 seconds is 0.4067 scf.
  The average flow rate of emissions at 18 inches WC is 8.07 scfh.

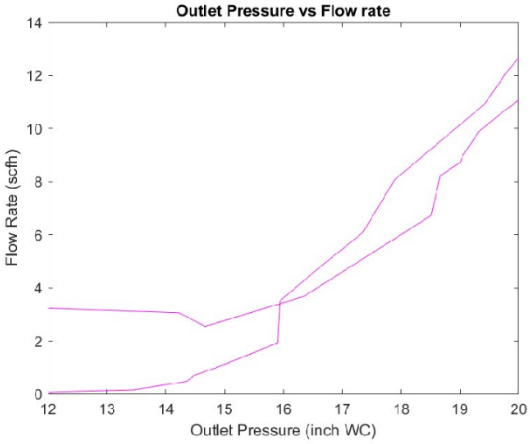




89

GTI ENERGY



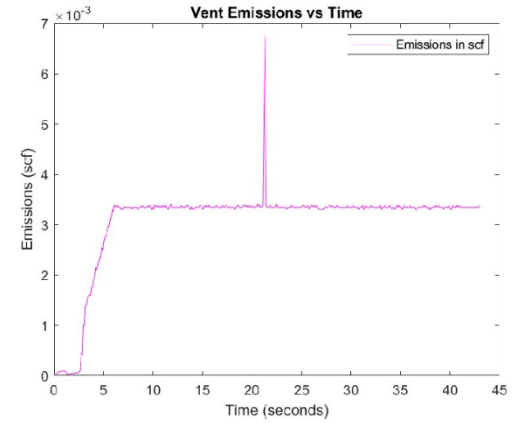


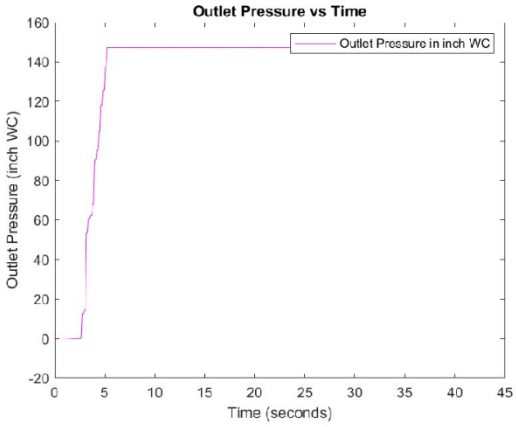
90

GTI ENERGY

- **222489-021_DT**

  The volume of total emissions in 42.96 seconds is 1.2595 scf.

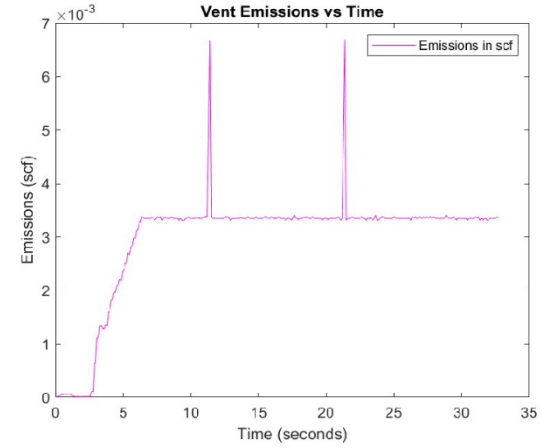


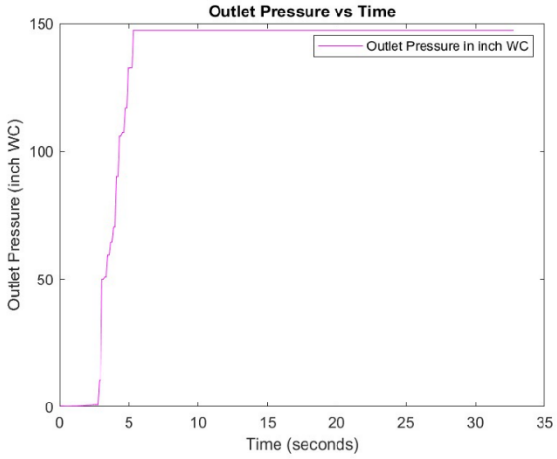


- **222489-021_LD**

GTI ENERGY

The volume of total emissions in 32.73 seconds is 0.9226 scf.



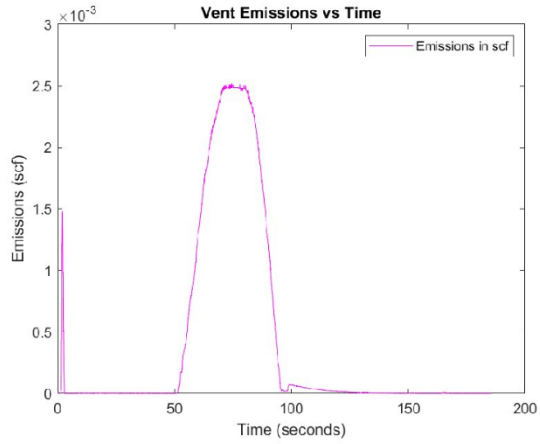


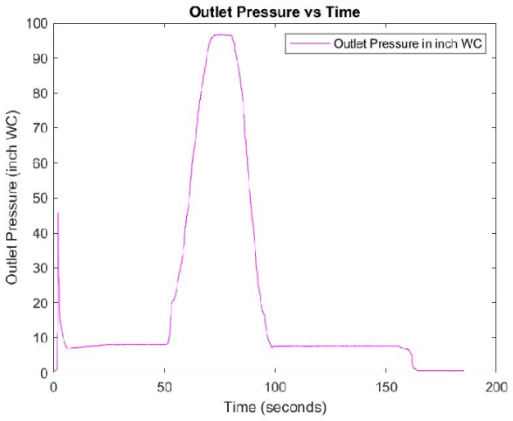
92

7" WC Outlet, 3/16" Orifice, 60-psig Inlet

- **222489-019**

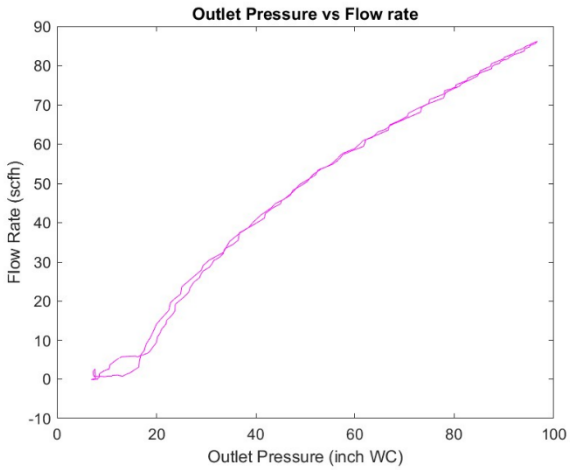
  The volume of total emissions in 185.45 seconds is 0.7218 scf.
  The average flow rate of emissions at 18 inches WC is 7.90 scfh.

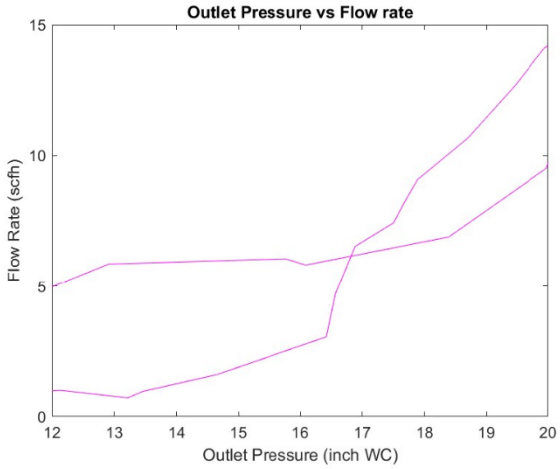




93

GTI ENERGY

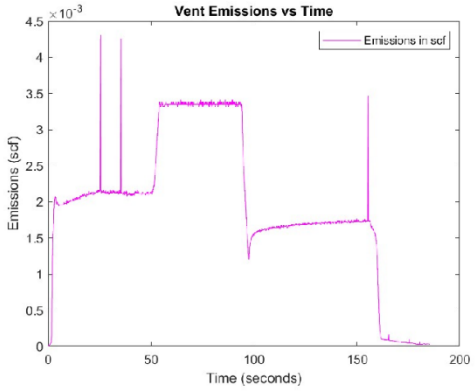


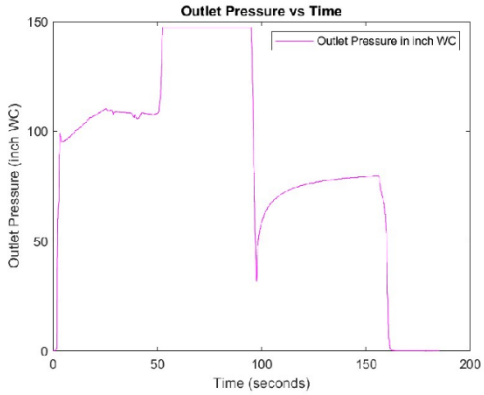


94

GTI ENERGY

- **222489-019_DT**
  The volume of total emissions in 185.41 seconds is 3.4412 scf.



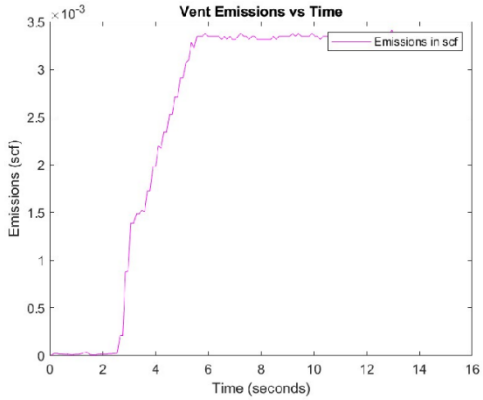


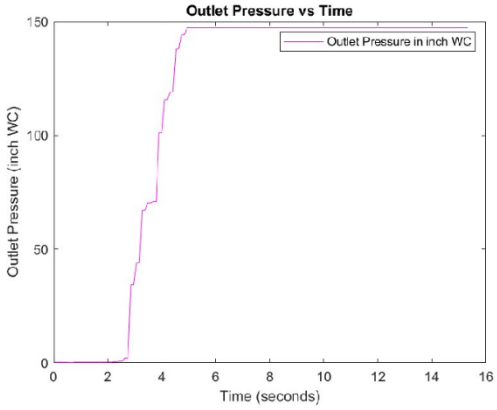
95

GTI ENERGY

- **222489-019_LD**

  The volume of total emissions in 15.34 seconds is 0.3750 scf.



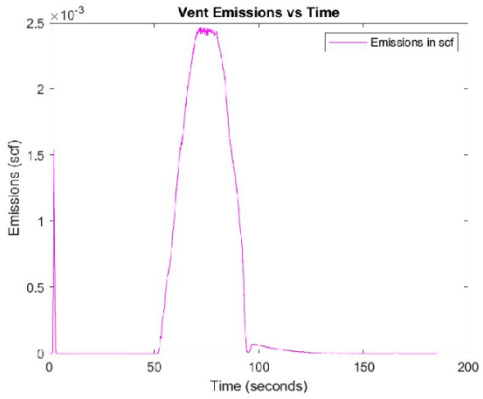


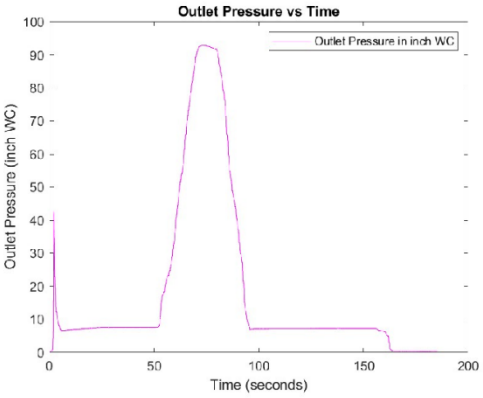
- **222489-020**

96

GTI ENERGY

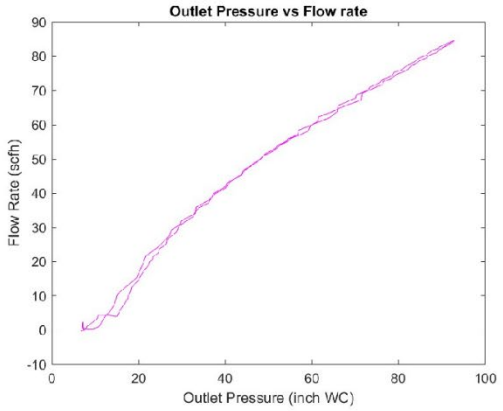
The volume of total emissions in 185.41 seconds is 0.6722 scf.
The average flow rate of emissions at 18 inches WC is 10.67 scfh.

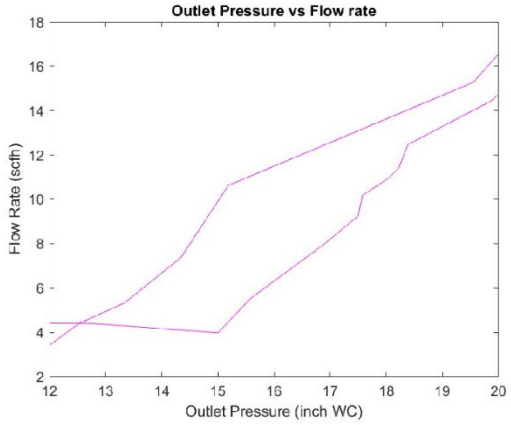




97

GTI ENERGY



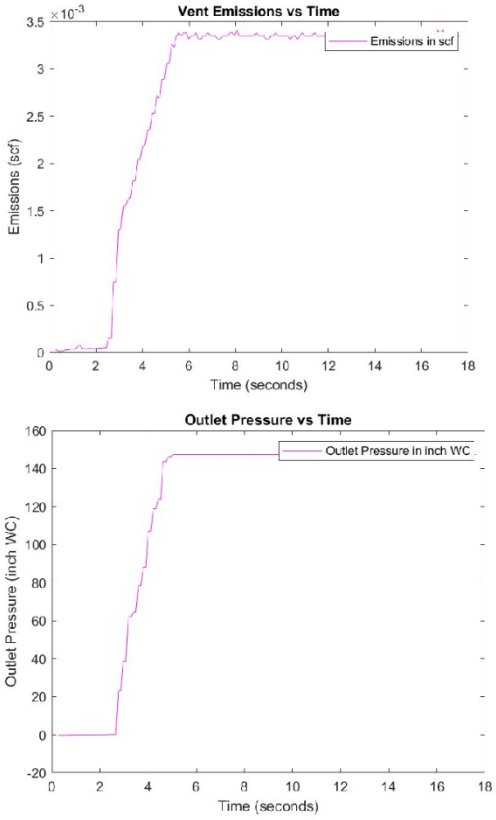


98

GTI ENERGY

- **222489-020_DT**

  The volume of total emissions in 17.64 seconds is 0.4527 scf.

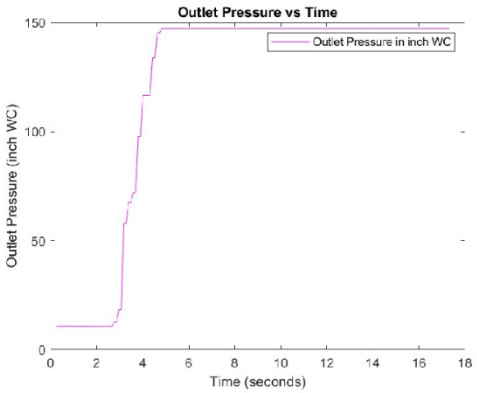


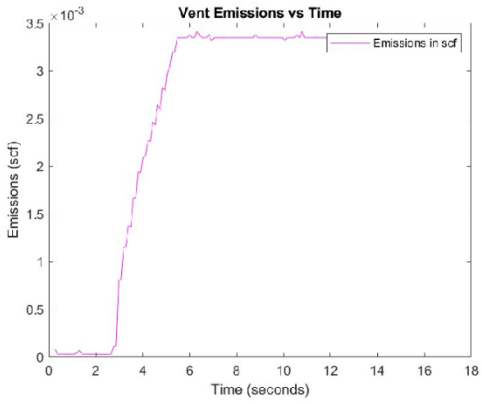
- **222489-020_LD**

99

GTI ENERGY

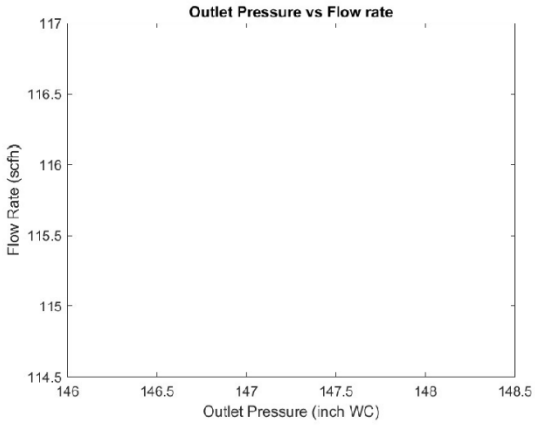
The volume of total emissions in 17.33 seconds is 0.4372 scf.
The average flow rate of emissions at 18 inches WC is 27.75 scfh.

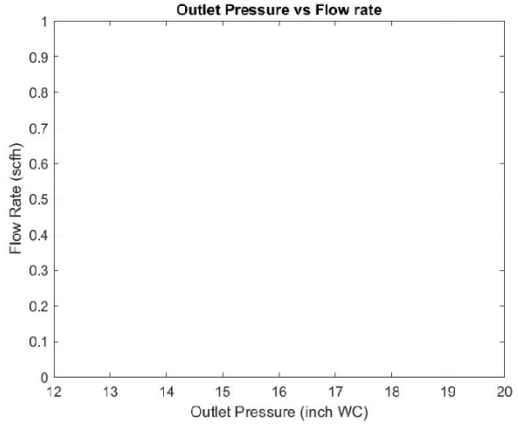




100

GTI ENERGY





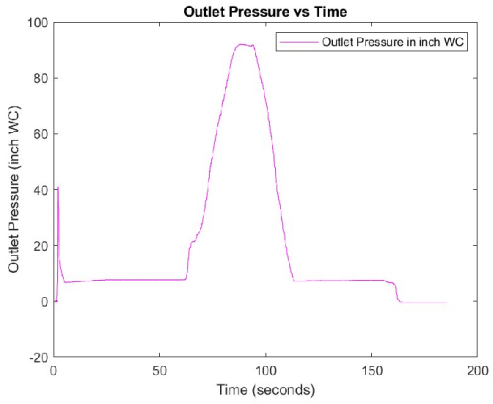
101

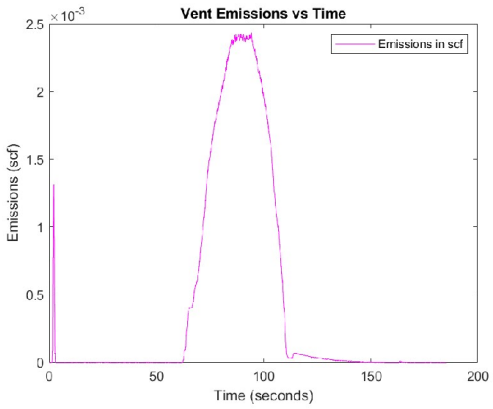
GTI ENERGY

- **222489-021**

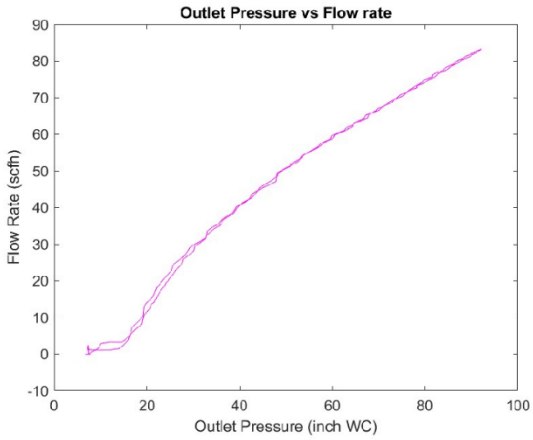
The volume of total emissions in 185.35 seconds is 0.7459 scf.

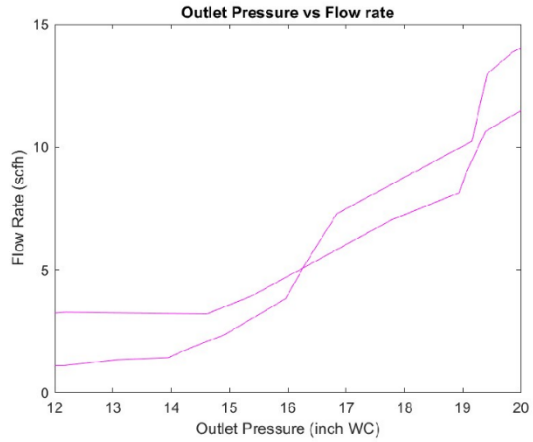
The average flow rate of emissions at 18 inches WC is 7.04 scfh.





102



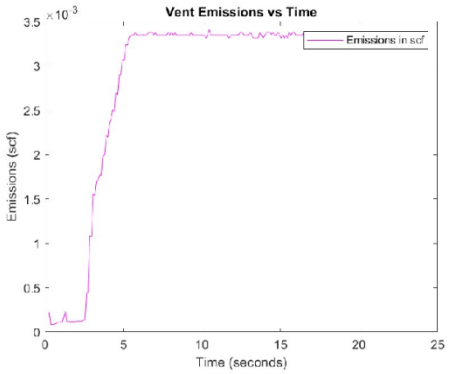


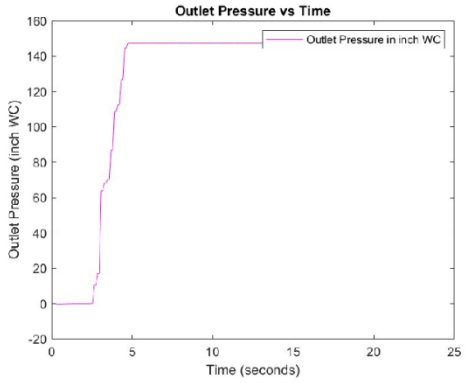
103

GTI ENERGY

- **222489-021_DT**

  The volume of total emissions in 23.46 seconds is 0.6431 scf.



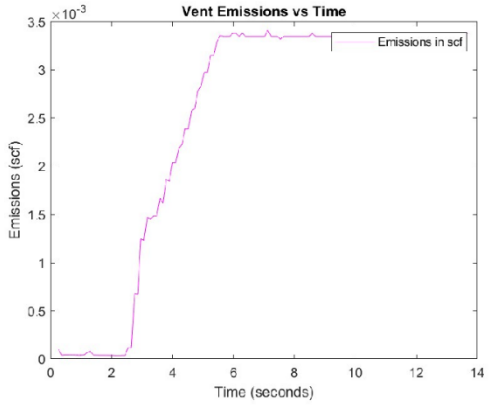


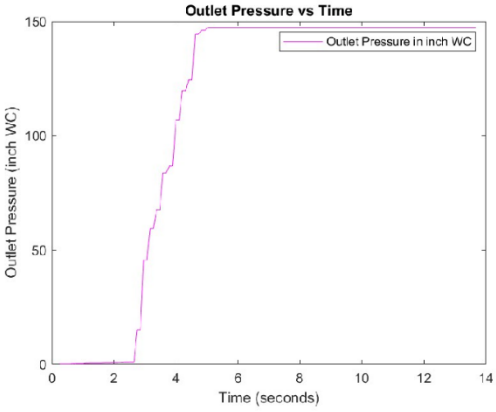
- **222489-021_LD**

104

GTI ENERGY

The volume of total emissions in 13.68 seconds is 0.3225 scf.





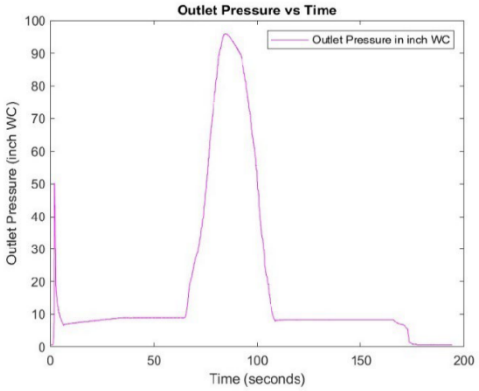
105

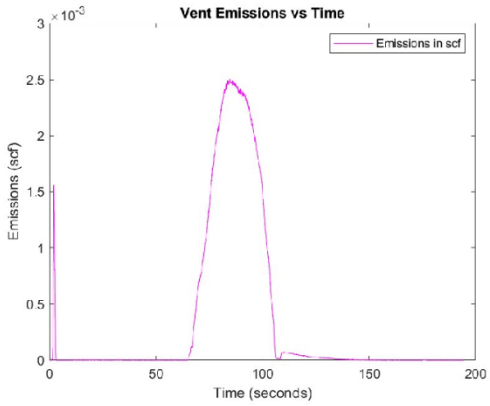
GTI ENERGY

7" WC Outlet, 3/16" Orifice, 100-psig Inlet

- **222489-019**

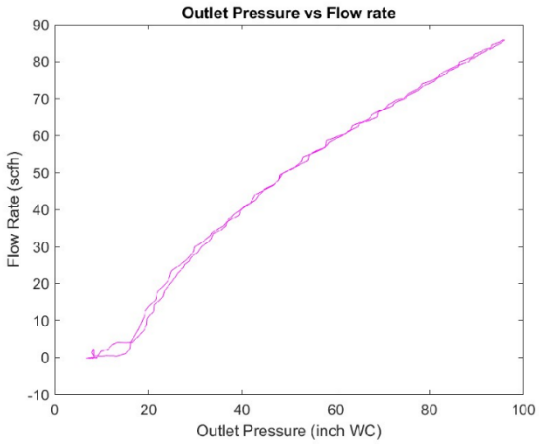
  The volume of total emissions in 194.42 seconds is 0.6453 scf.
  The average flow rate of emissions at 18 inches WC is 6.59 scfh.

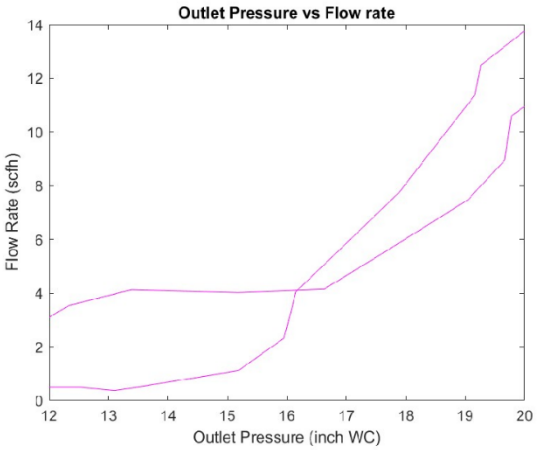




106

GTI ENERGY

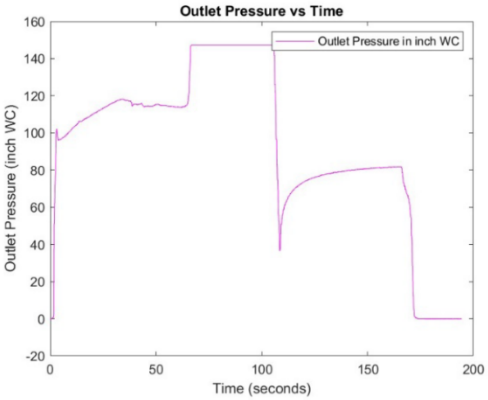


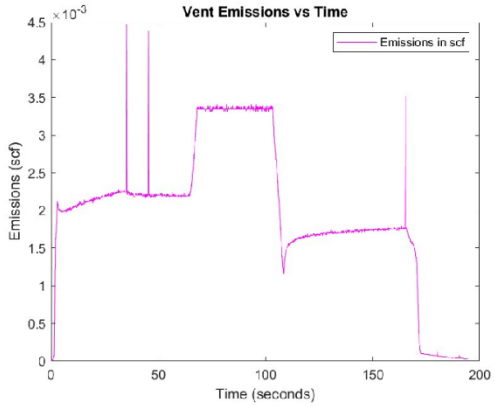


107

GTI ENERGY

- **222489-019_DT**
  The volume of total emissions in 194.33 seconds is 3.6668 scf.

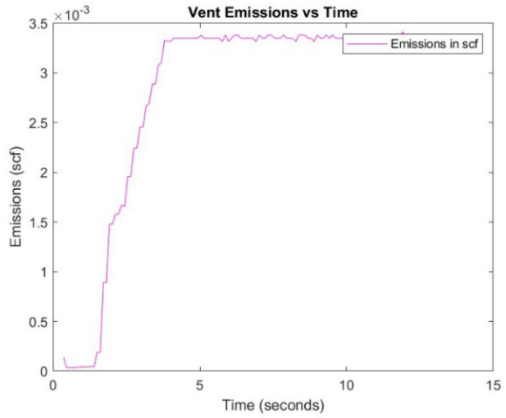


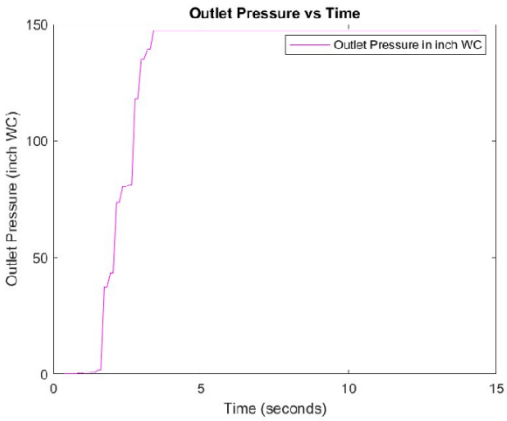


108

GTI ENERGY

- **222489-019_LD**
  The volume of total emissions in 14.42 seconds is 0.3882 scf.

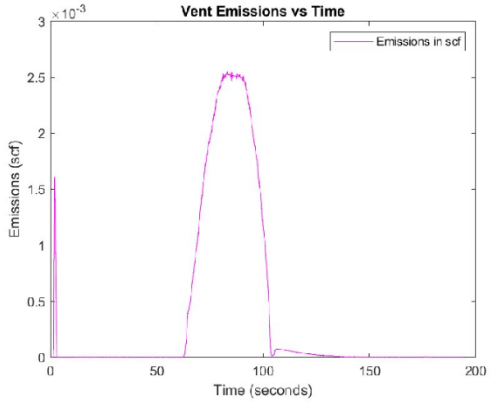


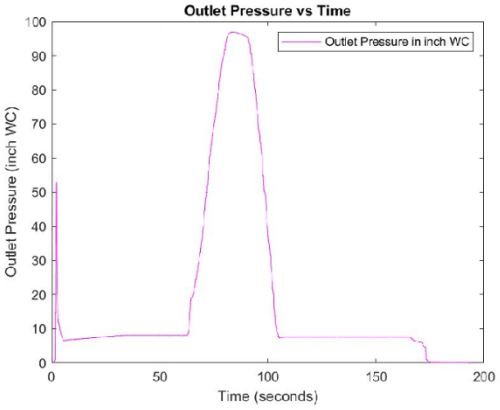


109

GTI ENERGY

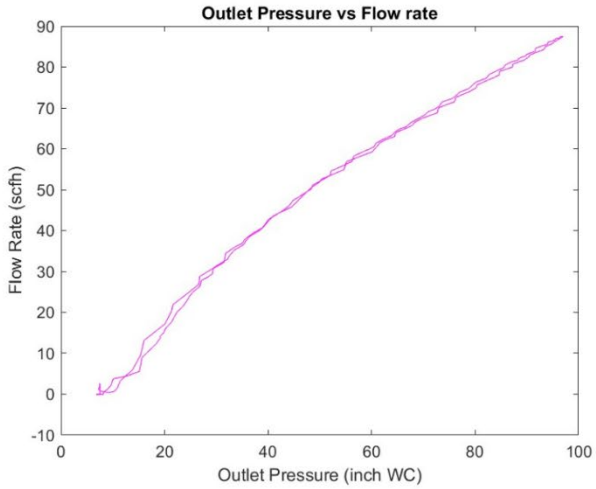
- **222489-020**
  The volume of total emissions in 194.48 seconds is 0.7082 scf.
  The average flow rate of emissions at 18 inches WC is 12.20 scfh.

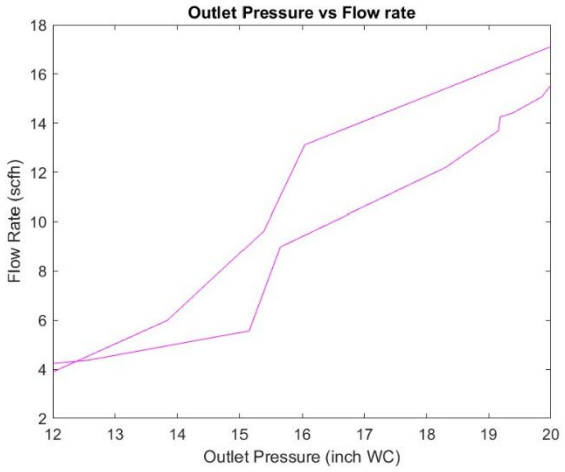




110

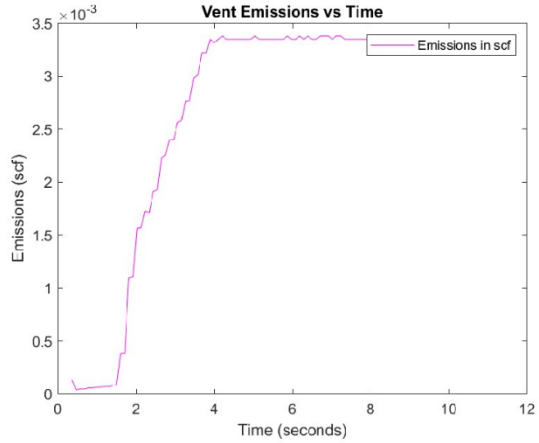
GTI ENERGY

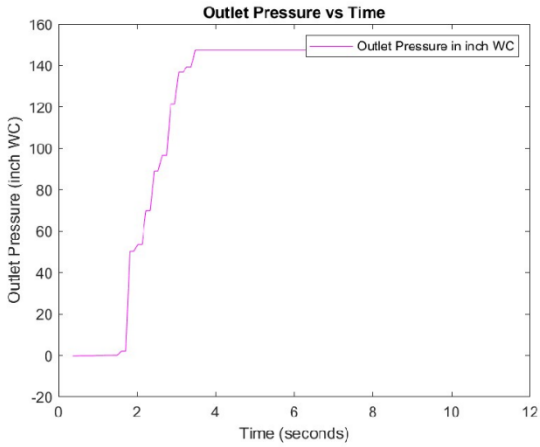

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
90
80
70
60
50
40
30
20
10
0
-10
0
20
40
60
80
100


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
18
16
14
12
10
8
6
4
2
12
13
14
15
16
17
18
19
20

111

- **222489-020_DT**
  The volume of total emissions in 10.67 seconds is 0.2682 scf.

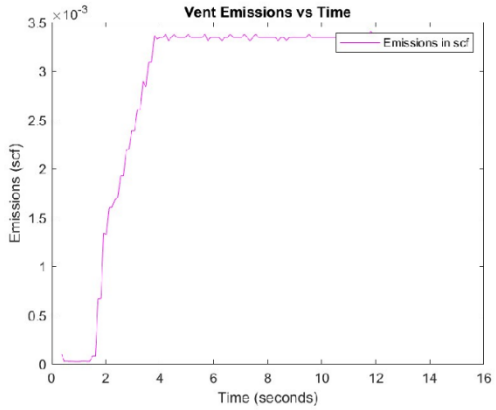


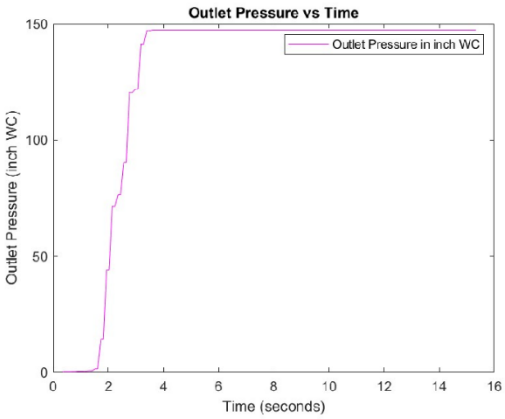


112

GTI ENERGY

- **222489-020_LD**
  The volume of total emissions in 15.36 seconds is 0.4169 scf.

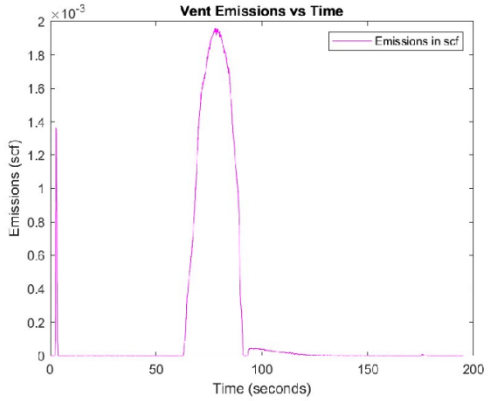


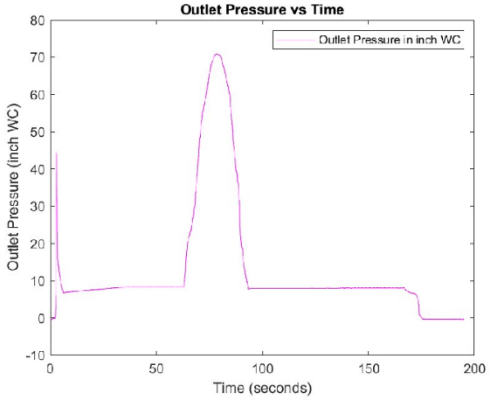


113

GTI ENERGY

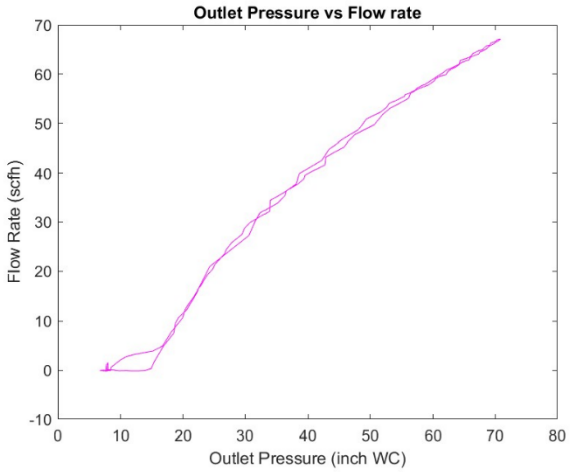
- **222489-021**
  The volume of total emissions in 195.34 seconds is 0.3694 scf.
  The average flow rate of emissions at 18 inches WC is 7.76 scfh.

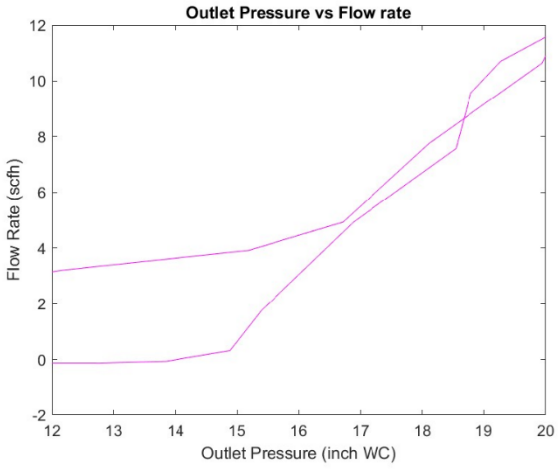




114

GTI ENERGY

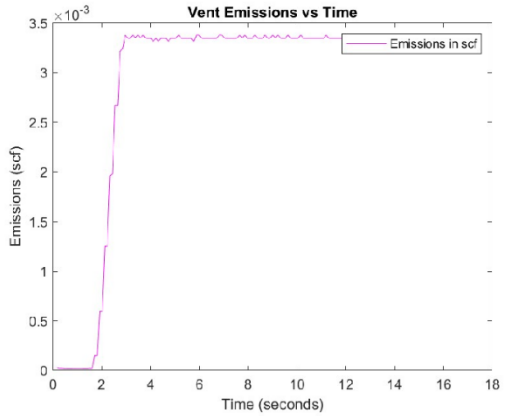


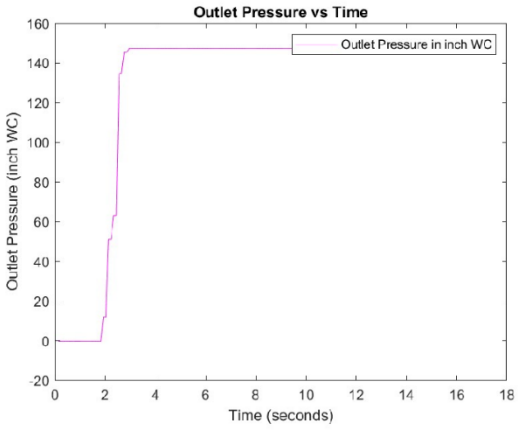


115

GTI ENERGY

- **222489-021_DT**
  The volume of total emissions in 16.81 seconds is 0.4695 scf.

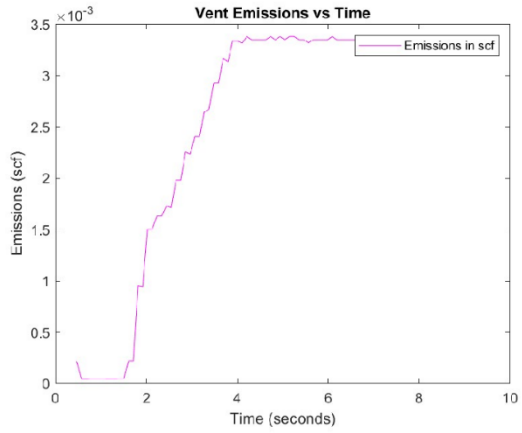


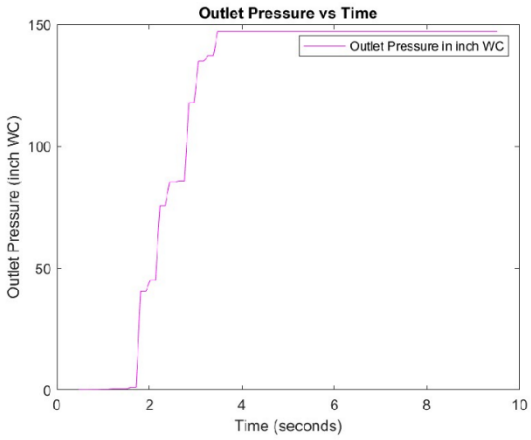


116

GTI ENERGY

- **222489-021_LD**
  The volume of total emissions in 9.52 seconds is 0.2278 scf.



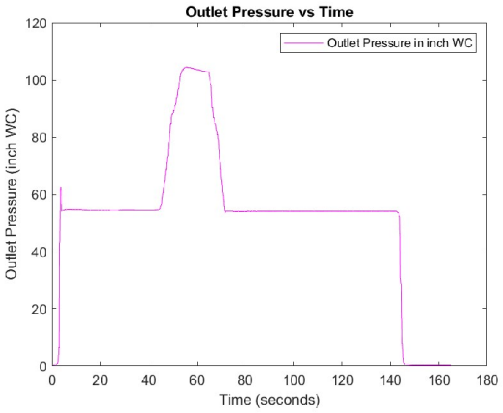


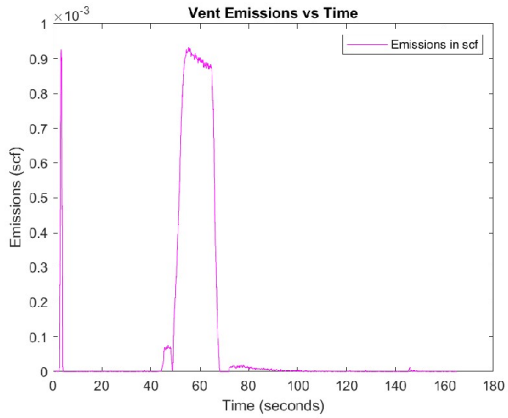
117

GTI ENERGY

2-psig Outlet, 3/16" Orifice, 10-psig Inlet

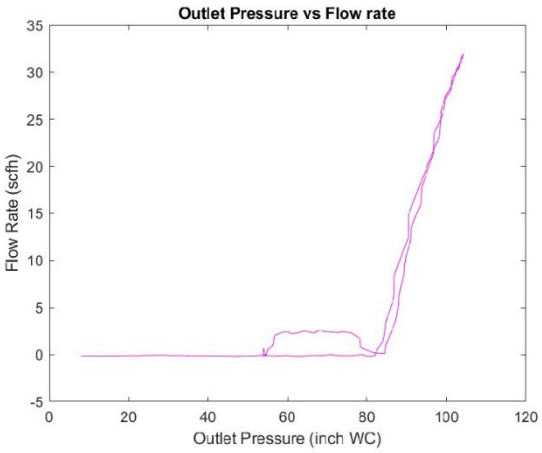
- **222489-022**
  The volume of total emissions in 165.23 seconds is 0.1416 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 9.25 scfh.

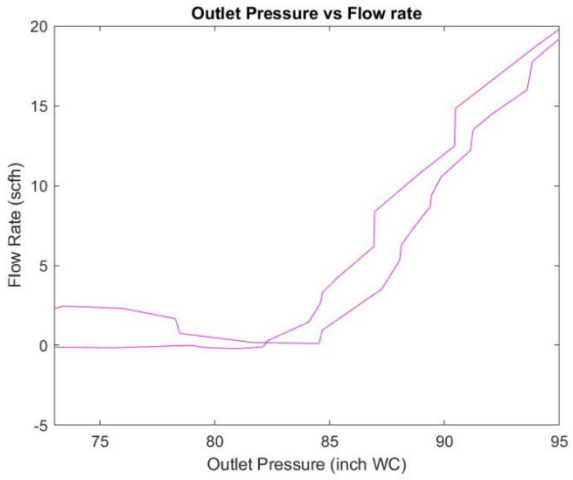




118

GTI ENERGY

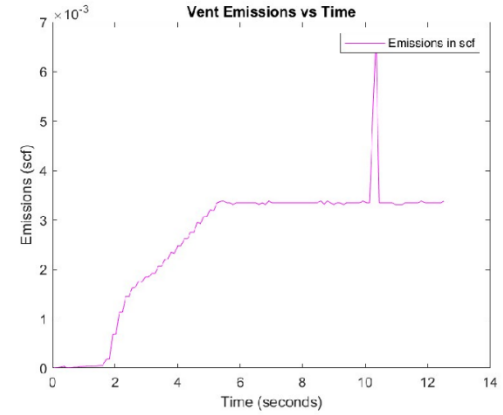


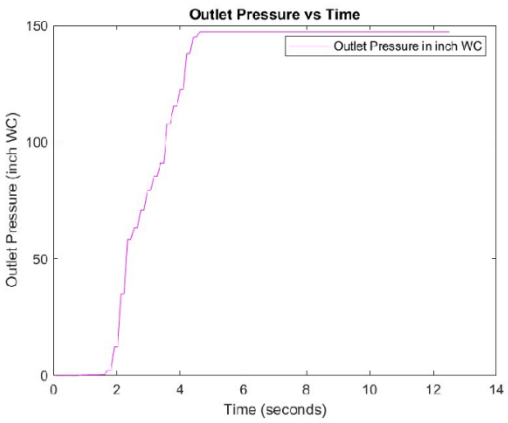


119

GTI ENERGY

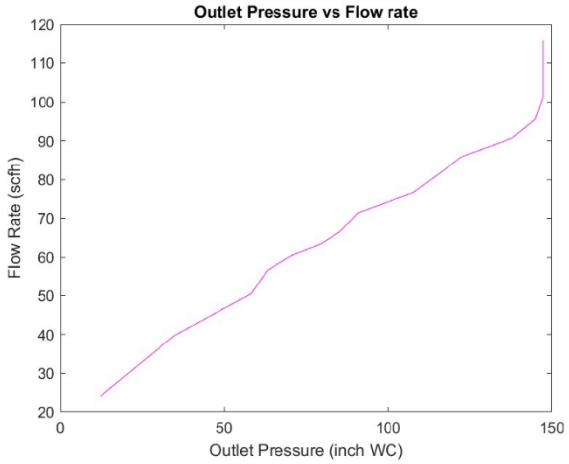
- **222489-022_DT**
  The volume of total emissions in 12.53 seconds is 0.3069 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 71.44 scfh.

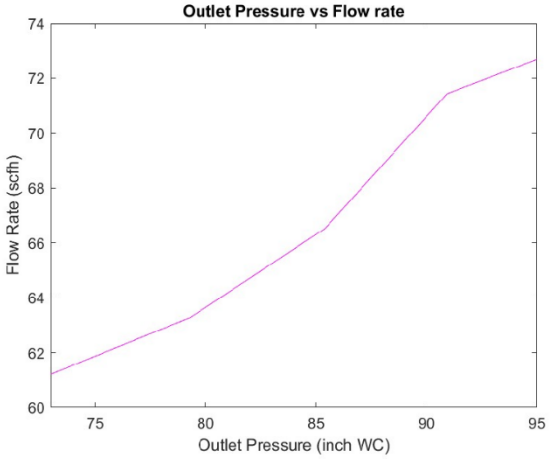




120

GTI ENERGY

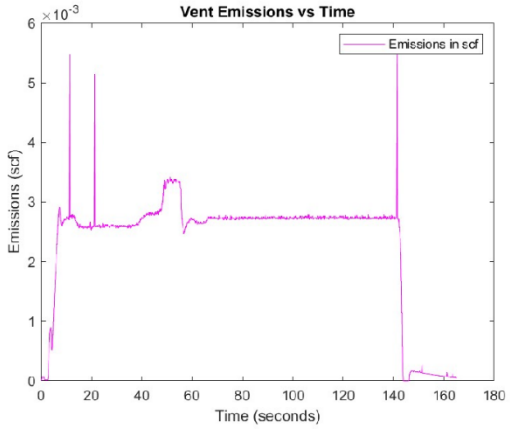


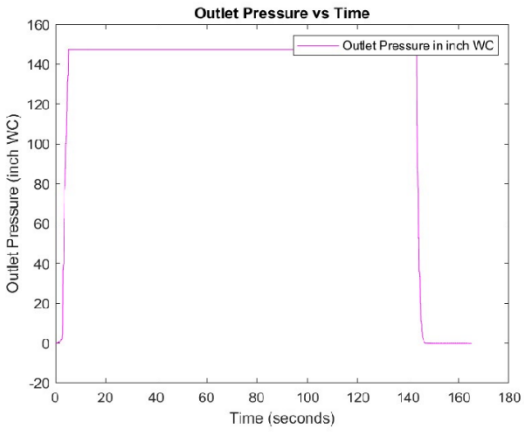


121

GTI ENERGY

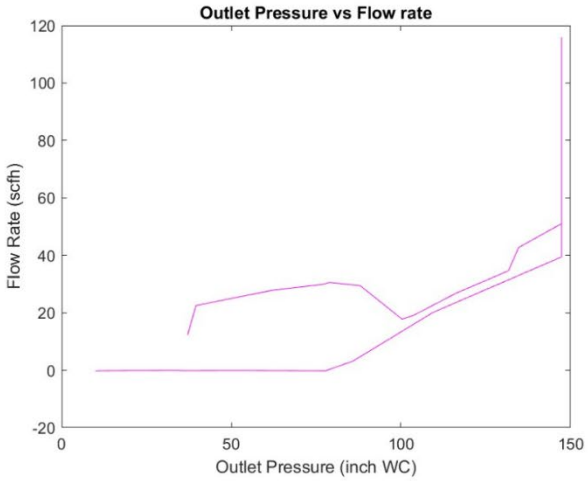
- **222489-022_LD**
  The volume of total emissions in 165.26 seconds is 3.6549 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 29.45 scfh.

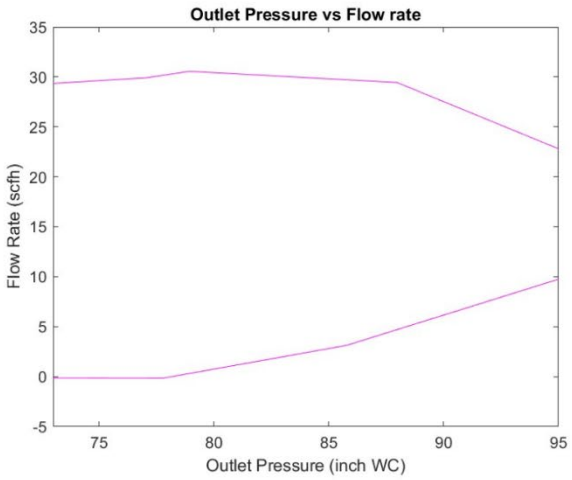




122

GTI ENERGY

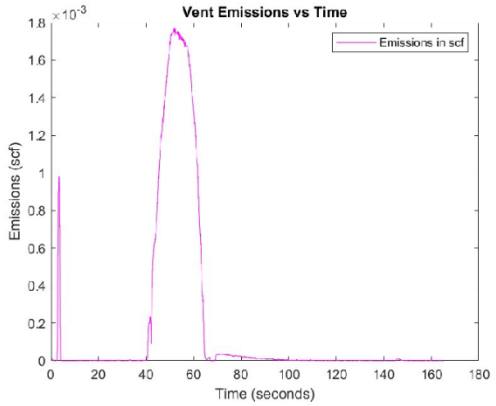


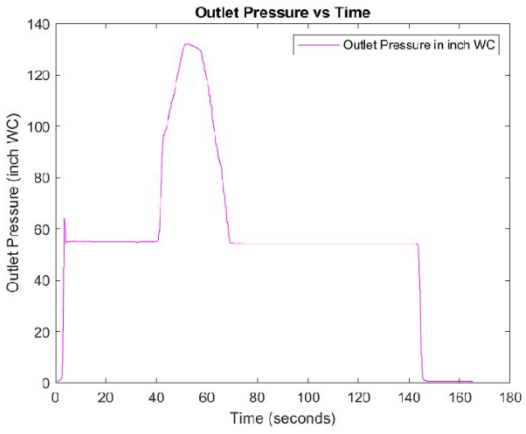


123

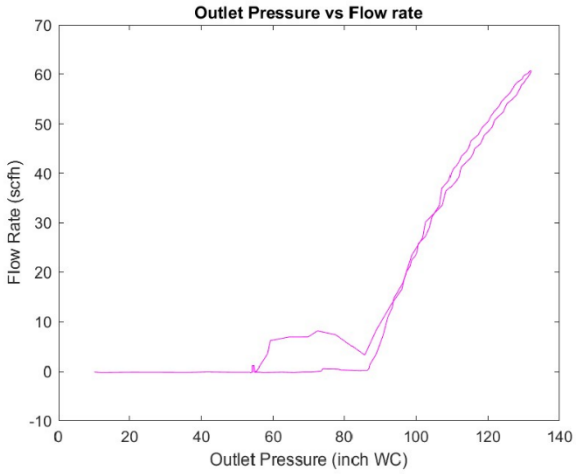
GTI ENERGY

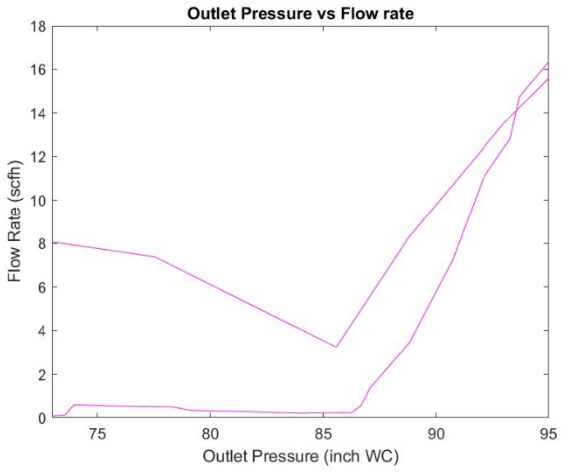
- **222489-023**
  The volume of total emissions in 165.15 seconds is 0.2898 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 3.52 scfh.





124

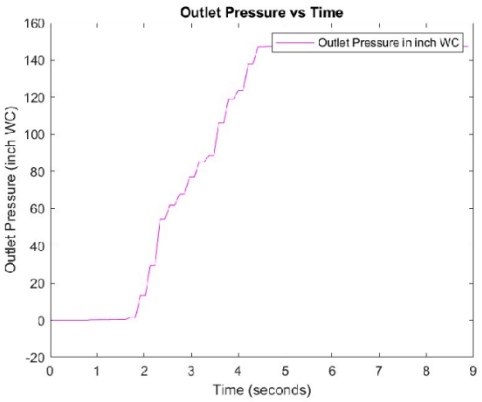


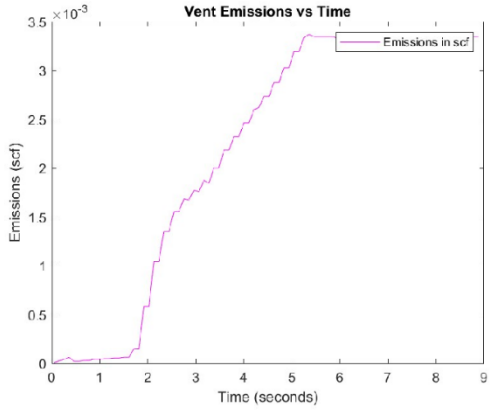


125

GTI ENERGY

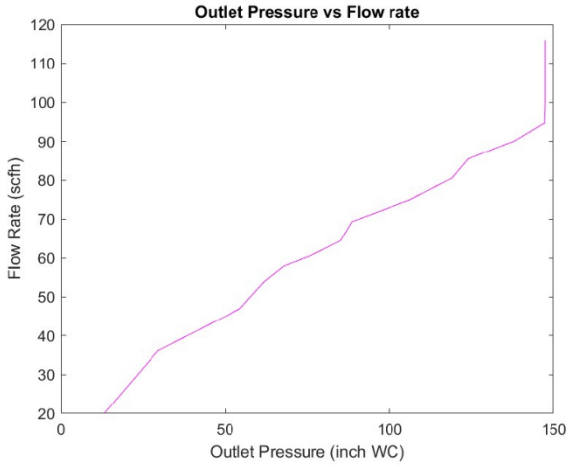
- **222489-023_DT**
  The volume of total emissions in 8.89 seconds is 0.1879 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 69.34 scfh.

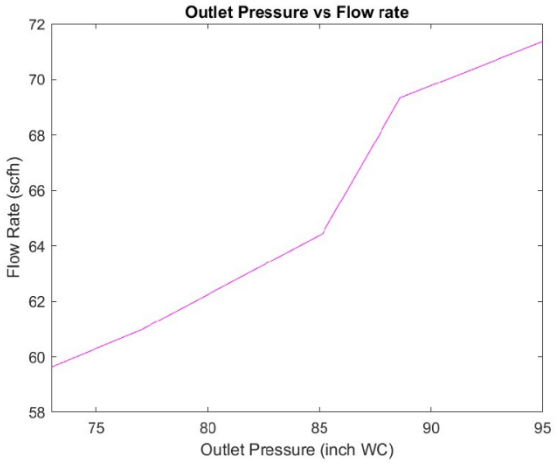




126

GTI ENERGY





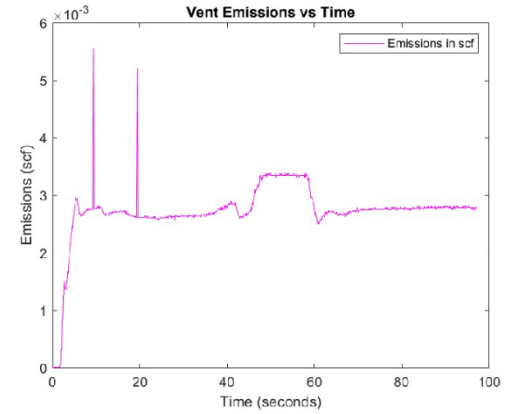
127

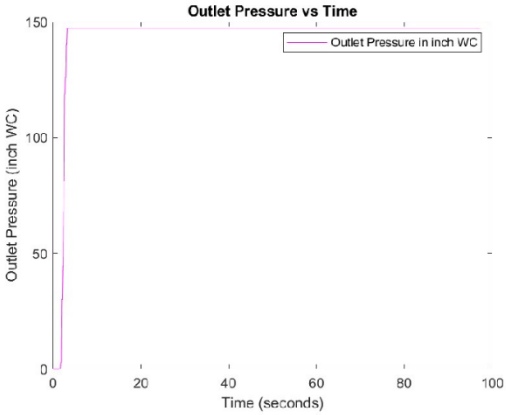
GTI ENERGY

- 222489-023_LD

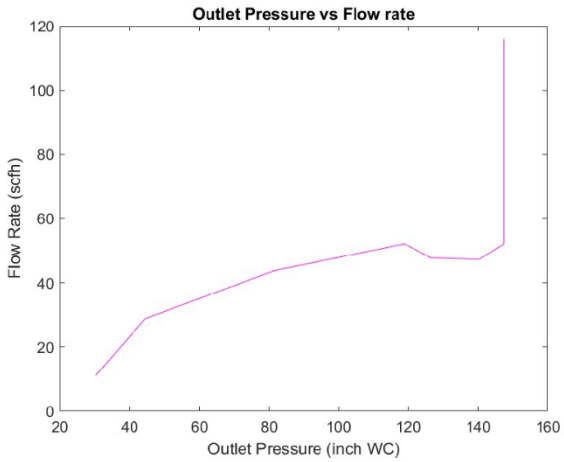
Commented [JW2]: Avg calculation out of range

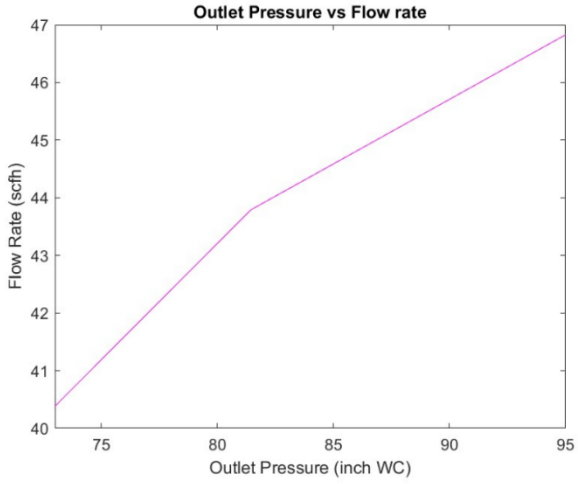
The volume of total emissions in 97.30 seconds is 2.5384 scf.





128

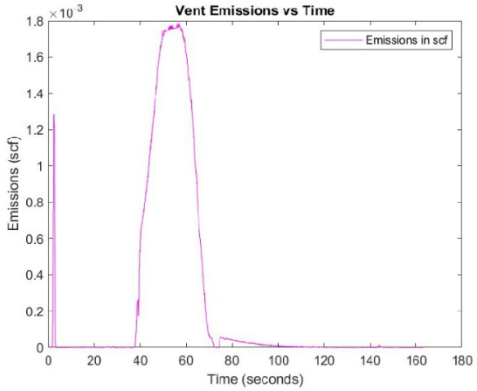


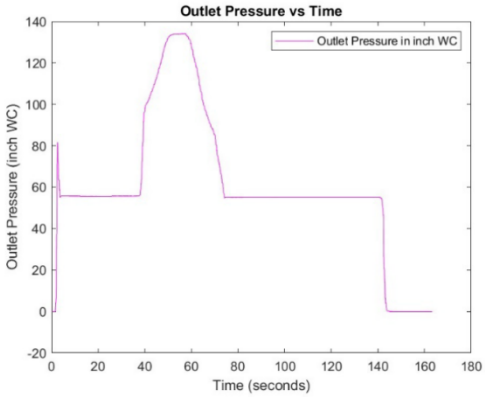


129

GTI ENERGY

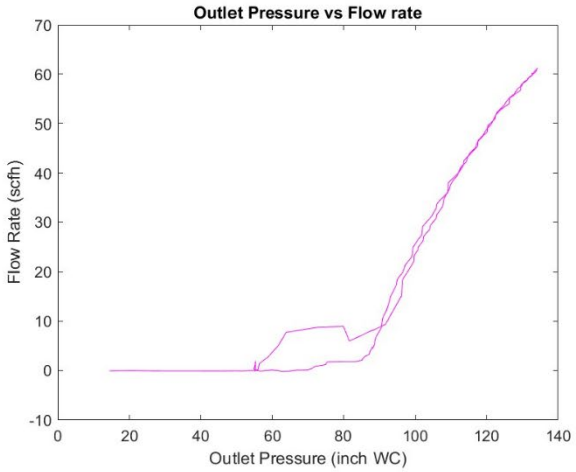
- **222489-024**
  The volume of total emissions in 163.30 seconds is 0.3805 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 6.30 scfh.

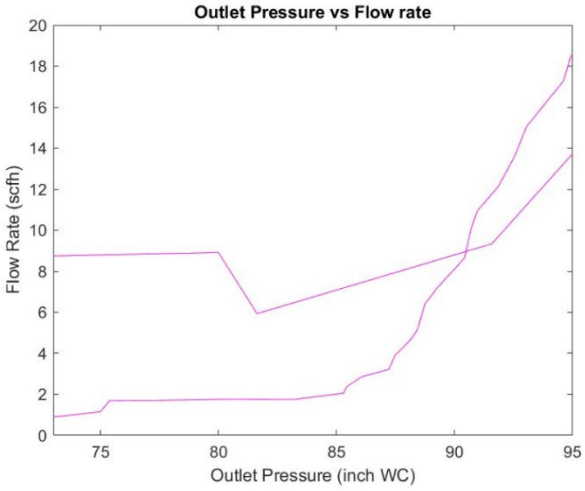




130

GTI ENERGY

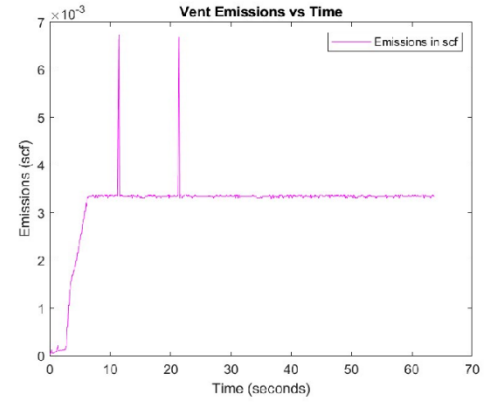


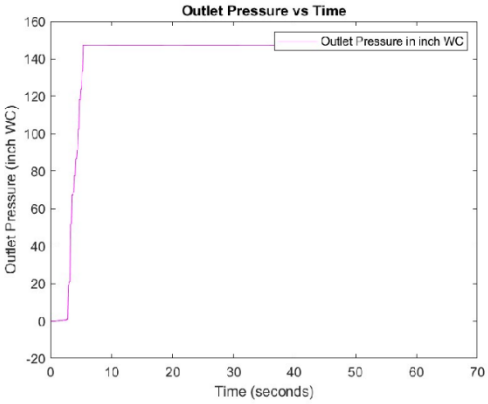


131

GTI ENERGY

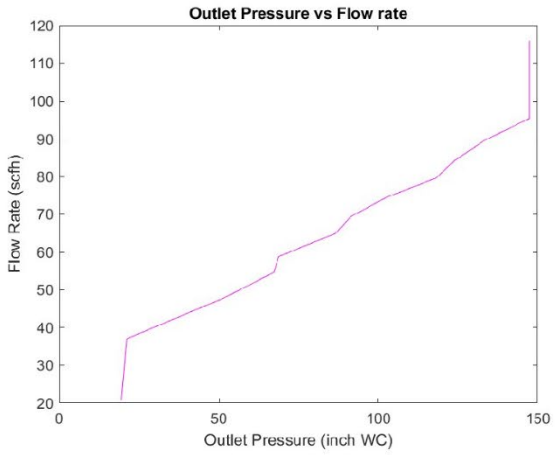
- **222489-024_DT**
  The volume of total emissions in 63.74 seconds is 1.9264 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 67.12 scfh.

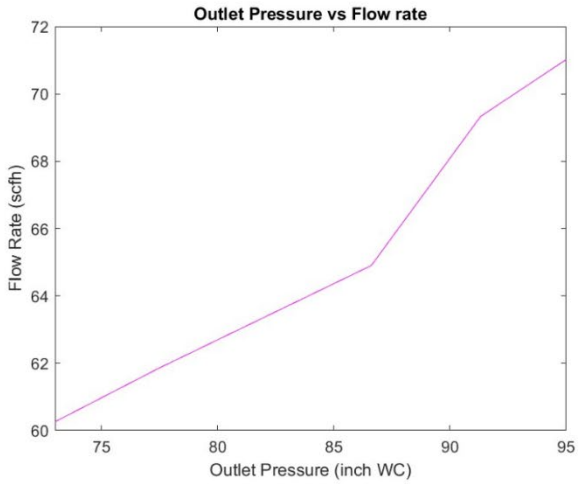




132

GTI ENERGY





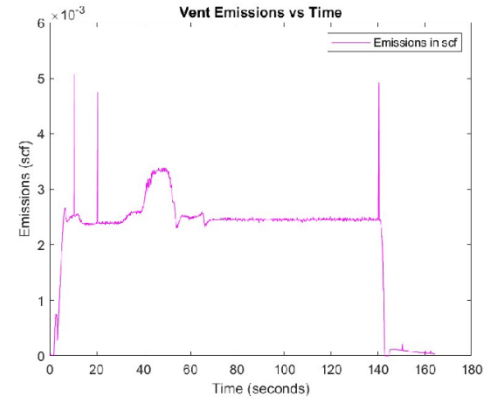
133

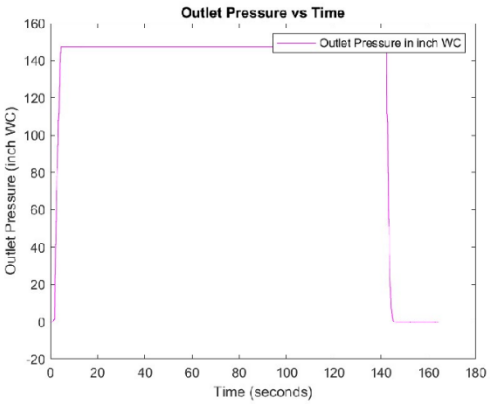
GTI ENERGY

- 222489-024_LD

Commented [JW3]: Avg calculation out of range

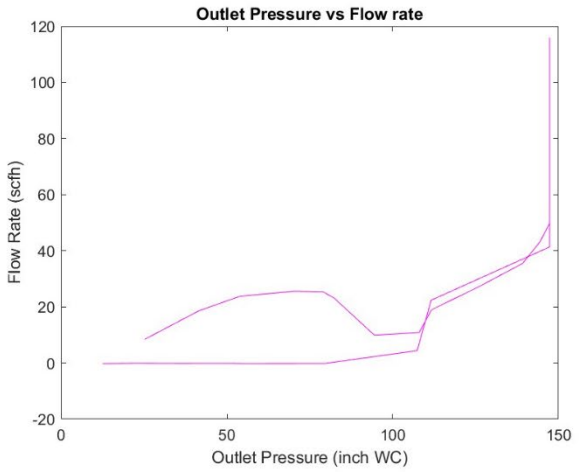
The volume of total emissions in 164.34 seconds is 3.3746 scf.

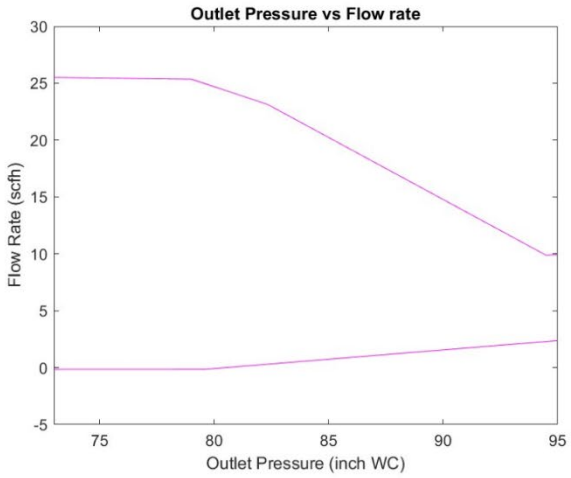




134

GTI ENERGY





135

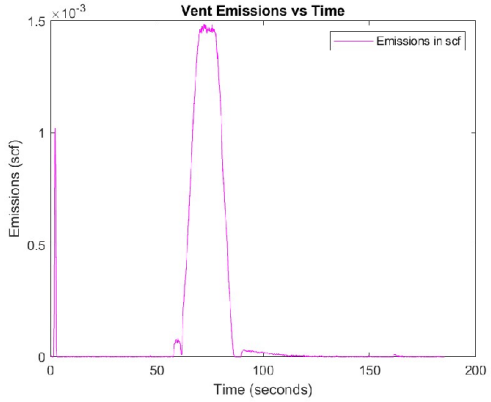
GTI ENERGY

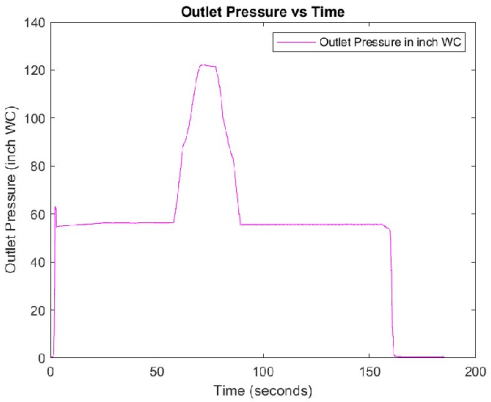
2-psig Outlet, 3/16" Orifice, 60-psig Inlet

- **222489-022**

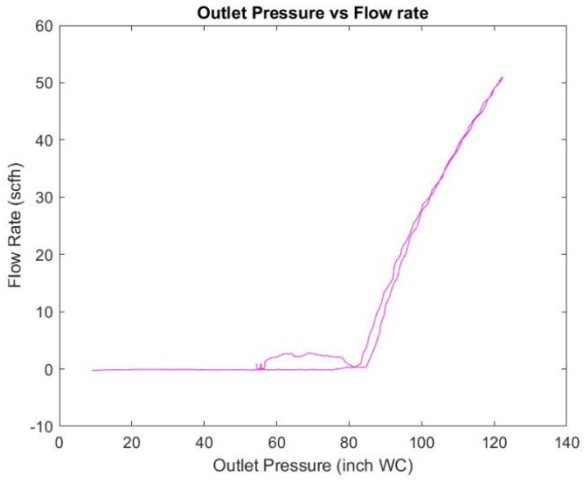
  The volume of total emissions in 185.37 seconds is 0.2424 scf.

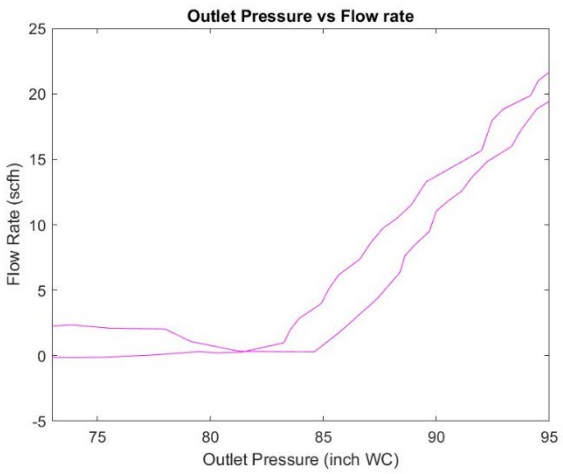
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 9.49 scfh.





136





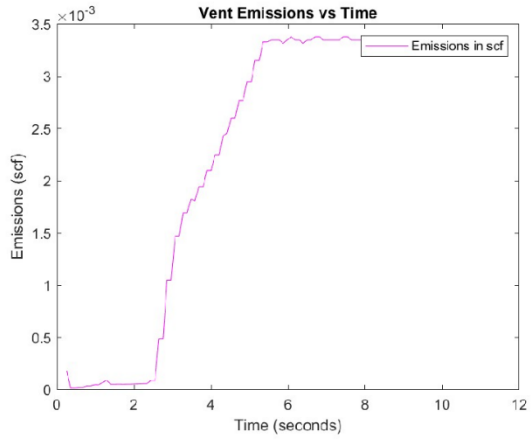
137

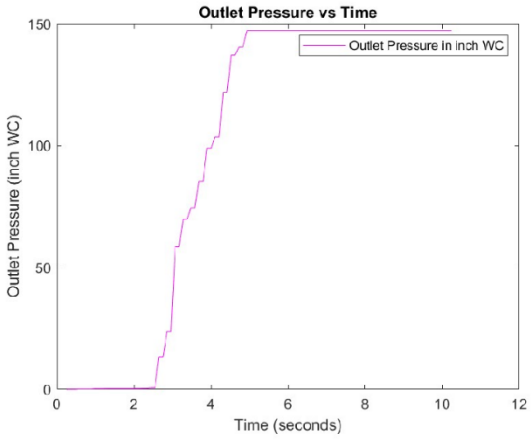
GTI ENERGY

- 222489-022_DT

The volume of total emissions in 10.24 seconds is 0.2155 scf.

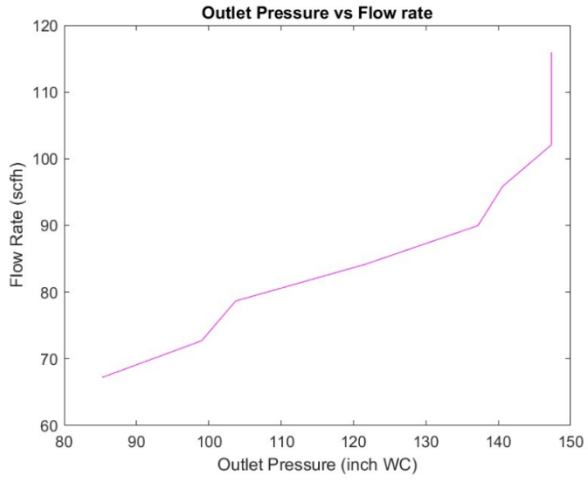
Commented [JW4]: Avg calculation out of range

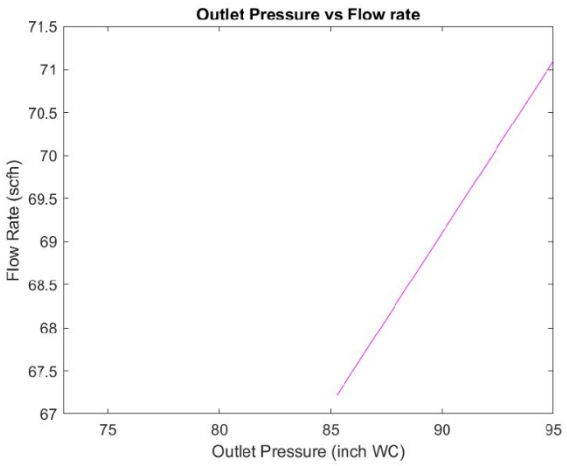




138

GTI ENERGY


Outlet Pressure vs Flow rate
Flow Rate (scfh)
120
110
100
90
80
70
60
80
90
100
110
120
130
140
150
Outlet Pressure (inch WC)

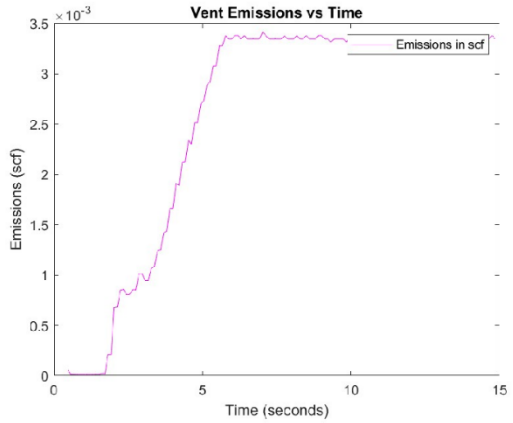

Outlet Pressure vs Flow rate
Flow Rate (scfh)
71.5
71
70.5
70
69.5
69
68.5
68
67.5
67
75
80
85
90
95
Outlet Pressure (inch WC)

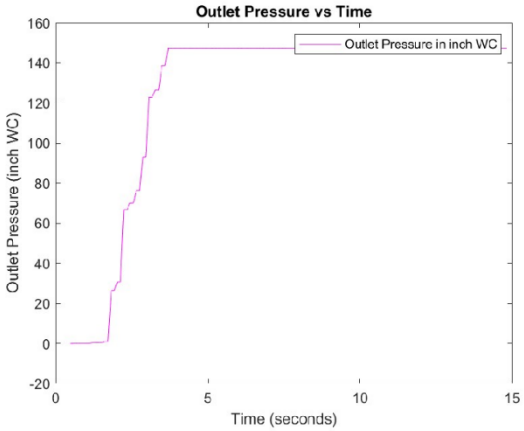
139

- 222489-022_LD

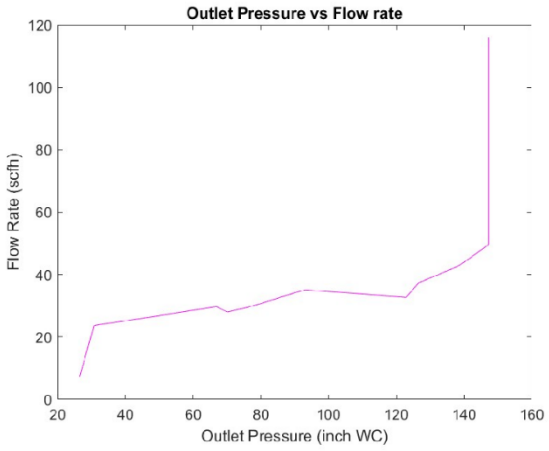
Commented [JW5]: Avg calculation out of range

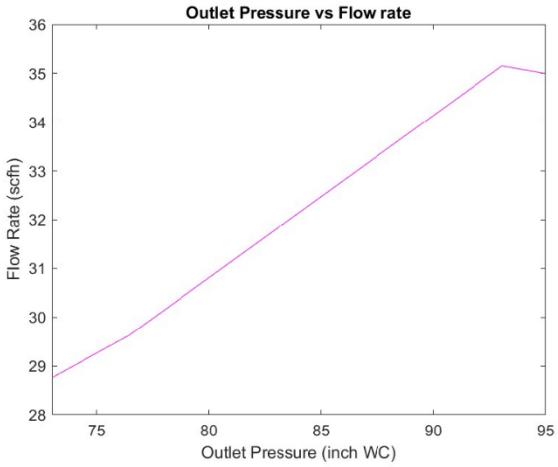
The volume of total emissions in 14.84 seconds is 0.3590 scf.





140

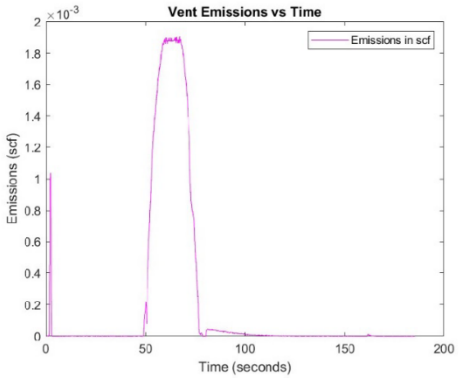


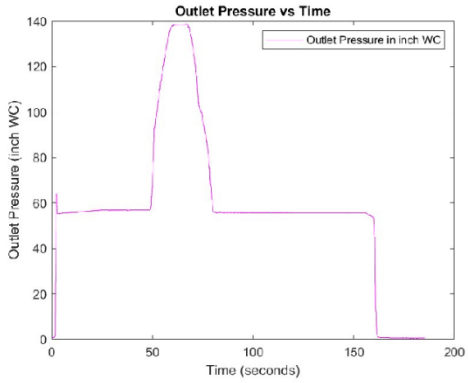


141

GTI ENERGY

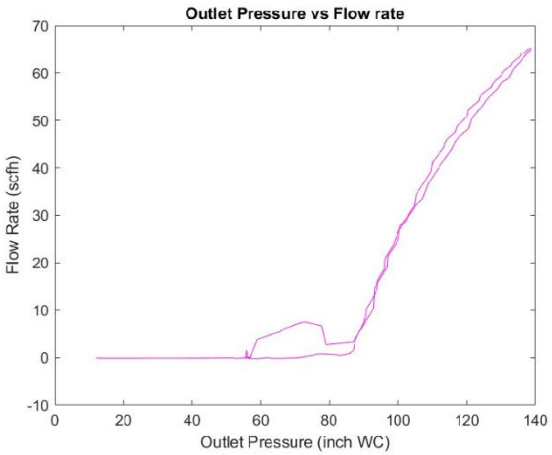
- **222489-023**
  The volume of total emissions in 185.41 seconds is 0.3738 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 5.81 scfh.

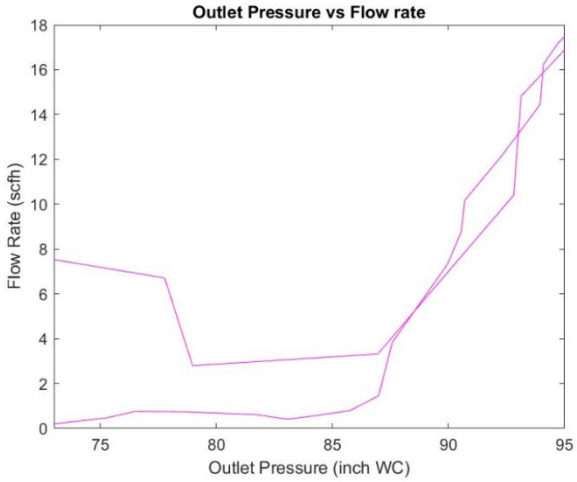




142

GTI ENERGY

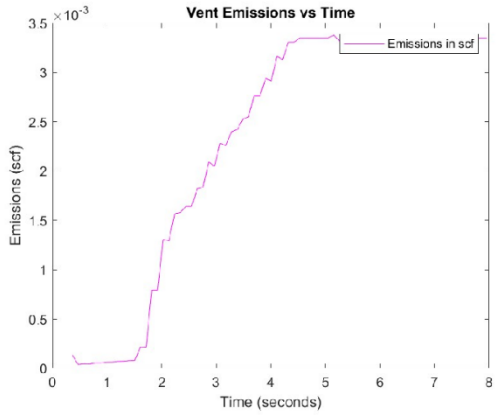


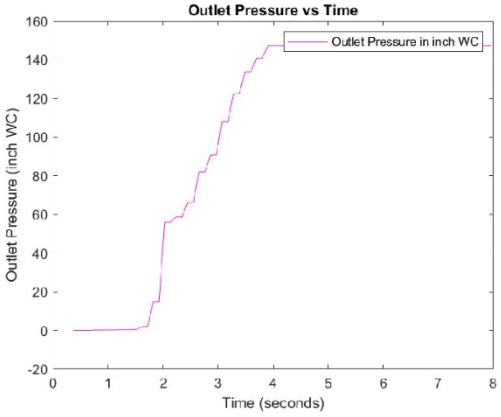


143

GTI ENERGY

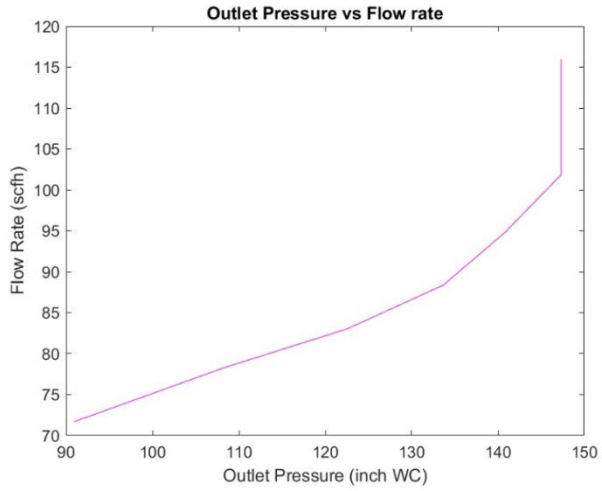
- **222489-023_DT**
  The volume of total emissions in 7.96 seconds is 0.1723 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 71.69 scfh.

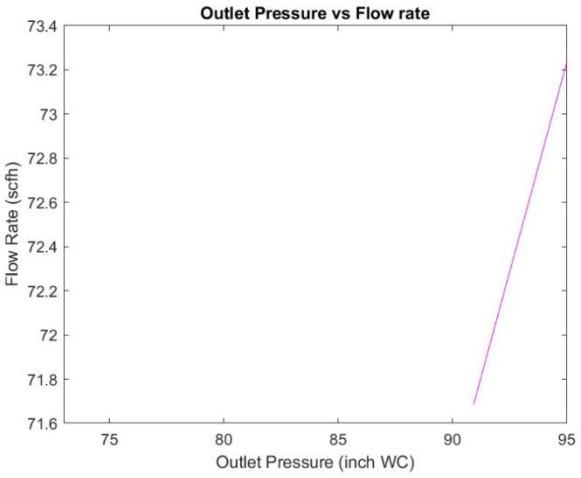




144

GTI ENERGY





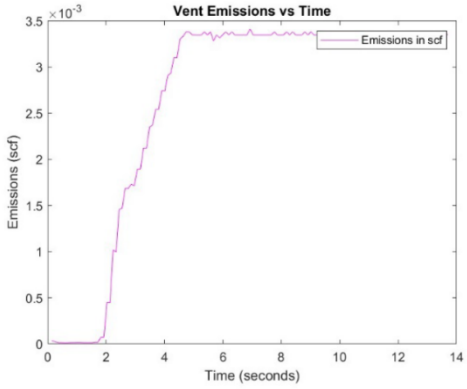
145

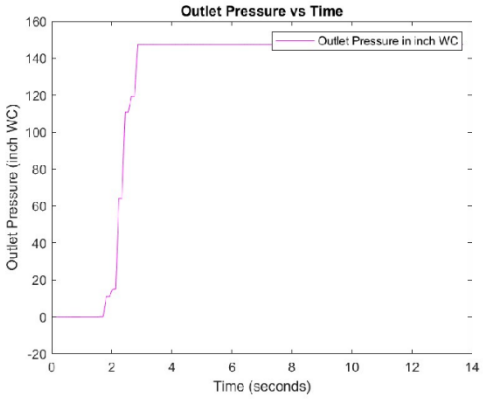
GTI ENERGY

- 222489-023_LD

Commented [JW6]: Avg calculation out of range

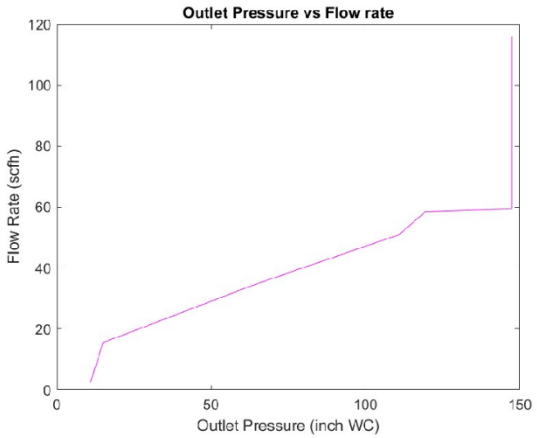
The volume of total emissions in 13.70 seconds is 0.3469 scf.

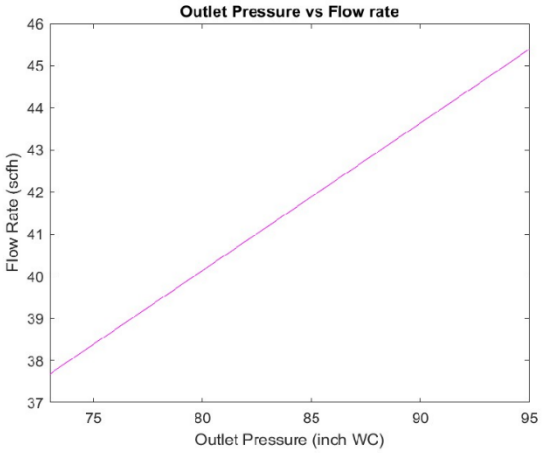




146

GTI ENERGY

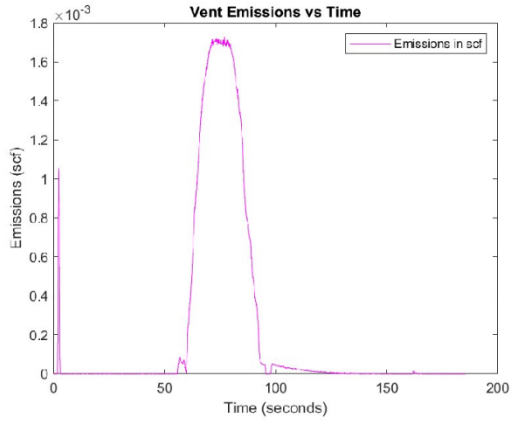


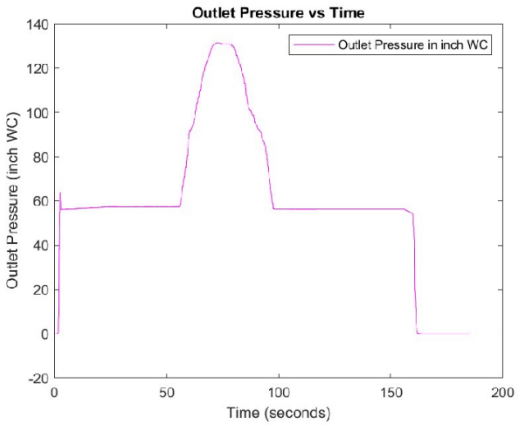


147

GTI ENERGY

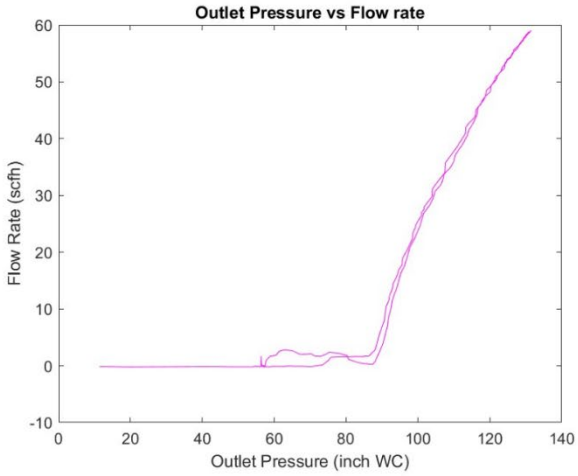
- **222489-024**
  The volume of total emissions in 185.44 seconds is 0.3920 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 4.02 scfh.

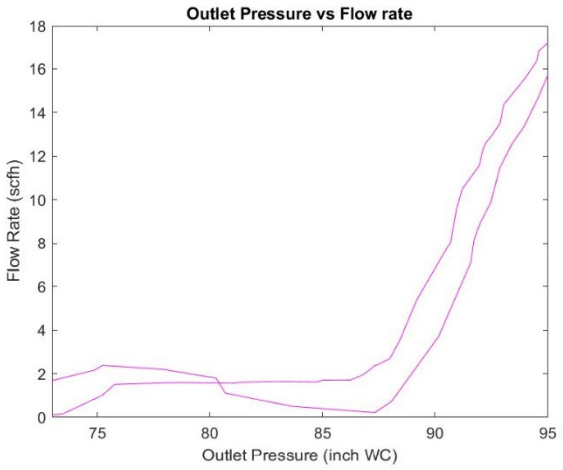




148

GTI ENERGY





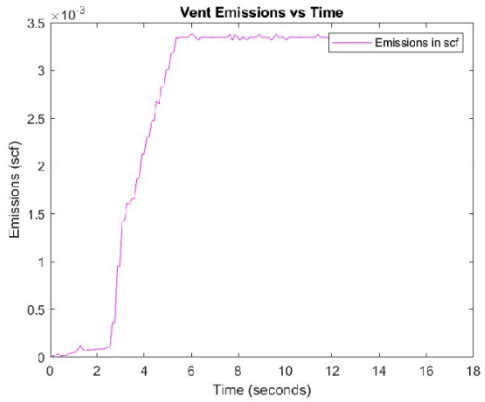
149

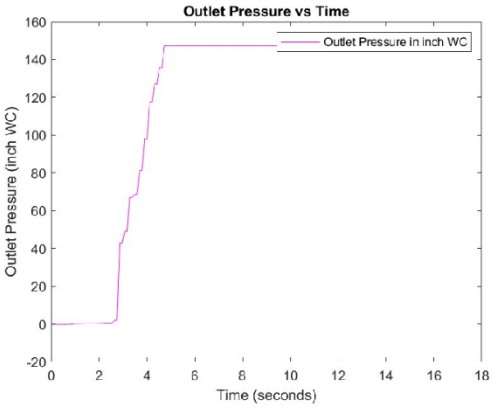
GTI ENERGY

- 222489-024_DT

The volume of total emissions in 16.07 seconds is 0.4029 scf.

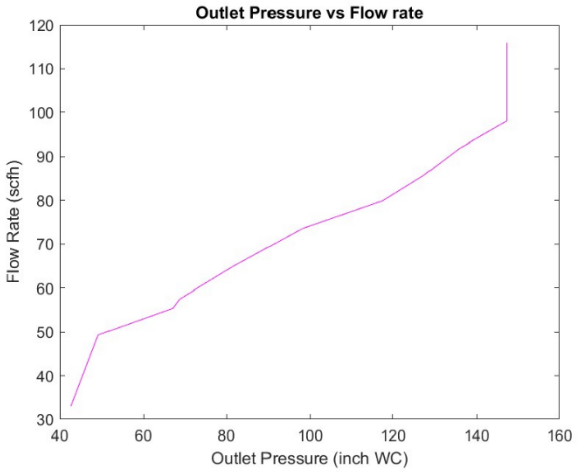
Commented [JW7]: Avg calculation out of range

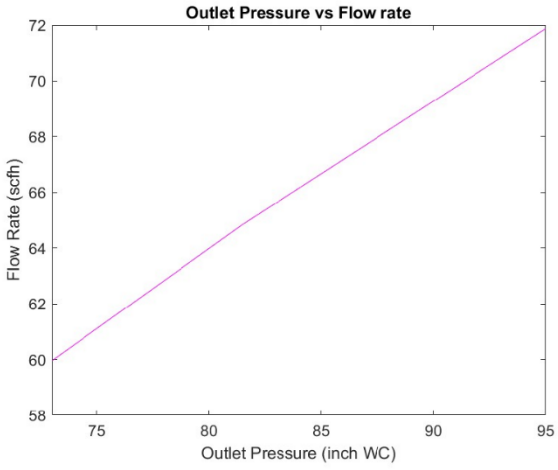




150

GTI ENERGY





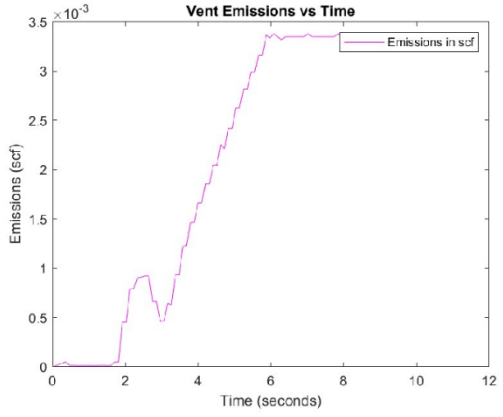
151

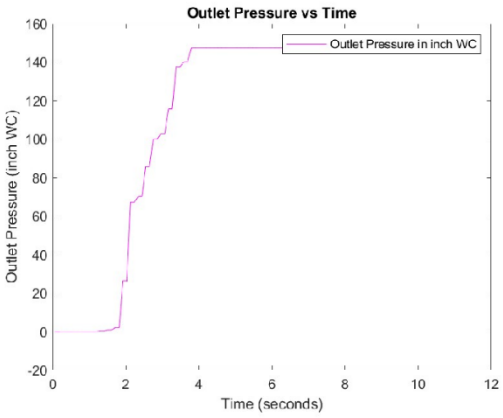
GTI ENERGY

- **222489-024_LD**

  The volume of total emissions in 10.87 seconds is 0.2252 scf.

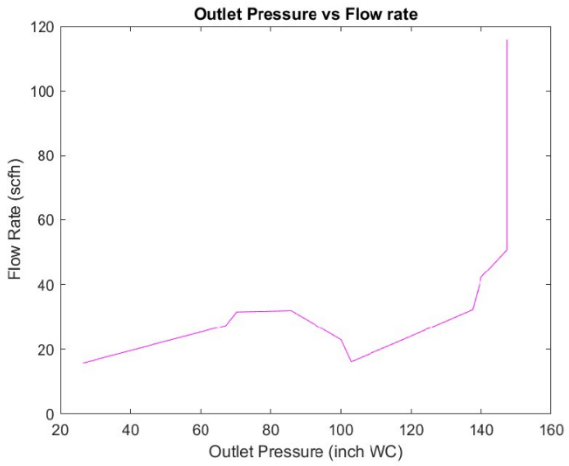
Commented [JW8]: Avg calculation out of range

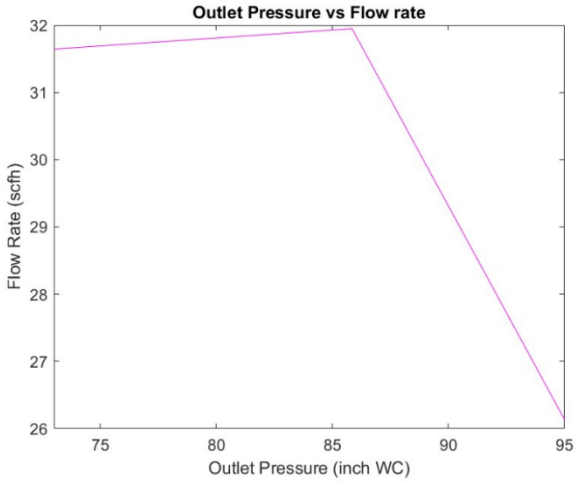




152

GTI ENERGY





153

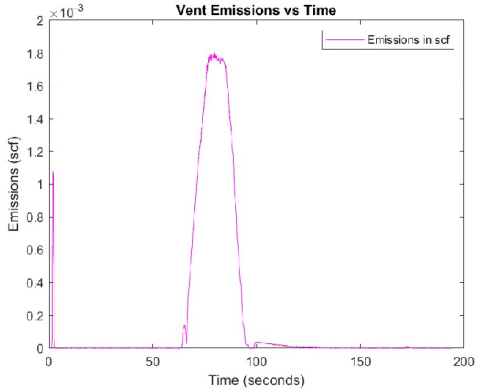
GTI ENERGY

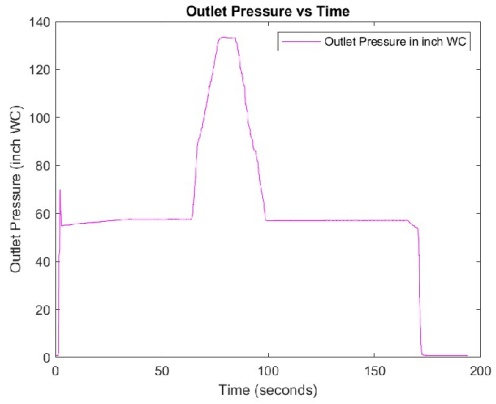
2-psig Outlet, 3/16" Orifice, 100-psig Inlet

- **222489-022**

  The volume of total emissions in 194.26 seconds is 0.3381 scf.

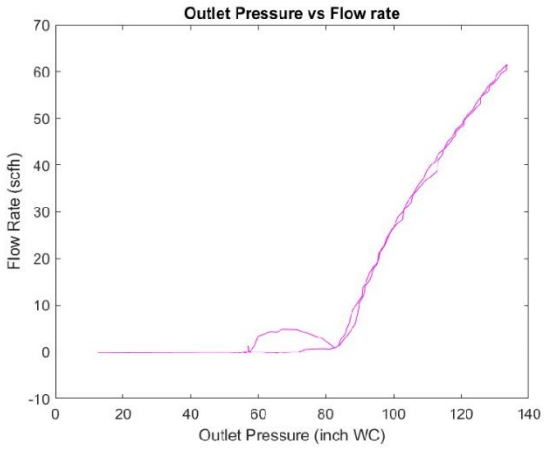
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 9.08 scfh.

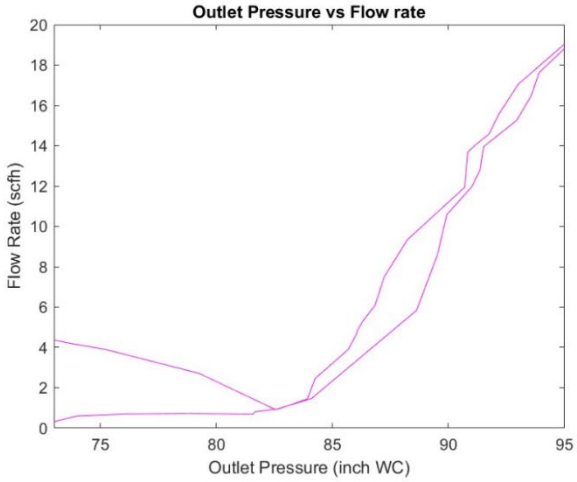




154

GTI ENERGY

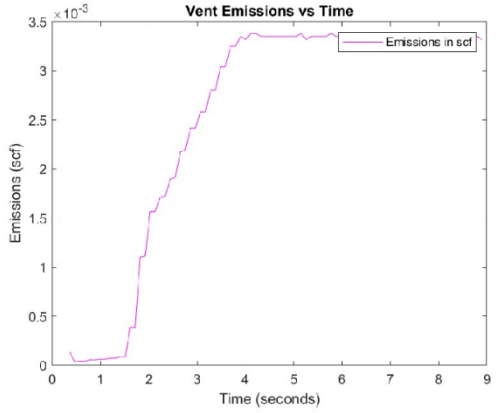


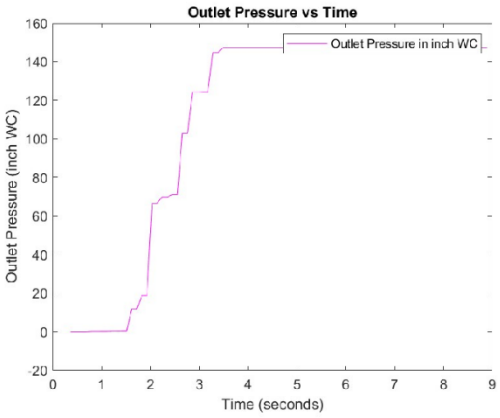


155

GTI ENERGY

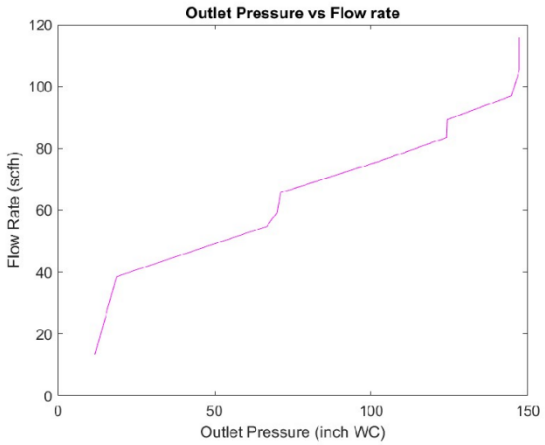
- **222489-022_DT**
  The volume of total emissions in 8.90 seconds is 0.2110 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 38.57 scfh.

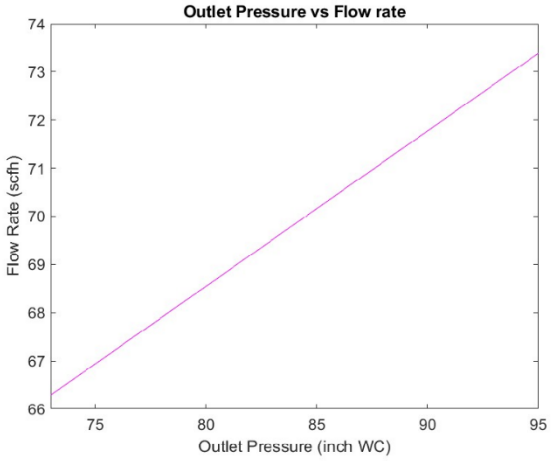




156

GTI ENERGY





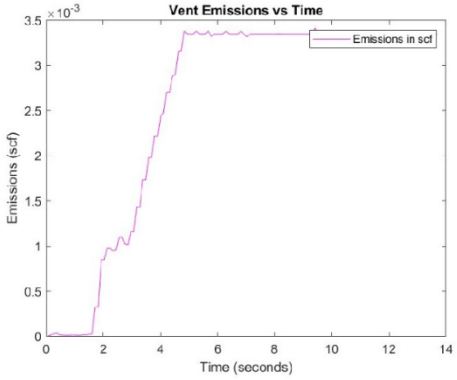
157

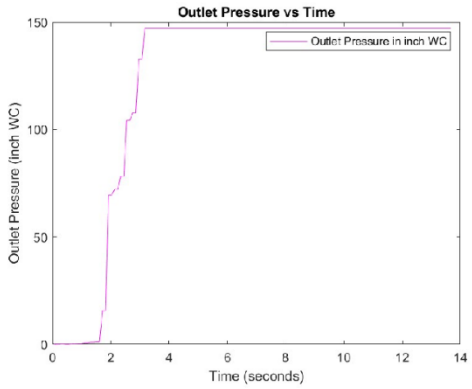
GTI ENERGY

- 222489-022_LD

Commented [JW9]: Avg calculation out of range

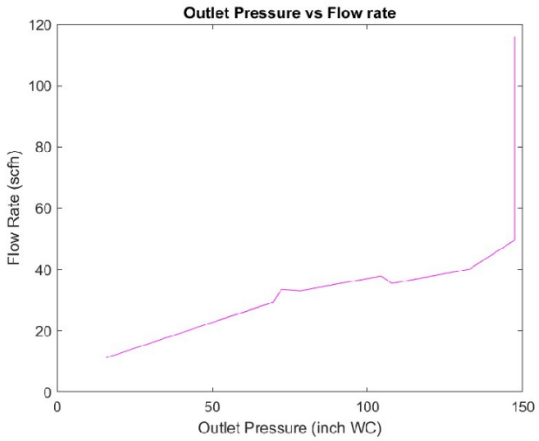
The volume of total emissions in 13.69 seconds is 0.3385 scf.

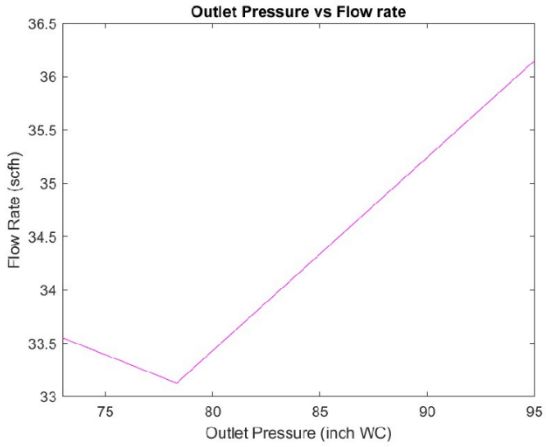




158

GTI ENERGY

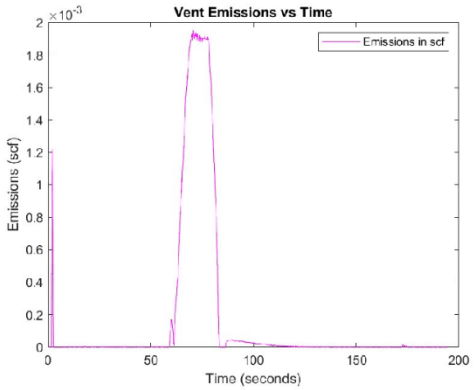


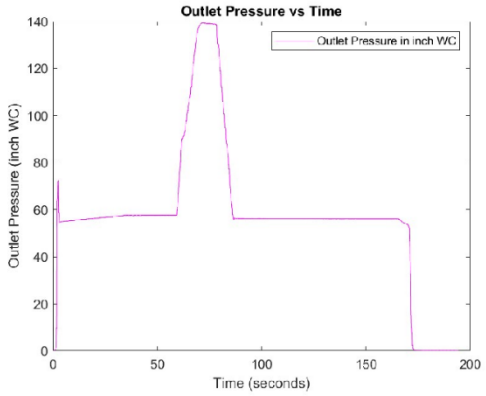


159

GTI ENERGY

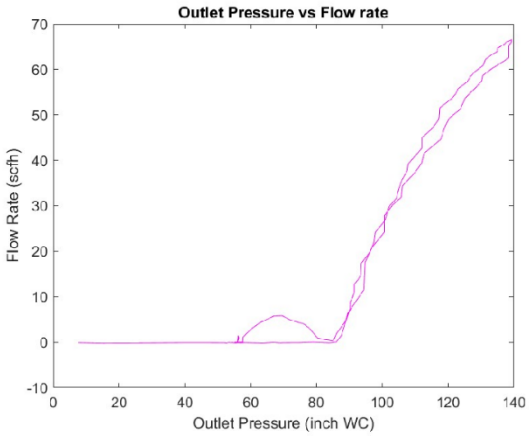
- **222489-023**
  The volume of total emissions in 194.41 seconds is 0.3134 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 4.87 scfh.

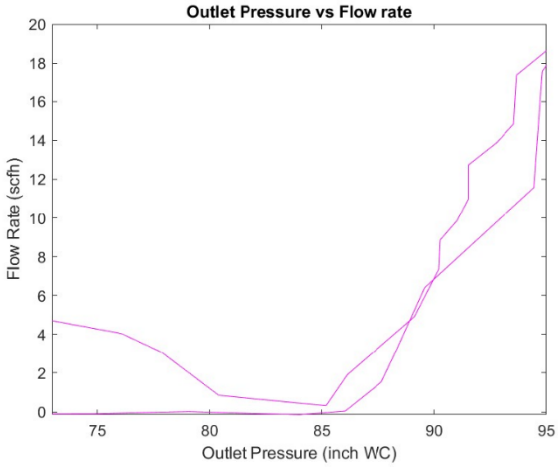




160

GTI ENERGY





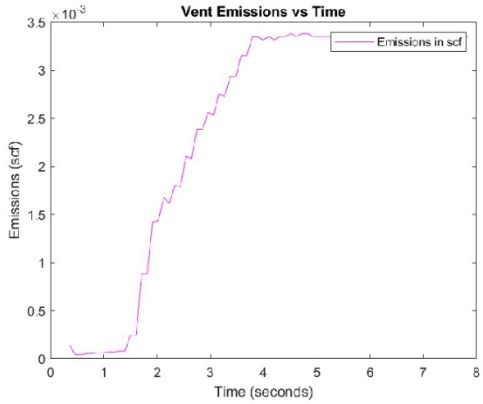
161

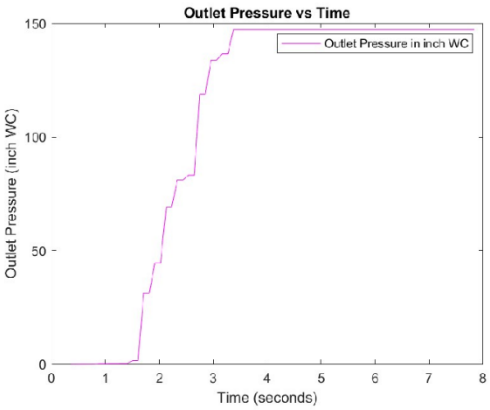
GTI ENERGY

- 222489-023_DT

Commented [JW10]: Avg calculation out of range

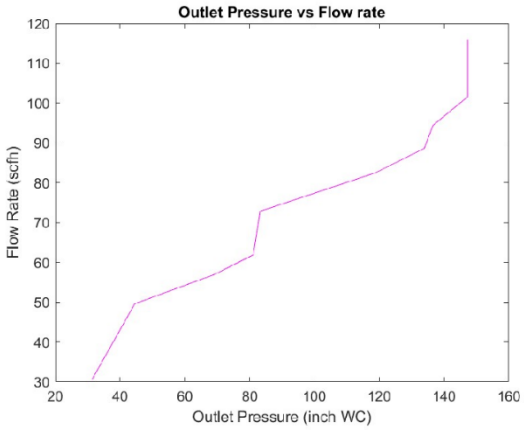
The volume of total emissions in 7.84 seconds is 0.1784 scf.

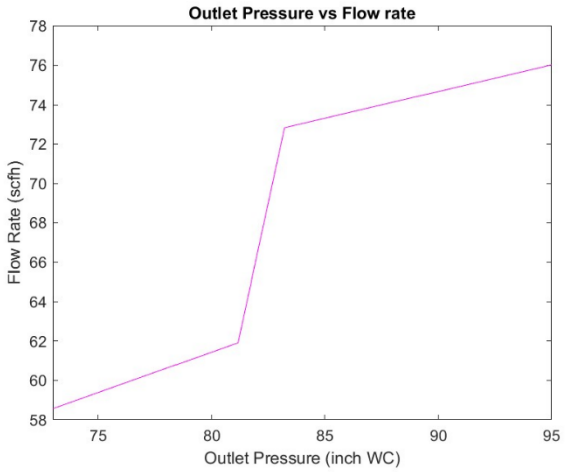




162

GTI ENERGY

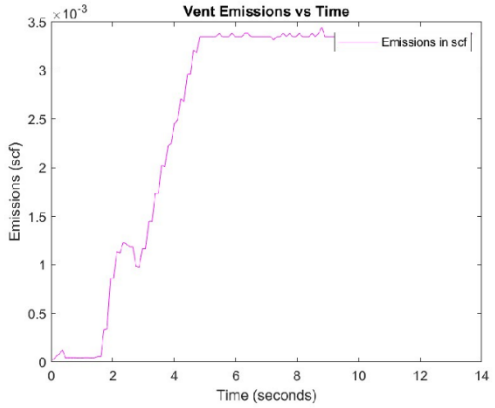


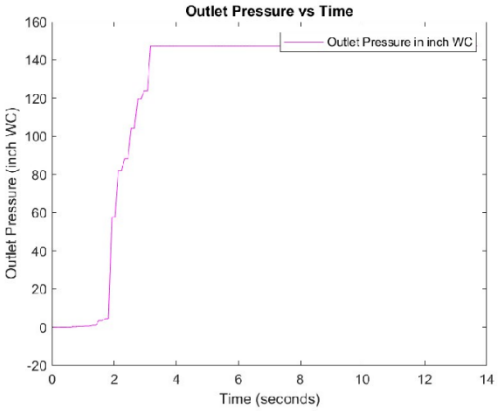


163

GTI ENERGY

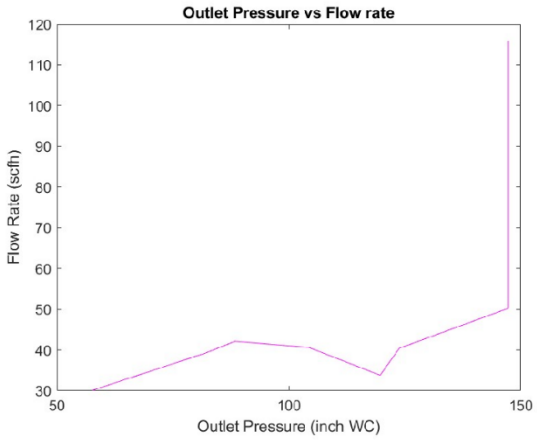
- **222489-023_LD**
  The volume of total emissions in 13.69 seconds is 0.3408 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 42.13 scfh.

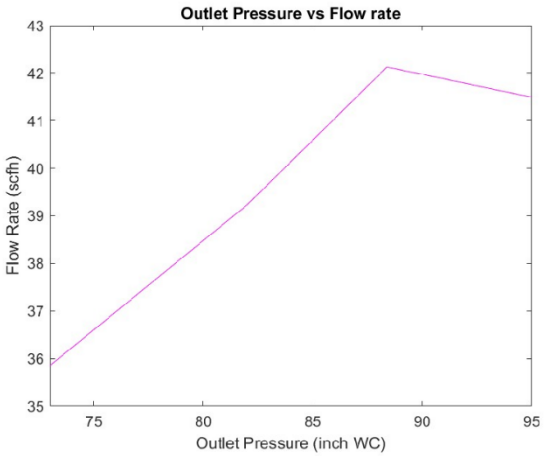




164

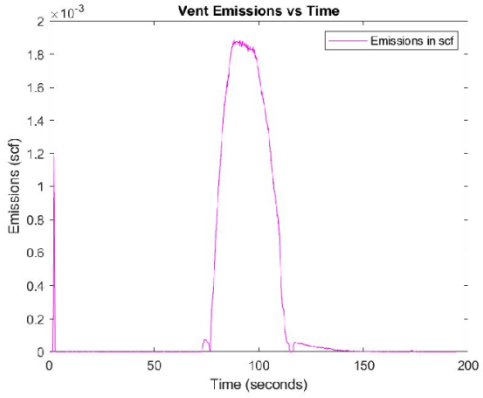
GTI ENERGY

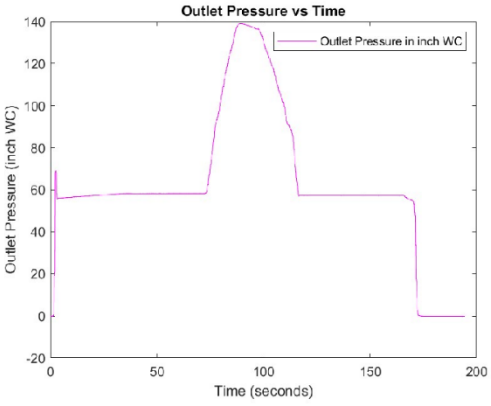

Outlet Pressure vs Flow rate
Flow Rate (scfh)
120
110
100
90
80
70
60
50
40
30
50
100
150
Outlet Pressure (inch WC)


Outlet Pressure vs Flow rate
Flow Rate (scfh)
43
42
41
40
39
38
37
36
35
75
80
85
90
95
Outlet Pressure (inch WC)

165

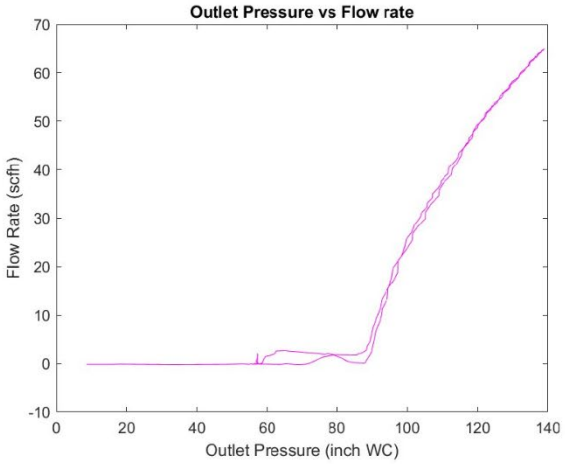
- **222489-024**
  The volume of total emissions in 194.43 seconds is 0.4826 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 5.12 scfh.

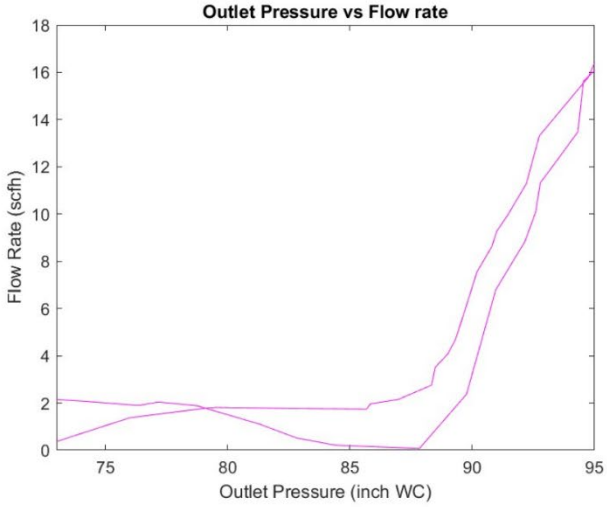




166

GTI ENERGY

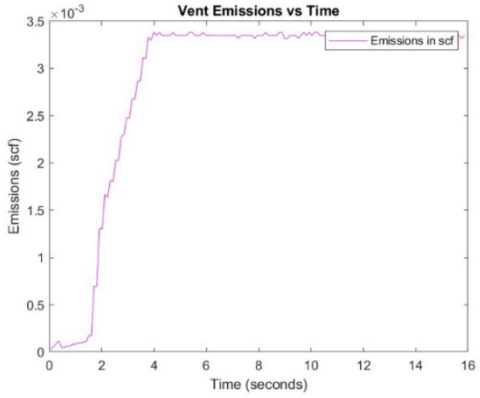


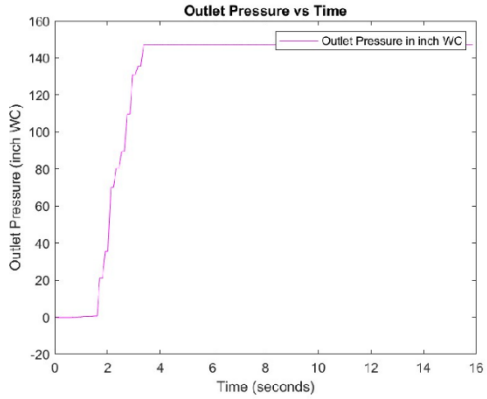


167

GTI ENERGY

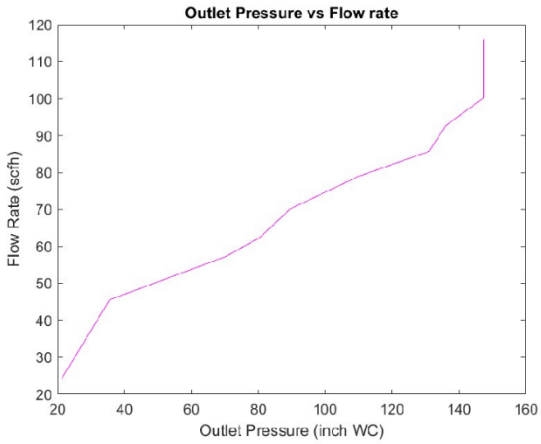
- **222489-024_DT**
  The volume of total emissions in 15.86 seconds is 0.4352 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 70.19 scfh.

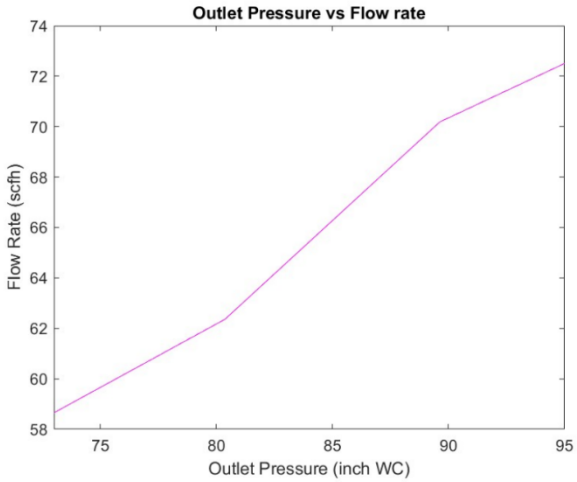




168

GTI ENERGY





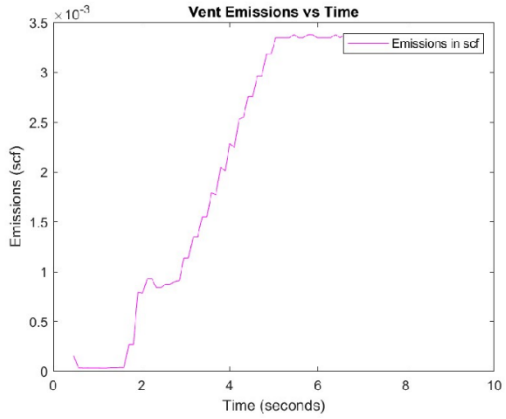
169

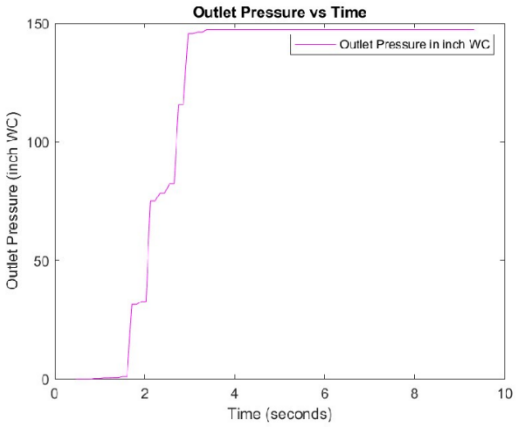
GTI ENERGY

- 222489-024_LD

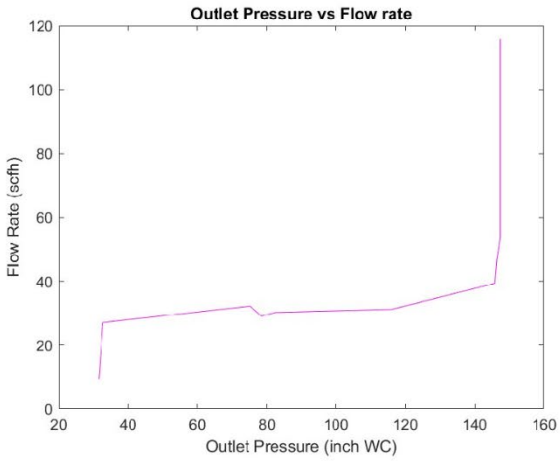
Commented [JW11]: Avg calculation out of range

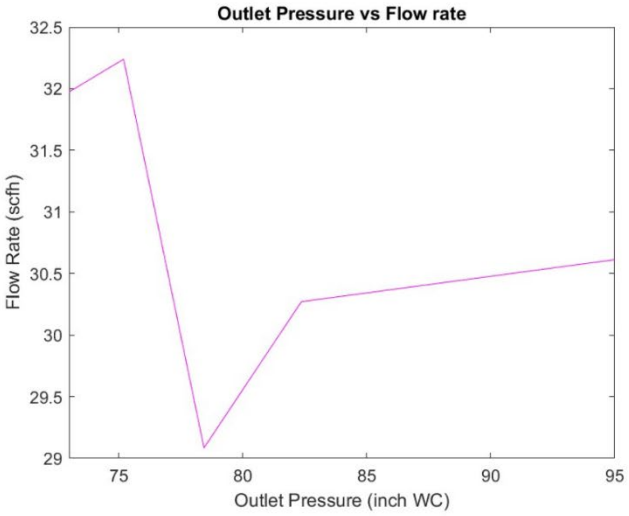
The volume of total emissions in 9.32 seconds is 0.1939 scf.





170



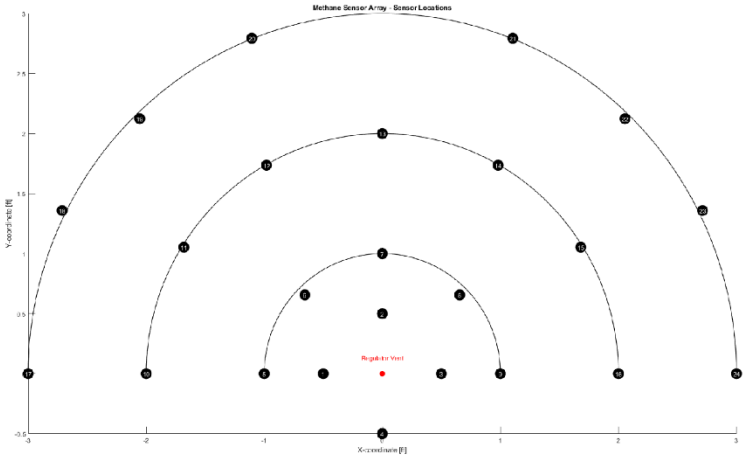


171

GTI ENERGY

Methane Concentration Maps

Sensor Locations

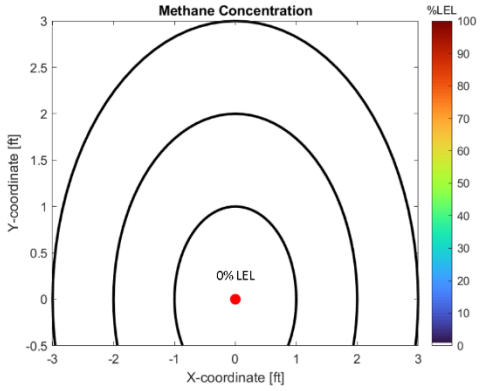


172

GTI ENERGY

7" WC

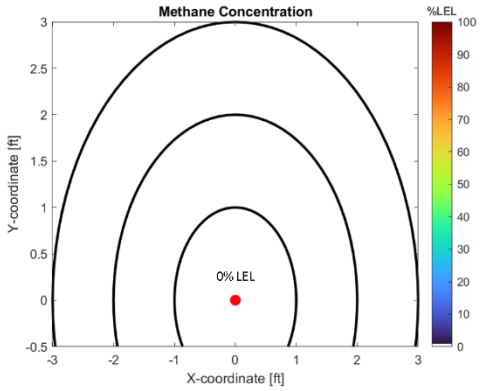
	7 in-WC	222489-020_multi lockup_sensor1 6in	Sigma = .3
IRV1	Normal Condition – Multi Lockup	Standard Array Configuration	6 in from vent



173

GTI ENERGY

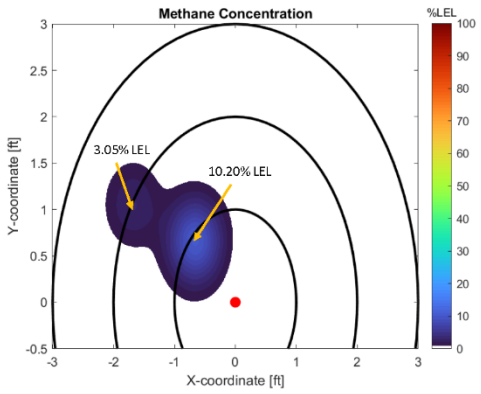
	7 in-WC	222489-020_multi lockup_sensor1 next to vent	Sigma = .3
IRV1	Normal Condition – Multi Lockup	Standard Array Configuration	1 in from vent



174

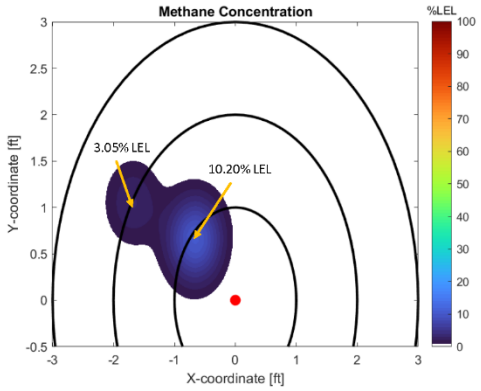
GTI ENERGY

	7 in-WC	222489-020_single lockup_sensor1 6in	Sigma = .3
IRV1	Normal Condition – Single Lockup	Standard Array Configuration	6 in from vent



175

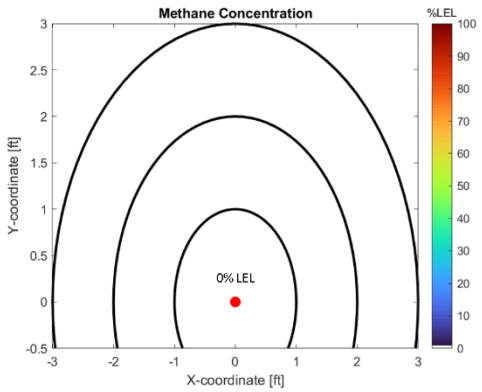
	7 in-WC	222489-020_single lockup_sensor1 next to vent	Sigma = .3
IRV1	Normal Condition – Single Lockup	Standard Array Configuration	1 in from vent



176

2-psig

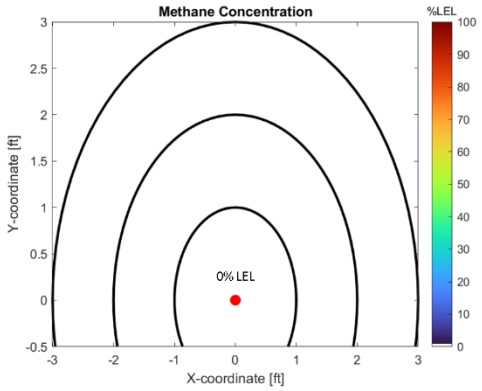
	2 PSI	222489-023_multi lockup_sensor1 6in	Sigma = .3
IRV1	Normal Condition – Multi Lockup	Standard Array Configuration	6 in from vent



177

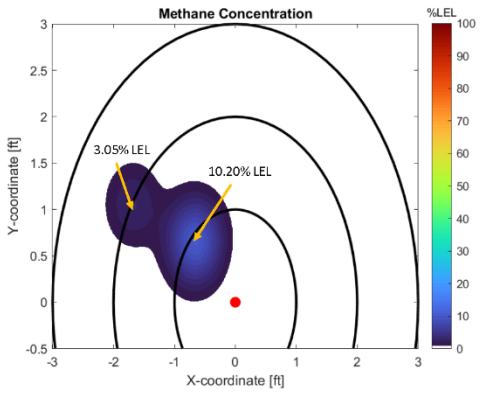
GTI ENERGY

	2 PSI	222489-023_multi lockup_sensor1 next to vent	Sigma = .3
IRV1	Normal Condition – Multi Lockup	Standard Array Configuration	1 in from vent



178

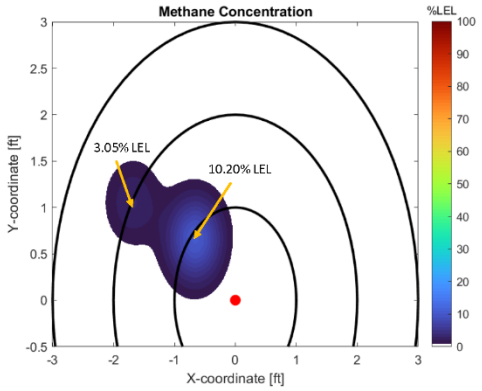
	2 PSI	222489-023_single lockup_sensor1 6in	Sigma = .3
IRV1	Normal Condition – Single Lockup	Standard Array Configuration	6 in from vent



179

GTI ENERGY

	2 PSI	222489-023_single lockup_sensor1 next to vent	Sigma = .3
IRV1	Normal Condition – Single Lockup	Standard Array Configuration	1 in from vent



180

Appendix F – IRV2 Manufacturer Test Data

GTI ENERGY
solutions that transform

REPORT
GTI ENERGY PROJECT NUMBER 23059

Comparison of Compact Service Regulators – Results of Testing

IRV2 Summary

GTI Energy Technical Contact:
Joe Carlstrom
Joseph Irwin, PE
Tom Bates
Jake Witecha

1700 S. Mount Prospect Rd.
Des Plaines, Illinois 60018
www.gti.energy

Introduction

This report was created to review data obtained during PHMSA project 693JK32110001 and OTD project 5.22.j - Design and Placement of Compact Service Regulators with subject matter experts from the manufacturer. The following Part 1 and Part 2 matrix outlines the test methodology used to obtain data for analysis purposes for safe clearance distances.

Part 1 Test methodology

All testing was performed on the rig with air and software formula coefficients for natural gas.

Test	Standard/Procedure reference	Conditions	Test Criteria	Parameters
Modified Lock-Up Test	ANSI B109.4 -[5.3.5]	Temperature: Ambient; Inlet pressure: 10, 60, 100 psig; Flow: 100, 200, 300, until maximum manufacturer specifications [SCFH Air]	Outlet pressure Max 9"±0.5 iwc 2.15±0.15 psig (2psig reg.)	Lock up [iwc]
			Flow rate at vent 2.5 SCFH (vent limited) 100 SCFH (IRV)	Vent flow rate [SCFH]
Modified Relief Point Test	ANSI B109.4 -[5.3.8]	Temperature: Ambient; Inlet pressure: 10, 60, 100 psig; Outlet pressure: slowly increase until slam shut closes or maximum allowable pressure reached	Outlet pressure MAX 17"±0.5 iwc; 3.3±0.15iwc psig (2psig reg.)	Relief point [iwc]
			Flow rate at vent 2.5 SCFH (vent limited) 100 SCFH (IRV)	Vent flow rate [SCFH]

Part 2 Test Methodology

Testing was performed in an enclosed and controlled environment with natural gas. Safety rules were implemented to monitor and limit the amounts of natural gas. When an accumulation of natural gas greater than 100% LEL was detected by multiple sensors the natural gas source was terminated and the test concluded.

Single Lock-Up Test	ANSI B109.4 - [5.3.5]	**Temperature**: Ambient; **Inlet pressure**: 60 psig; **Flow Rate**: 390 SCFH (7 iwc reg.) 1260 SCFH (2 psig reg.) **Lockup condition**: One lock up induced, wait 30 seconds for gas concentration dissipate to 0% LEL, repeat 10 times.	Outlet pressure Max 9"±0.5 iwc (7 iwc reg.) 2.15±0.15 psig (2psig reg.)	Lock up pressure [iwc]
			Methane concentration at vent 0%LEL (vent limited) 3%LEL (IRV)	Methane Concentration [% LEL]
Multi Lock-Up Test	ANSI B109.4 - [5.3.5]	**Temperature**: Ambient; **Inlet pressure**: 60 psig; **Flow Rate**: 390 SCFH (7 iwc reg.) 1260 SCFH (2 psig reg.) **Lockup condition**: Two lock ups induced in quick succession, wait 30 seconds for gas concentration dissipate to 0%LEL, repeat 3 times, after 3 repetitions increase the number of lockups by 1 to a maximum of 4.	Outlet pressure Max 9"±0.5 iwc (7 inW/C reg.) 2.15±0.15 psig (2psig reg.)	Lock up pressure [inW/C]
			Methane concentration at vent 0%LEL (vent limited) 3%LEL (IRV)	Methane Concentration [% LEL]

GTI ENERGY

Summary

Modified Lockup Tests

Average Emission Rate [SCFH], Normal Conditions, 7" WC

Model	10-psig inlet	60-psig inlet	100-psig inlet
IRV2	0.3784	0.1458	0.1460

Average Emission Rate [SCFH], Primary Diaphragm Tear, 7" WC

Model	10-psig inlet	60-psig inlet	100-psig inlet
IRV2	21.7961	24.3462	23.7980

Average Emission Rate [SCFH], Lever Disconnect, 7" WC

Model	10-psig inlet	60-psig inlet	100-psig inlet
IRV2	51.3911	84.7076	N/A*

*Flow rate exceeded flow meter range

Average Emission Rate [SCFH], Normal Conditions, 2-psig

Model	10-psig inlet	60-psig inlet	100-psig inlet
IRV2	0.4370	0.2488	0.2157

Average Emission Rate [SCFH], Primary Diaphragm Tear, 2-psig

Model	10-psig inlet	60-psig inlet	100-psig inlet
IRV2	5.5616	1.9925	1.6050

Average Emission Rate [SCFH], Lever Disconnect, 2-psig

Model	10-psig inlet	60-psig inlet	100-psig inlet
IRV2	39.9689	90.5385	N/A*

*Flow rate exceeded flow meter range

Relief Tests

Average Emission Rate [SCFH], Normal Conditions, 7" WC

Model	10-psig inlet	60-psig inlet	100-psig inlet
IRV2	8.2533	7.7933	7.6500

Average Emission Rate [SCFH], Primary Diaphragm Tear, 7" WC

Model	10-psig inlet	60-psig inlet	100-psig inlet
IRV2	NA*	NA*	11.5850

*Flow rate exceeded flow meter range

Average Emission Rate [SCFH], Lever Disconnect, 7" WC

Model	10-psig inlet	60-psig inlet	100-psig inlet
IRV2	NA*	N/A*	N/A*

*Flow rate exceeded flow meter range

Average Emission Rate [SCFH], Normal Conditions, 2-psig

Model	10-psig inlet	60-psig inlet	100-psig inlet
IRV2	10.5533	10.2067	10.8533

Average Emission Rate [SCFH], Primary Diaphragm Tear, 2-psig

Model	10-psig inlet	60-psig inlet	100-psig inlet
IRV2	12.0633	12.9600	11.5100

Average Emission Rate [SCFH], Lever Disconnect, 2-psig

Model	10-psig inlet	60-psig inlet	100-psig inlet
IRV2	16.3200	N/A*	N/A*

*Flow rate exceeded flow meter range

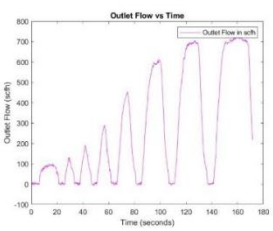
Modified Lockup Tests

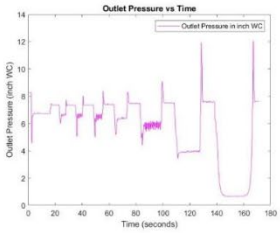
7" WC Outlet, 3/16" Orifice, 10-psig Inlet

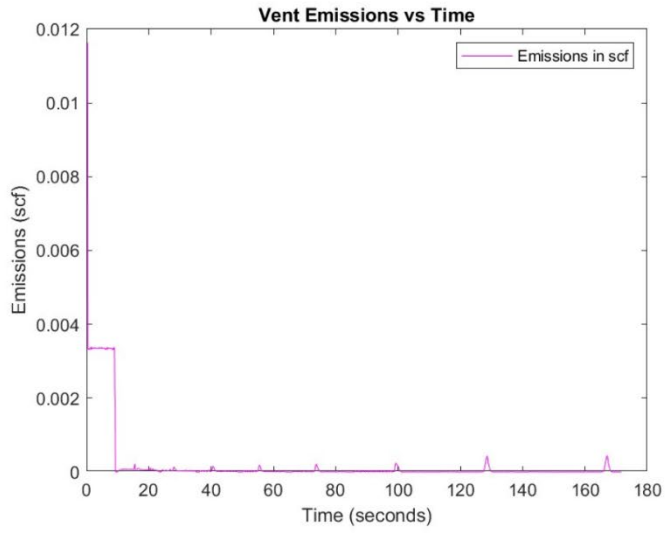
- 222489-001

The volume of total emissions in 171.66 seconds is 0.3281 scf.

The flow rate of emissions is 6.8816 scfh.







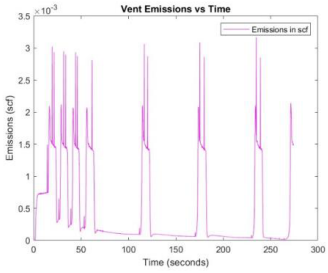
7

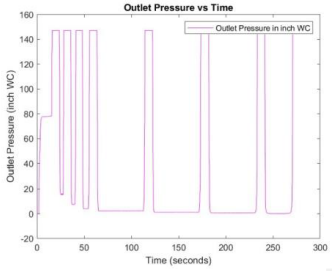
GTI ENERGY

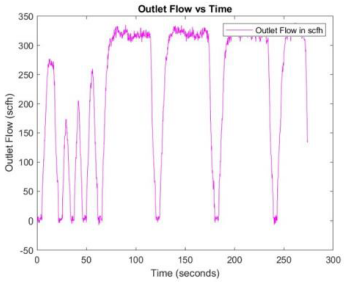
- 222489-001-DT

The volume of total emissions in 274.18 seconds is 1.1846 scf.

The flow rate of emissions is 15.5546 scfh.







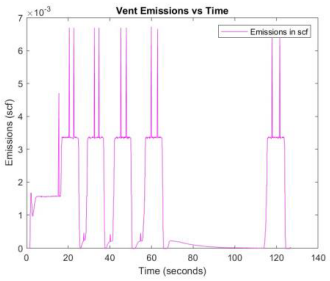
8

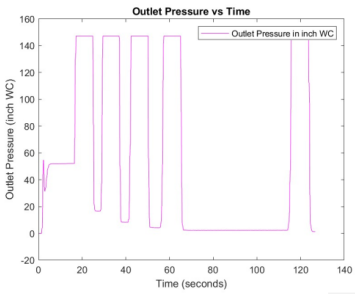
GTI ENERGY

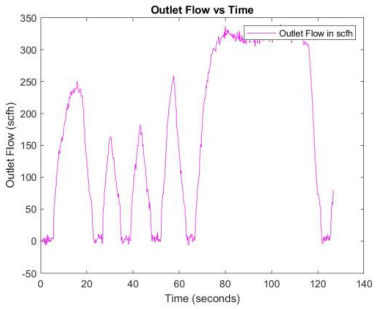
- 222489-001-LD

The volume of total emissions in 126.72 seconds is 1.6541 scf.

The flow rate of emissions is 46.9904 scfh.



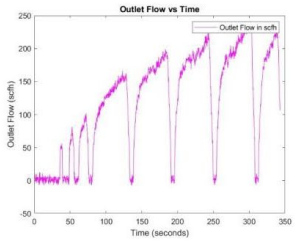


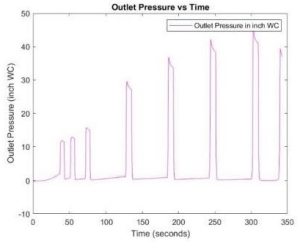


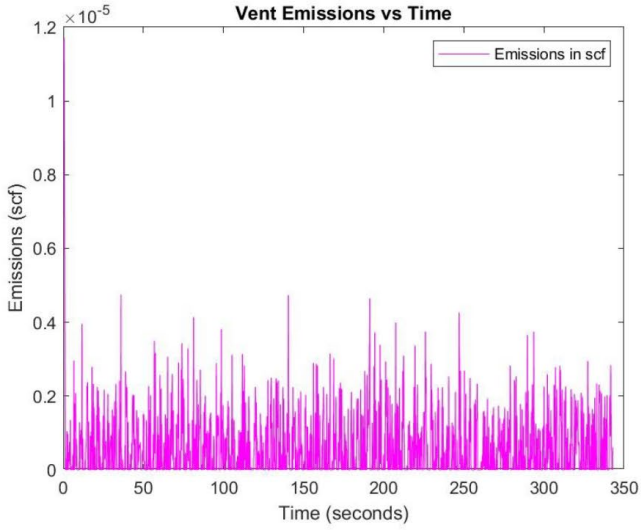
9

GTI ENERGY

- 222489-001-BV
  The volume of total emissions in 343.01 seconds is 0.0020 scf.
  The flow rate of emissions is 0.0215 scfh.



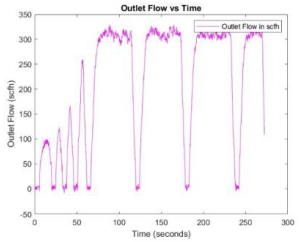


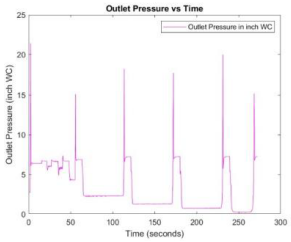


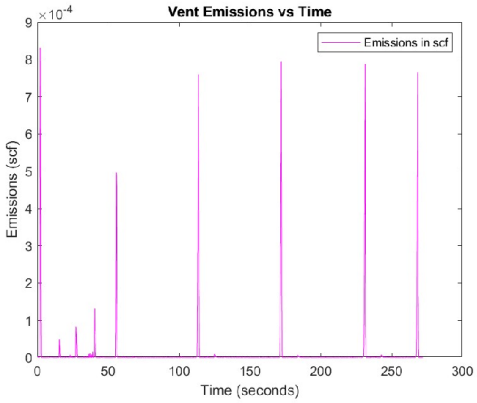
10

GTI ENERGY

- 222489-002
  The volume of total emissions in 272.42 seconds is 0.0295 scf.
  The flow rate of emissions is 0.3900 scfh.



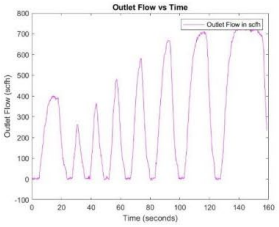


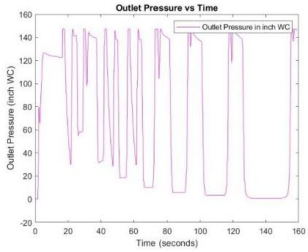


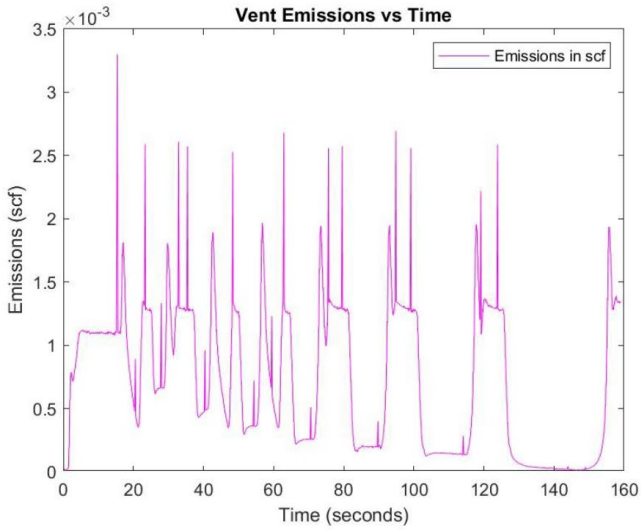
11

GTI ENERGY

- 222489-002-DT
  The volume of total emissions in 158.90 seconds is 1.0795 scf.
  The flow rate of emissions is 24.4568 scfh.



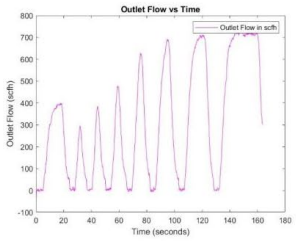


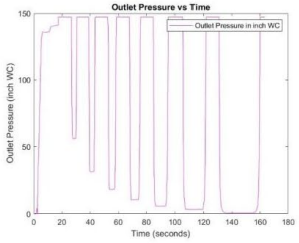


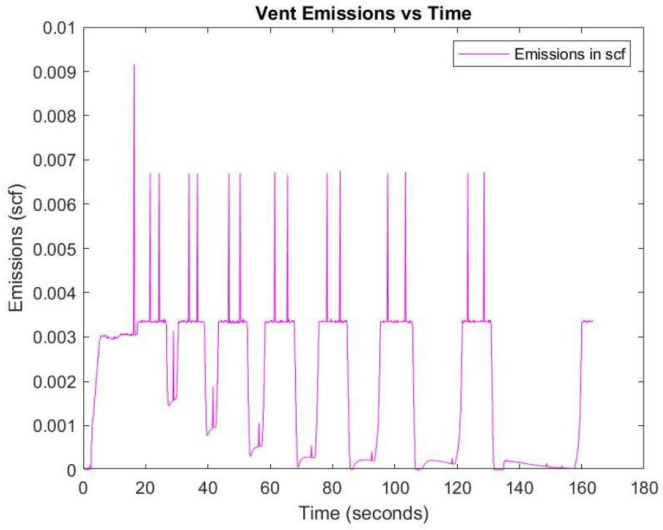
12

GTI ENERGY

- 222489-002-LD
  The volume of total emissions in 163.53 seconds is 2.9636 scf.
  The flow rate of emissions is 65.2415 scfh.



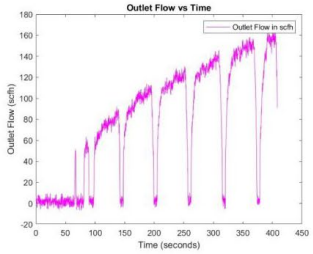


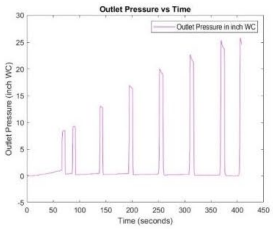


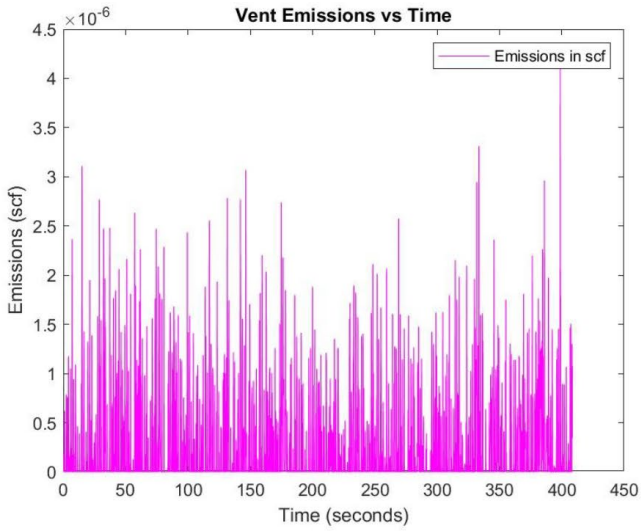
13

GTI ENERGY

- 222489-002-BV
  The volume of total emissions in 408.69 seconds is 0.0011 scf.
  The flow rate of emissions is 0.0099 scfh.



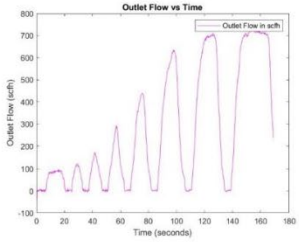


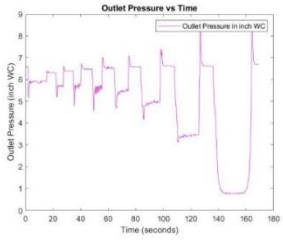


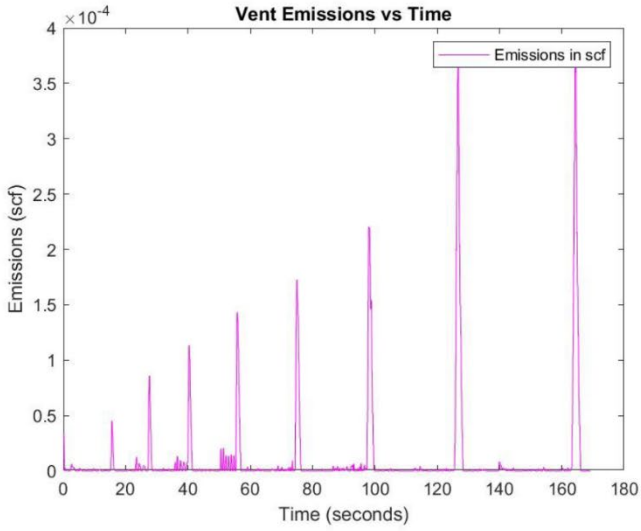
14

GTI ENERGY

- 222489-003
  The volume of total emissions in 169.22 seconds is 0.0172 scf.
  The flow rate of emissions is 0.3668 scfh.

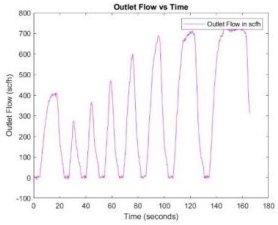


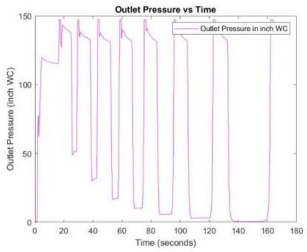


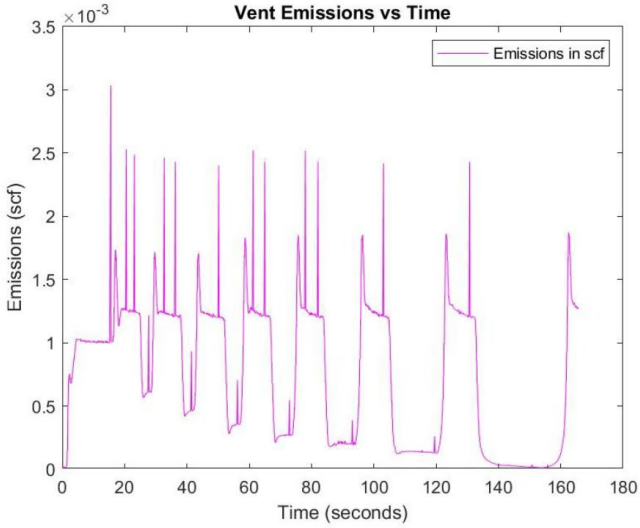


GTI ENERGY

- 222489-003-DT
  The volume of total emissions in 165.73 seconds is 1.1683 scf.
  The flow rate of emissions is 25.3768 scfh.



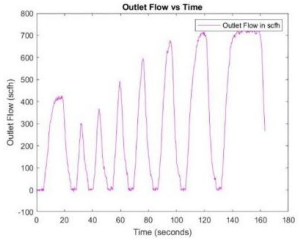


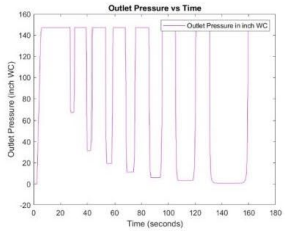


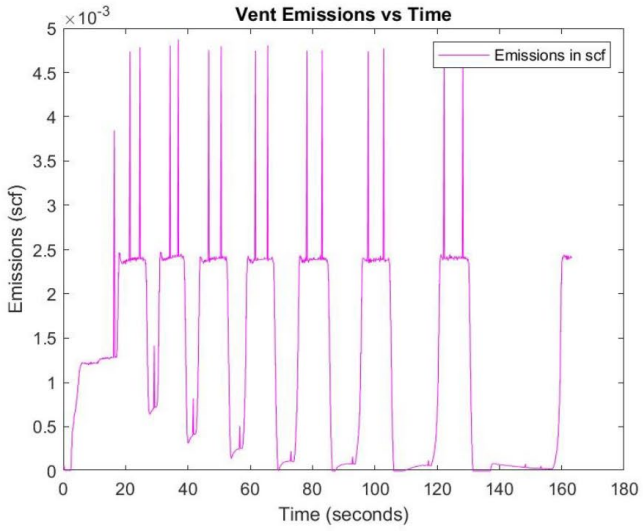
16

GTI ENERGY

- 222489-003-LD
  The volume of total emissions in 163.15 seconds is 1.9007 scf.
  The flow rate of emissions is 41.9414 scfh.

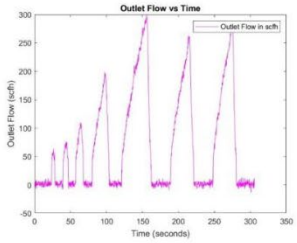


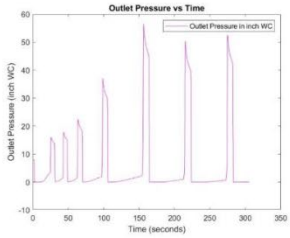


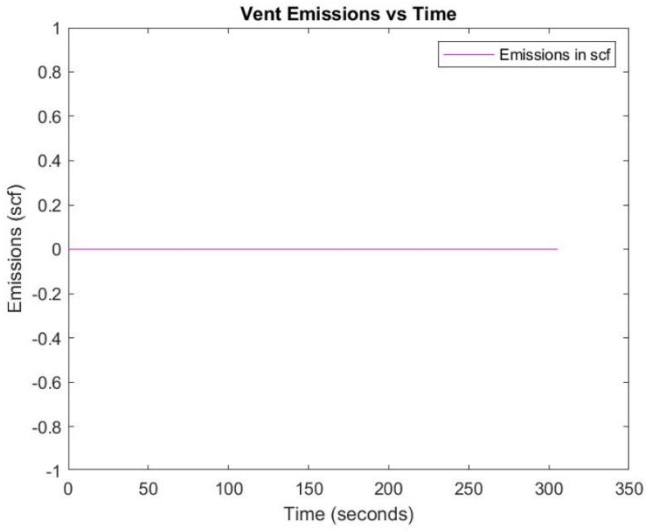


GTI ENERGY

- 222489-003-BV
  The volume of total emissions in 305.50 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.







18

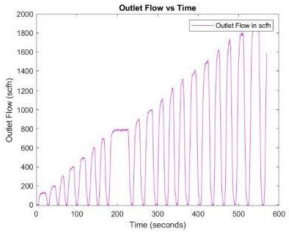
GTI ENERGY

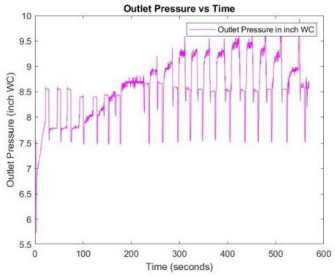
7" WC Outlet, 3/16" Orifice, 60-psig Inlet

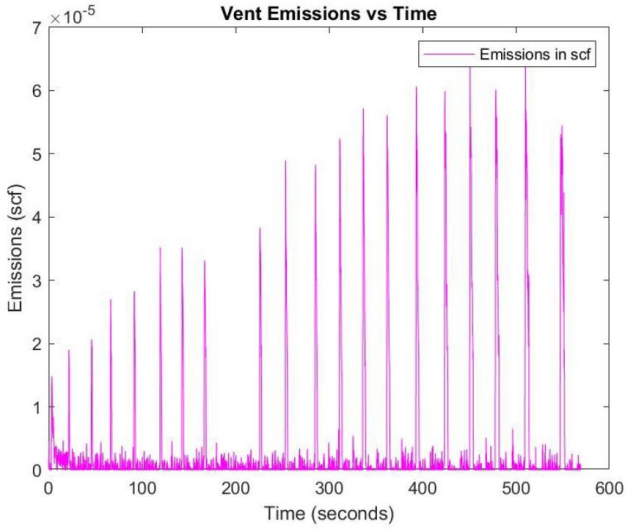
- 222489-001

The volume of total emissions in 567.82 seconds is 0.0404 scf.

The flow rate of emissions is 0.2562 scfh.

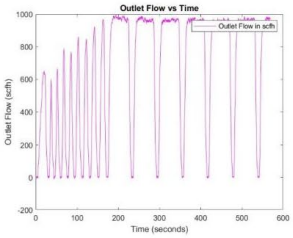


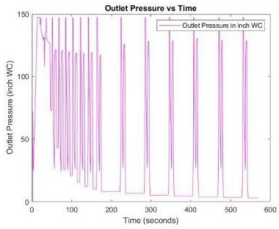


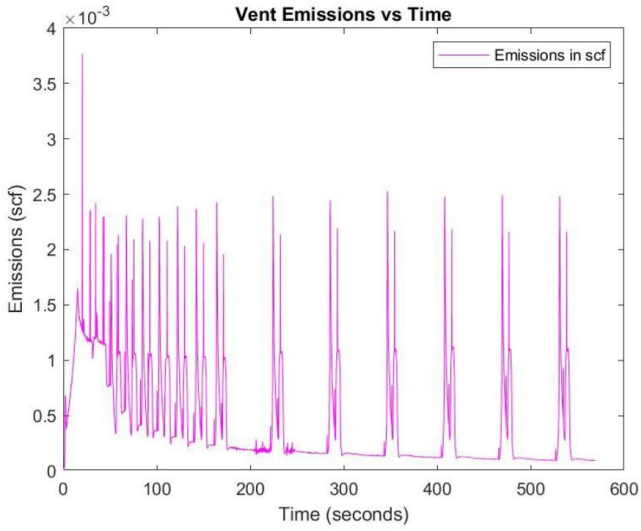


GTI ENERGY

- 222489-001-DT
  The volume of total emissions in 569.02 seconds is 2.4107 scf.
  The flow rate of emissions is 15.2520 scfh.



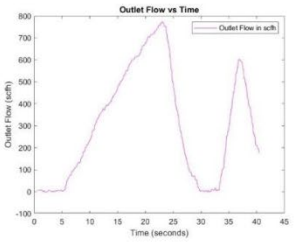


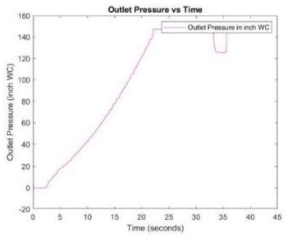


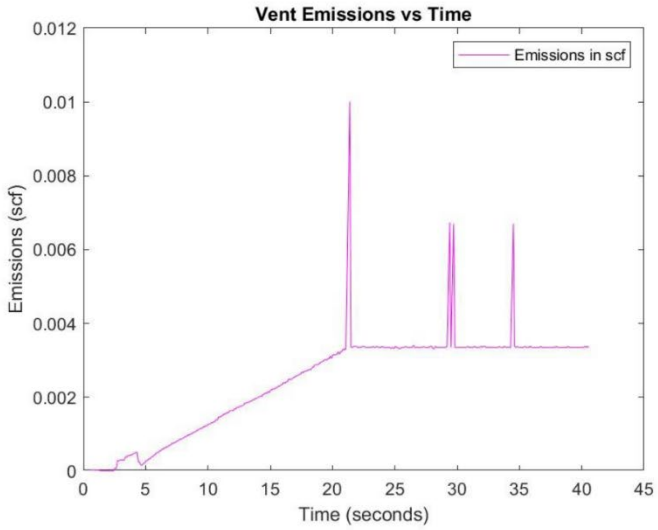
- 222489-001-LD

GTI ENERGY

The volume of total emissions in 40.55 seconds is 0.9180 scf.
The flow rate of emissions is 81.4968 scfh.





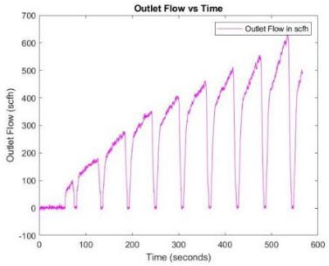


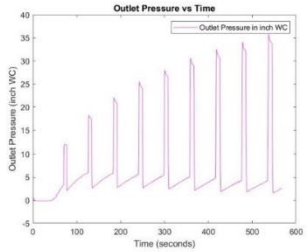
- 222489-001-BV

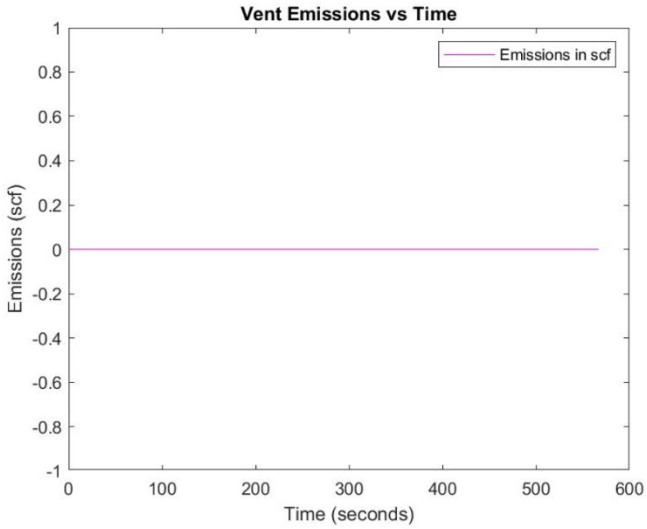
GTI ENERGY

The volume of total emissions in 566.93 seconds is 0.0000 scf.

The flow rate of emissions is 0.0000 scfh.







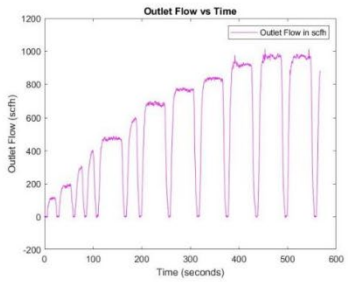
22

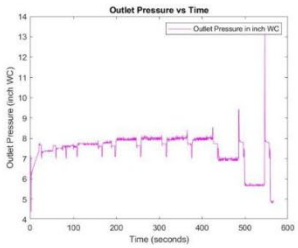
GTI ENERGY

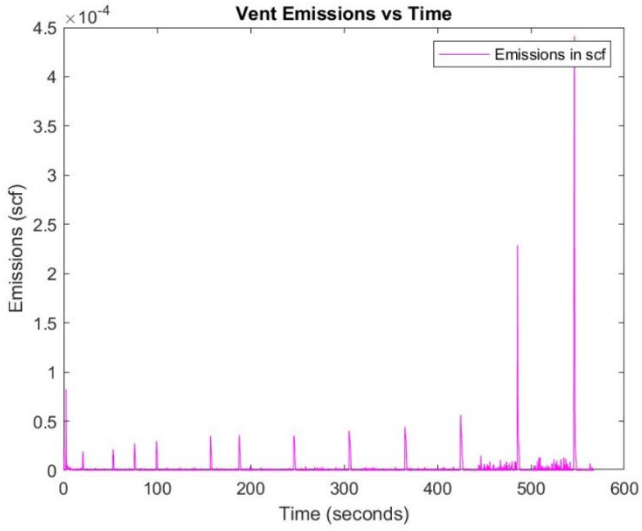
- 222489-002

The volume of total emissions in 567.46 seconds is 0.0122 scf.

The flow rate of emissions is 0.0774 scfh.



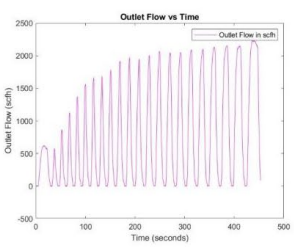


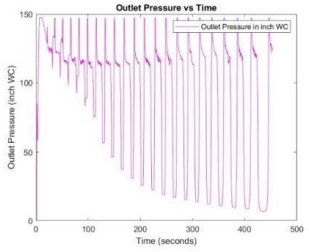


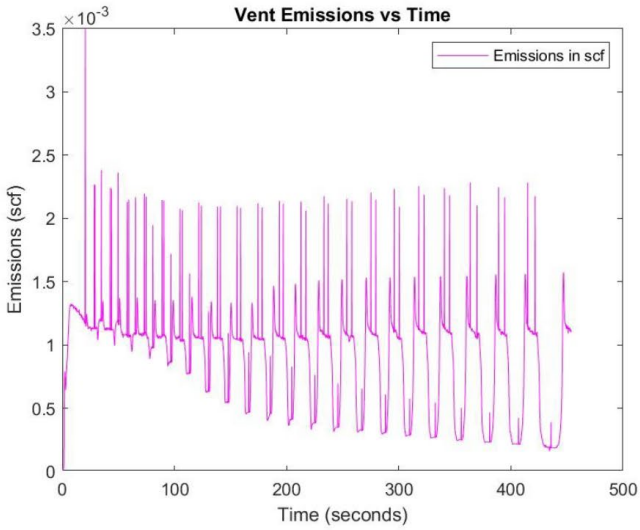
23

GTI ENERGY

- 222489-002-DT
  The volume of total emissions in 453.67 seconds is 3.8356 scf.
  The flow rate of emissions is 30.4365 scfh.

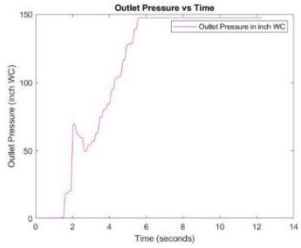


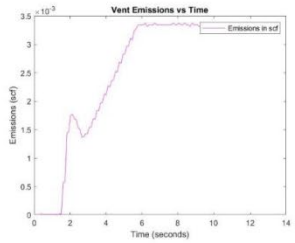


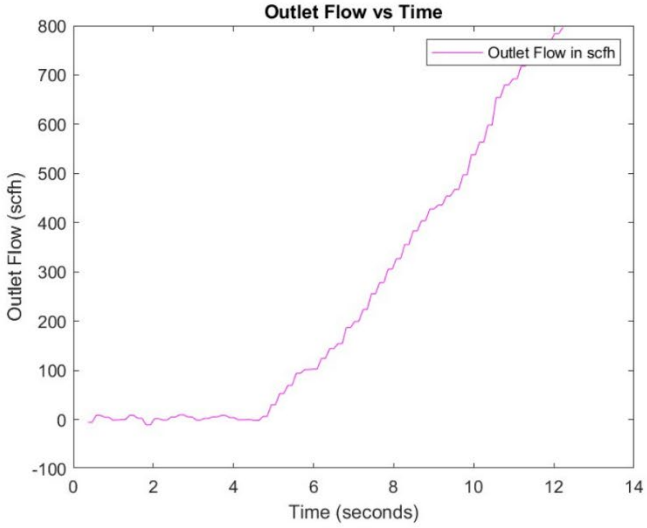


GTI ENERGY

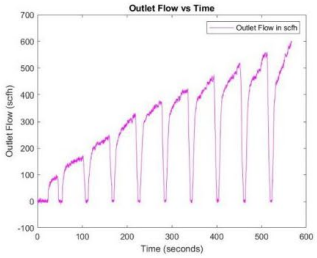
- 222489-002-LD
  The volume of total emissions in 12.23 seconds is 0.2931 scf.
  The flow rate of emissions is 86.3130 scfh.

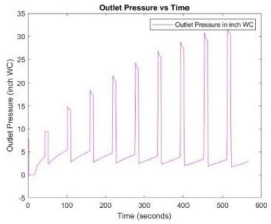


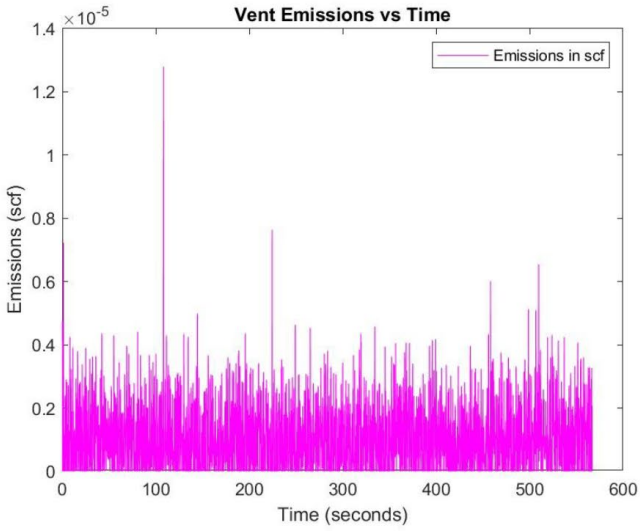




- 222489-002-BV
  The volume of total emissions in 567.07 seconds is 0.0061 scf.
  The flow rate of emissions is 0.0386 scfh.



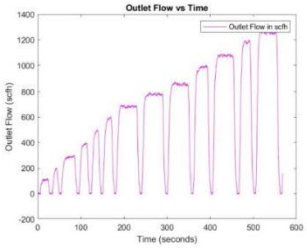


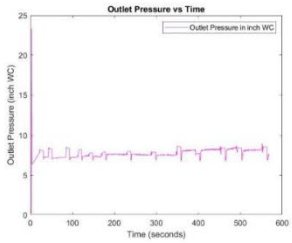


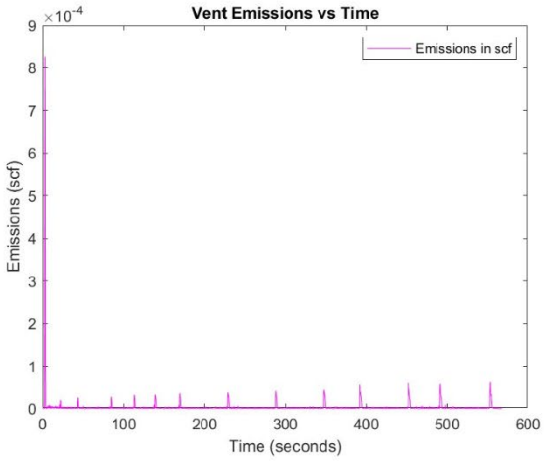
26

GTI ENERGY

- 222489-003
  The volume of total emissions in 568.25 seconds is 0.0164 scf.
  The flow rate of emissions is 0.1037 scfh.





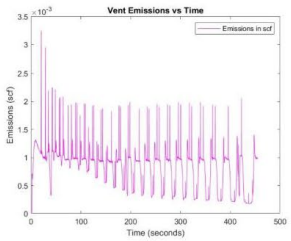


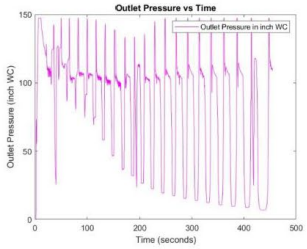
- 222489-003-DT

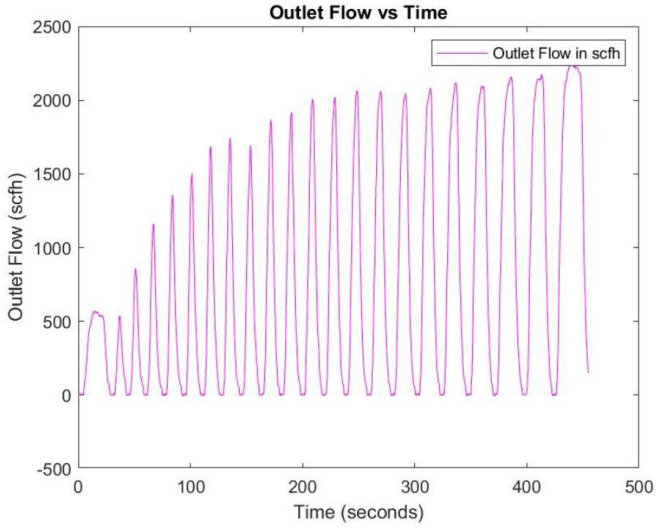
27

GTI ENERGY

The volume of total emissions in 454.79 seconds is 3.4552 scf.
The flow rate of emissions is 27.3502 scfh.



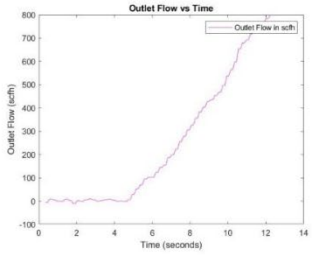


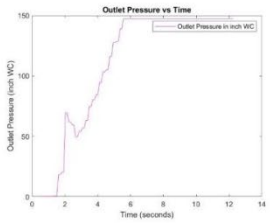


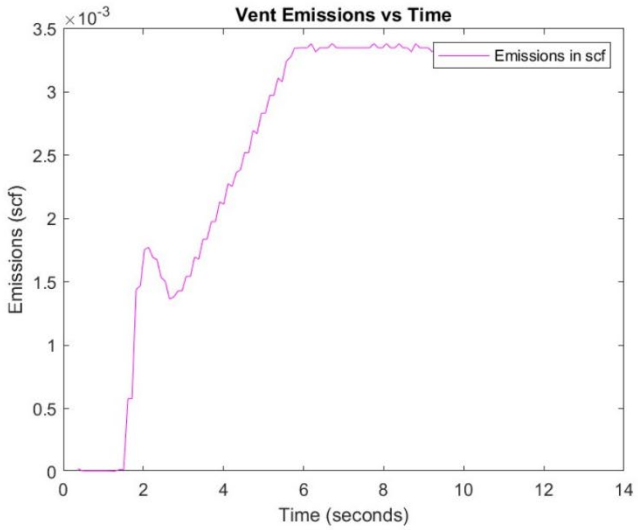
28

GTI ENERGY

- 222489-003-LD
  The volume of total emissions in 12.23 seconds is 0.2931 scf.
  The flow rate of emissions is 86.3130 scfh.



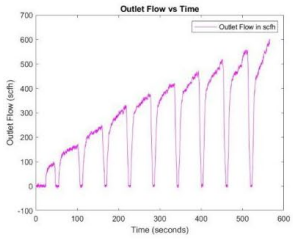


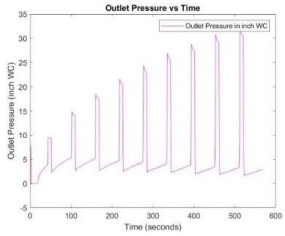


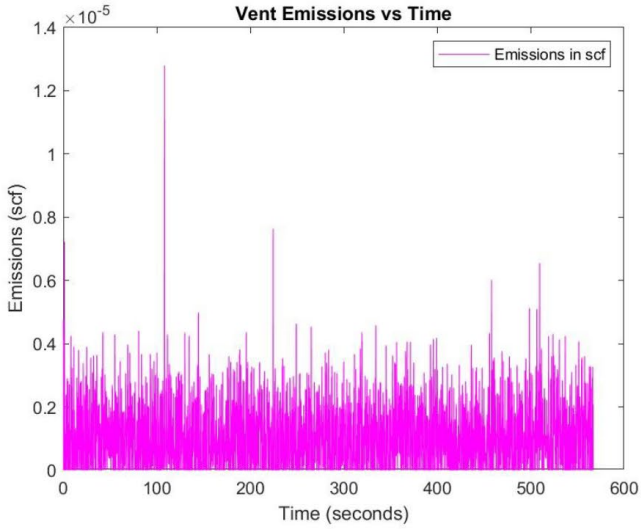
29

GTI ENERGY

- 222489-003-BV
  The volume of total emissions in 567.07 seconds is 0.0061 scf.
  The flow rate of emissions is 0.0386 scfh







30

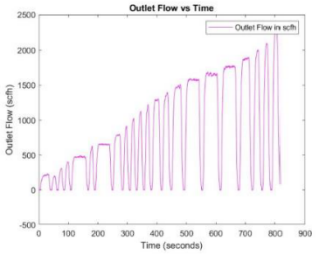
GTI ENERGY

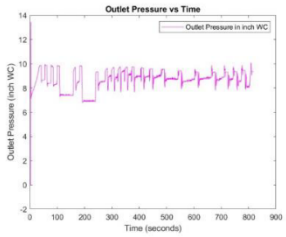
7" WC Outlet, 3/16" Orifice, 100-psig Inlet

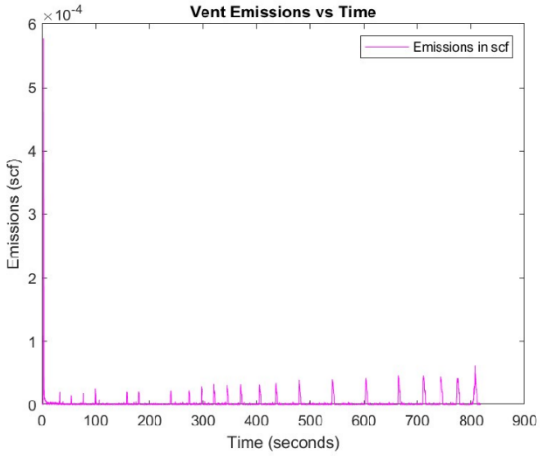
- 222489-001

  The volume of total emissions in 817.46 seconds is 0.0251 scf.

  The flow rate of emissions is 0.1106 scfh.



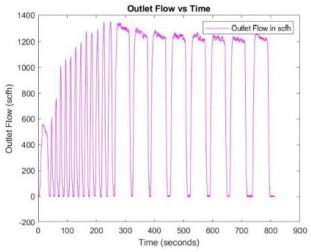


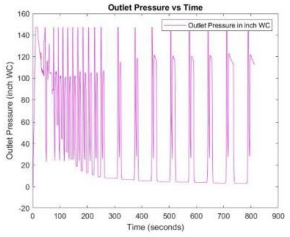


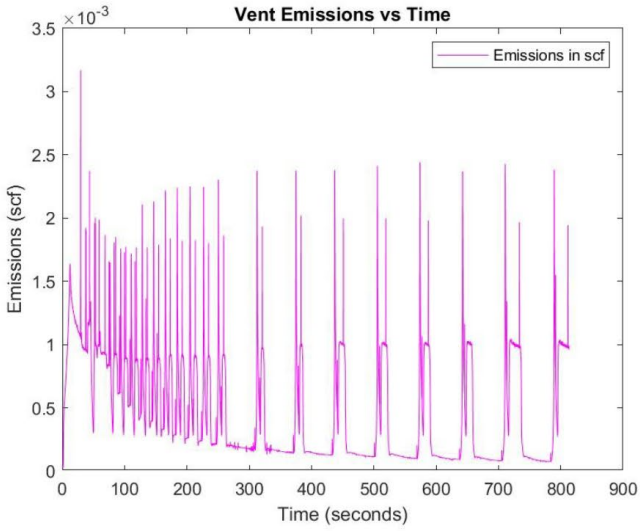
31

GTI ENERGY

- 222489-001_DT
  The volume of total emissions in 813.51 seconds is 3.7007 scf.
  The flow rate of emissions is 16.3766 scfh.



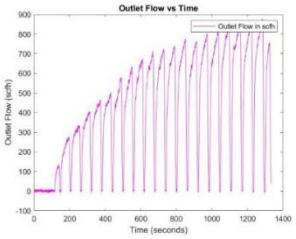


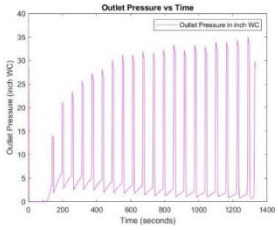


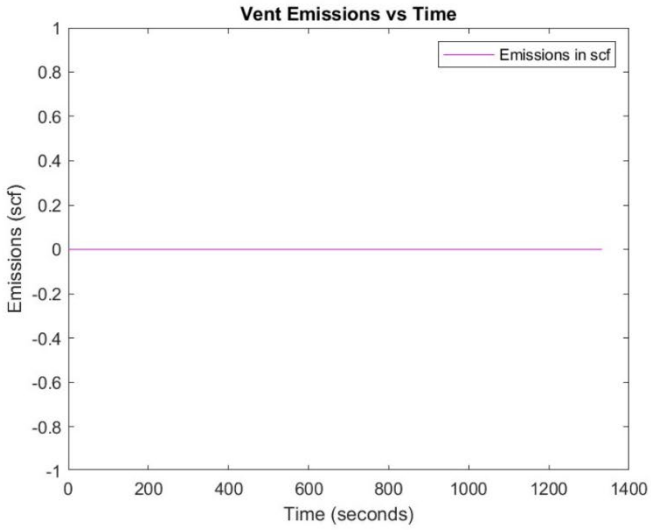
32

GTI ENERGY

- 222489-001_BV
  The volume of total emissions in 1332.38 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.

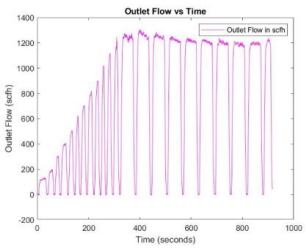


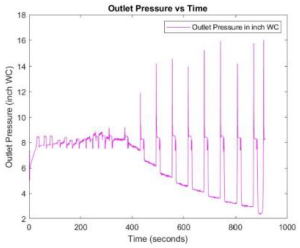


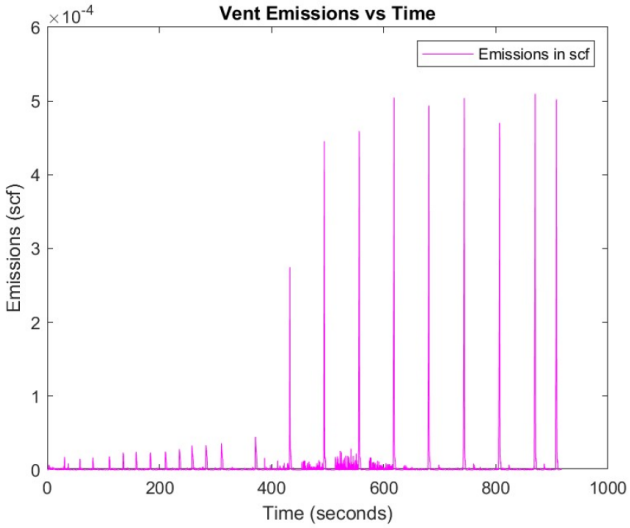


GTI ENERGY

- 222489-002
  The volume of total emissions in 916.59 seconds is 0.0510 scf.
  The flow rate of emissions is 0.2004 scfh.



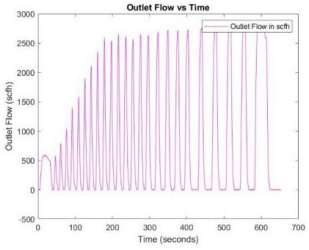


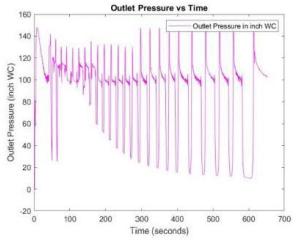


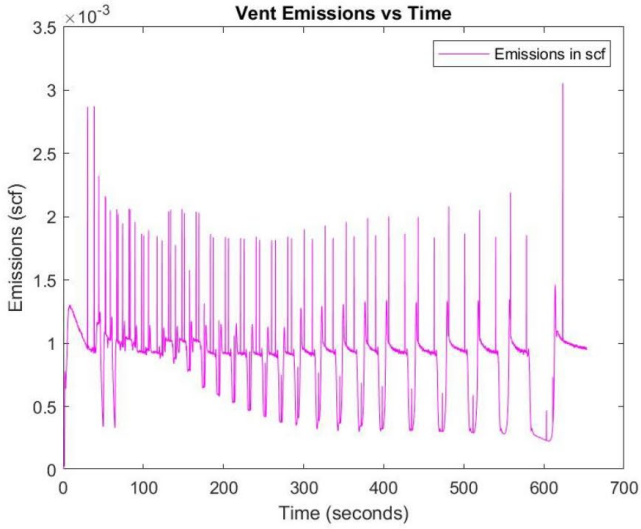
34

GTI ENERGY

- 222489-002_DT
  The volume of total emissions in 653.36 seconds is 5.3275 scf.
  The flow rate of emissions is 29.3544 scfh.



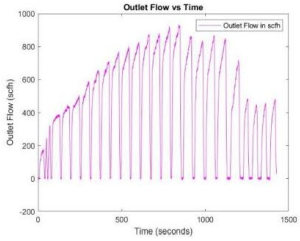


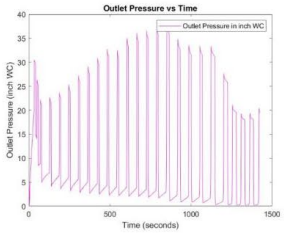


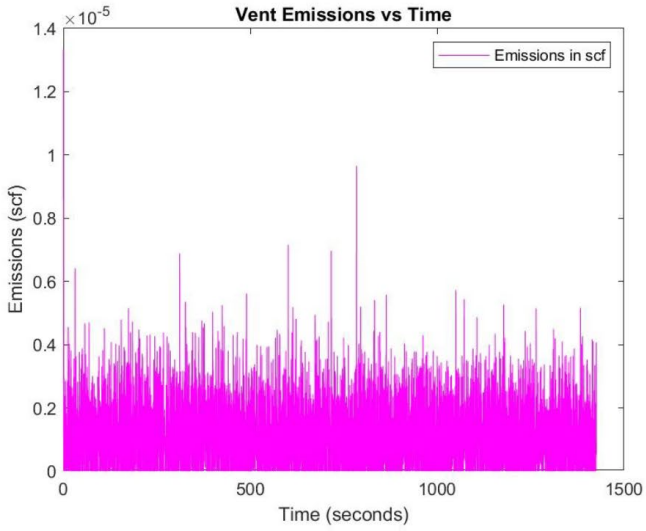
35

GTI ENERGY

- 222489-002_BV
  The volume of total emissions in 1425.92 seconds is 0.0158 scf.
  The flow rate of emissions is 0.0400 scfh.

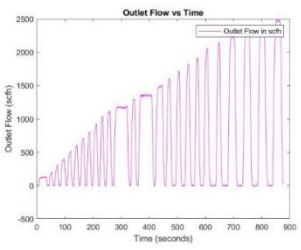


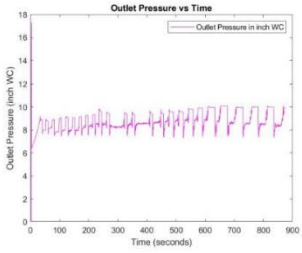


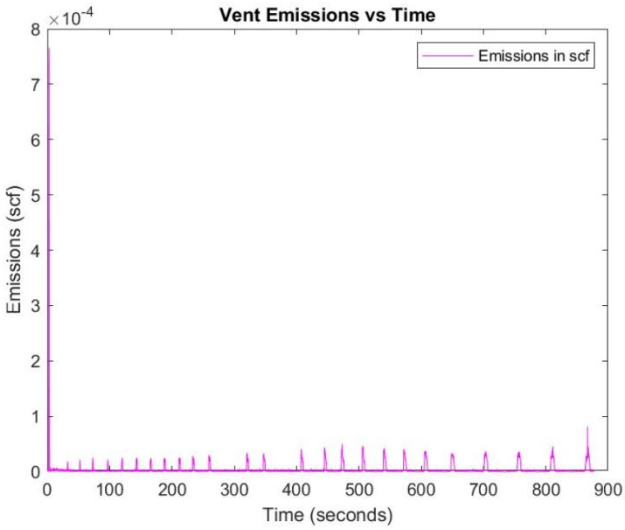


GTI ENERGY

- 222489-003
  The volume of total emissions in 877.12 seconds is 0.0309 scf.
  The flow rate of emissions is 0.1269 scfh.



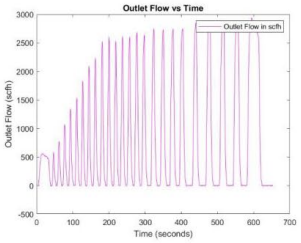


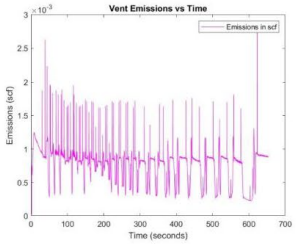


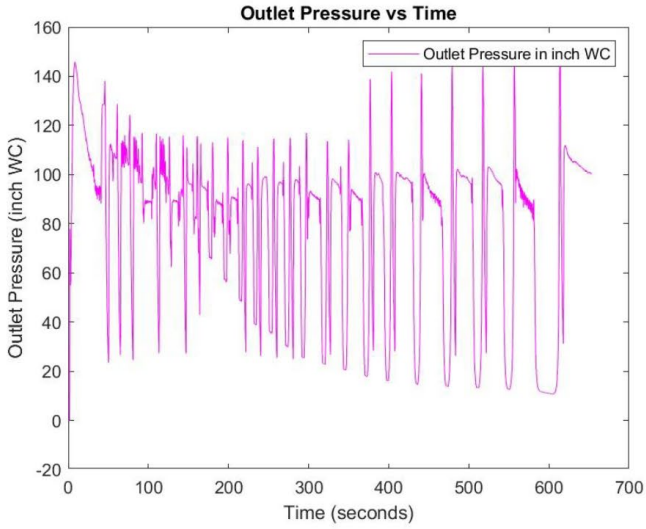
37

GTI ENERGY

- 222489-003_DT
  The volume of total emissions in 653.19 seconds is 4.6564 scf.
  The flow rate of emissions is 25.6631 scfh.



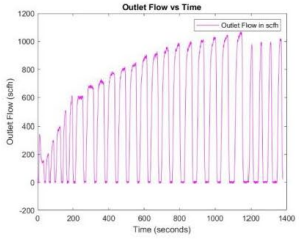


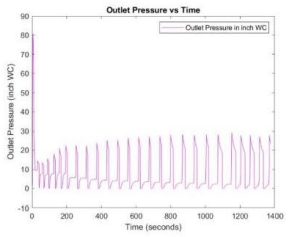


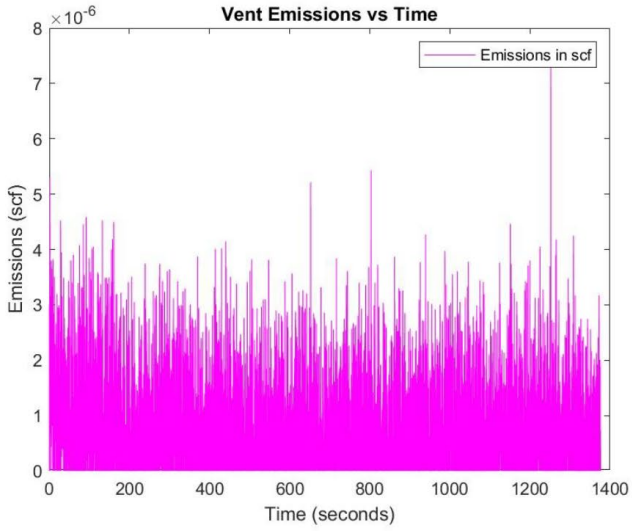
38

GTI ENERGY

- 222489-003_BV
  The volume of total emissions in 1376.58 seconds is 0.0100 scf.
  The flow rate of emissions is 0.0261 scfh.







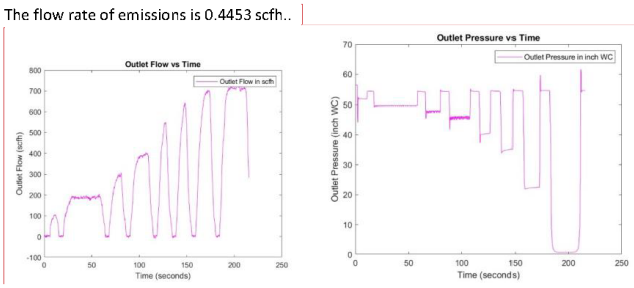
GTI ENERGY

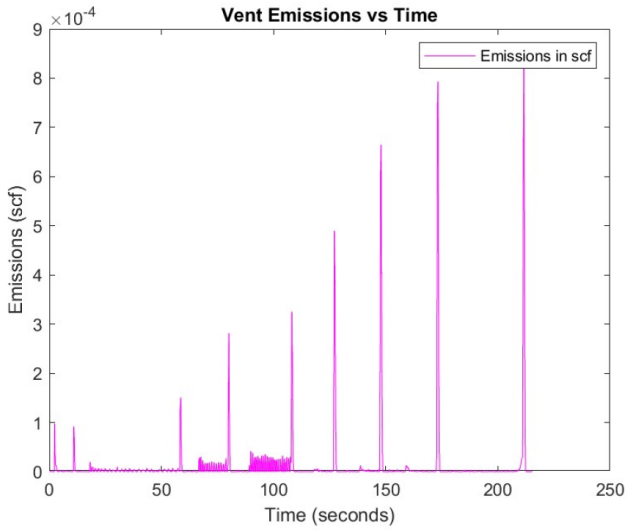
2-psig Outlet, 3/16" Orifice, 10-psig Inlet

- 222489-045

The volume of total emissions in 215.39 seconds is 0.0266 scf.
The flow rate of emissions is 0.4453 scfh..

Commented [JW1]: Graphs don't look correct. I've tried re-exporting the .tdms file to .csv several times but it comes out the same each time. Could someone else take a look?

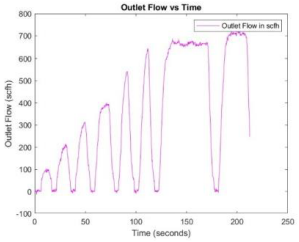


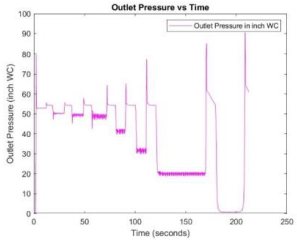


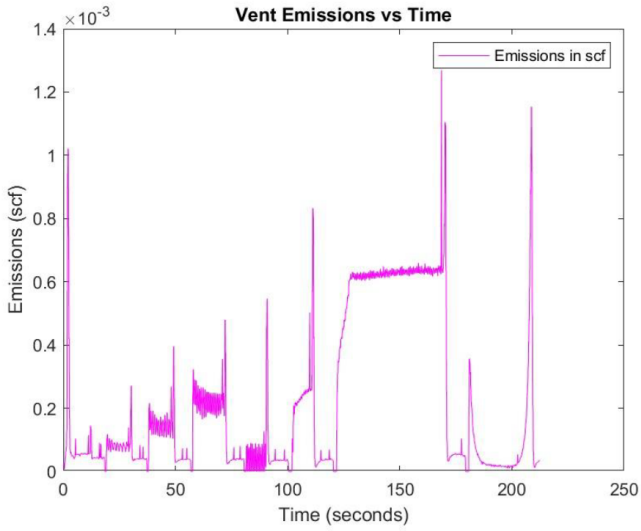
40

GTI ENERGY

- 222489-045_DT
  The volume of total emissions in 212.43 seconds is 0.4423 scf.
  The flow rate of emissions is 7.4949 scfh.



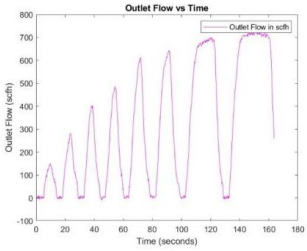


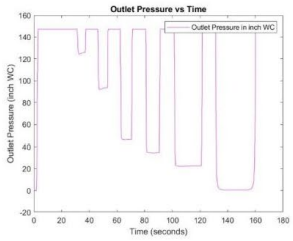


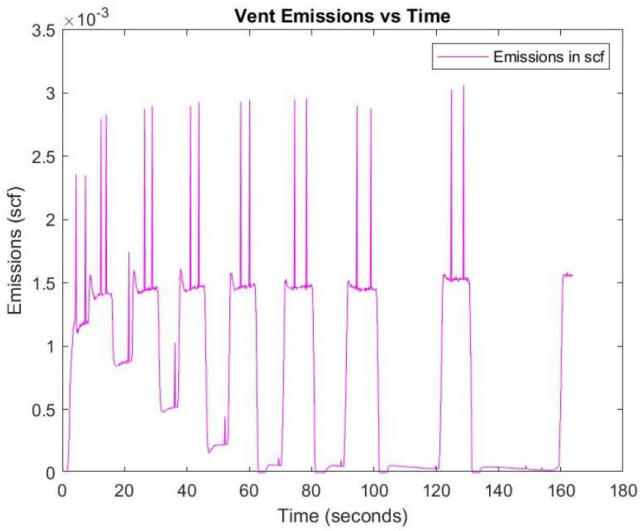
- 222489-045_LD

GTI ENERGY

The volume of total emissions in 163.75 seconds is 1.1364 scf.
The flow rate of emissions is 24.9834 scfh.





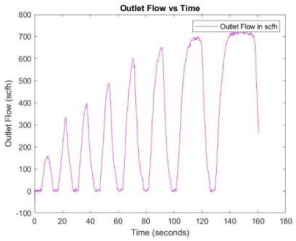


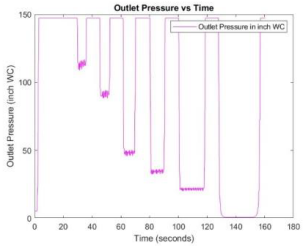
- 222489-045_BV

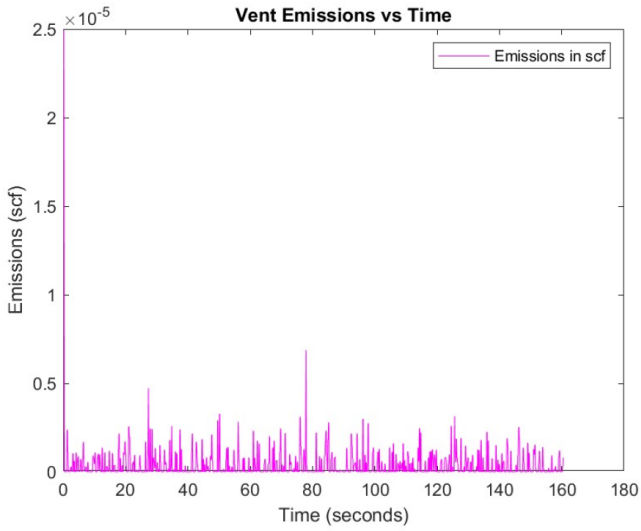
42

GTI ENERGY

The volume of total emissions in 160.48 seconds is 0.0006 scf.
The flow rate of emissions is 0.0133 scfh.





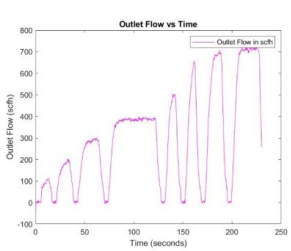


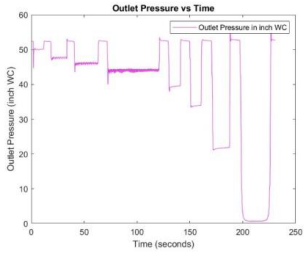
- 222489-046

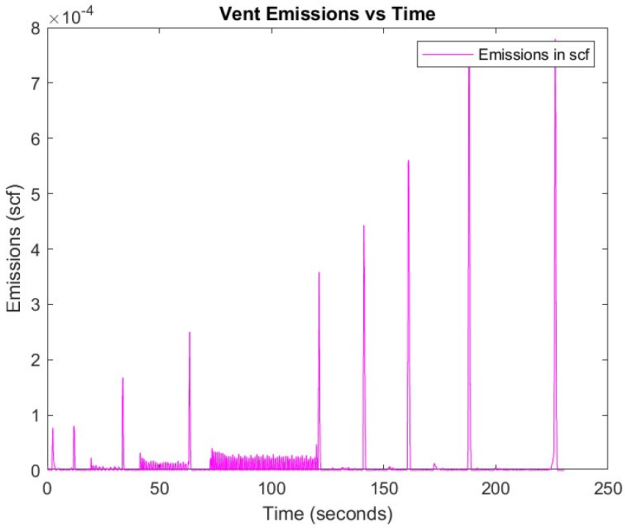
43

GTI ENERGY

The volume of total emissions in 230.45 seconds is 0.0281 scf.
The flow rate of emissions is 0.4389 scfh.



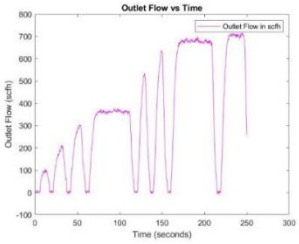


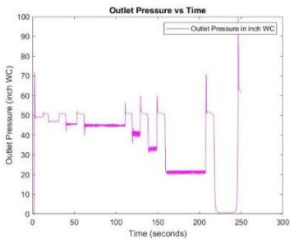


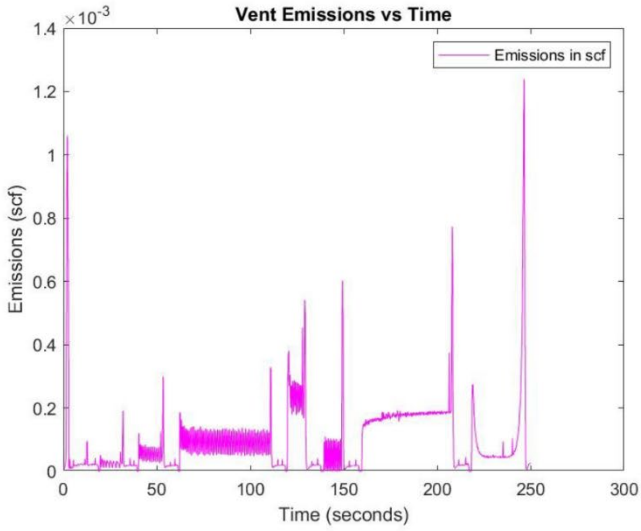
- 222489-046_DT

GTI ENERGY

The volume of total emissions in 250.15 seconds is 0.2314 scf.
The flow rate of emissions is 3.3301 scfh.





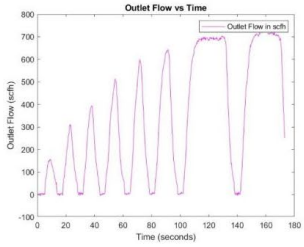


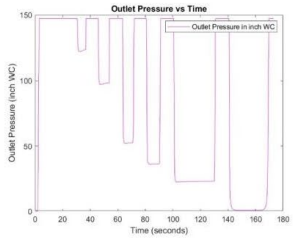
- 222489-046_LD

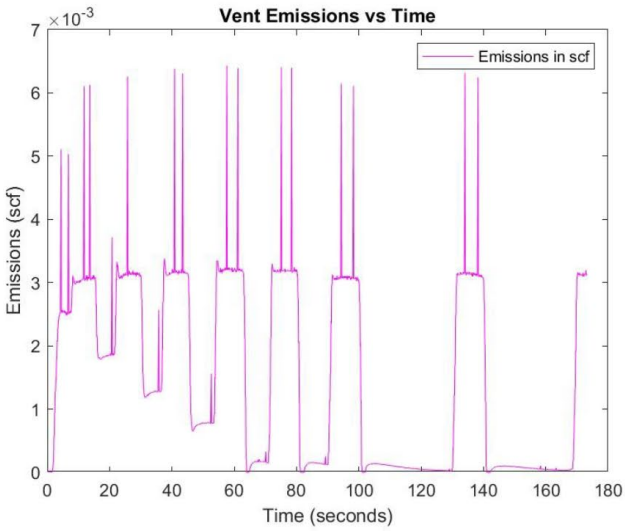
45

GTI ENERGY

The volume of total emissions in 173.13 seconds is 2.4531 scf.
The flow rate of emissions is 51.0096 scfh.





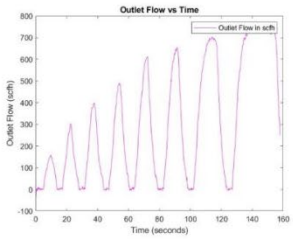


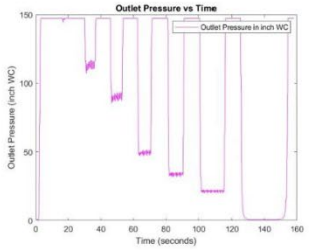
- 222489-046_BV

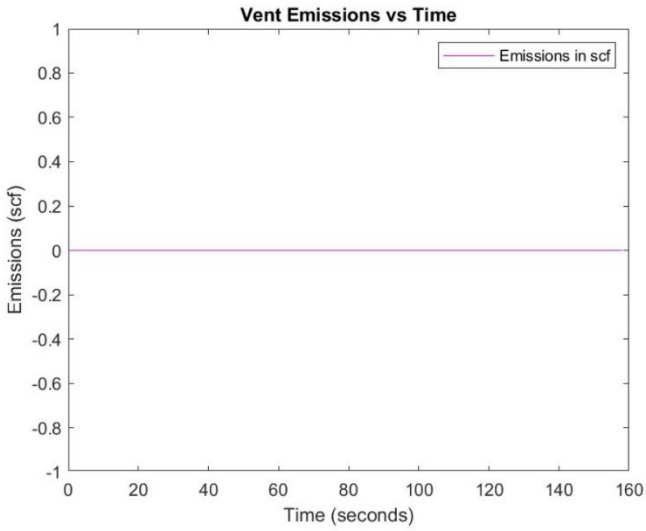
46

GTI ENERGY

The volume of total emissions in 158.07 seconds is 0.0000 scf.
The flow rate of emissions is 0.0000 scfh.



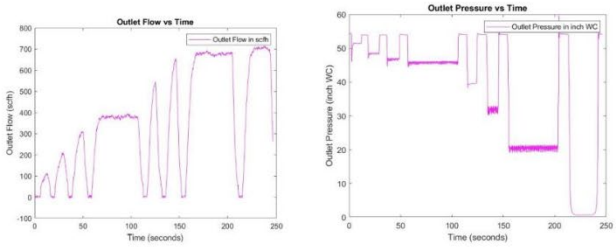


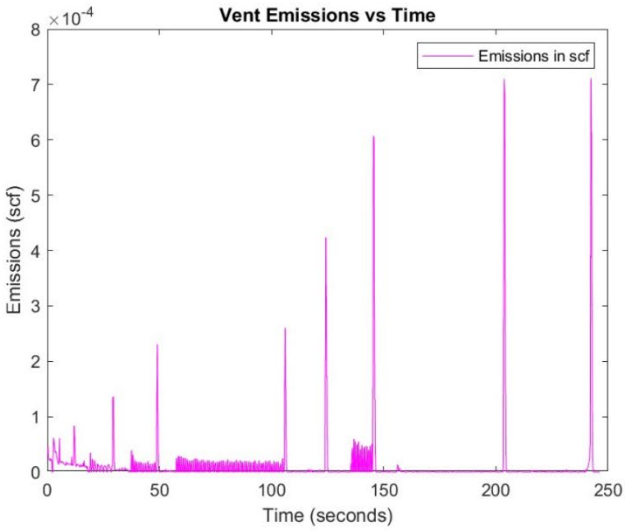


- 222489-047

GTI ENERGY

The volume of total emissions in 246.40 seconds is 0.0292 scf.
The flow rate of emissions is 0.4268 scfh.



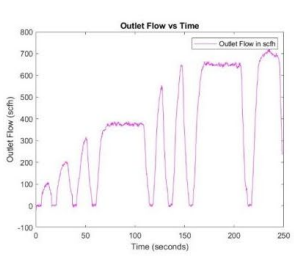


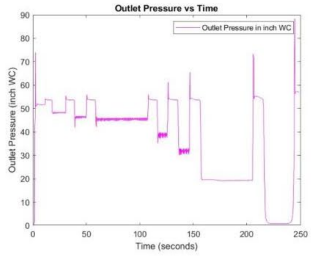
- 222489-047_DT

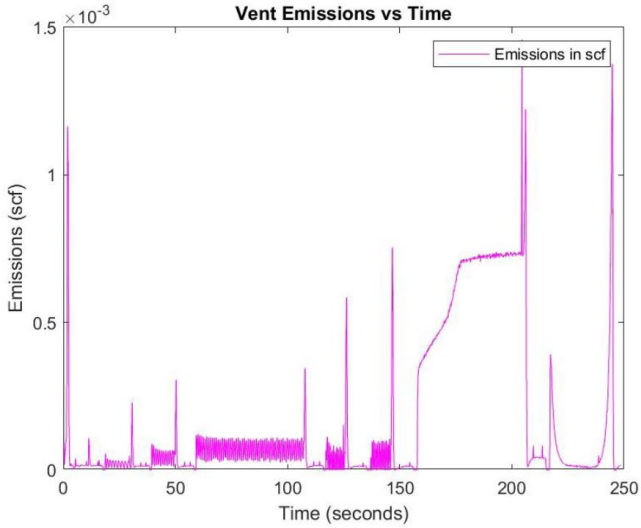
48

GTI ENERGY

The volume of total emissions in 248.48 seconds is 0.4045 scf.
The flow rate of emissions is 5.8597 scfh.

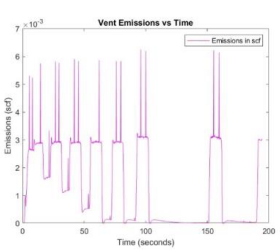


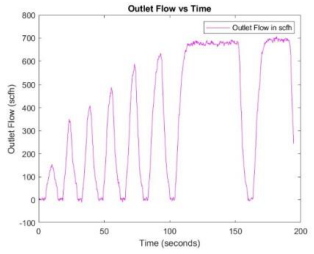


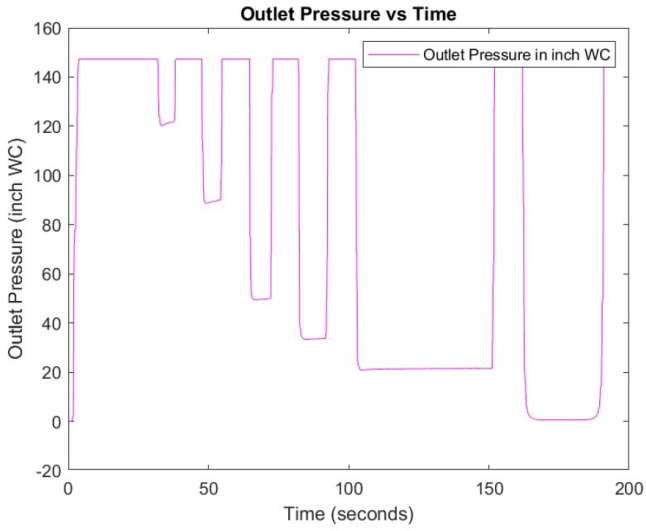


GTI ENERGY

- 222489-047_LD
  The volume of total emissions in 194.59 seconds is 2.3737 scf.
  The flow rate of emissions is 43.9138 scfh.

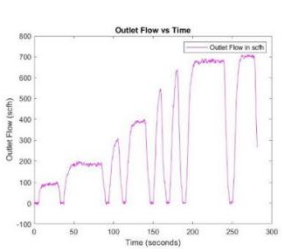


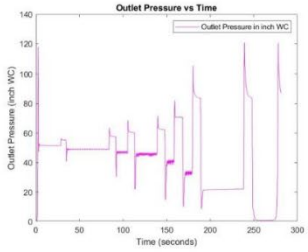


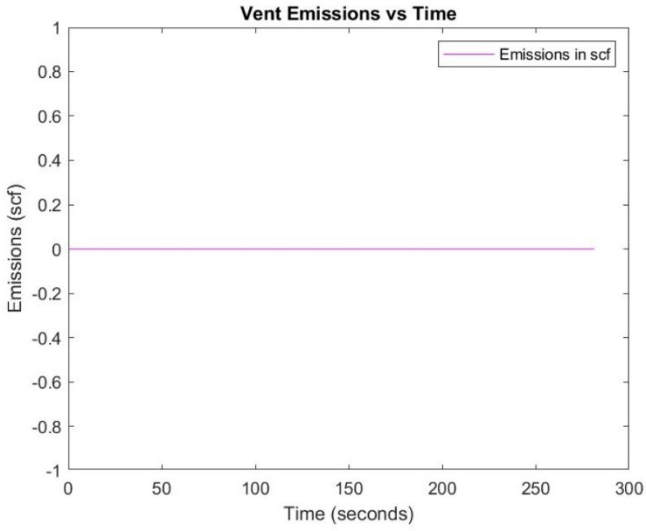


50

- 222489-047_BV
  The volume of total emissions in 281.41 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.





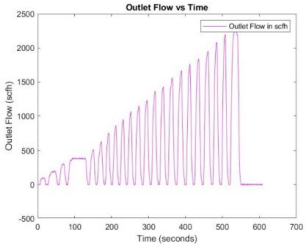


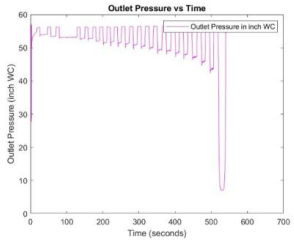
51

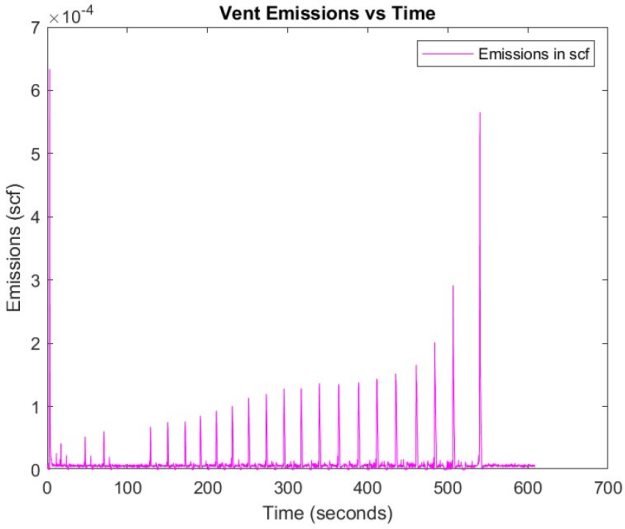
2-psig Outlet, 3/16" Orifice, 60-psig Inlet

- 222489-045

  The volume of total emissions in 608.48 seconds is 0.0674 scf.
  The flow rate of emissions is 0.3990 scfh.

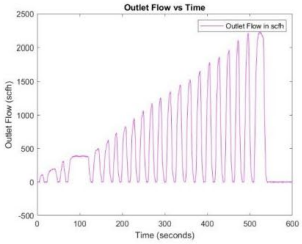


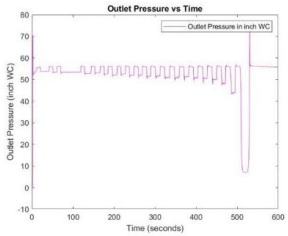


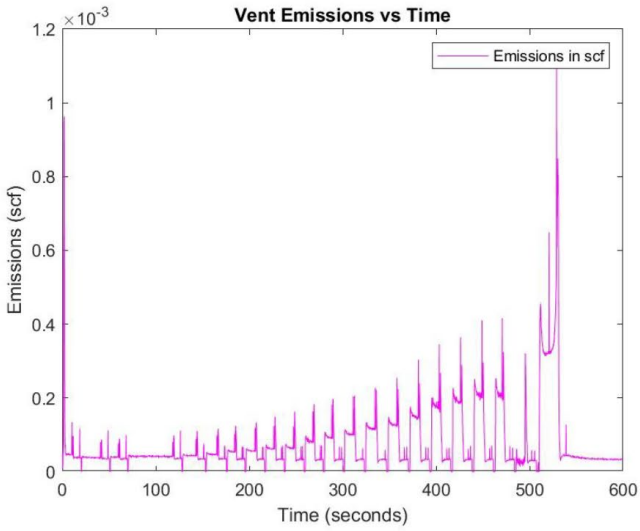


GTI ENERGY

- 222489-045_DT
  The volume of total emissions in 598.85 seconds is 0.4172 scf.
  The flow rate of emissions is 2.5081 scfh.

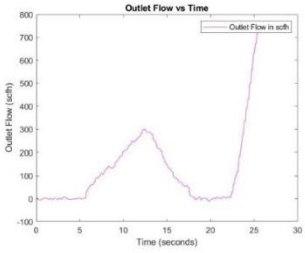


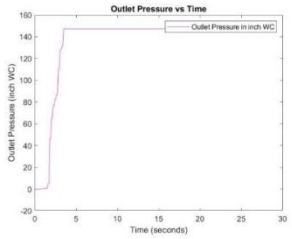


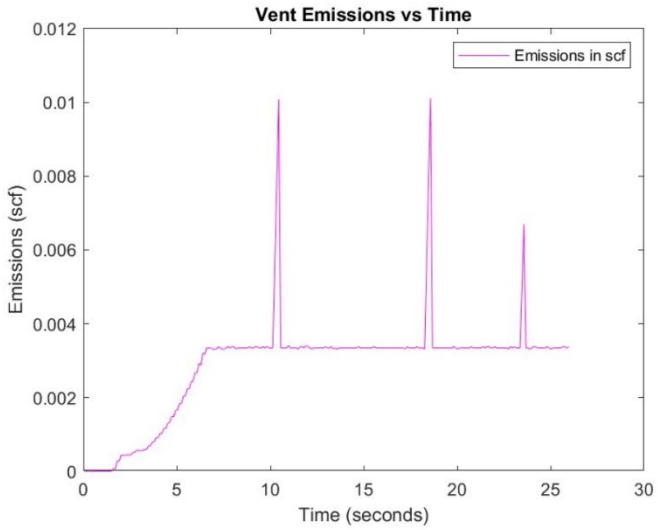


GTI ENERGY

- 222489-045_LD
  The volume of total emissions in 25.97 seconds is 0.6881 scf.
  The flow rate of emissions is 95.3757 scfh.

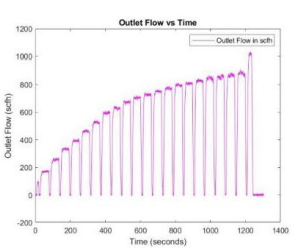


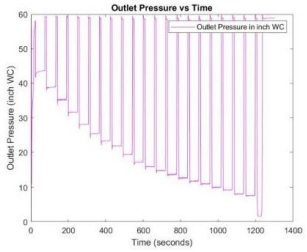


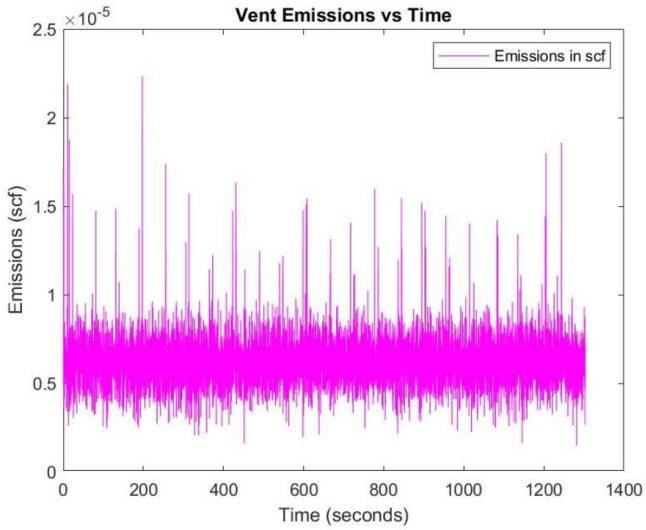


GTI ENERGY

- 222489-045_BV
  The volume of total emissions in 1303.39 seconds is 0.0770 scf.
  The flow rate of emissions is 0.2128 scfh.

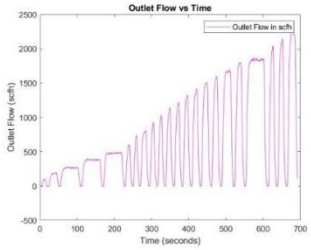


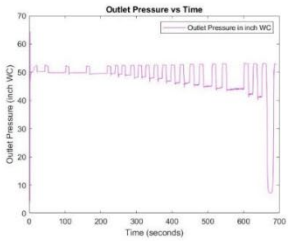


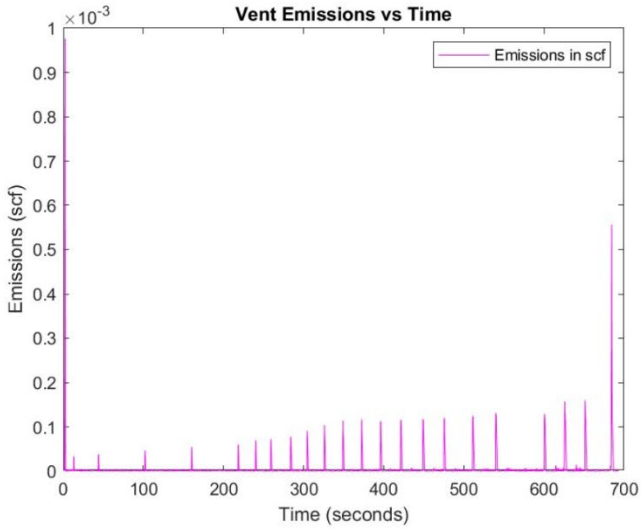


GTI ENERGY

- 222489-046
  The volume of total emissions in 692.91 seconds is 0.0354 scf.
  The flow rate of emissions is 0.1841 scfh.

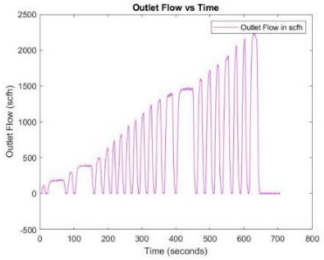


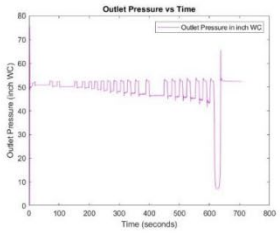


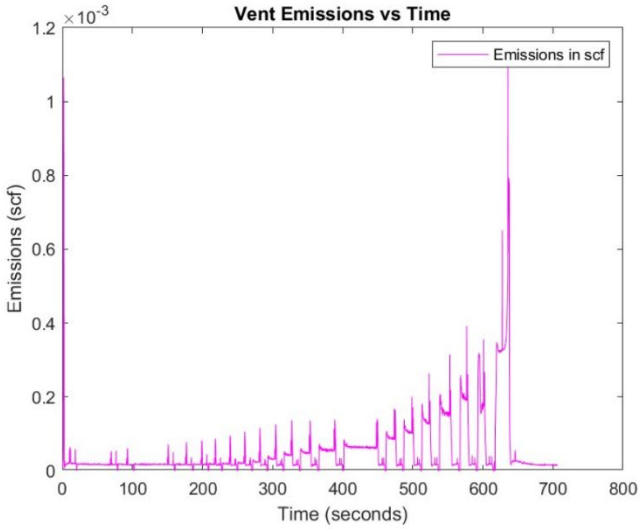


GTI ENERGY

- 222489-046_DT
  The volume of total emissions in 706.20 seconds is 0.3444 scf.
  The flow rate of emissions is 1.7557 scfh.



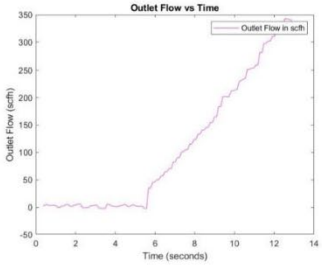


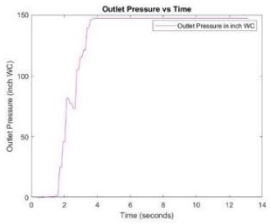


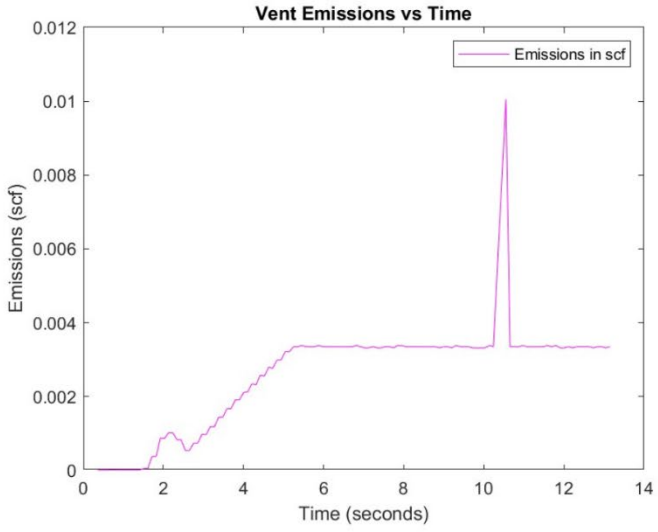
57

GTI ENERGY

- 222489-046_LD
  The volume of total emissions in 13.15 seconds is 0.3130 scf.
  The flow rate of emissions is 85.7013 scfh.



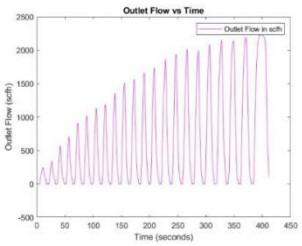


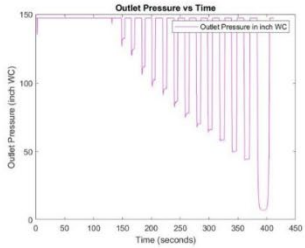


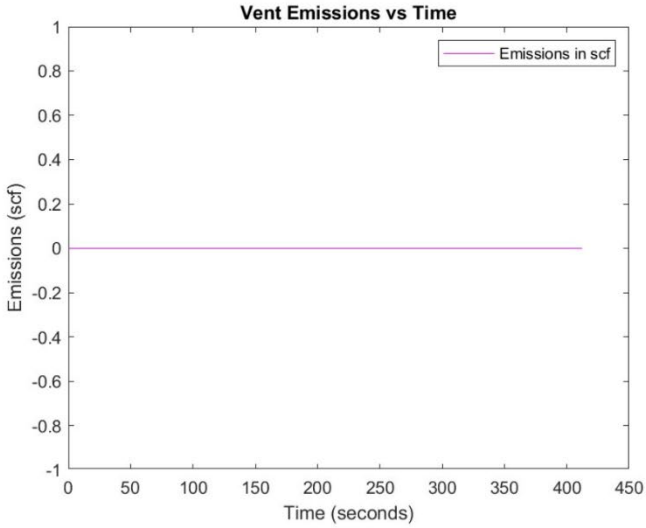
58

GTI ENERGY

- 222489-046_BV
  The volume of total emissions in 412.21 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.



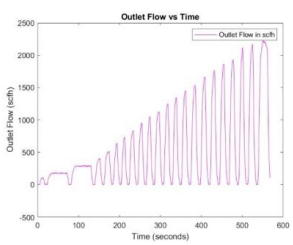


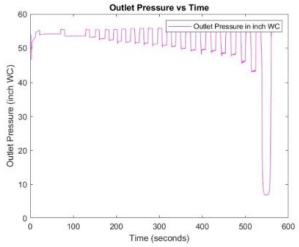


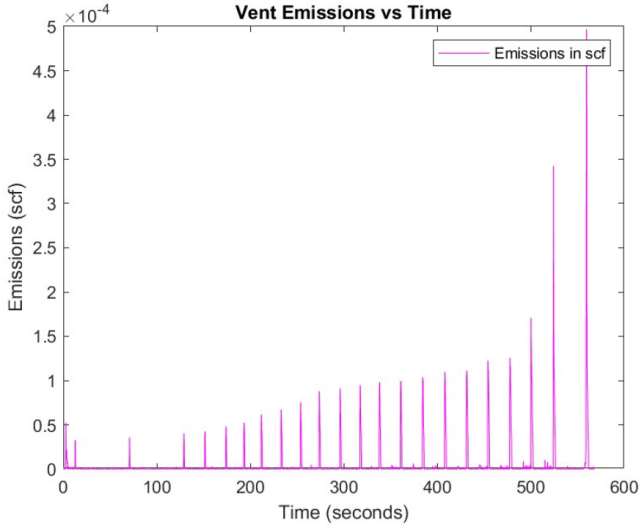
59

GTI ENERGY

- 222489-047
  The volume of total emissions in 568.23 seconds is 0.0258 scf.
  The flow rate of emissions is 0.1632 scfh.



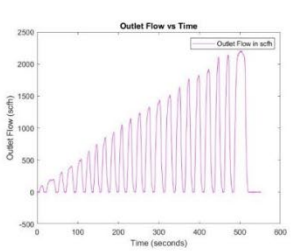


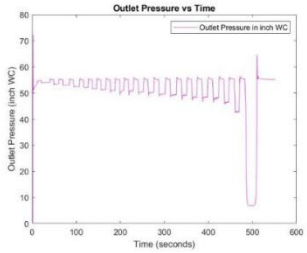


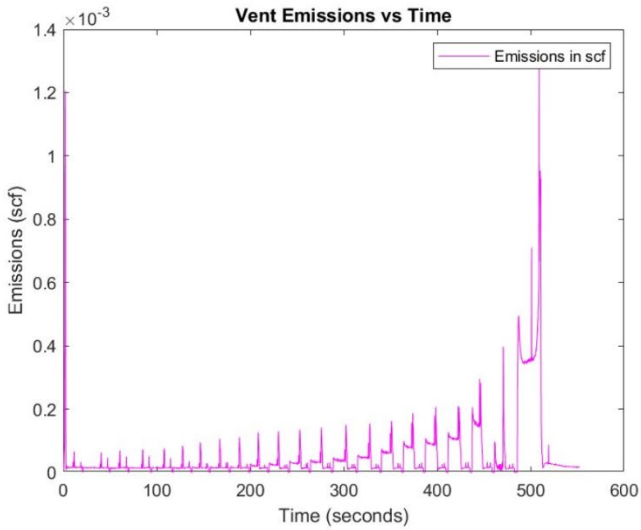
60

GTI ENERGY

- 222489-047_DT
  The volume of total emissions in 552.01 seconds is 0.2628 scf.
  The flow rate of emissions is 1.7138 scfh.



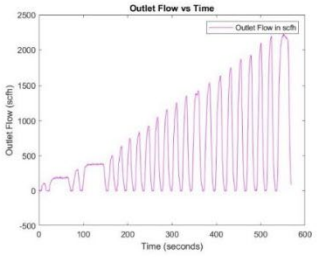


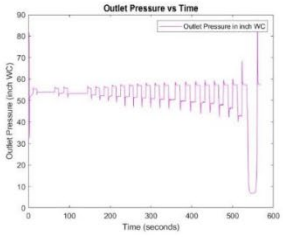


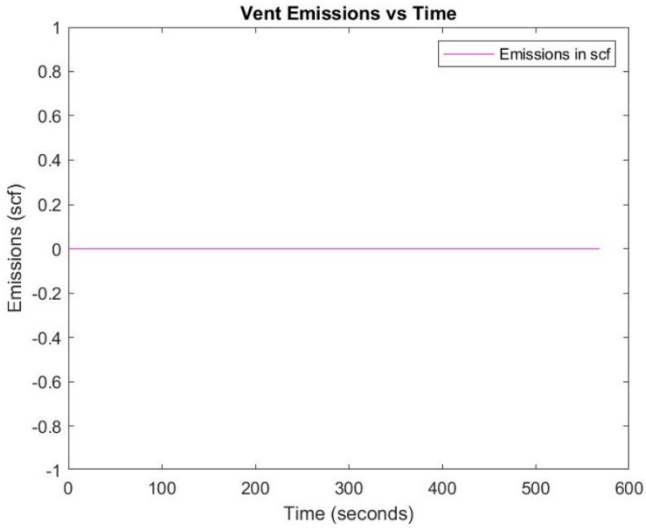
61

GTI ENERGY

- 222489-047_BV
  The volume of total emissions in 568.75 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.







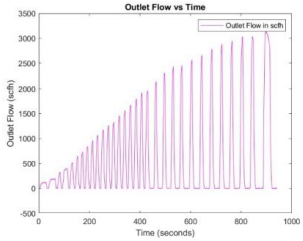
62

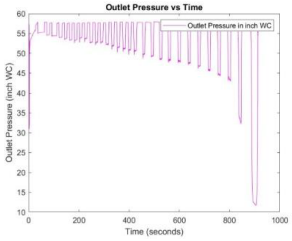
GTI ENERGY

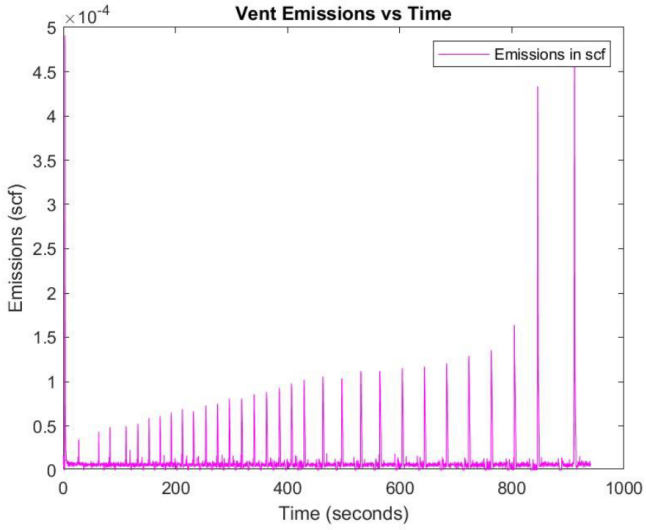
2-psig Outlet, 3/16" Orifice, 100-psig Inlet

- 222489-045

  The volume of total emissions in 940.77 seconds is 0.0960 scf.
  The flow rate of emissions is 0.3674 scfh.



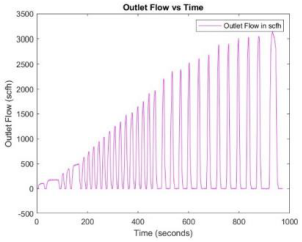


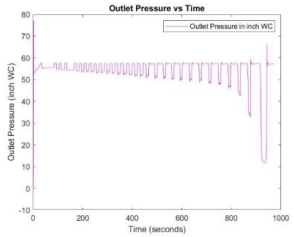


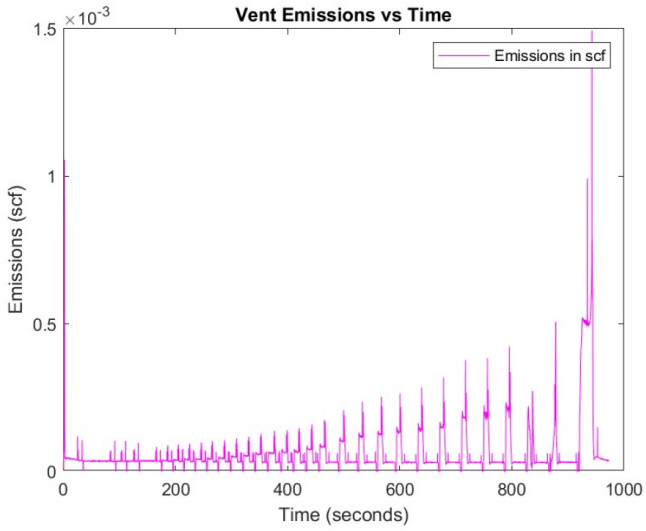
63

GTI ENERGY

- 222489-045_DT
  The volume of total emissions in 972.69 seconds is 0.5668 scf.
  The flow rate of emissions is 2.0978 scfh.

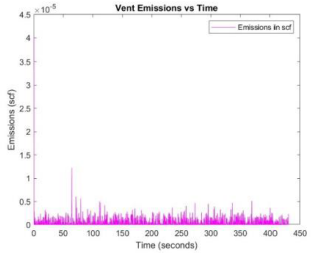


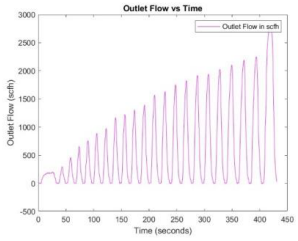


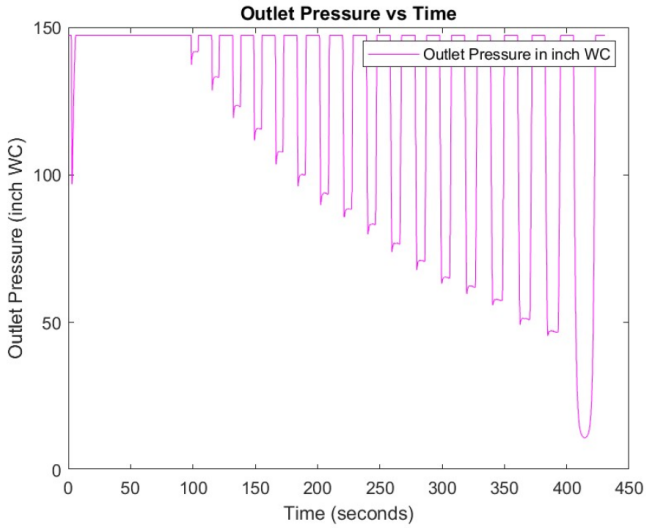


GTI ENERGY

- 222489-045_BV
  The volume of total emissions in 430.66 seconds is 0.0020 scf.
  The flow rate of emissions is 0.0164 scfh.



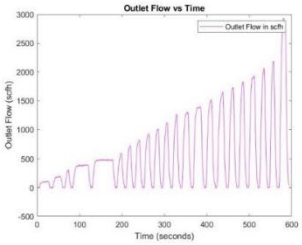


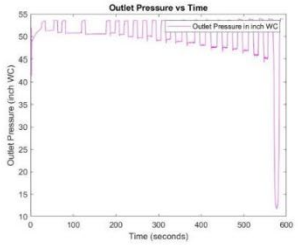


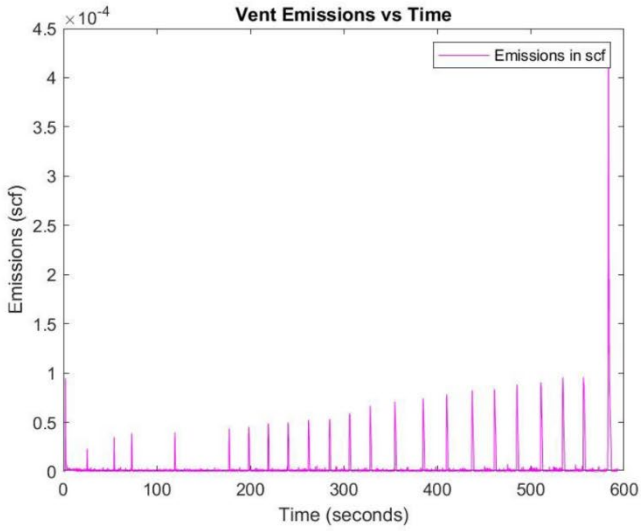
65

GTI ENERGY

- 222489-046
  The volume of total emissions in 593.41 seconds is 0.0232 scf.
  The flow rate of emissions is 0.1405 scfh.



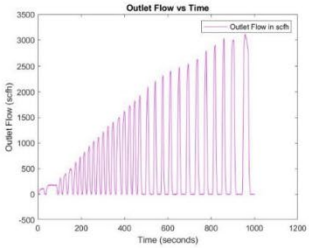


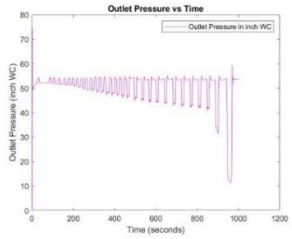


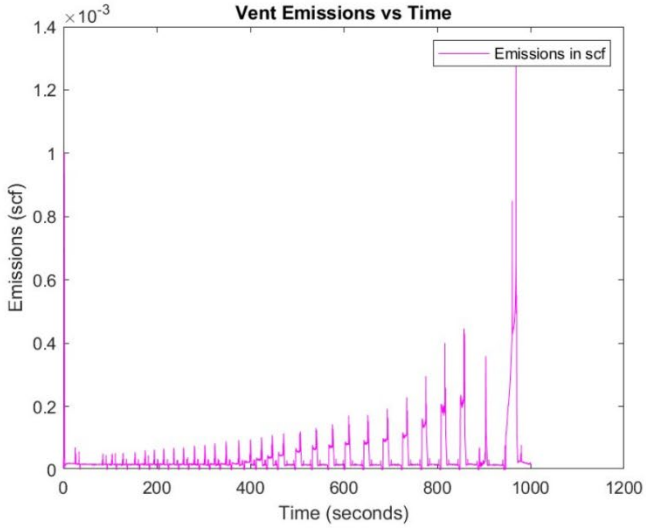
66

GTI ENERGY

- 222489-046_DT
  The volume of total emissions in 1000.18 seconds is 0.3629 scf.
  The flow rate of emissions is 1.3061 scfh.

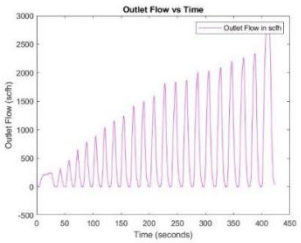


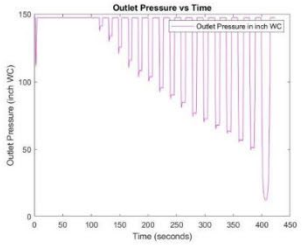


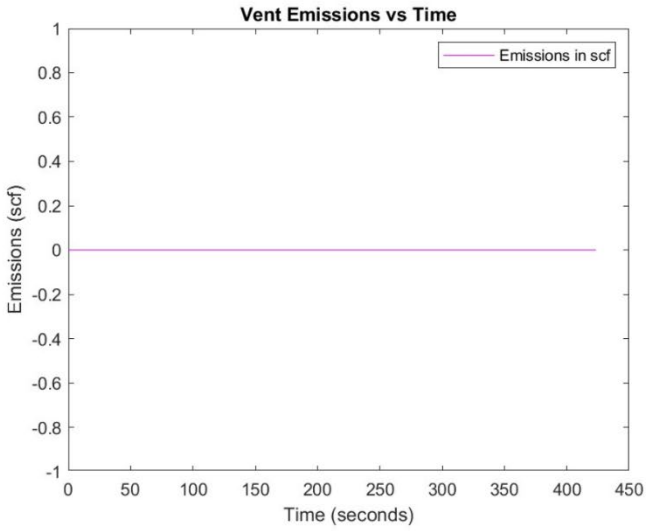


67

- 222489-046_BV
  The volume of total emissions in 423.48 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.



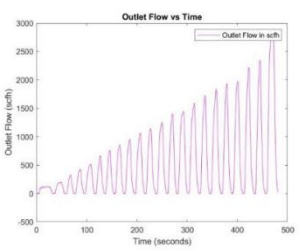


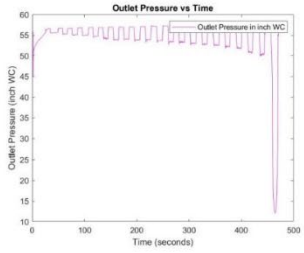


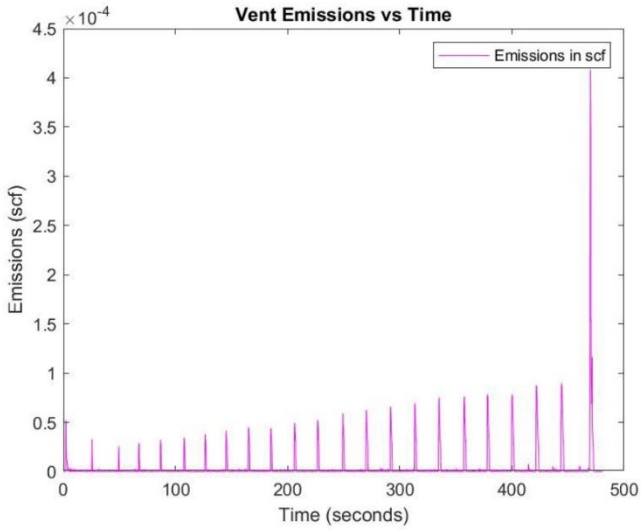
68

GTI ENERGY

- 222489-047
  The volume of total emissions in 480.54 seconds is 0.0186 scf.
  The flow rate of emissions is 0.1391 scfh.



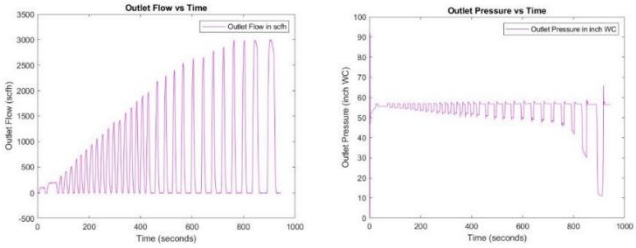


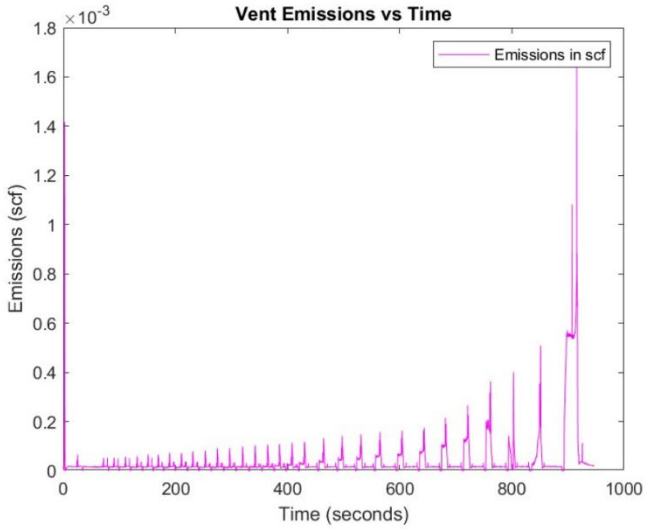


69

GTI ENERGY

- 222489-047_DT
  The volume of total emissions in 945.65 seconds is 0.3706 scf.
  The flow rate of emissions is 1.4110 scfh.

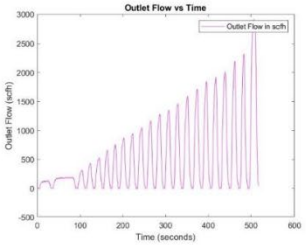


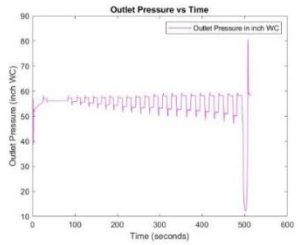


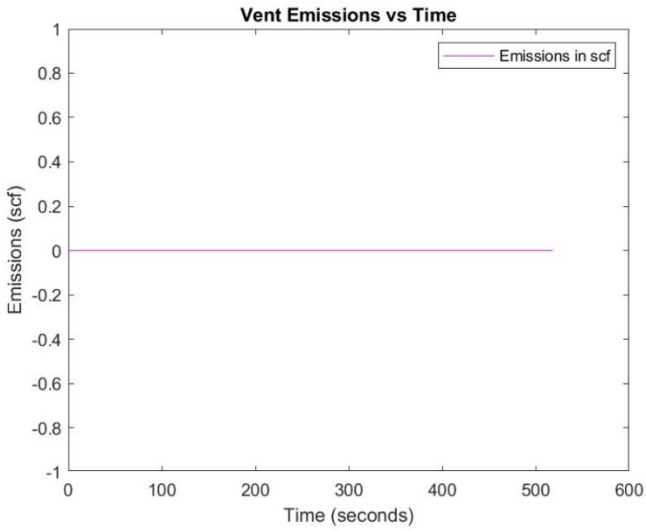
70

GTI ENERGY

- 222489-047_BV
  The volume of total emissions in 518.38 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.







GTI ENERGY

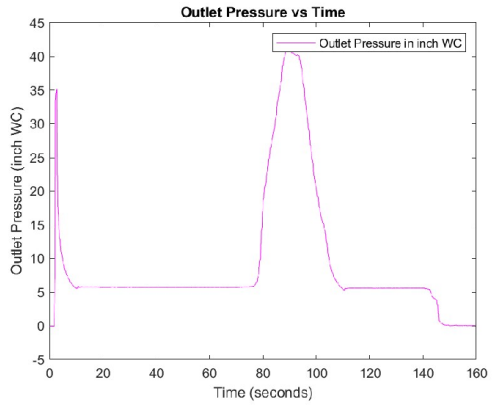
Relief Tests

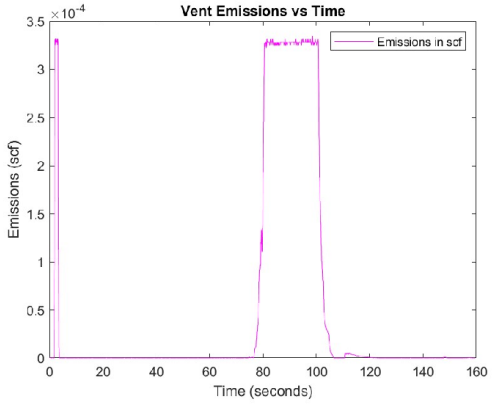
7" WC Outlet, 3/16" Orifice, 10-psig Inlet

- 222489-001

  The volume of total emissions in 159.37 seconds is 0.0754 scf.

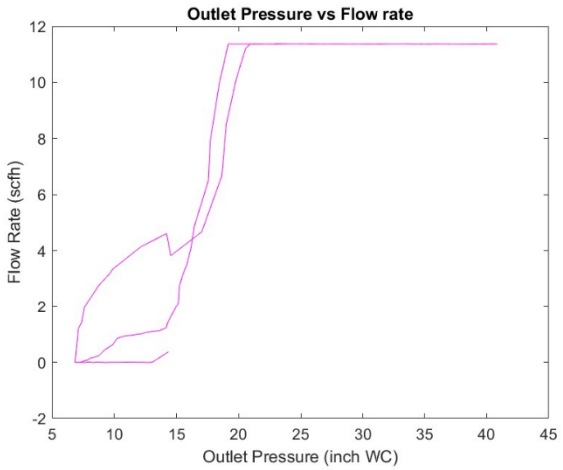
  The average flow rate of emissions at 18 inches WC is 8.94 scfh. (Average between 17.5 – 18.5 inches WC).

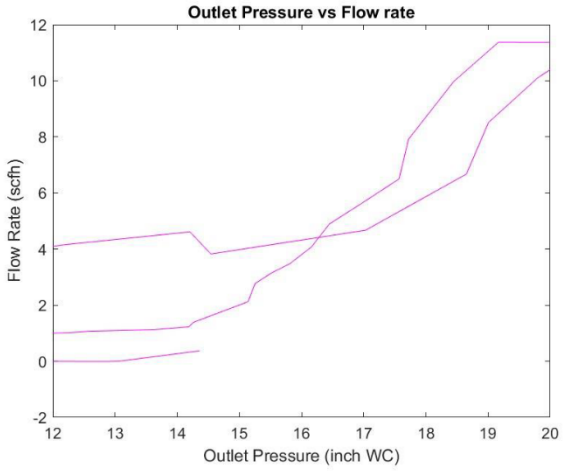




72

GTI ENERGY

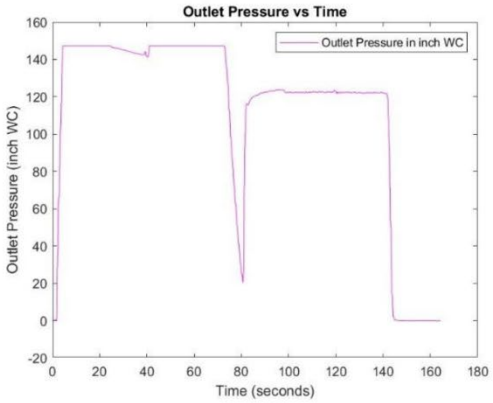


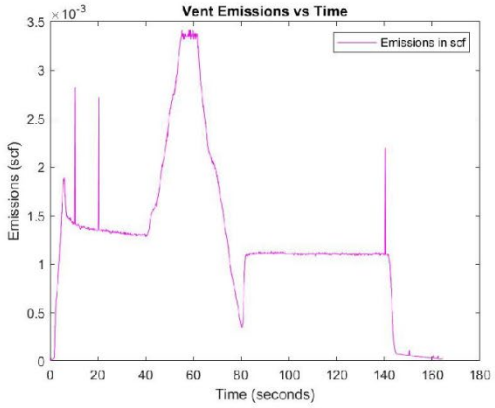


73

GTI ENERGY

- 222489-001_DT
  The volume of total emissions in 164.31 seconds is 1.9874 scf.



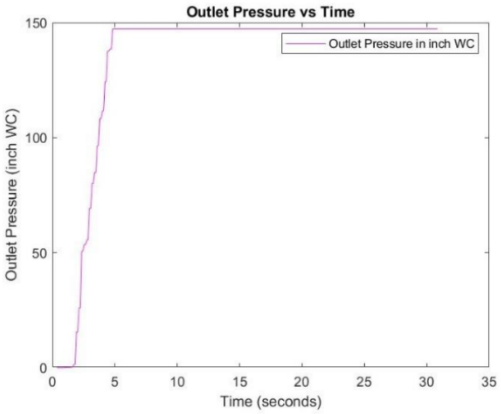


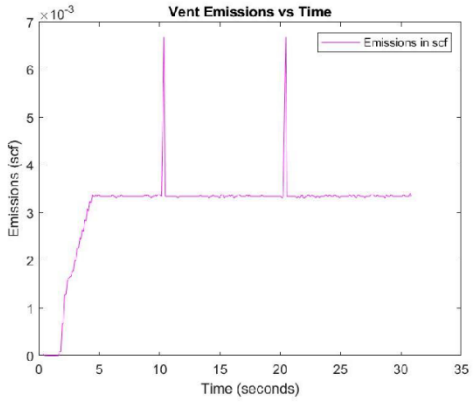
- 222489-001_LD

74

GTI ENERGY

The volume of total emissions in 30.86 seconds is 0.9062 scf.



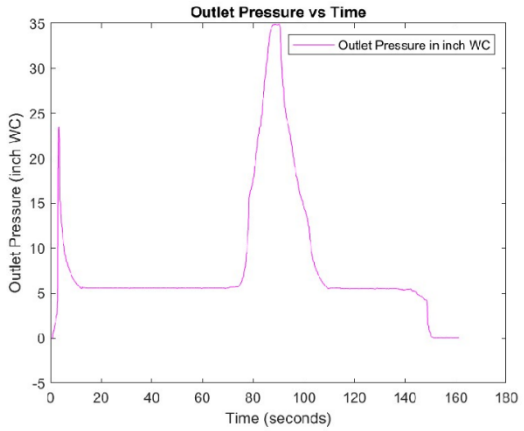


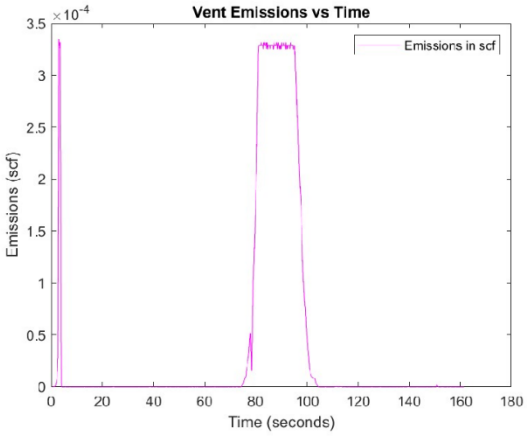
- 222489-002

75

GTI ENERGY

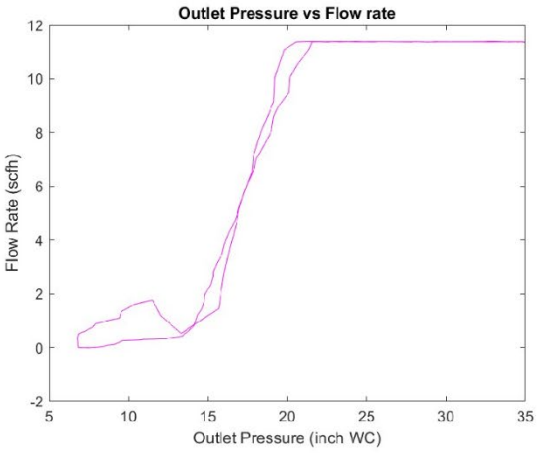
The volume of total emissions in 161.37 seconds is 0.0614 scf.
The average flow rate of emissions at 18 inches WC is 6.95 scfh.

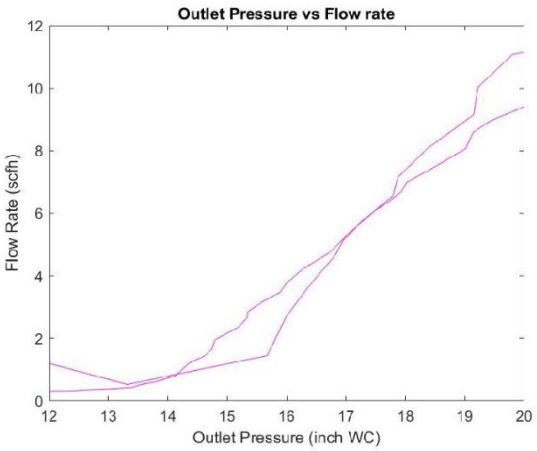




76

GTI ENERGY

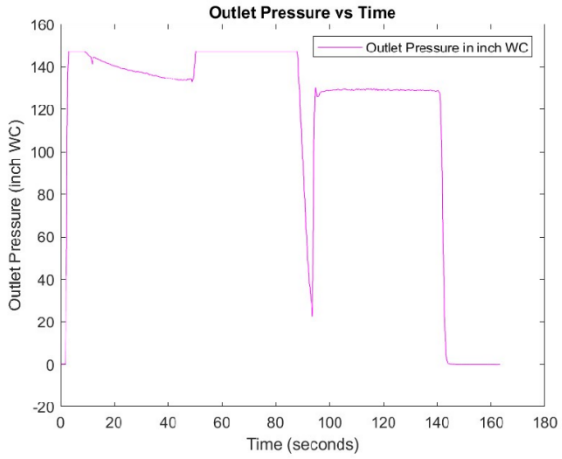


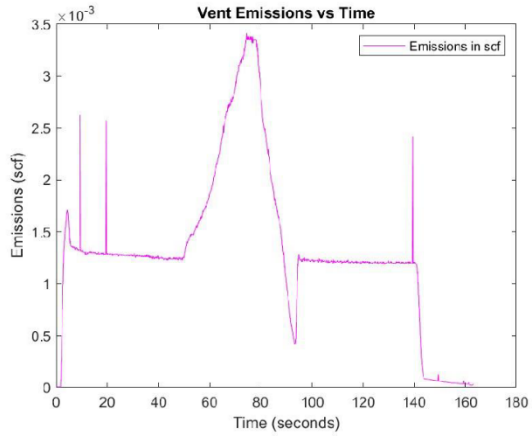


77

GTI ENERGY

- 222489-002_DT
  The volume of total emissions in 163.28 seconds is 2.0582 scf.



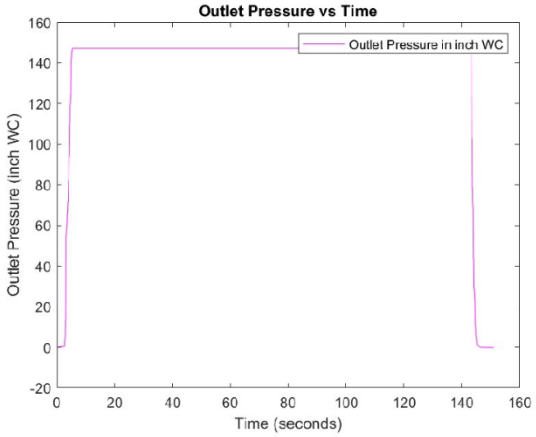


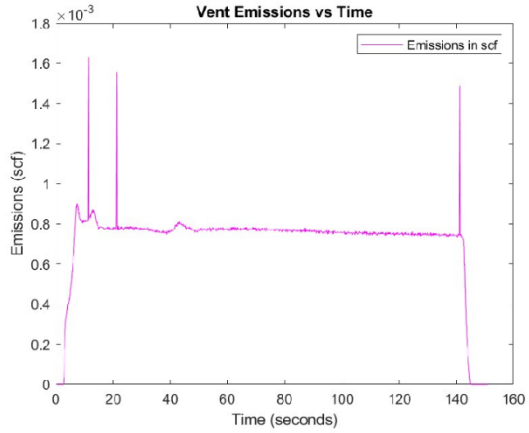
- 222489-002_LD

78

GTI ENERGY

The volume of total emissions in 151.08 seconds is 1.0263 scf.

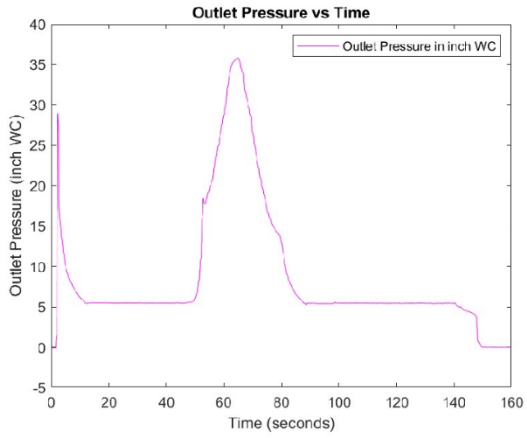


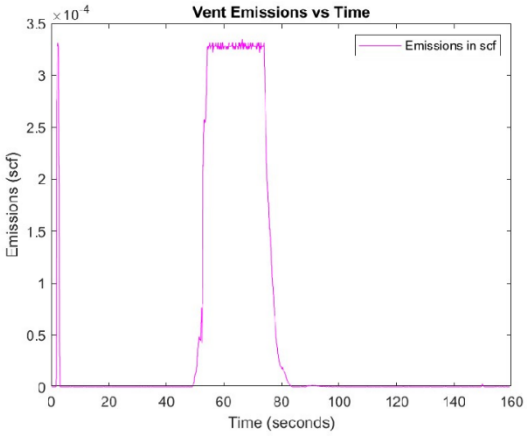


79

GTI ENERGY

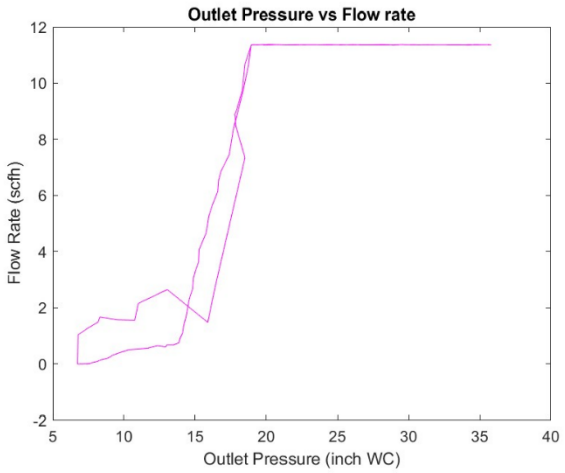
- 222489-003
  The volume of total emissions in 159.28 seconds is 0.0774 scf.
  The average flow rate of emissions at 18 inches WC is 8.87 scfh.

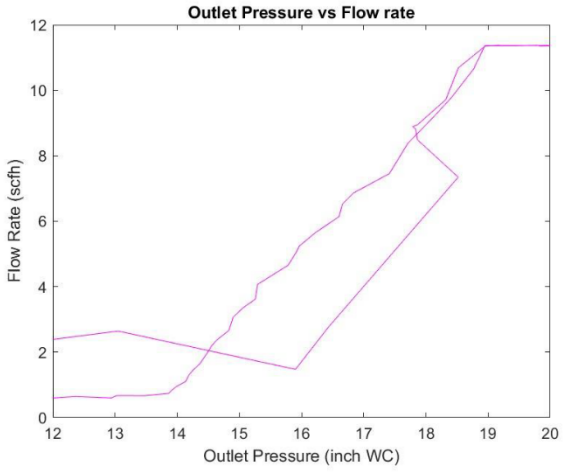




80

GTI ENERGY

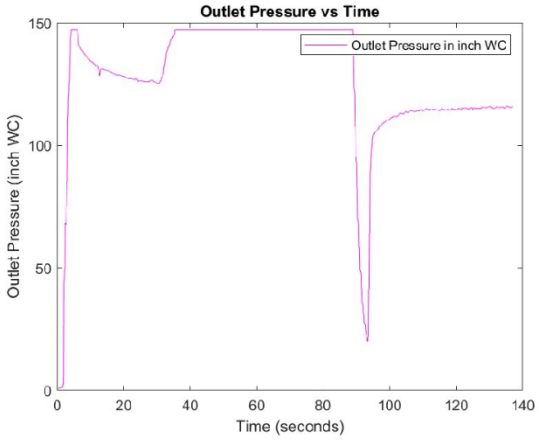


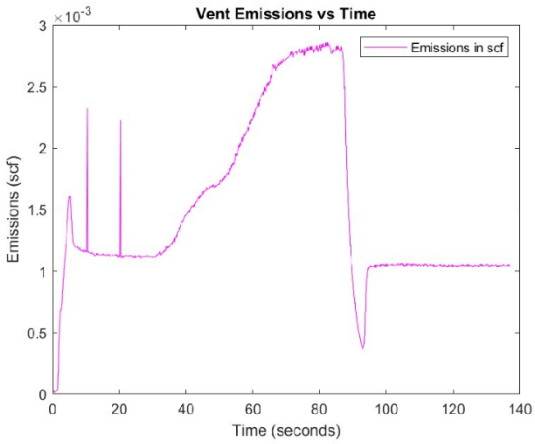


81

GTI ENERGY

- 222489-003_DT
  The volume of total emissions in 136.91 seconds is 1.9744 scf.

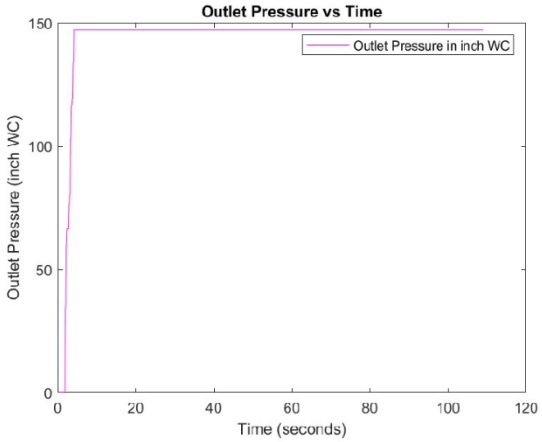


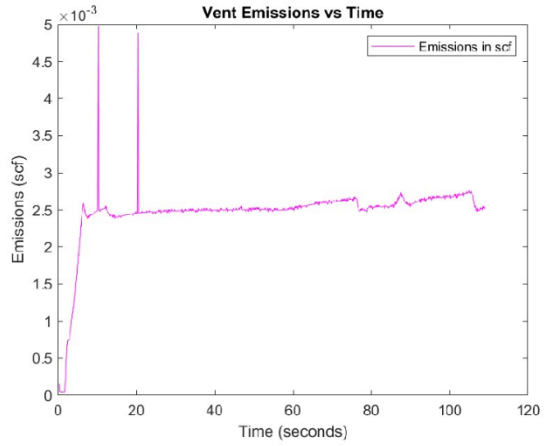


82

GTI ENERGY

- 222489-003_LD
  The volume of total emissions in 109.06 seconds is 2.5676 scf.





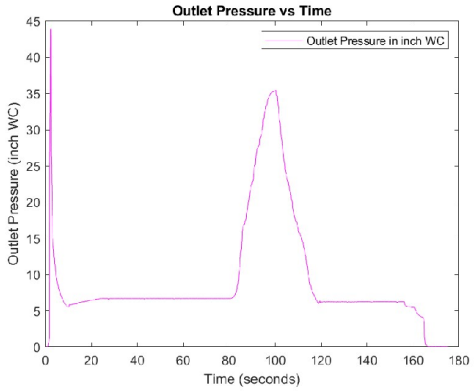
83

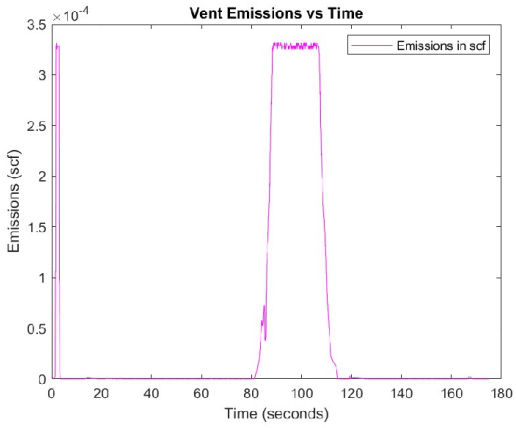
GTI ENERGY

7" WC Outlet, 3/16" Orifice, 60-psig Inlet

- 222489-001

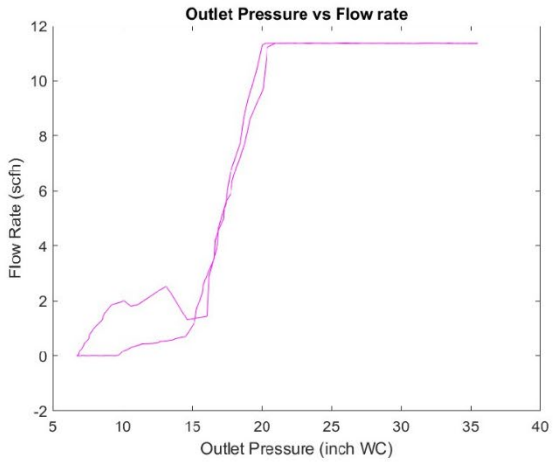
  The volume of total emissions in 175.30 seconds is 0.0766 scf.
  The average flow rate of emissions at 18 inches WC is 8.20 scfh.

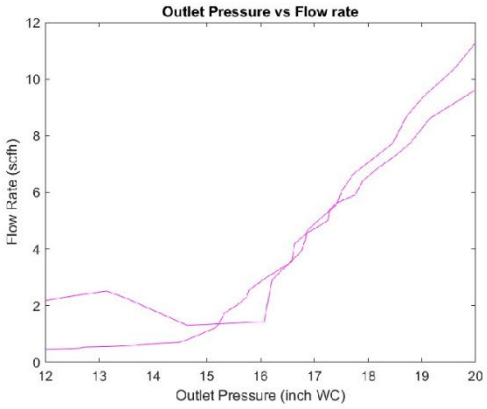




84

GTI ENERGY

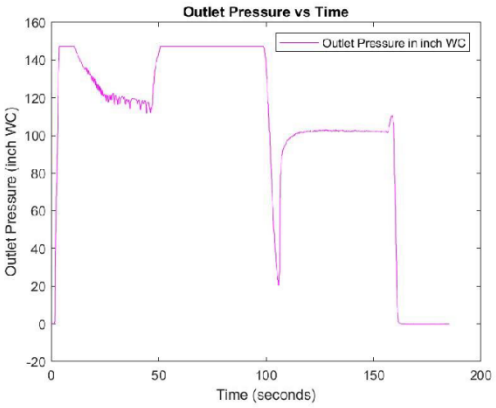


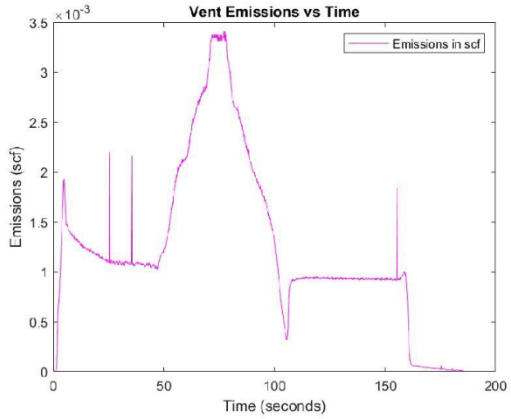


85

GTI ENERGY

- 222489-001_DT
  The volume of total emissions in 185.44 seconds is 2.2183 scf.





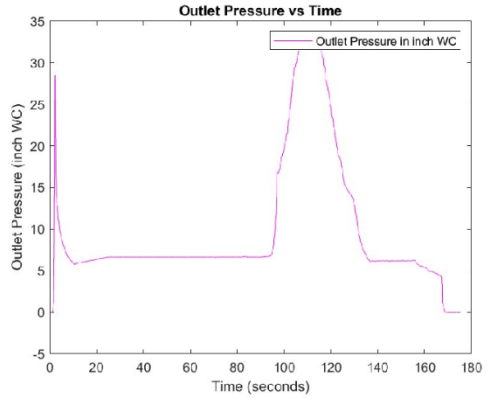
86

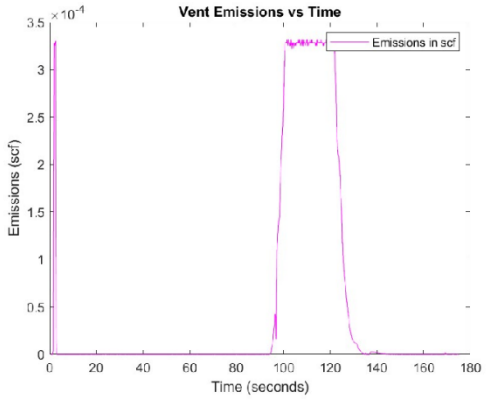
GTI ENERGY

- 222489-002

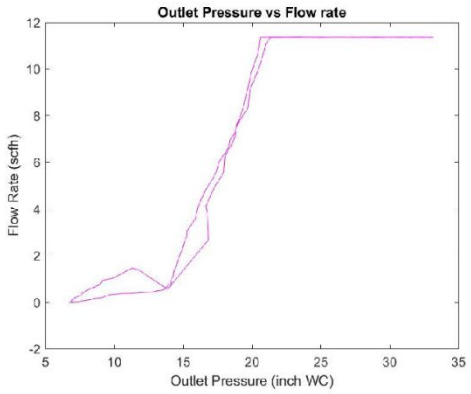
The volume of total emissions in 175.29 seconds is 0.0867 scf.

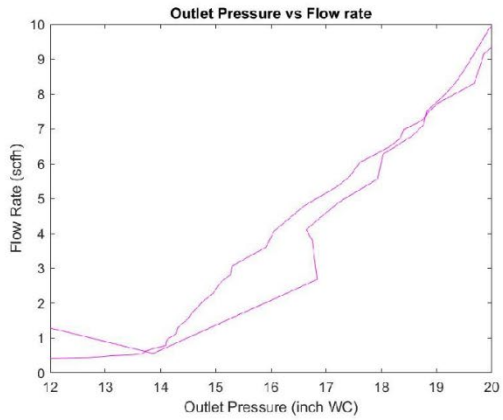
The average flow rate of emissions at 18 inches WC is 6.11 scfh.





87

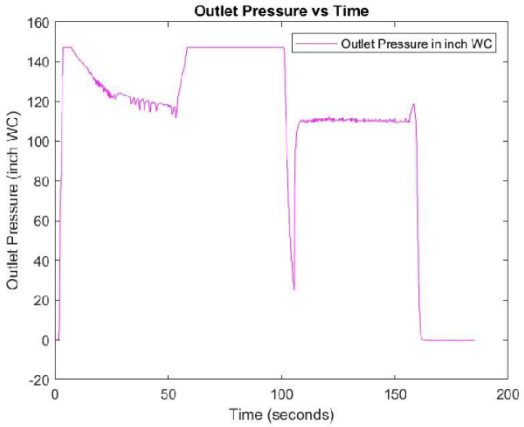


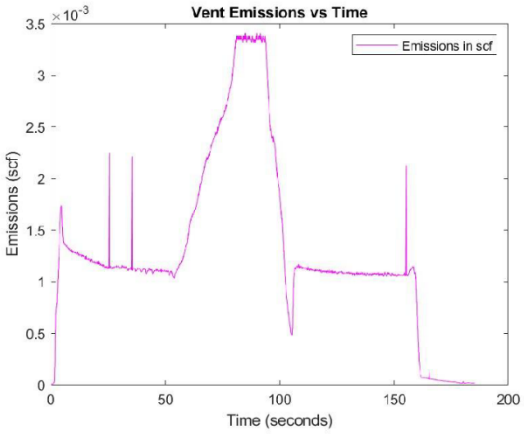


88

GTI ENERGY

- 222489-002_DT
  The volume of total emissions in 185.28 seconds is 2.3188 scf.

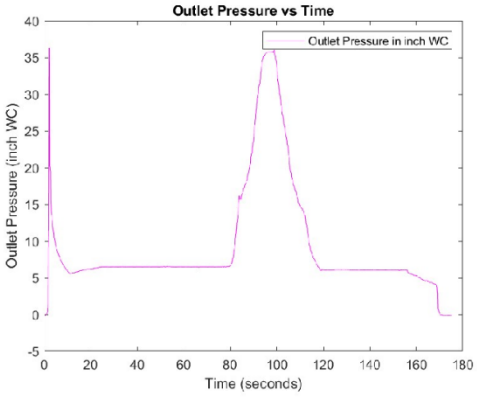


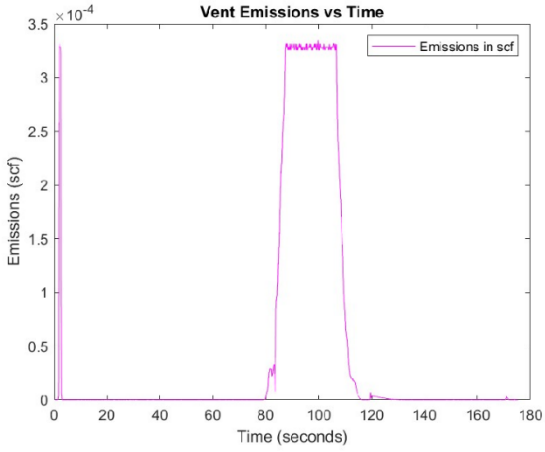


89

GTI ENERGY

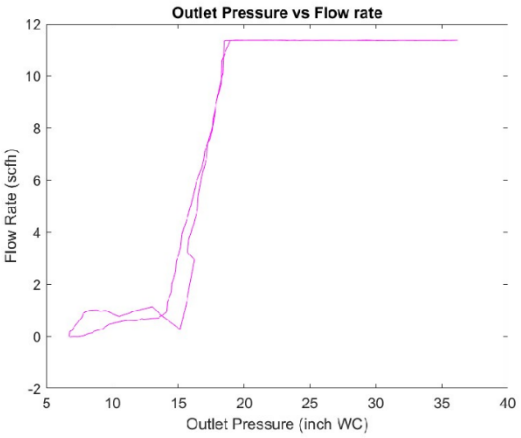
- 222489-003
  The volume of total emissions in 175.32 seconds is 0.0788 scf.
  The average flow rate of emissions at 18 inches WC is 9.07 scfh.

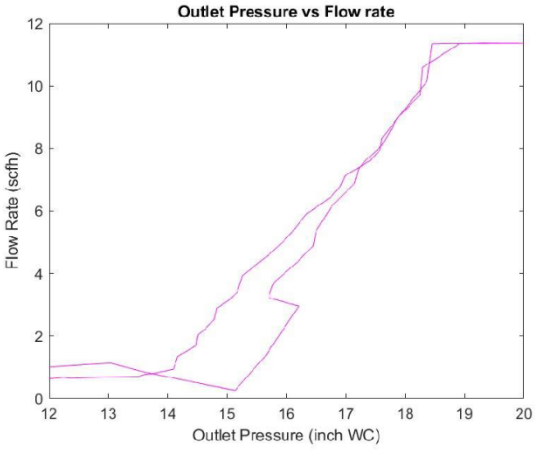




90

GTI ENERGY

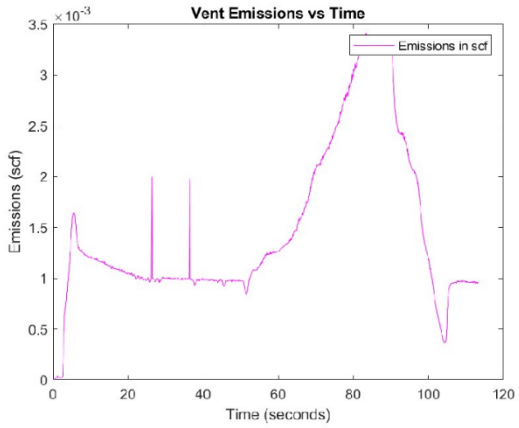


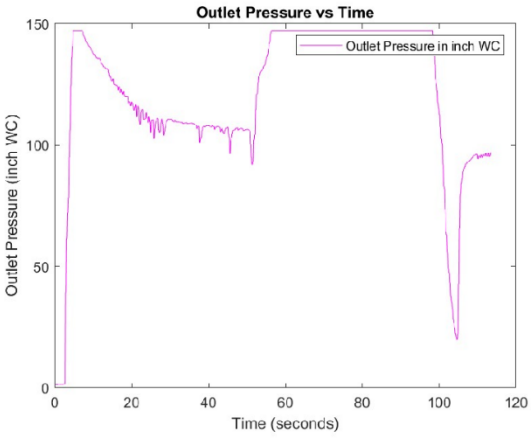


91

GTI ENERGY

- 222489-003_DT
  The volume of total emissions in 113.42 seconds is 1.6065 scf.





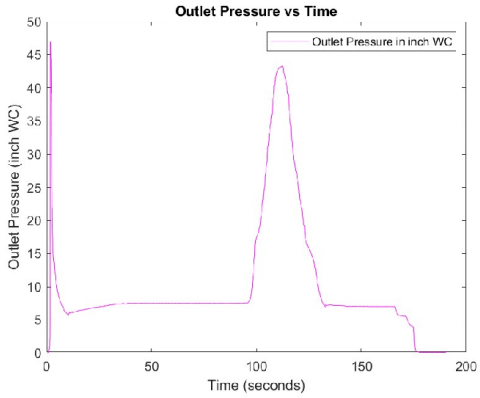
92

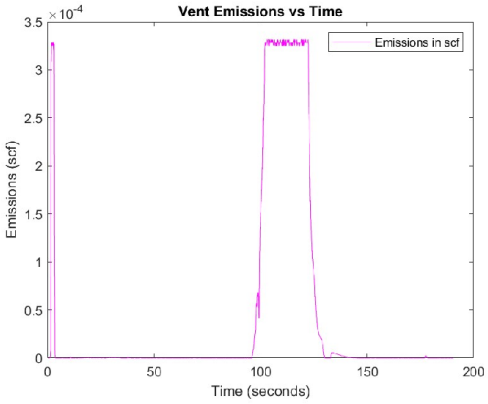
GTI ENERGY

7" WC Outlet, 3/16" Orifice, 100-psig Inlet

- 222489-001

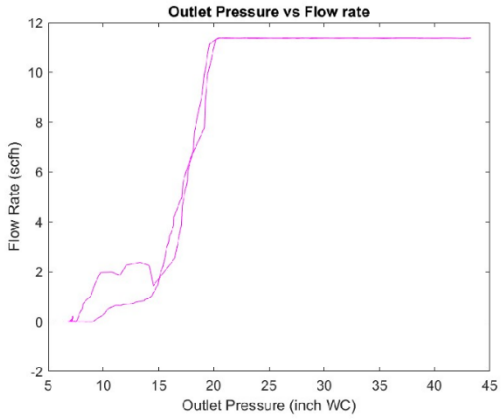
  The volume of total emissions in 190.37 seconds is 0.0812 scf.
  The average flow rate of emissions at 18 inches WC is 6.63 scfh.

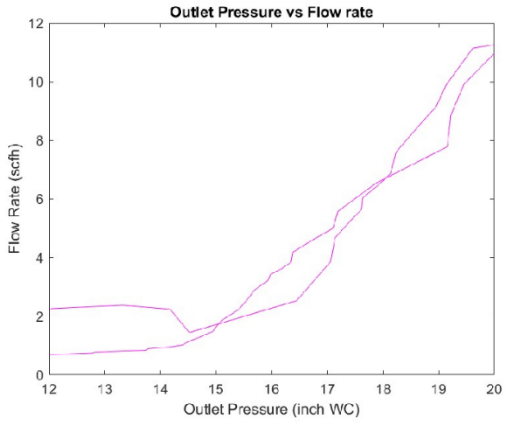




93

GTI ENERGY

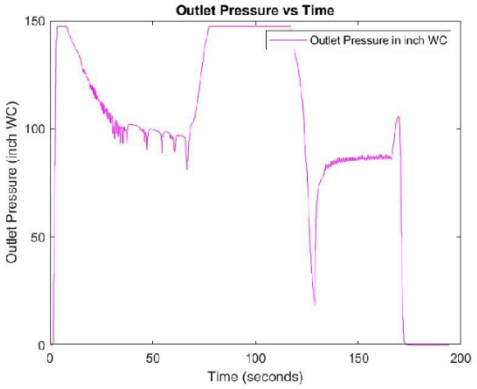


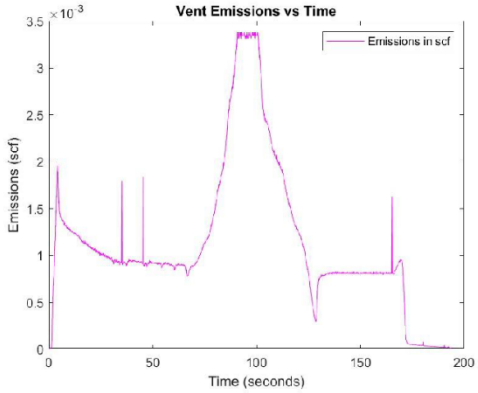


94

GTI ENERGY

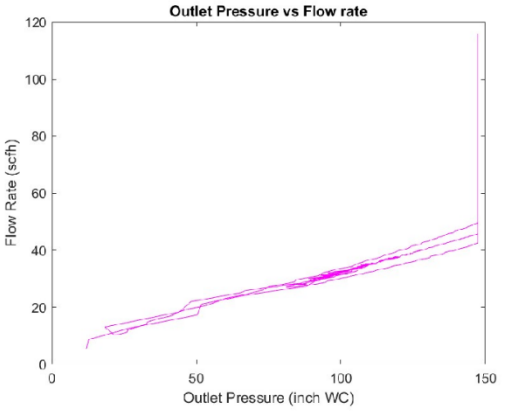
- 222489-001_DT
  The volume of total emissions in 194.40 seconds is 2.1235 scf.
  The average flow rate of emissions at 18 inches WC is 13.07 scfh.

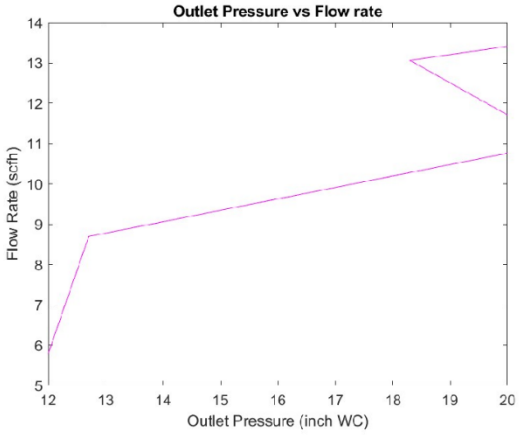




95

GTI ENERGY

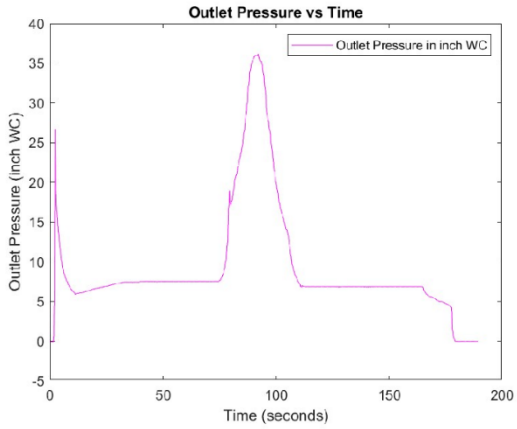


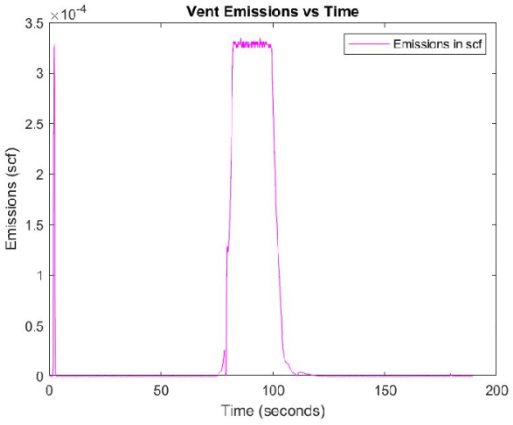


96

GTI ENERGY

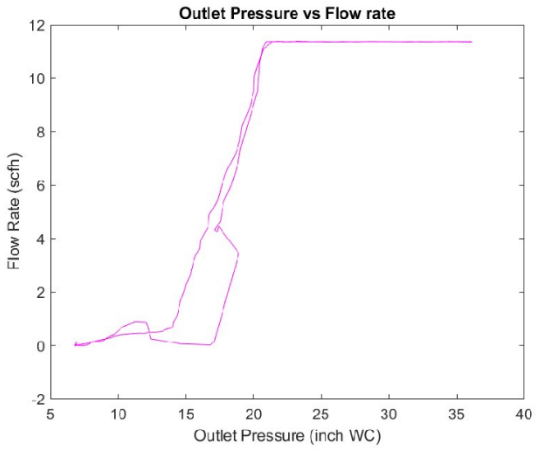
- 222489-002
  The volume of total emissions in 189.33 seconds is 0.0705 scf.
  The average flow rate of emissions at 18 inches WC is 6.52 scfh.

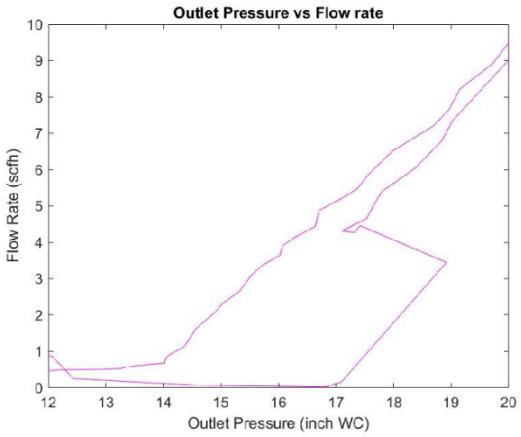




97

GTI ENERGY

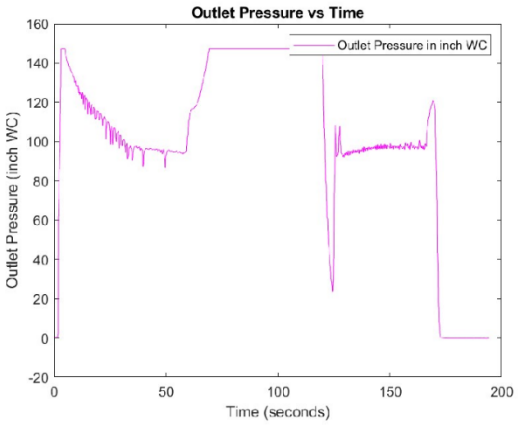


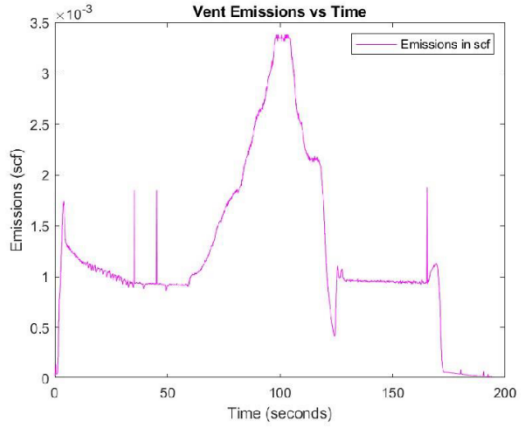


98

GTI ENERGY

- 222489-002_DT
  The volume of total emissions in 194.37 seconds is 2.2981 scf.

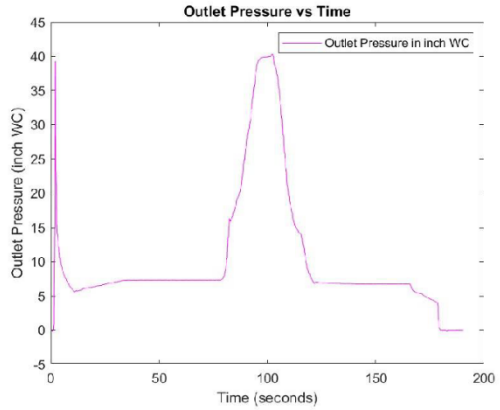


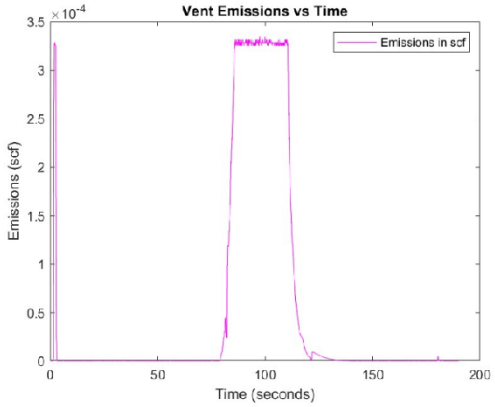


99

GTI ENERGY

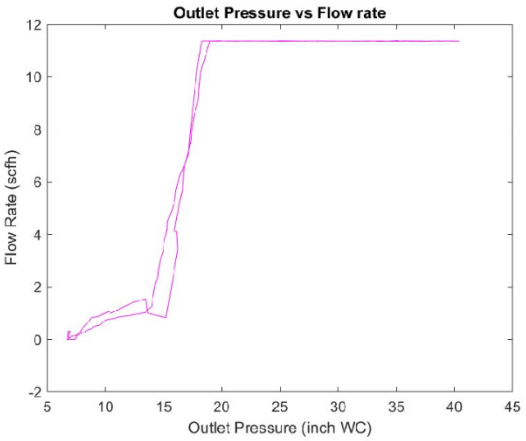
- 222489-003
  The volume of total emissions in 190.27 seconds is 0.0966 scf.
  The average flow rate of emissions at 18 inches WC is 9.80 scfh.

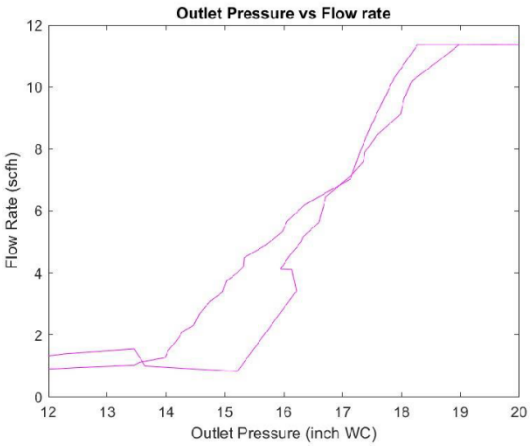




100

GTI ENERGY

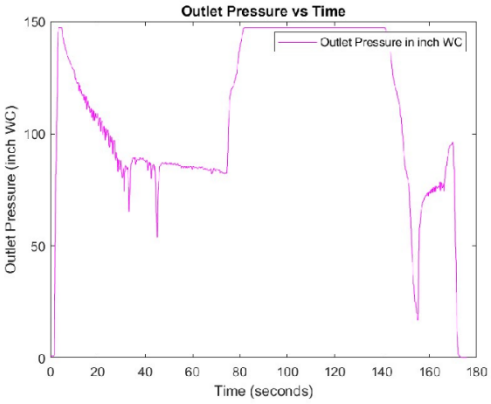


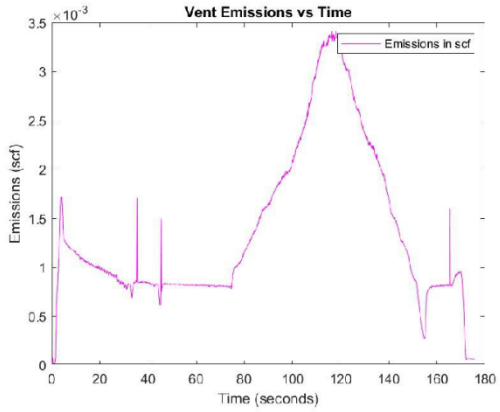


101

GTI ENERGY

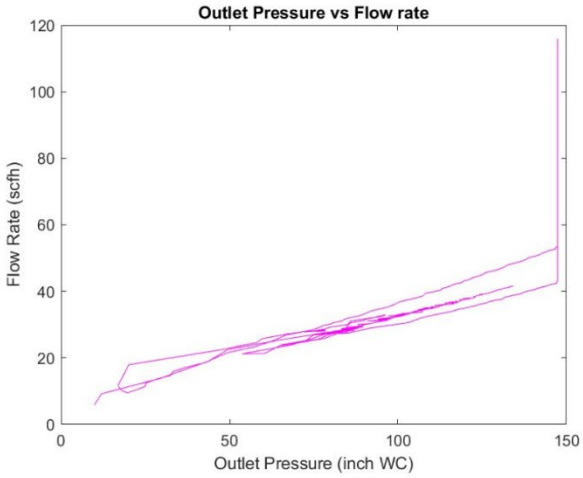
- 222489-003_DT
  The volume of total emissions in 175.91 seconds is 2.3189 scf.
  The average flow rate of emissions at 18 inches WC is 10.10 scfh.

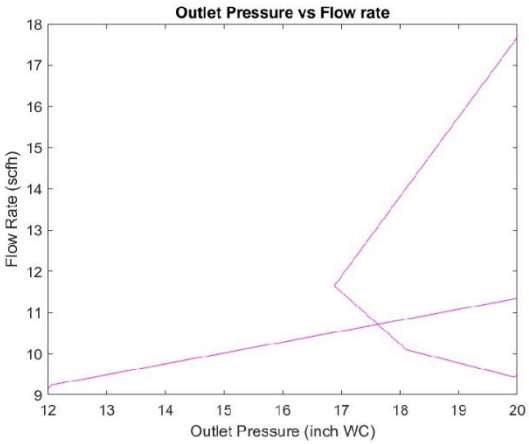




102

GTI ENERGY





103

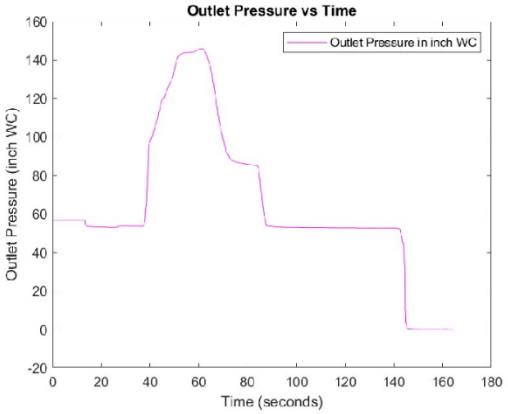
GTI ENERGY

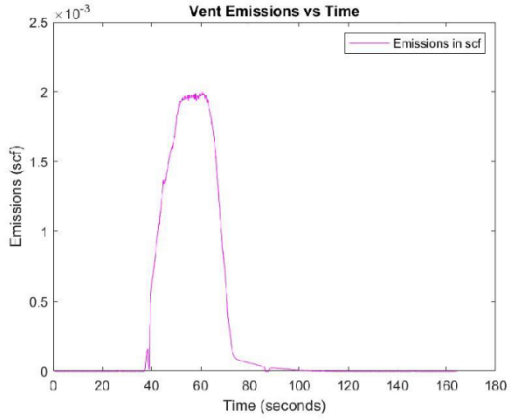
2-psig Outlet, 3/16" Orifice, 10-psig Inlet

- 222489-045

  The volume of total emissions in 164.29 seconds is 0.4852 scf.

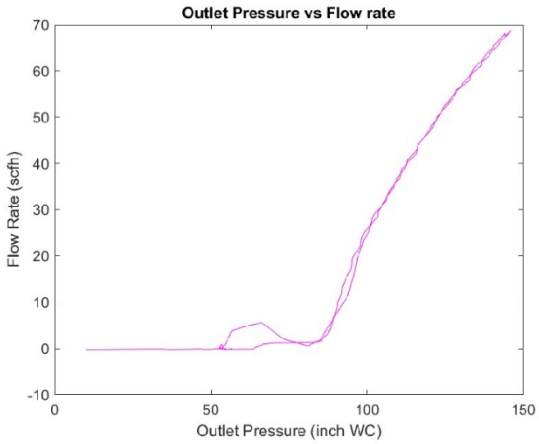
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 3.76 scfh.

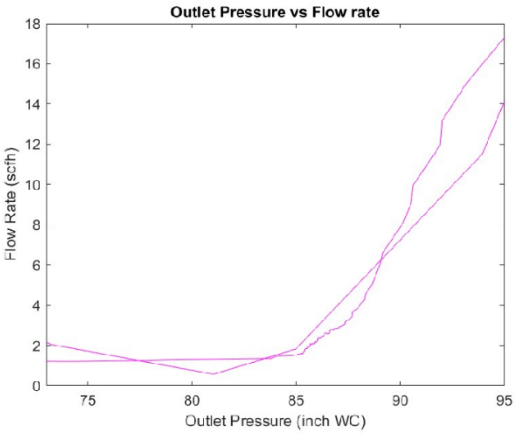




104

GTI ENERGY

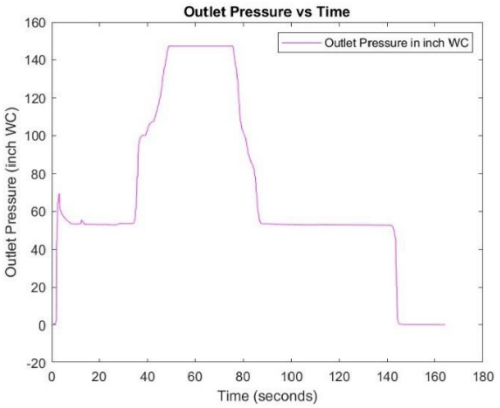


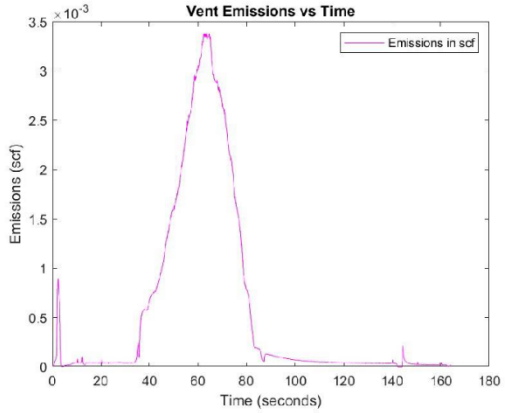


105

GTI ENERGY

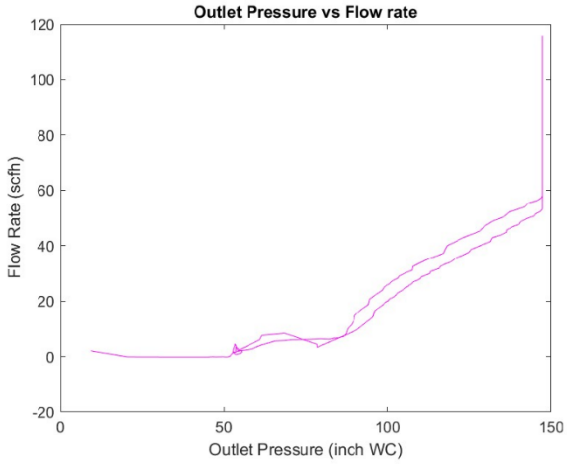
- 222489-045_DT
  The volume of total emissions in 164.32 seconds is 0.8969 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 10.57 scfh.

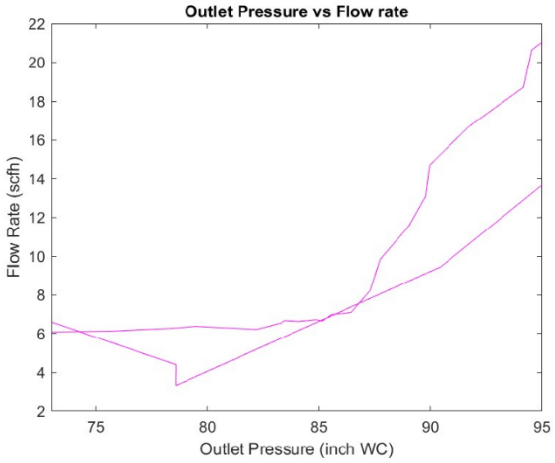




106

GTI ENERGY

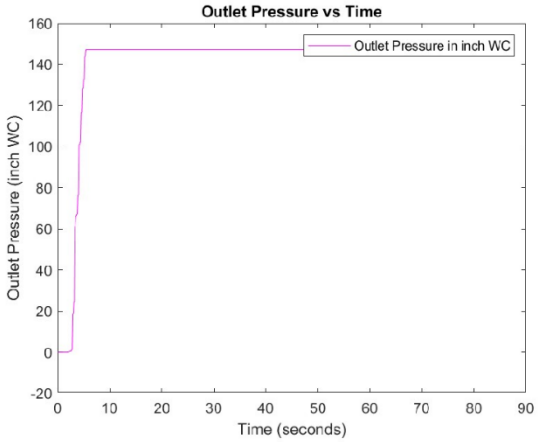


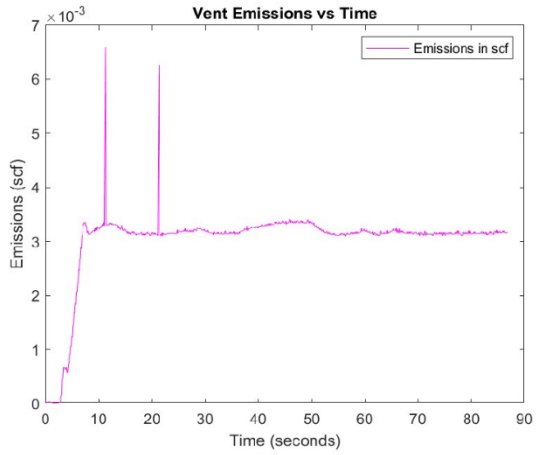


107

GTI ENERGY

- 222489-045_LD
  The volume of total emissions in 86.85 seconds is 2.5081 scf.

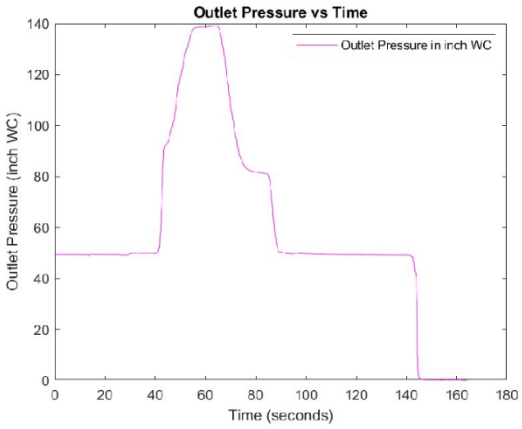


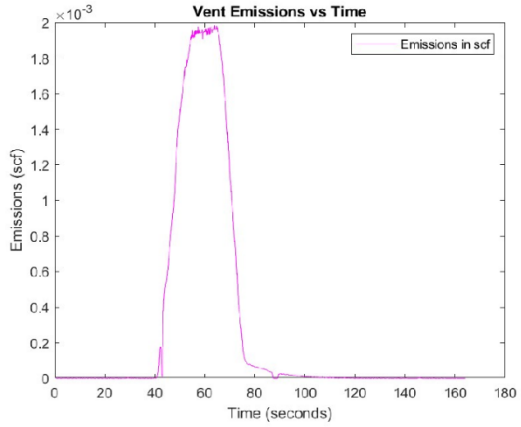


108

GTI ENERGY

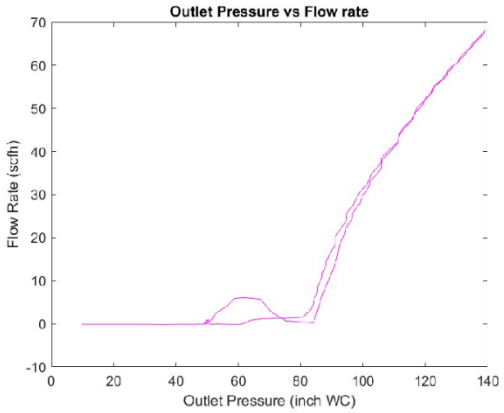
- 222489-046
  The volume of total emissions in 164.20 seconds is 0.4517 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 13.36 scfh.

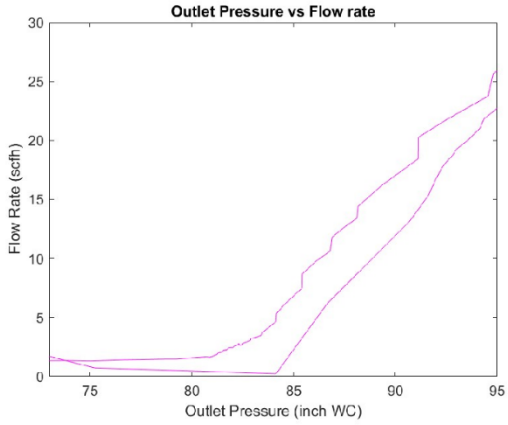




109

GTI ENERGY

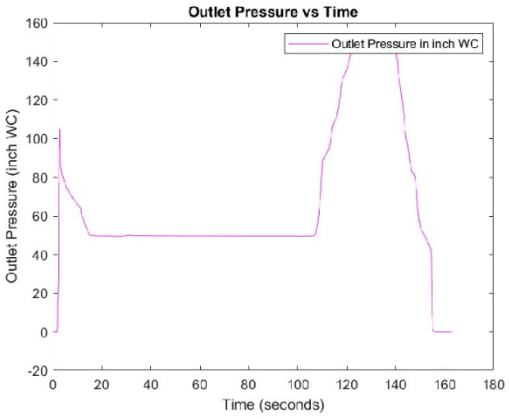


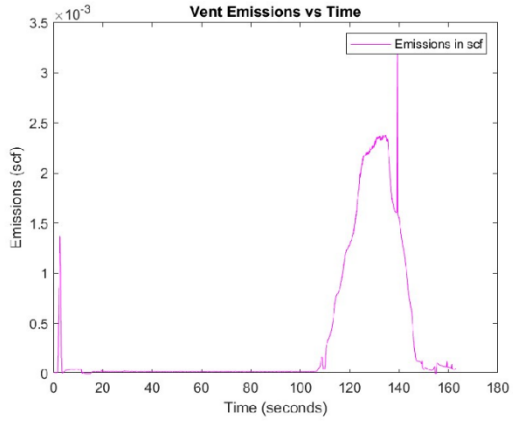


110

GTI ENERGY

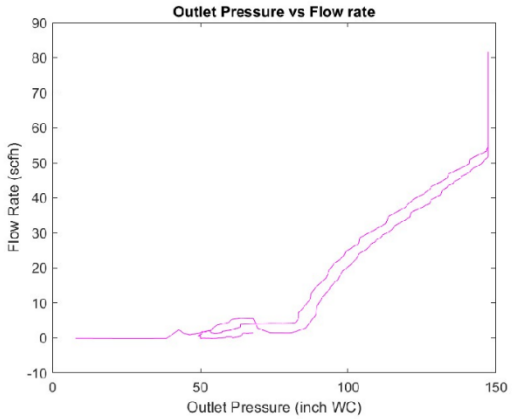
- 222489-046_DT
  The volume of total emissions in 163.24 seconds is 0.5580 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 11.53 scfh.

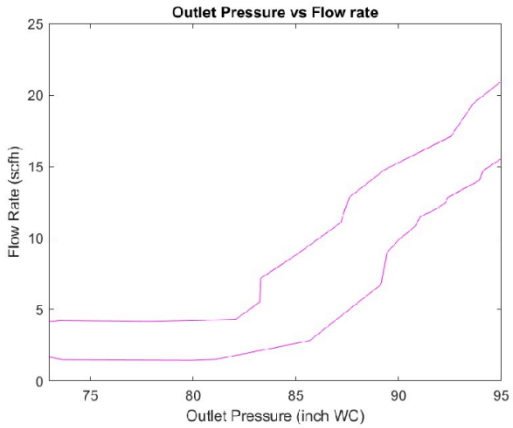




111

GTI ENERGY

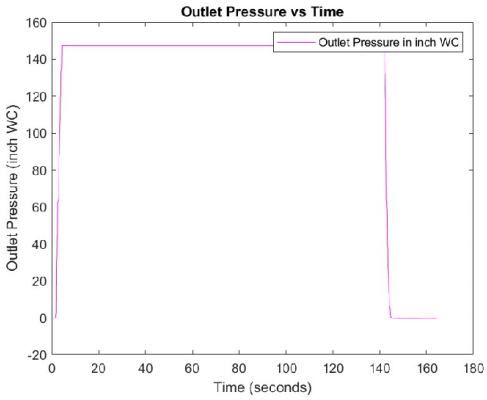


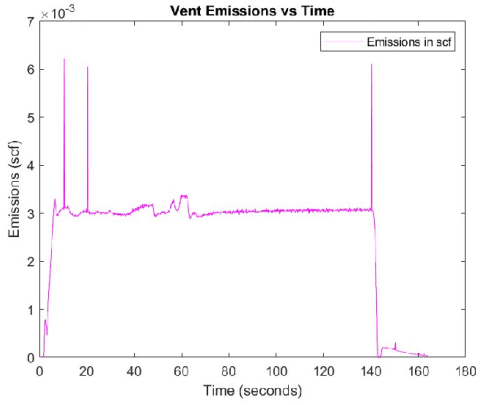


112

GTI ENERGY

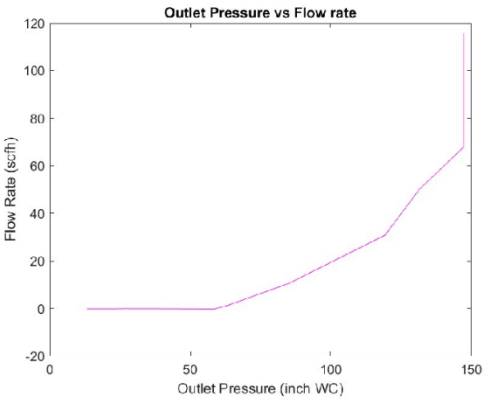
- 222489-046_LD
  The volume of total emissions in 164.23 seconds is 4.0723 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 16.32 scfh.

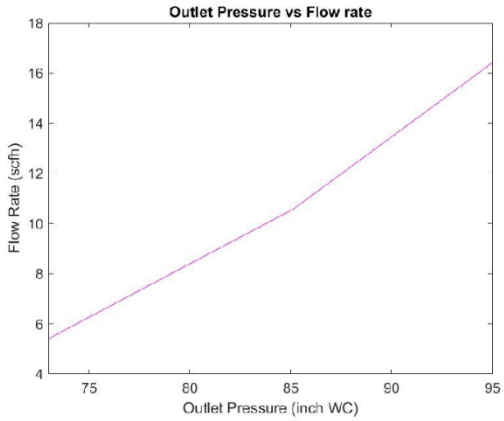




113

GTI ENERGY

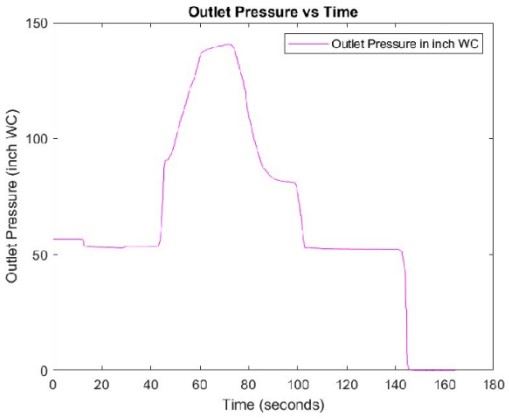


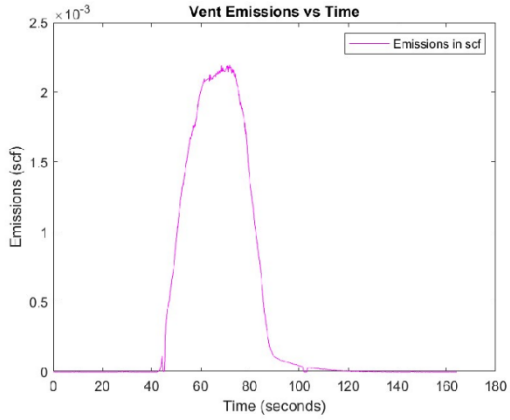


114

GTI ENERGY

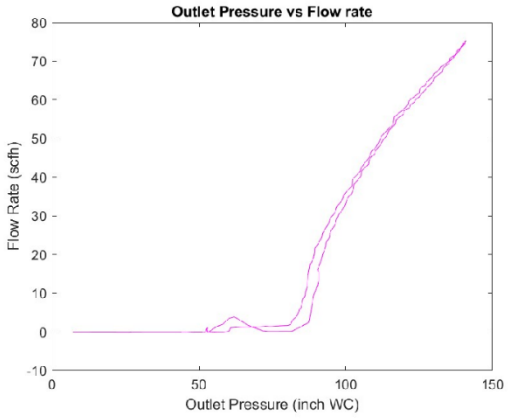
- 222489-047
  The volume of total emissions in 164.34 seconds is 0.6384 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 14.54 scfh.

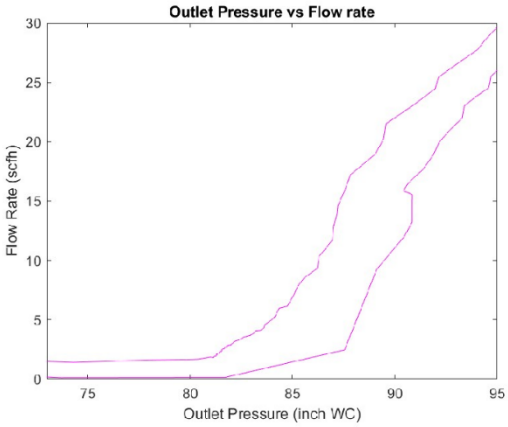




115

GTI ENERGY

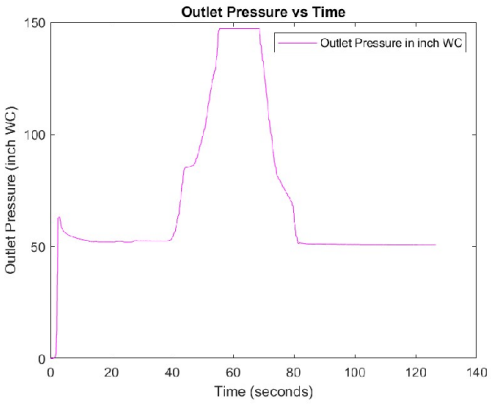


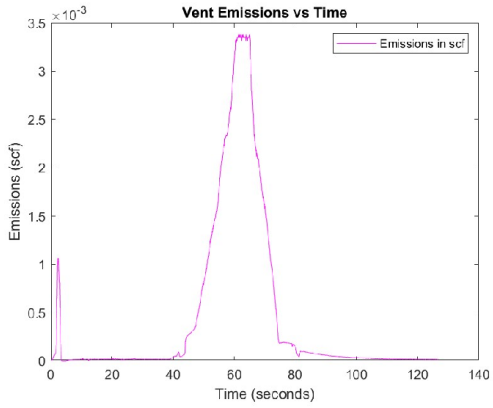


116

GTI ENERGY

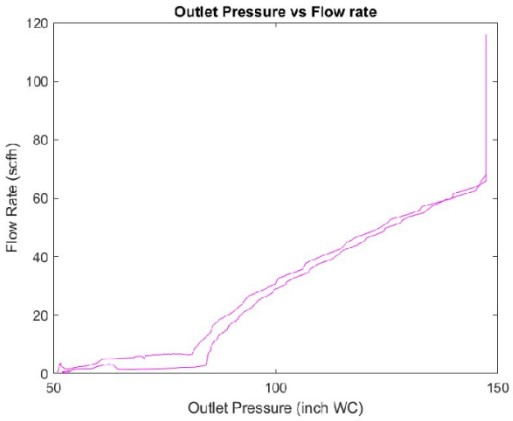
- 222489-047_DT
  The volume of total emissions in 126.68 seconds is 0.5526 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 14.09 scfh.

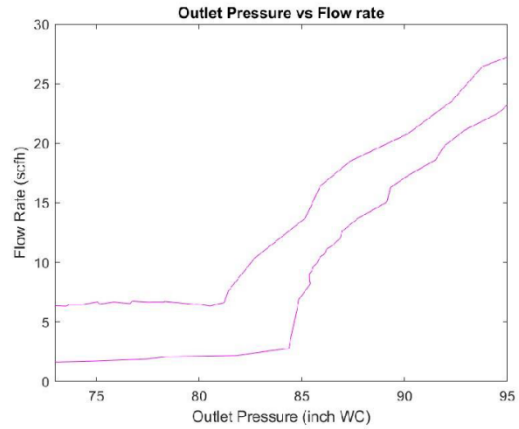




117

GTI ENERGY

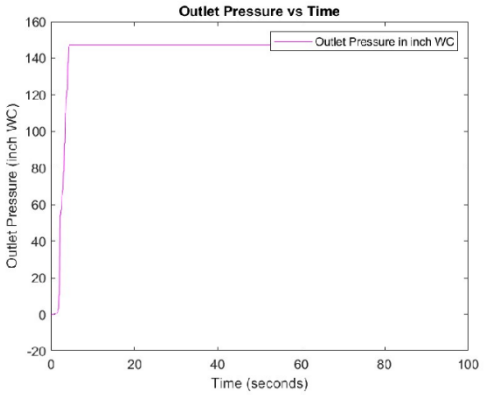


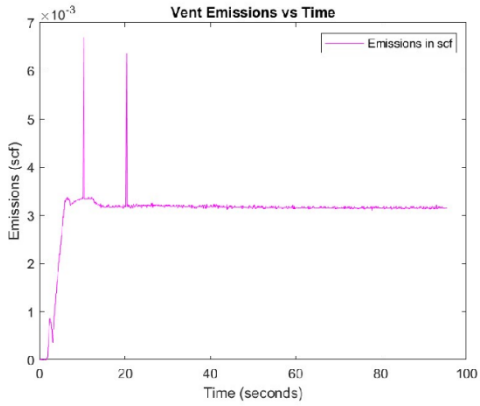


118

GTI ENERGY

- 222489-047_LD
  The volume of total emissions in 95.35 seconds is 2.8006 scf.





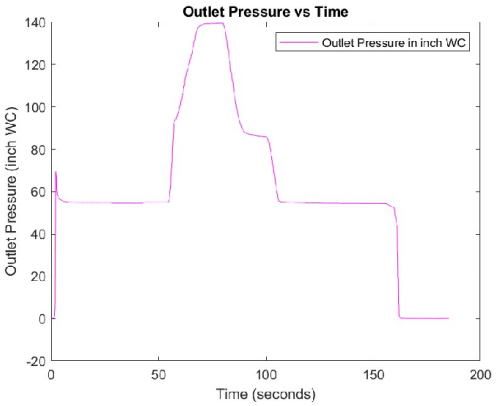
119

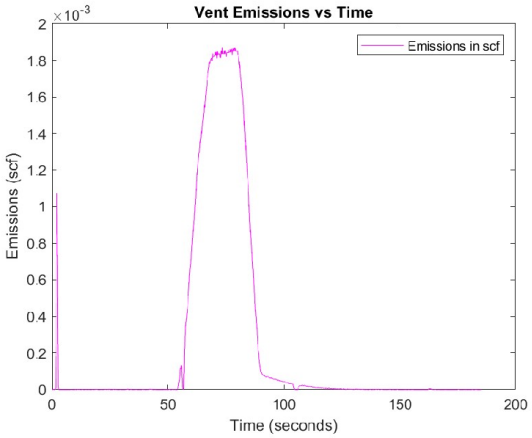
GTI ENERGY

2-psig Outlet, 3/16" Orifice, 60-psig Inlet

- 222489-045

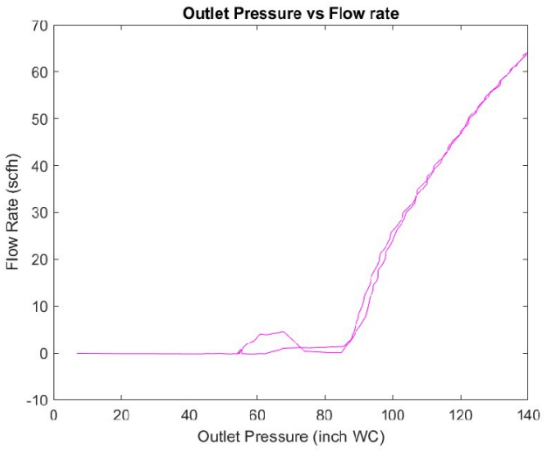
  The volume of total emissions in 185.32 seconds is 0.4411 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 2.77 scfh.

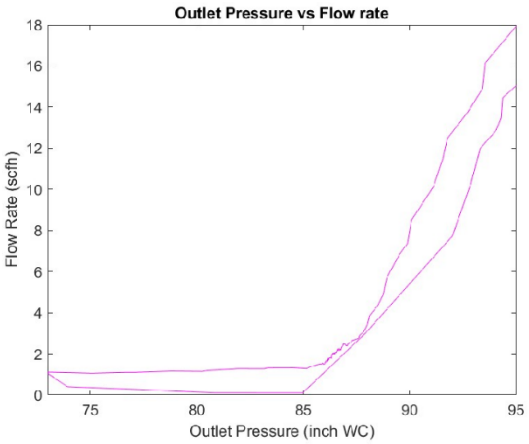




120

GTI ENERGY

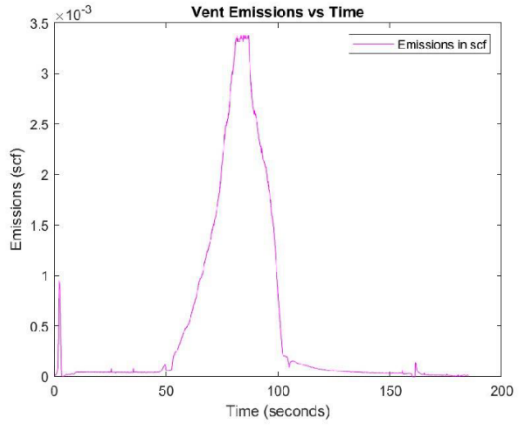


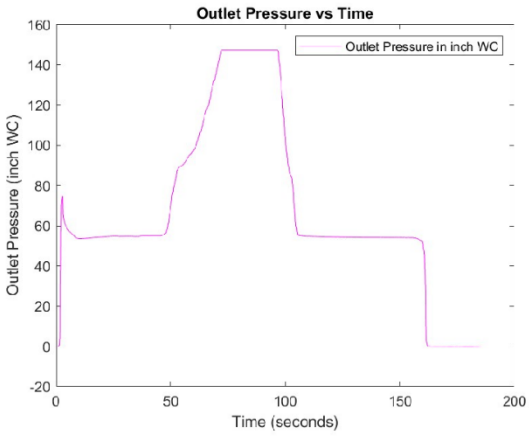


121

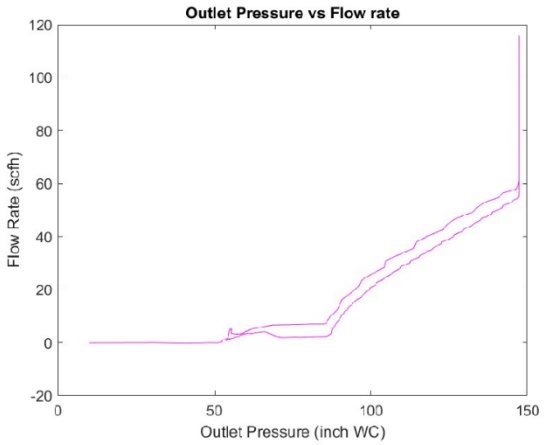
GTI ENERGY

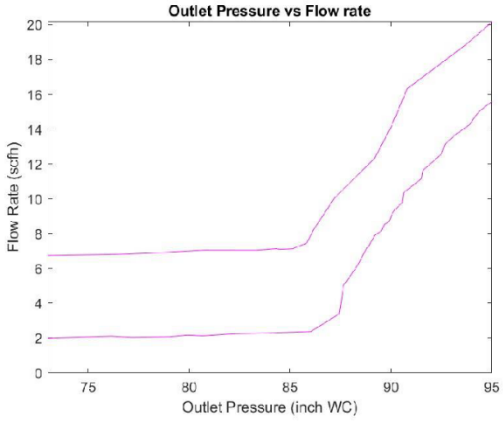
- 222489-045_DT
  The volume of total emissions in 185.26 seconds is 0.8859 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 8.74 scfh.





122

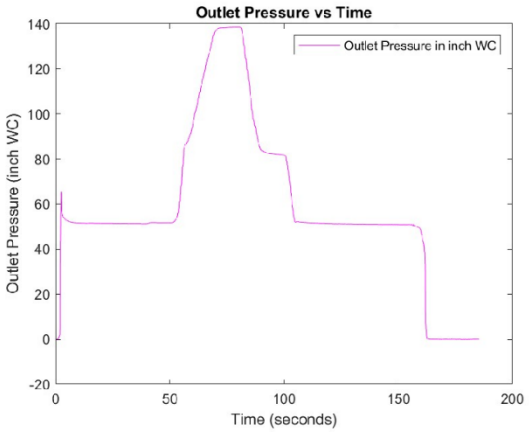


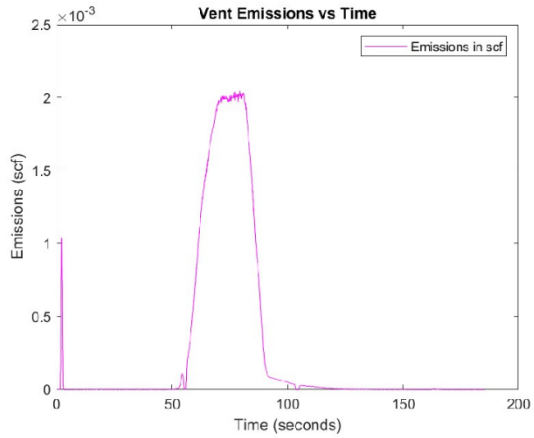


123

GTI ENERGY

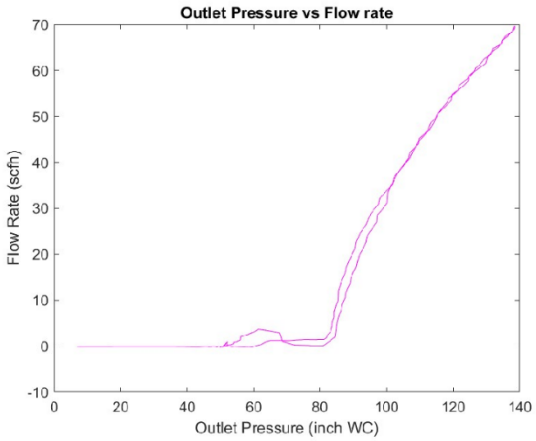
- 222489-046
  The volume of total emissions in 185.36 seconds is 0.4883 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 14.46 scfh.

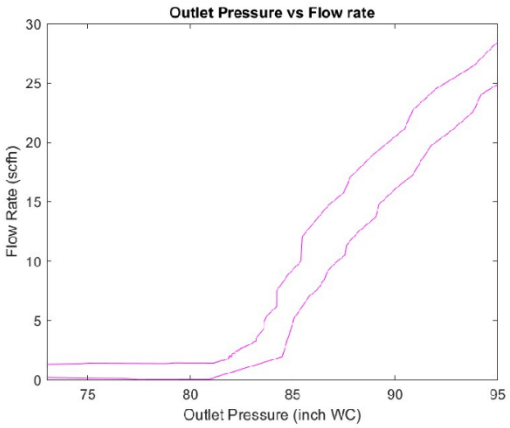




124

GTI ENERGY

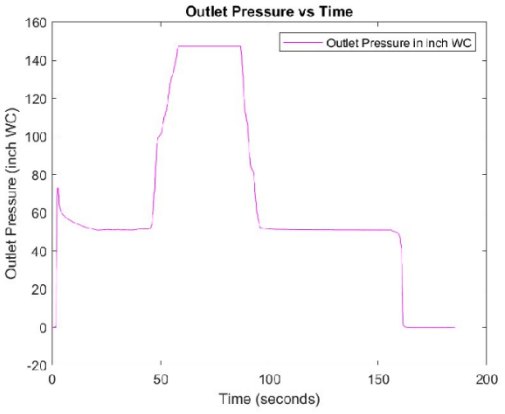


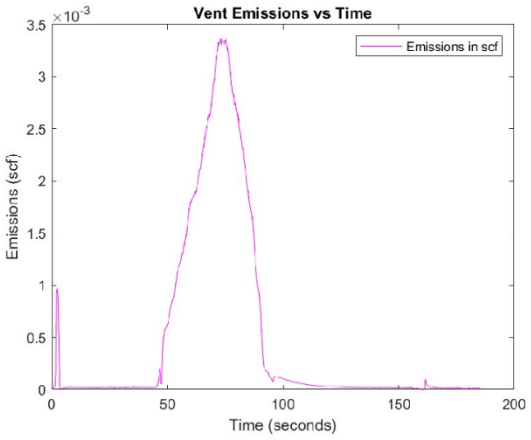


125

GTI ENERGY

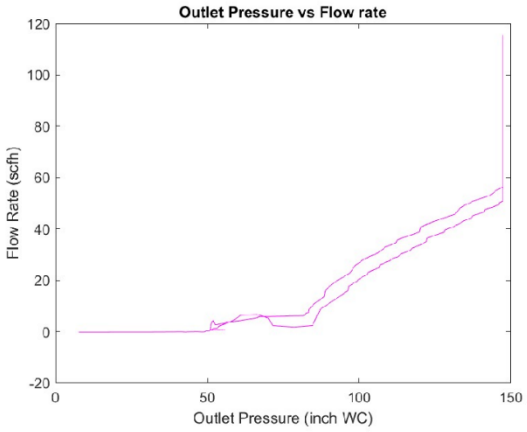
- 222489-046_DT
  The volume of total emissions in 185.40 seconds is 0.8787 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 12.87 scfh.

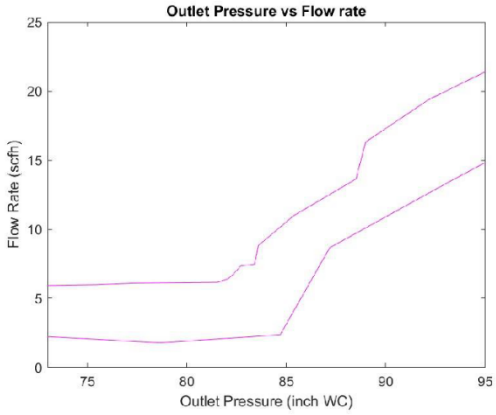




126

GTI ENERGY

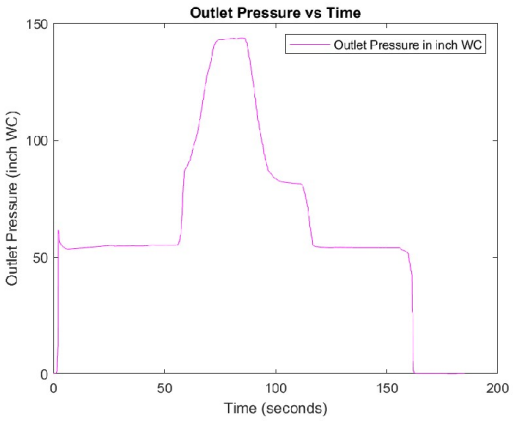


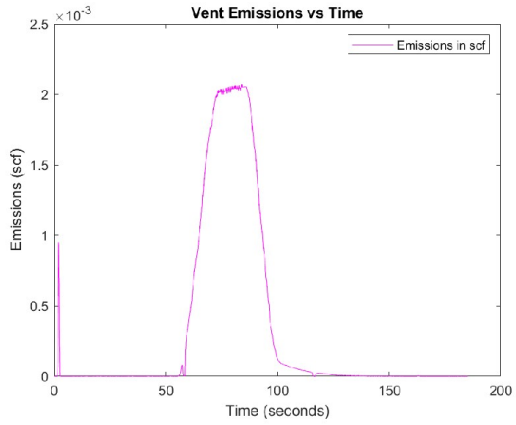


127

GTI ENERGY

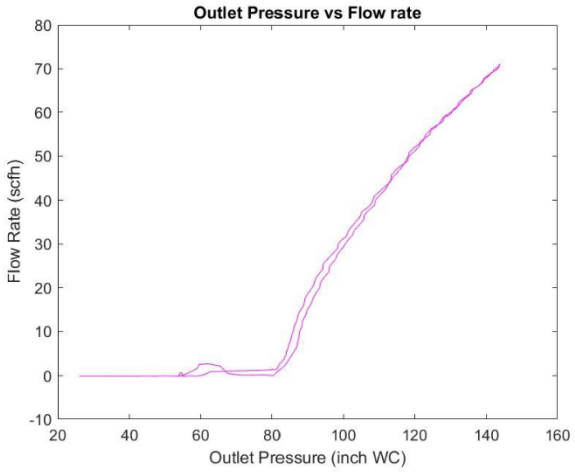
- 222489-047
  The volume of total emissions in 185.22 seconds is 0.5730 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 13.39 scfh.

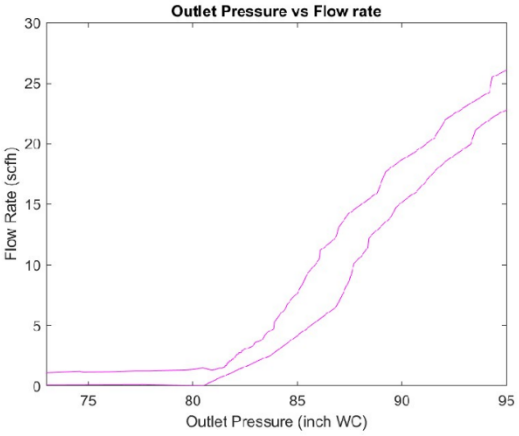




128

GTI ENERGY

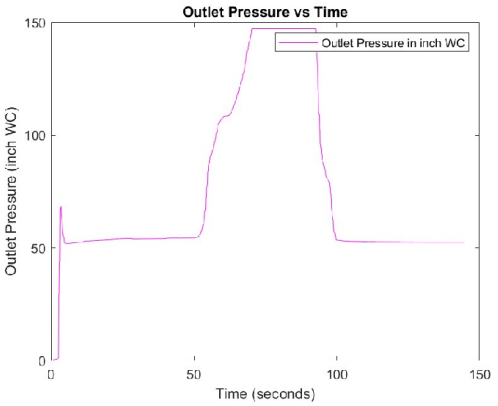


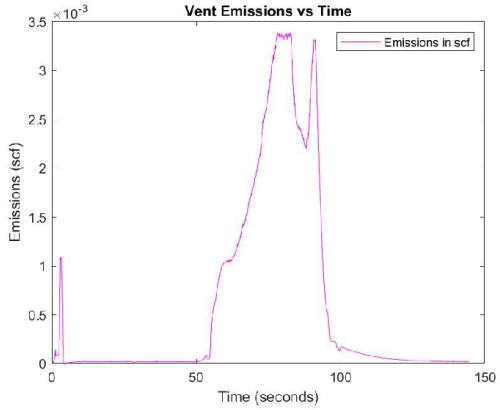


129

GTI ENERGY

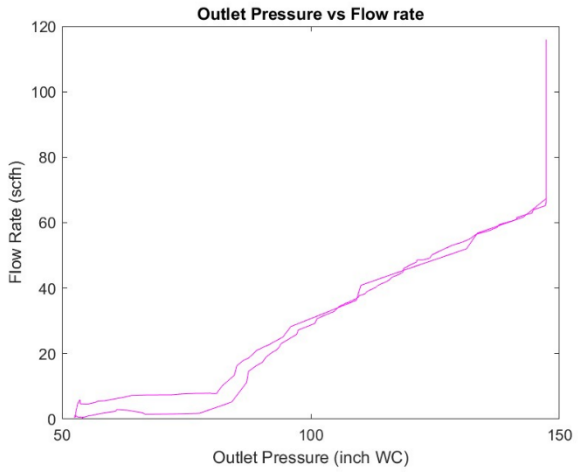
- 222489-047_DT
  The volume of total emissions in 144.65 seconds is 0.8466 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 17.27 scfh.

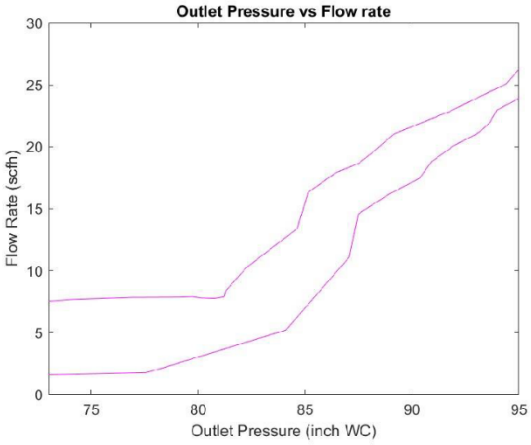




130

GTI ENERGY





131

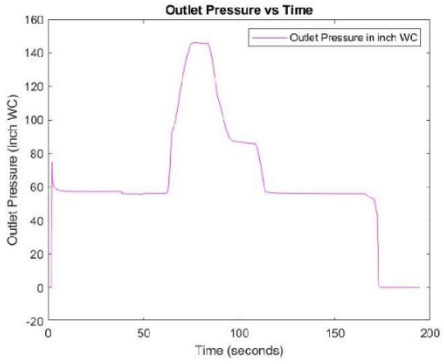
GTI ENERGY

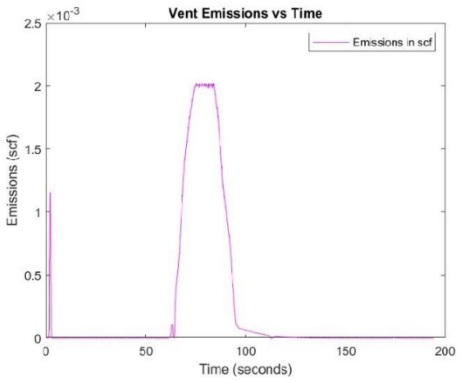
2-psig Outlet, 3/16" Orifice, 100-psig Inlet

- 222489-045

  The volume of total emissions in 194.35 seconds is 0.4427 scf.

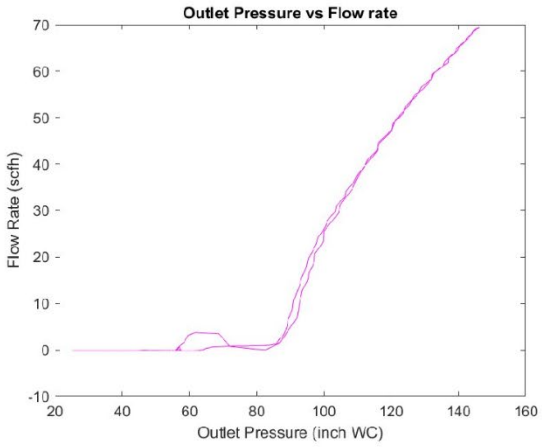
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 2.55 scfh.

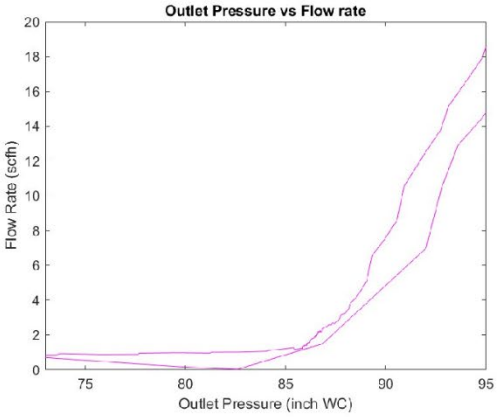




132

GTI ENERGY

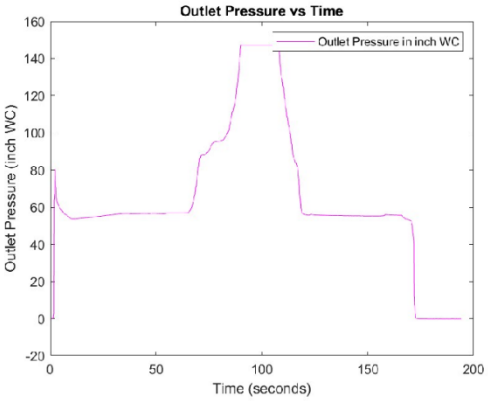


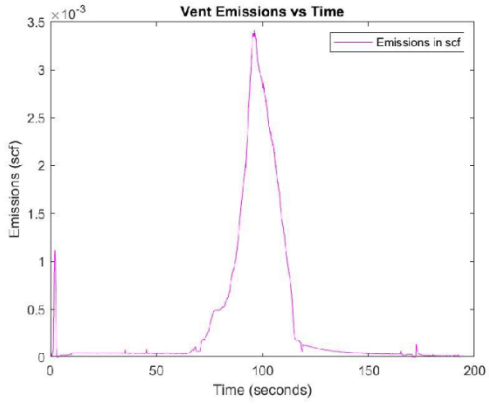


133

GTI ENERGY

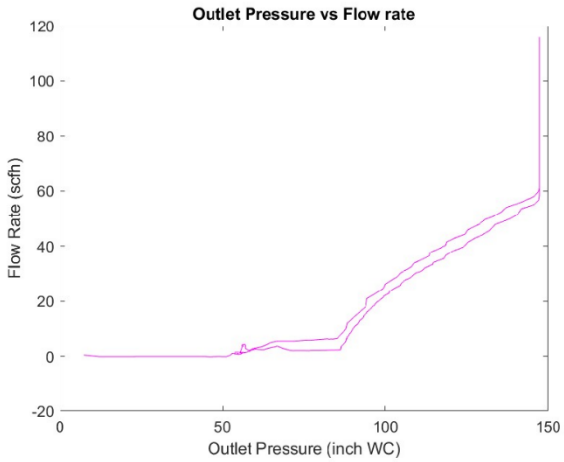
- 222489-045_DT
  The volume of total emissions in 194.41 seconds is 0.6923 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 7.83 scfh.

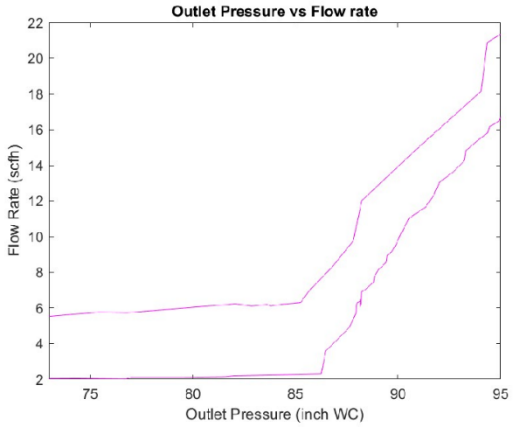




134

GTI ENERGY

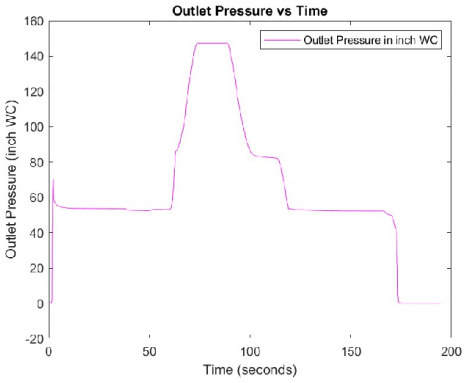


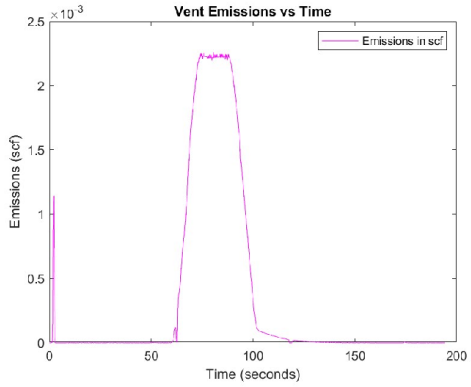


135

GTI ENERGY

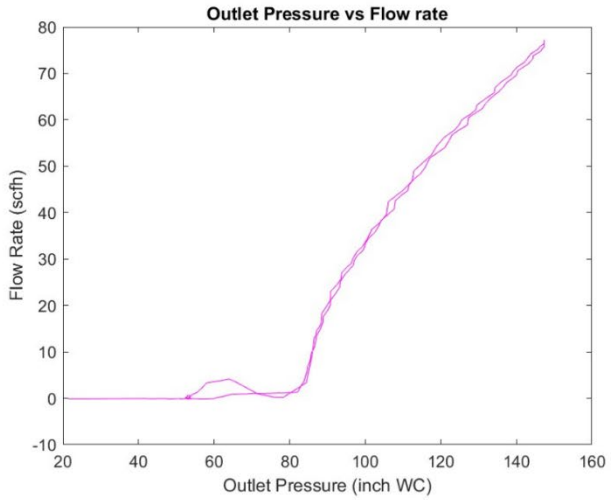
- 222489-046
  The volume of total emissions in 194.38 seconds is 0.6265 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 16.12 scfh.

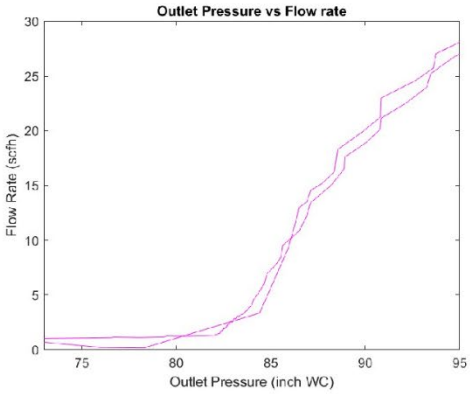




136

GTI ENERGY

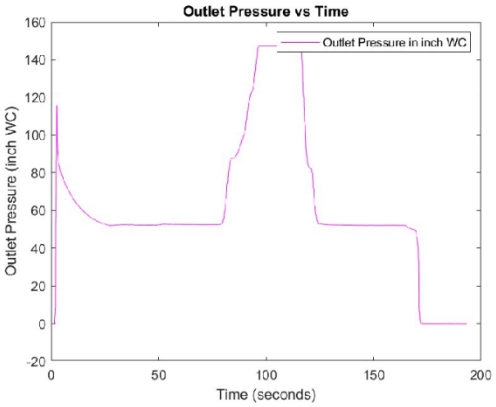


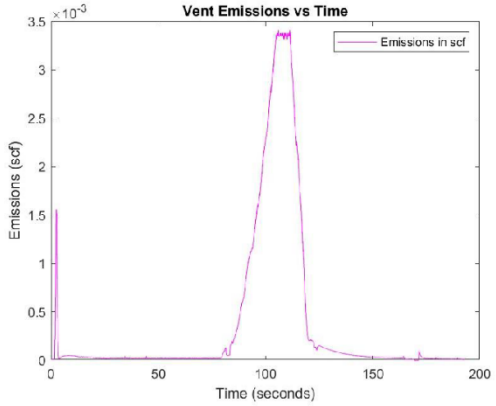


137

GTI ENERGY

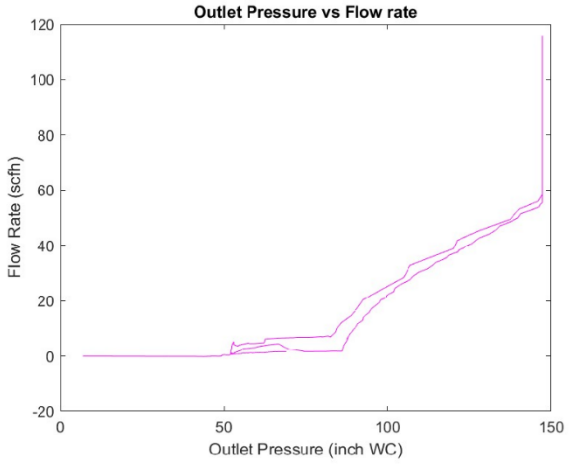
- 222489-046_DT
  The volume of total emissions in 193.38 seconds is 0.7142 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 10.13 scfh.

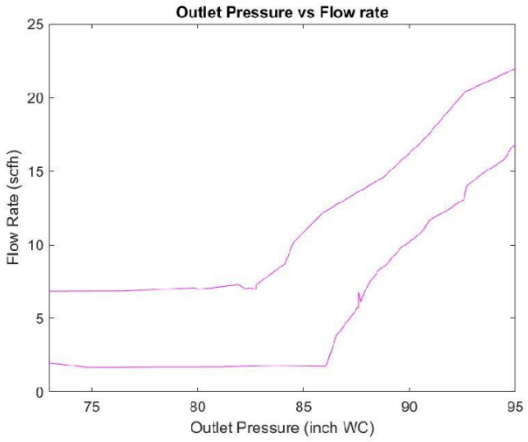




138

GTI ENERGY

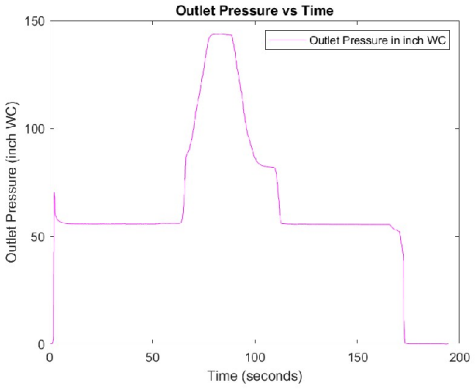


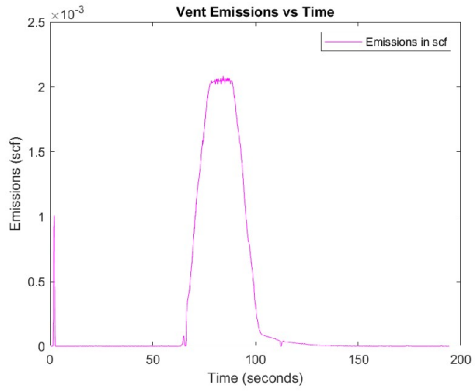


139

GTI ENERGY

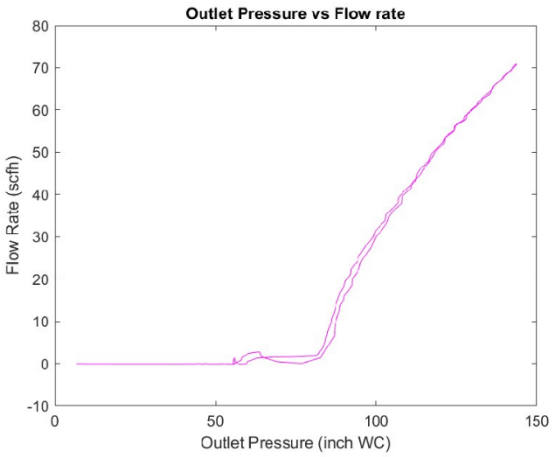
- 222489-047
  The volume of total emissions in 194.38 seconds is 0.4976 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 13.89 scfh.

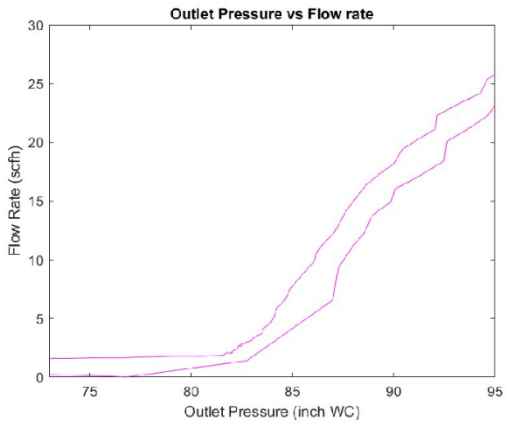




140

GTI ENERGY

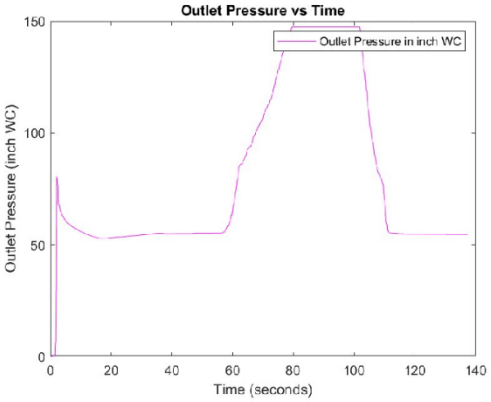


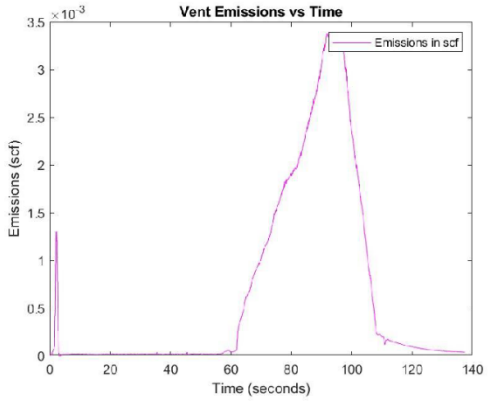


141

GTI ENERGY

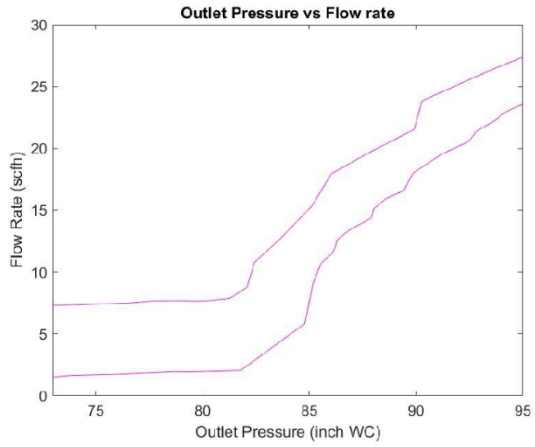
- 222489-047_DT
  The volume of total emissions in 137.46 seconds is 0.8847 scf.
  The average flow rate of emissions at 88.66 inches WC (3.2 PSI) is 16.57 scfh.

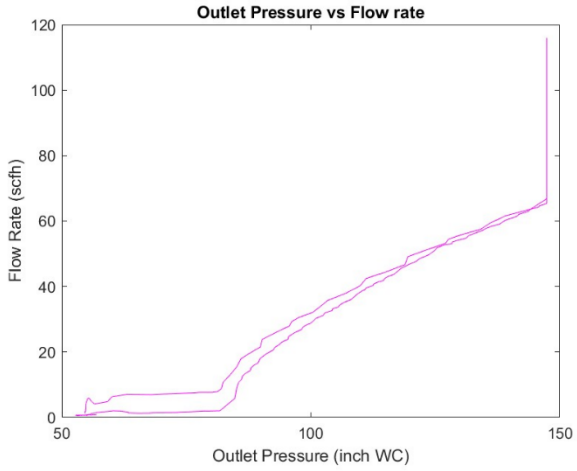




142

GTI ENERGY



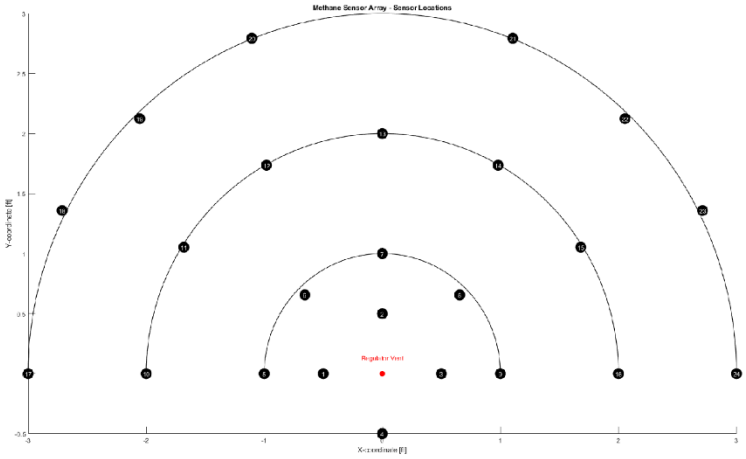


143

GTI ENERGY

Methane Concentration Maps

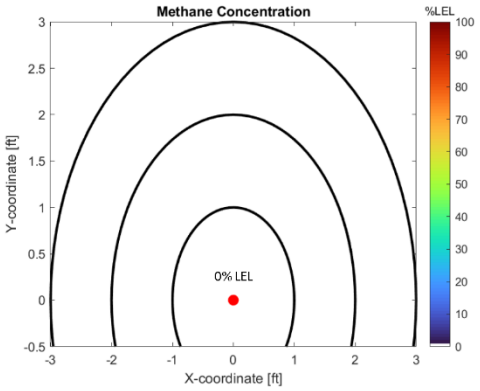
Sensor Locations



GTI ENERGY

7" WC

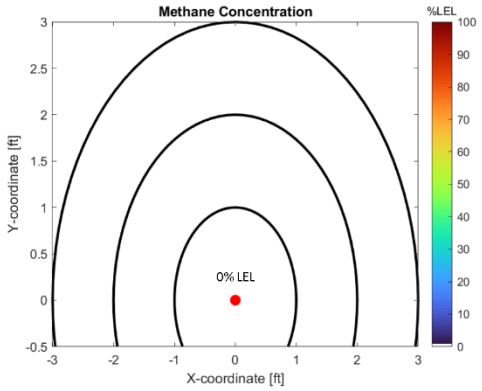
	7 In-WC	222489-002_multi lockup_sensor1 6in	Sigma = .3
IRV2	Normal Condition – Multi Lockup	Standard Array Configuration	6 in from vent



145

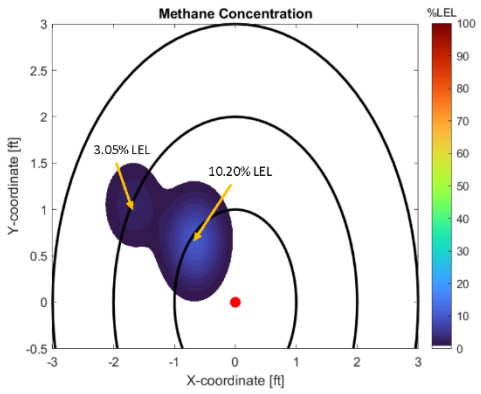
GTI ENERGY

	7 In-WC	222489-002_multi lockup_sensor1 next to vent	Sigma = .3
IRV2	Normal Condition – Multi Lockup	Standard Array Configuration	1 in from vent



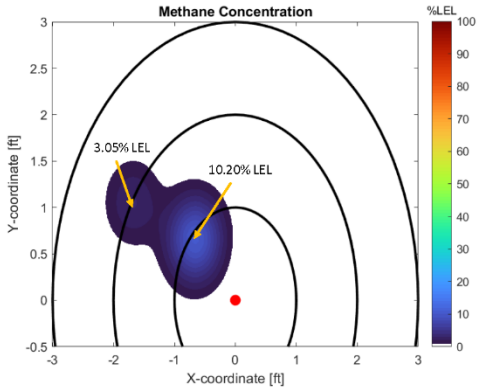
146

	7 In-WC	222489-002_single lockup_sensor1 6in	Sigma = .3
IRV2	Normal Condition – Single Lockup	Standard Array Configuration	6 in from vent



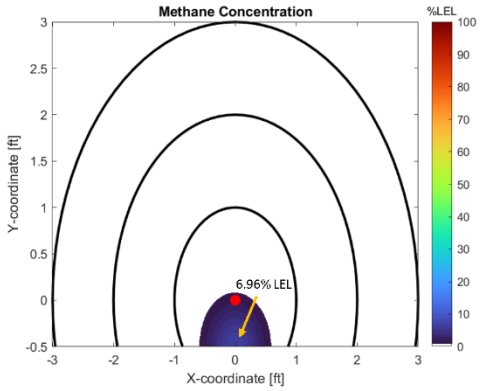
147

	7 In-WC	222489-002_single lockup_sensor1 next to vent	Sigma = .3
IRV2	Normal Condition – Single Lockup	Standard Array Configuration	1 in from vent



148

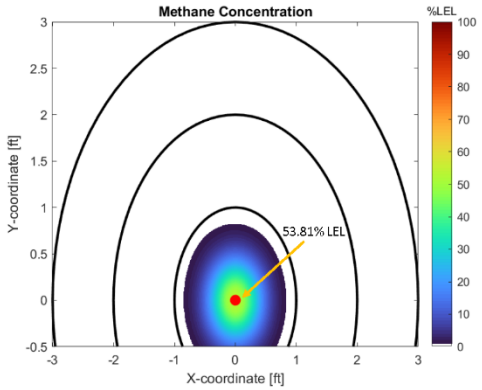
	7 In-WC	222489-002_multi lockup_sensor1 6in retest	Sigma = .3
IRV2	Normal Condition – Multi Lockup	Standard Array Configuration	6 in from vent



149

GTI ENERGY

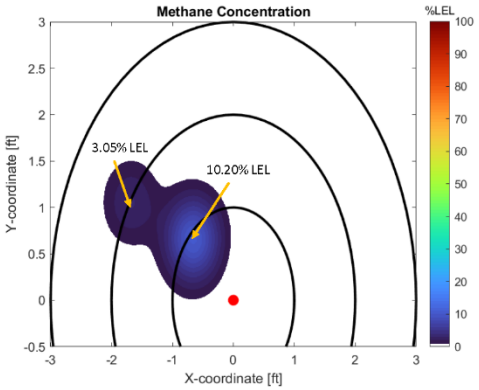
	7 In-WC	222489-002_multi lockup_sensor1 next to vent retest	Sigma = .3
IRV2	Normal Condition – Multi Lockup	Standard Array Configuration	1 in from vent



150

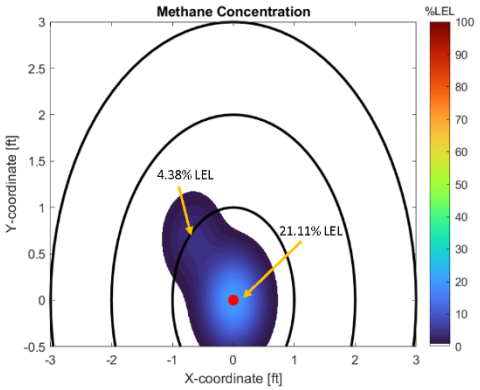
GTI ENERGY

	7 In-WC	222489-002_single lockup_sensor1 6in retest	Sigma = .3
IRV2	Normal Condition – Single Lockup	Standard Array Configuration	6 in from vent



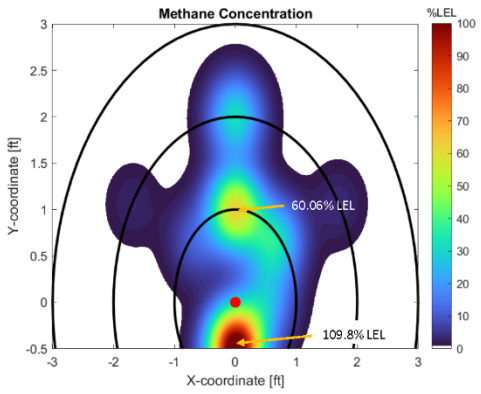
151

	7 In-WC	222489-002_single lockup_sensor1 next to vent retest	Sigma = .3
IRV2	Normal Condition – Single Lockup	Standard Array Configuration	1 in from vent



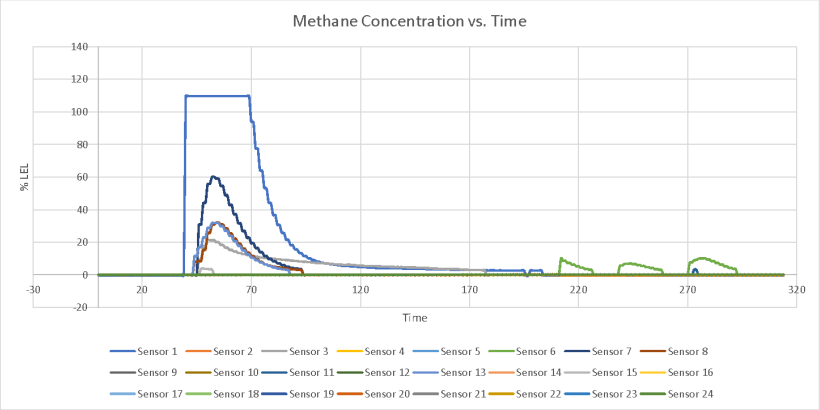
152

	7 In-WC	7-12-23_DT1_1	Sigma = .3
IRV2	Diaphragm Tear	Standard Array Configuration	6 in from vent



153

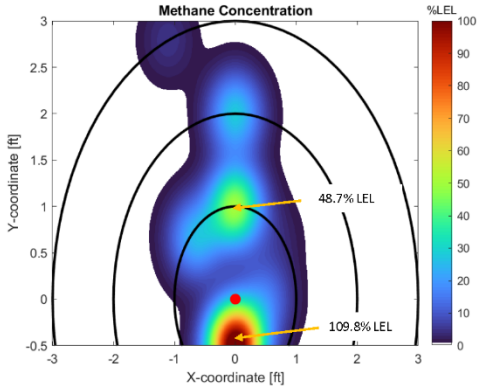
GTI ENERGY



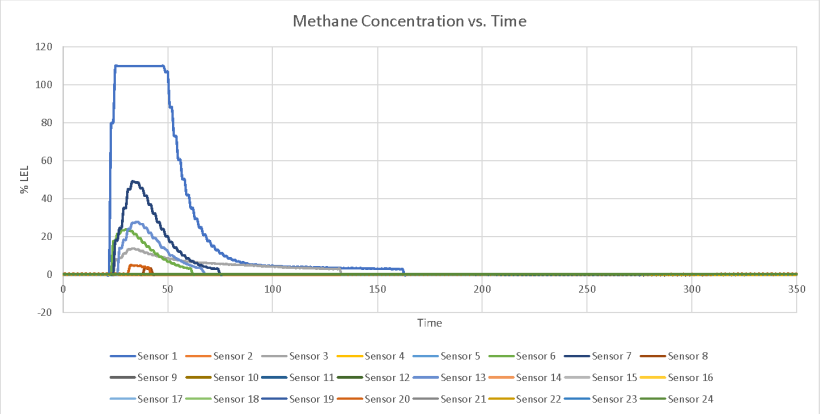
154

GTI ENERGY

	7 In-WC	7-12-23_DT1_2	Sigma = .3
IRV2	Diaphragm Tear	Standard Array Configuration	6 in from vent



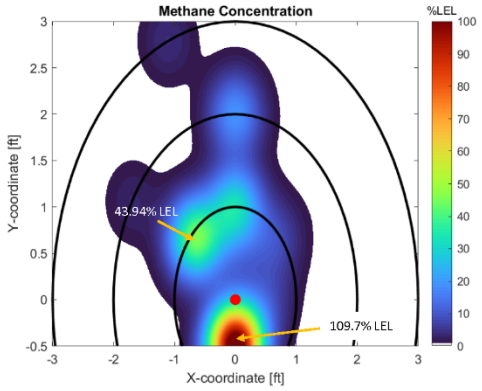
155



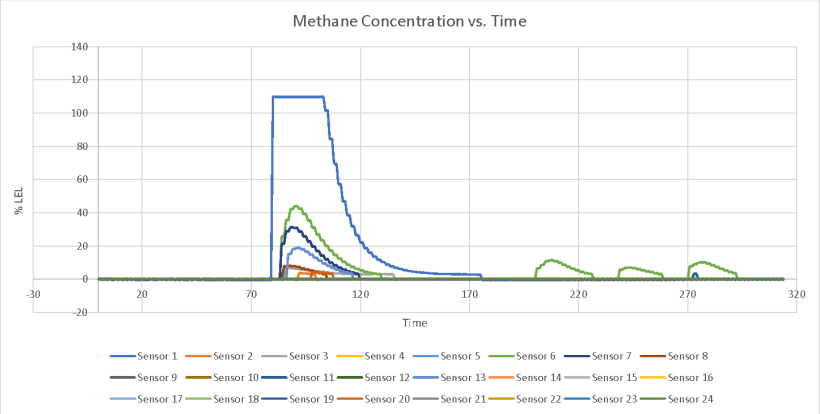
156

GTI ENERGY

	7 In-WC	7-12-23_DT1_3	Sigma = .3
IRV2	Diaphragm Tear	Standard Array Configuration	6 in from vent



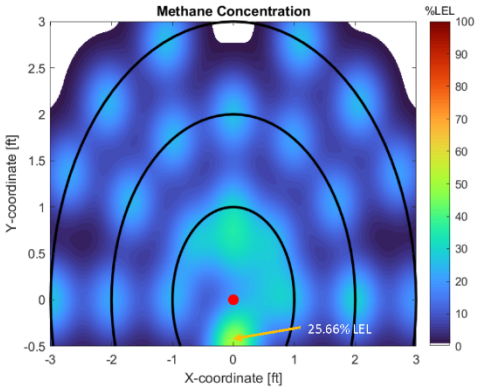
157



158

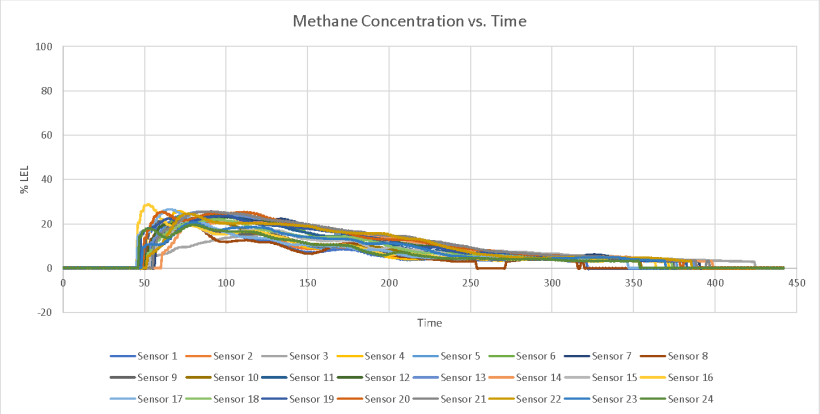
GTI ENERGY

	7 In-WC	7-12-23_LD_1	Sigma = .3
IRV2	Lever Disconnect	Standard Array Configuration	6 in from vent



159

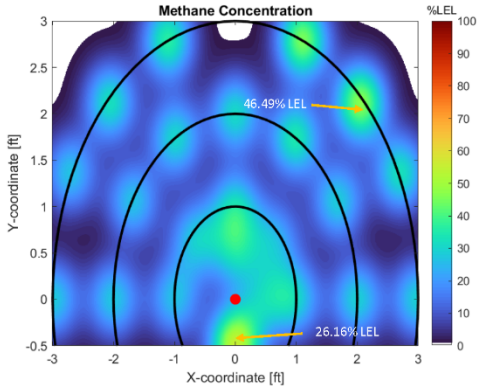
GTI ENERGY



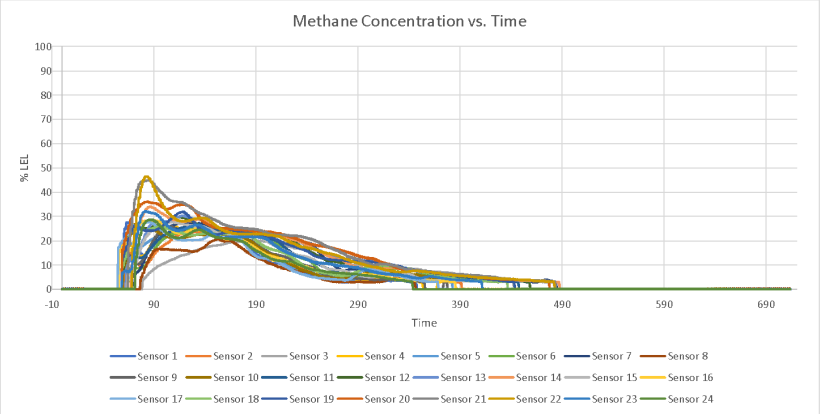
160

GTI ENERGY

	7 In-WC	7-12-23_LD_2	Sigma = .3
IRV2	Lever Disconnect	Standard Array Configuration	6 in from vent



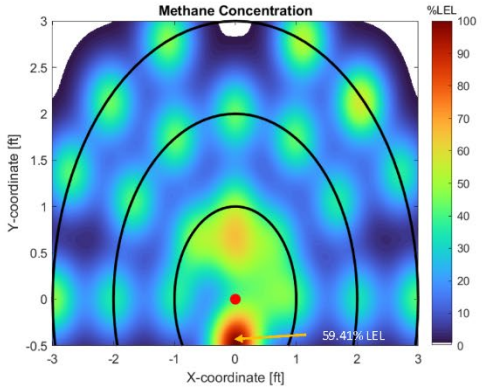
161



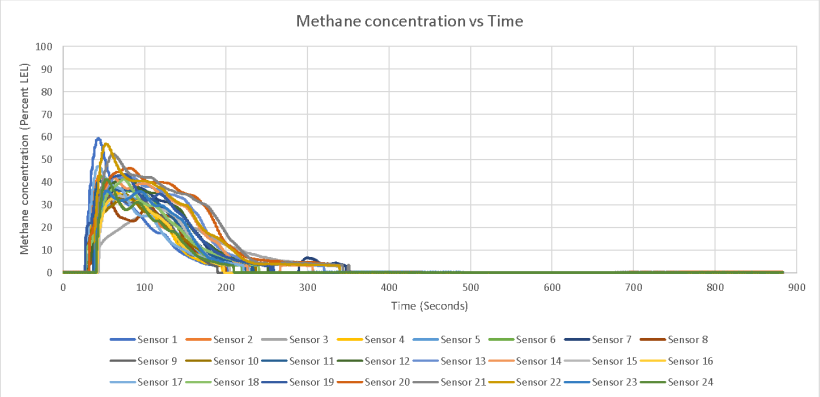
162

GTI ENERGY

	7 In-WC	7-12-23_LD_3	Sigma = .3
IRV2	Lever Disconnect	Standard Array Configuration	6 in from vent



163

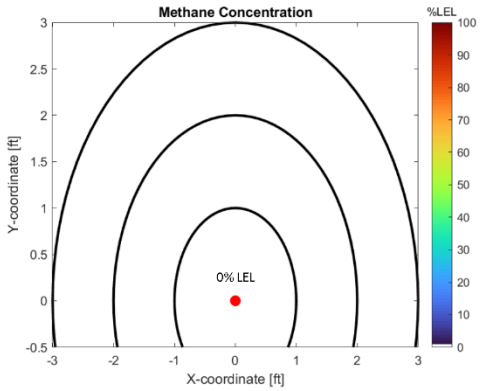


164

GTI ENERGY

2 psig

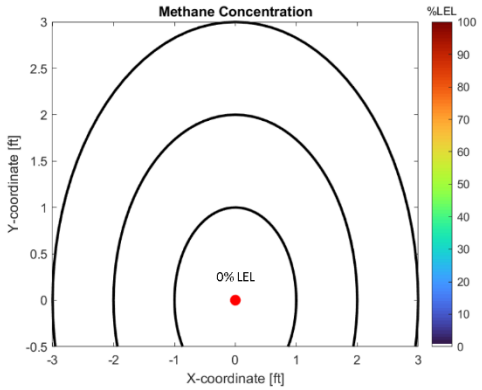
	2 PSI	222489-047_multi lockup_sensor1 6in	Sigma = .3
IRV2	Normal Condition – Multi Lockup	Standard Array Configuration	6 in from vent



165

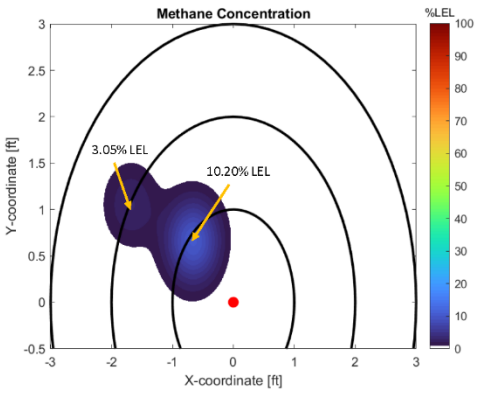
GTI ENERGY

	2 PSI	222489-047_multi lockup_sensor1 next to vent	Sigma = .3
IRV2	Normal Condition – Multi Lockup	Standard Array Configuration	1 in from vent



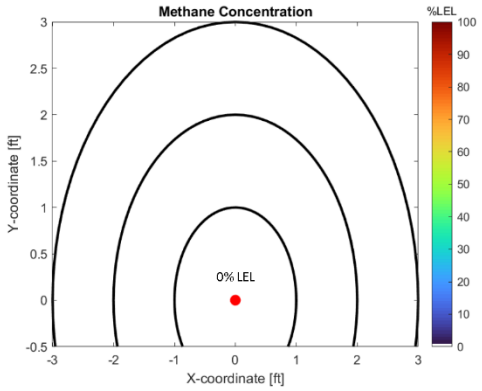
166

	2 PSI	222489-047_single lockup_sensor1 6in	Sigma = .3
IRV2	Normal Condition – Single Lockup	Standard Array Configuration	6 in from vent



167

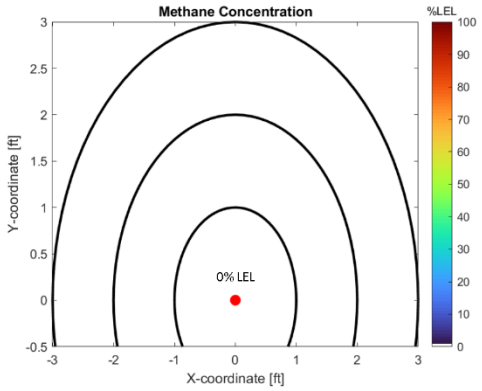
	2 PSI	222489-047_single lockup_sensor1 next to vent	Sigma = .3
IRV2	Normal Condition – Single Lockup	Standard Array Configuration	1 in from vent



168

GTI ENERGY

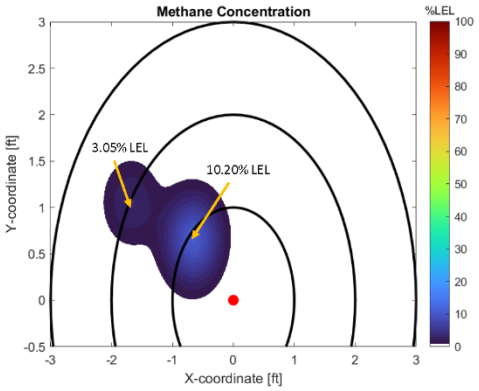
	2 PSI	222489-047_multi lockup_sensor1 next to vent retest	Sigma = .3
IRV2	Normal Condition – Multi Lockup	Standard Array Configuration	1 in from vent



169

GTI ENERGY

	2 PSI	222489-047_single lockup_sensor1 next to vent retest	Sigma = .3
IRV2	Normal Condition – Single Lockup	Standard Array Configuration	1 in from vent



170

Appendix G – IRV4 Manufacturer Test Data

GTI ENERGY
solutions that transform

REPORT
GTI ENERGY PROJECT NUMBER 23059

Comparison of Compact Service Regulators – Results of Testing

IRV4 Summary

GTI Energy Technical Contact:
Joe Carlstrom
Joseph Irwin, PE
Tom Bates
Jake Witecha

1700 S. Mount Prospect Rd.
Des Plaines, Illinois 60018
www.gti.energy

Introduction

This report was created to review data obtained during PHMSA project 693JK32110001 and OTD project 5.22.j - Design and Placement of Compact Service Regulators with subject matter experts from the manufacturer. The following Part 1 and Part 2 matrix outlines the test methodology used to obtain data for analysis purposes for safe clearance distances.

Part 1 Test methodology

All testing was performed on the rig with air and software formula coefficients for natural gas.

Test	Standard/Procedure reference	Conditions	Test Criteria	Parameters
Modified Lock-Up Test	ANSI B109.4 -[5.3.5]	Temperature: Ambient; Inlet pressure: 10, 60, 100 psig; Flow: 100, 200, 300, until maximum manufacturer specifications [SCFH Air]	Outlet pressure Max 9"±0.5 iwc 2.15±0.15 psig (2psig reg.)	Lock up [iwc]
			Flow rate at vent 2.5 SCFH (vent limited) 100 SCFH (IRV)	Vent flow rate [SCFH]
Modified Relief Point Test	ANSI B109.4 -[5.3.8]	Temperature: Ambient; Inlet pressure: 10, 60, 100 psig; Outlet pressure: slowly increase until slam shut closes or maximum allowable pressure reached	Outlet pressure MAX 17"±0.5 iwc; 3.3±0.15iwc psig (2psig reg.)	Relief point [iwc]
			Flow rate at vent 2.5 SCFH (vent limited) 100 SCFH (IRV)	Vent flow rate [SCFH]

Part 2 Test Methodology

Testing was performed in an enclosed and controlled environment with natural gas. Safety rules were implemented to monitor and limit the amounts of natural gas. When an accumulation of natural gas greater than 100% LEL was detected by multiple sensors the natural gas source was terminated and the test concluded.

Single Lock-Up Test	ANSI B109.4 - [5.3.5]	**Temperature**: Ambient; **Inlet pressure**: 60 psig; **Flow Rate**: 390 SCFH (7 iwc reg.) 1260 SCFH (2 psig reg.) **Lockup condition**: One lock up induced, wait 30 seconds for gas concentration dissipate to 0% LEL, repeat 10 times.	Outlet pressure Max 9"±0.5 iwc (7 iwc reg.) 2.15±0.15 psig (2psig reg.)	Lock up pressure [iwc]
			Methane concentration at vent 0% LEL (vent limited) 3% LEL (IRV)	Methane Concentration [% LEL]
Multi Lock-Up Test	ANSI B109.4 - [5.3.5]	**Temperature**: Ambient; **Inlet pressure**: 60 psig; **Flow Rate**: 390 SCFH (7 iwc reg.) 1260 SCFH (2 psig reg.) **Lockup condition**: Two lock ups induced in quick succession, wait 30 seconds for gas concentration dissipate to 0% LEL, repeat 3 times, after 3 repetitions increase the number of lockups by 1 to a maximum of 4.	Outlet pressure Max 9"±0.5 iwc (7 inWC reg.) 2.15±0.15 psig (2psig reg.)	Lock up pressure [inWC]
			Methane concentration at vent 0% LEL (vent limited) 3% LEL (IRV)	Methane Concentration [% LEL]

Summary

Modified Lockup Tests

Average Emission Rate [SCFH], Normal Conditions, 7" WC

Model	10-psig inlet	60-psig inlet	100-psig inlet
IRV4	1.0202	0.3694	0.3700

Average Emission Rate [SCFH], Primary Diaphragm Tear, 7" WC

Model	10-psig inlet	60-psig inlet	100-psig inlet
IRV4	25.9009	17.0180	27.0437

Average Emission Rate [SCFH], Lever Disconnect, 7" WC

Model	10-psig inlet	60-psig inlet	100-psig inlet
IRV4	1.2464	1.8568	2.5462

Relief Tests

Average Emission Rate [SCFH], Normal Conditions, 7" WC

Model	10-psig inlet	60-psig inlet	100-psig inlet
IRV4	14.0967	8.4367	11.9533

Average Emission Rate [SCFH], Primary Diaphragm Tear, 7" WC

Model	10-psig inlet	60-psig inlet	100-psig inlet
IRV4	16.9150	19.6133	17.5933

Average Emission Rate [SCFH], Lever Disconnect, 7" WC

Model	10-psig inlet	60-psig inlet	100-psig inlet
IRV4	28.5400	21.9550	NA*

* Flow rate exceeded meter range

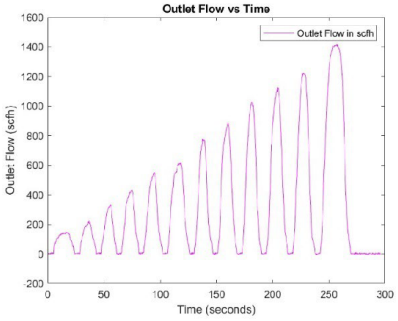
Modified Lockup Tests

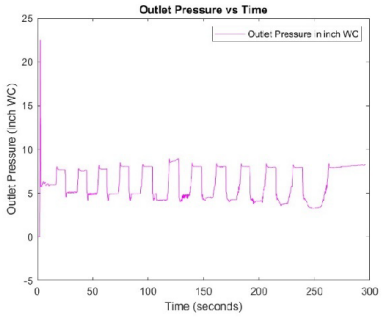
7” WC Outlet, 10-psig Inlet

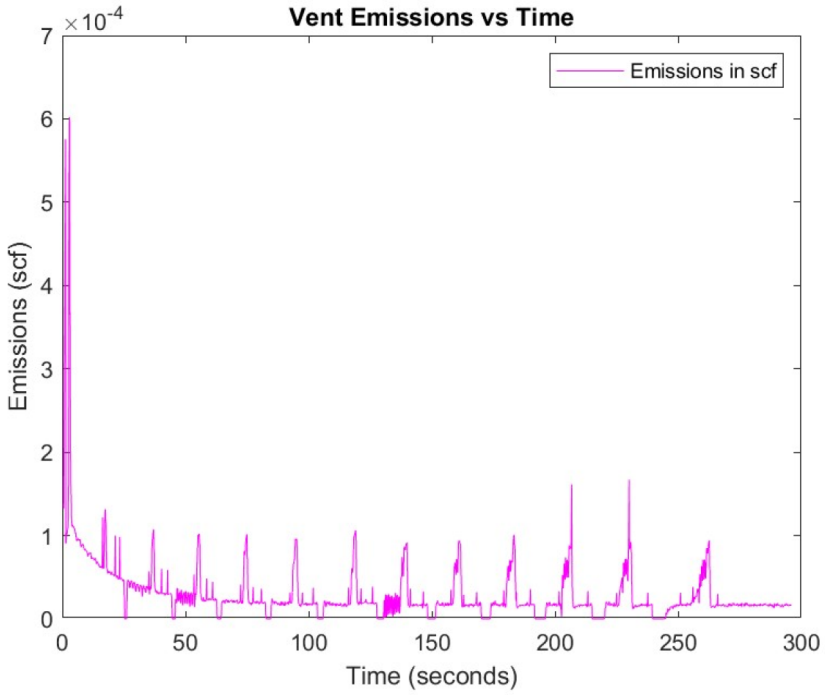
- 222489-051 (1/2” ori)

  The volume of total emissions in 296.00 seconds is 0.0808 scf.

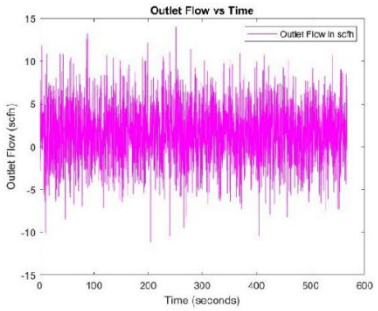
  The flow rate of emissions is 0.9823 scfh.

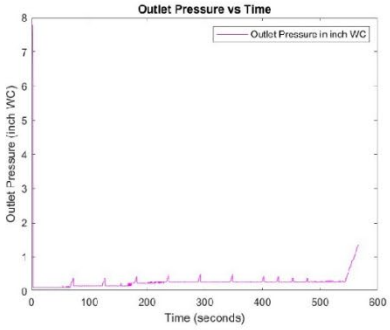


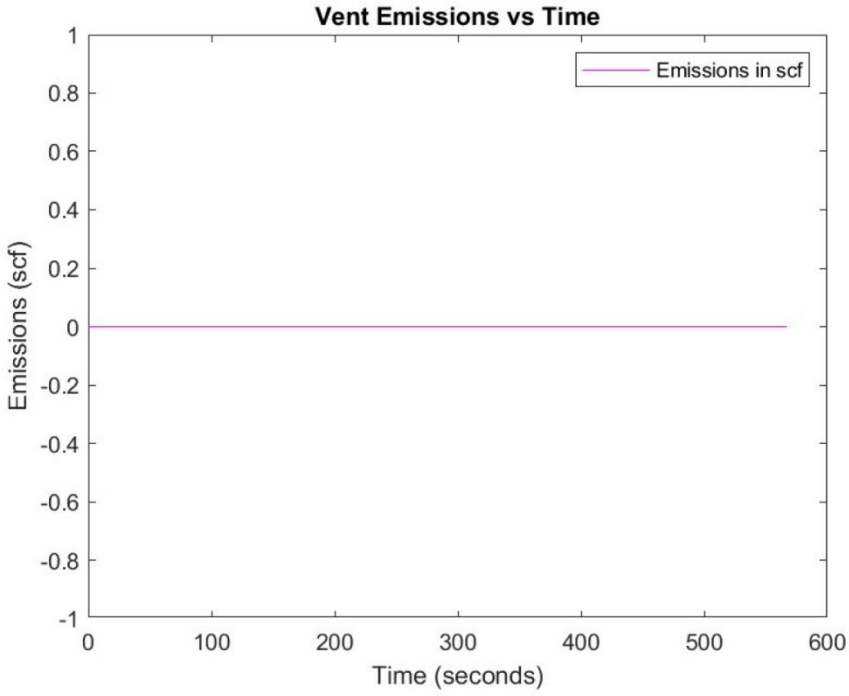




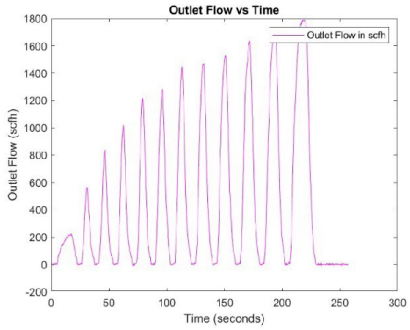
- 222489-051_BV (1/2" ori)
  The volume of total emissions in 567.13 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.

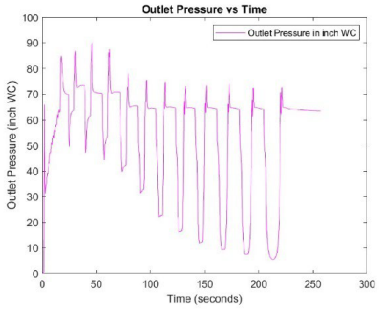


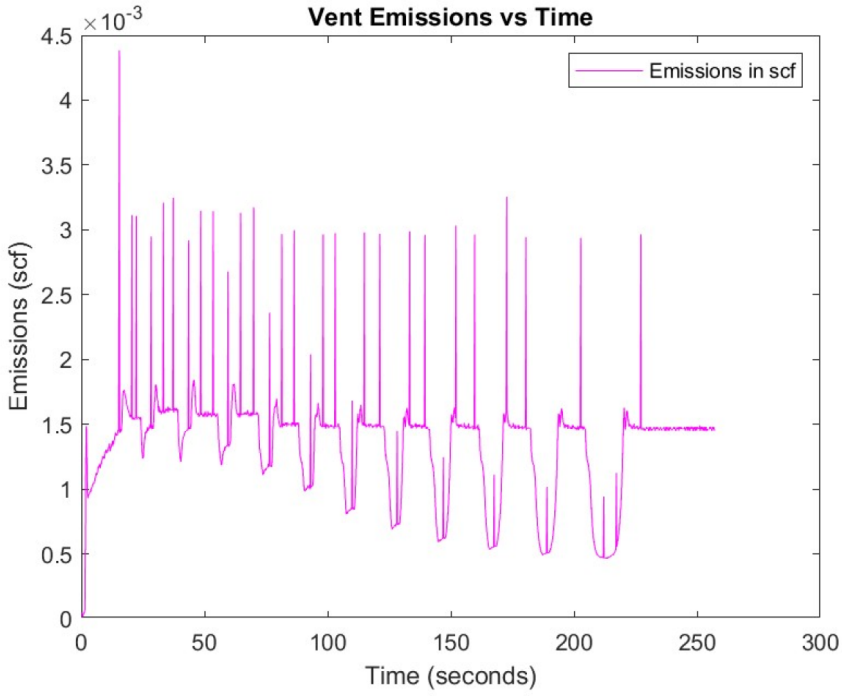




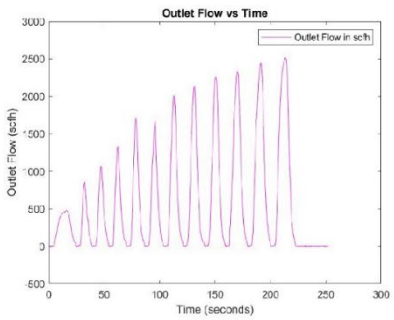
- 222489-051_DT (1/2” ori)
  The volume of total emissions in 257.10 seconds is 3.2214 scf.
  The flow rate of emissions is 45.1073 scfh.

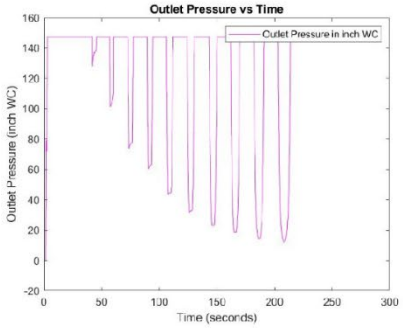


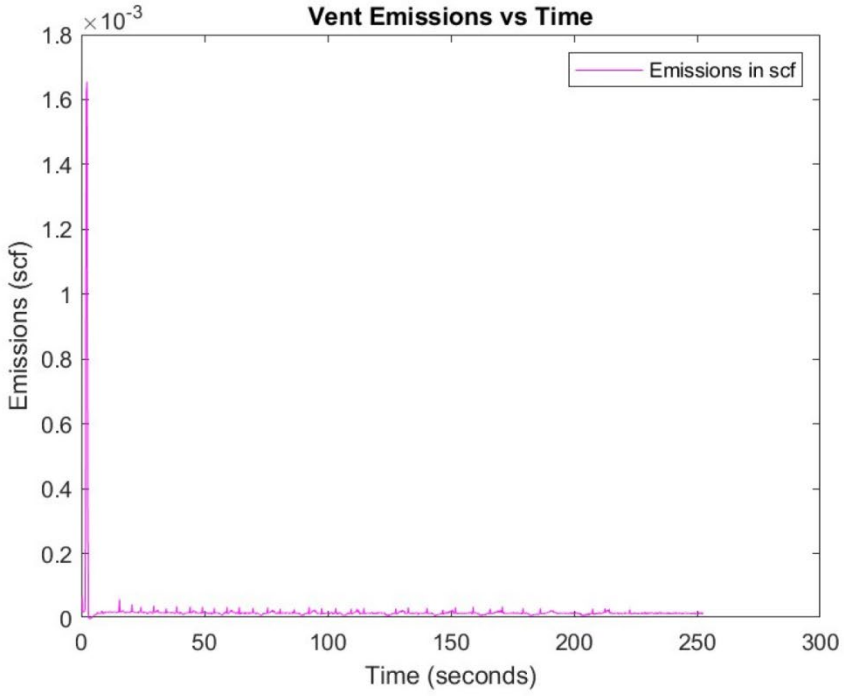




- 222489-051_LD (1/2" ori)
  The volume of total emissions in 252.56 seconds is 0.0506 scf.
  The flow rate of emissions is 0.7212 scfh.

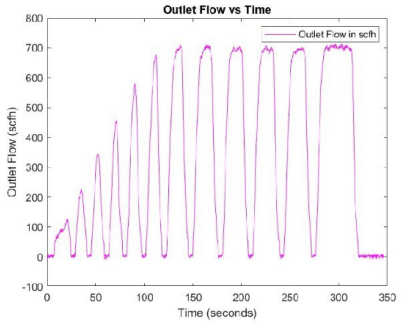


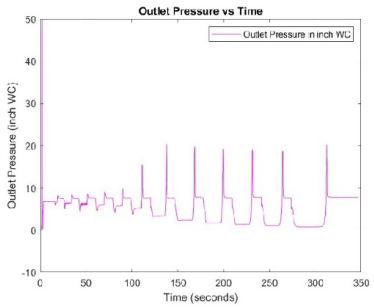


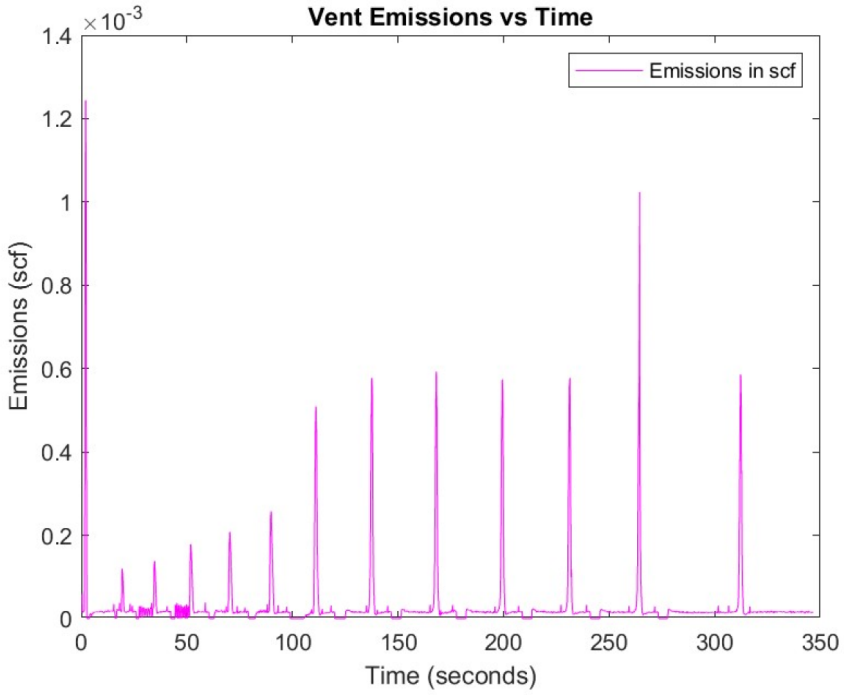


GTI ENERGY

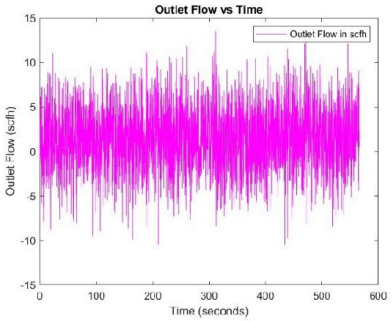
- 222489-052
  The volume of total emissions in 346.60 seconds is 0.1014 scf.
  The flow rate of emissions is 1.0531 scfh.

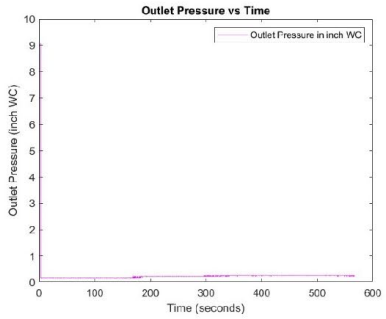


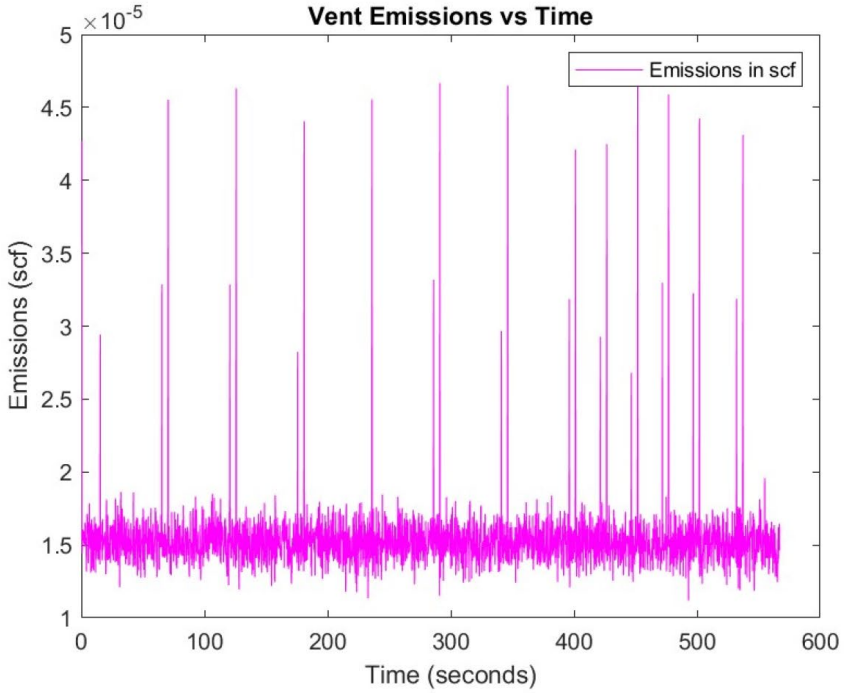




- 222489-052_BV
  The volume of total emissions in 567.06 seconds is 0.0826 scf.
  The flow rate of emissions is 0.5247 scfh.

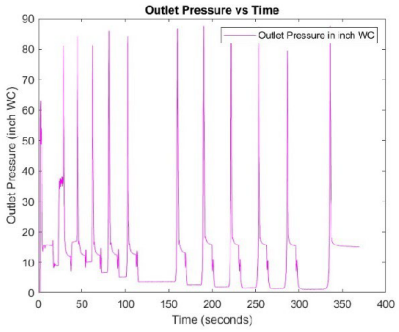


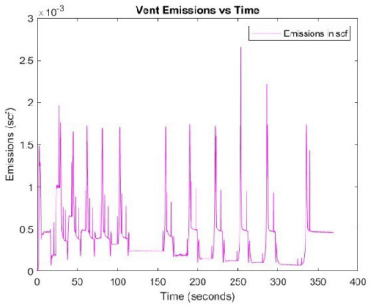


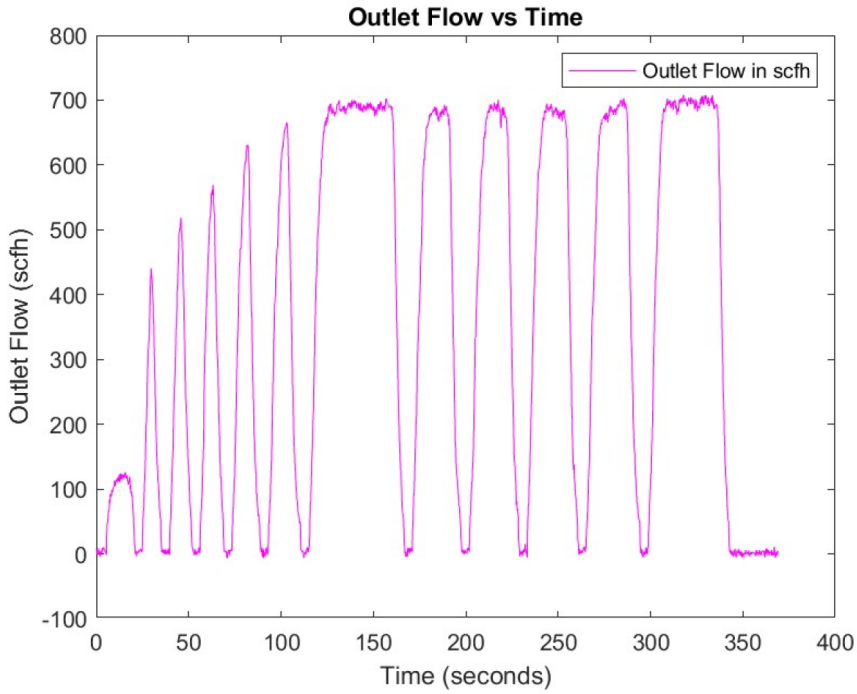


GTI ENERGY

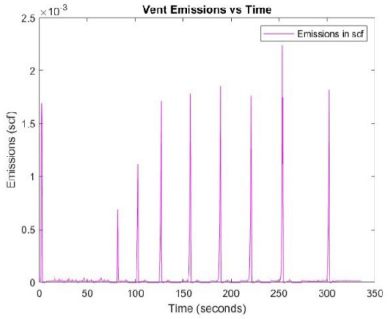
- 222489-052_DT
  The volume of total emissions in 369.34 seconds is 1.3282 scf.
  The flow rate of emissions is 12.9456 scfh.

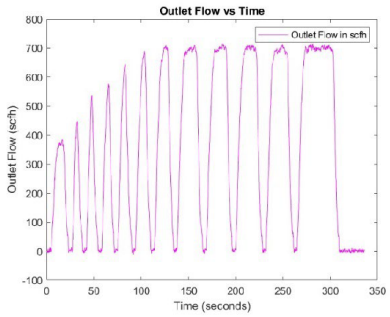


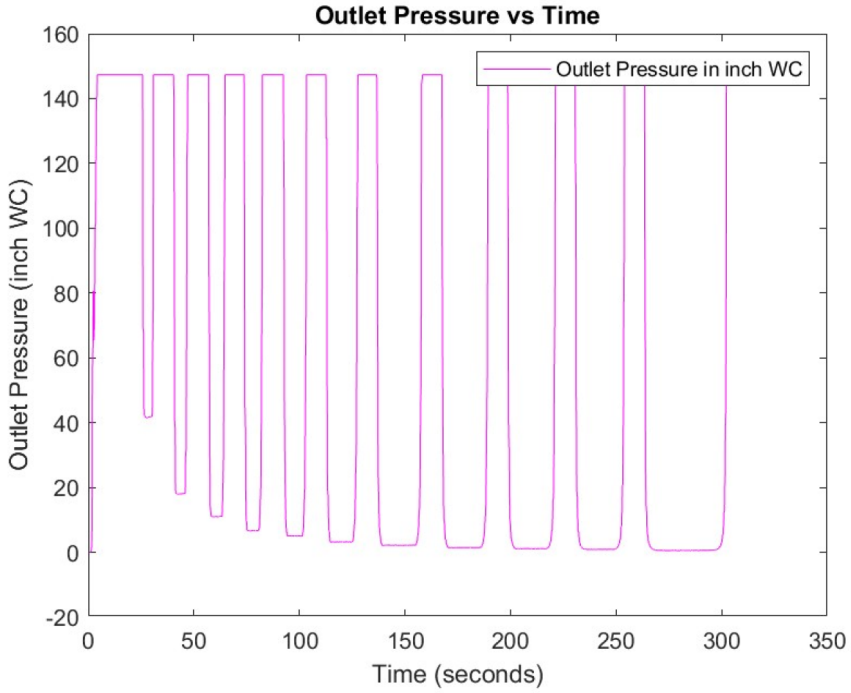




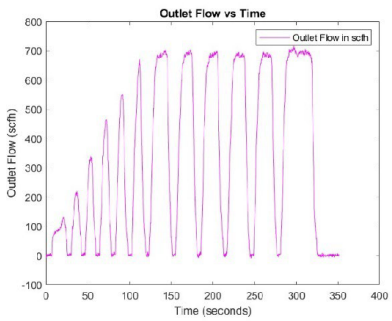
- 222489-052_LD
  The volume of total emissions in 335.99 seconds is 0.1541 scf.
  The flow rate of emissions is 1.6510 scfh.

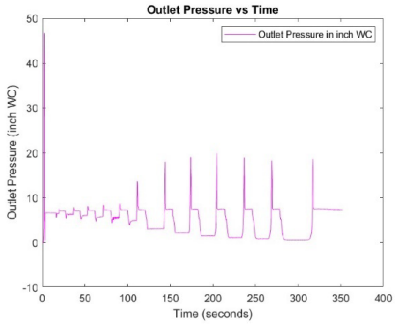


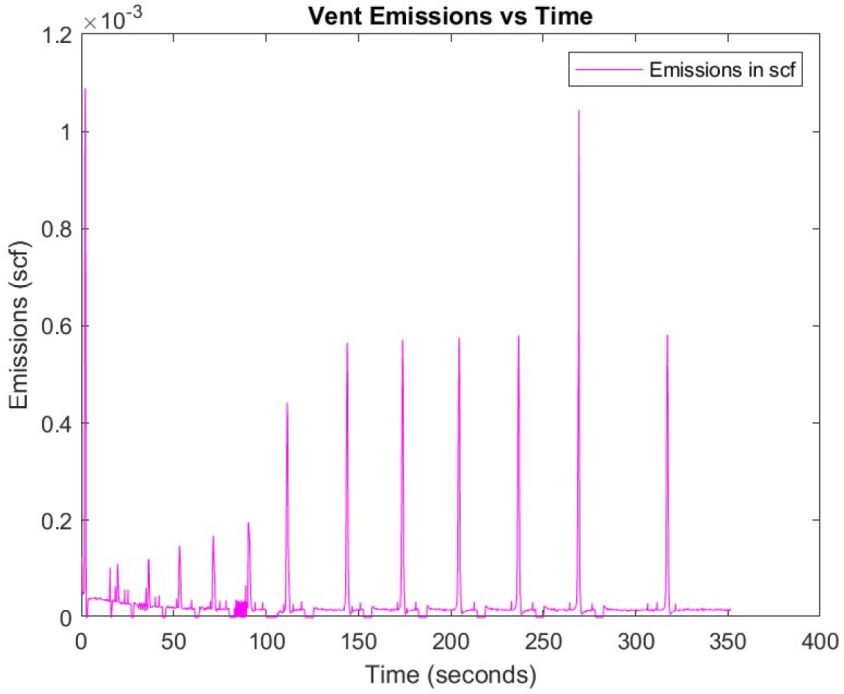




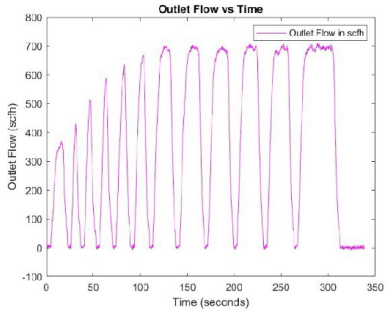
- 222489-053
  The volume of total emissions in 351.60 seconds is 0.1001 scf.
  The flow rate of emissions is 1.0252 scfh.

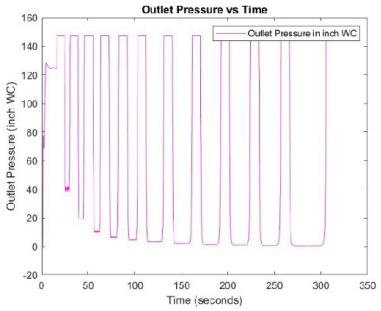


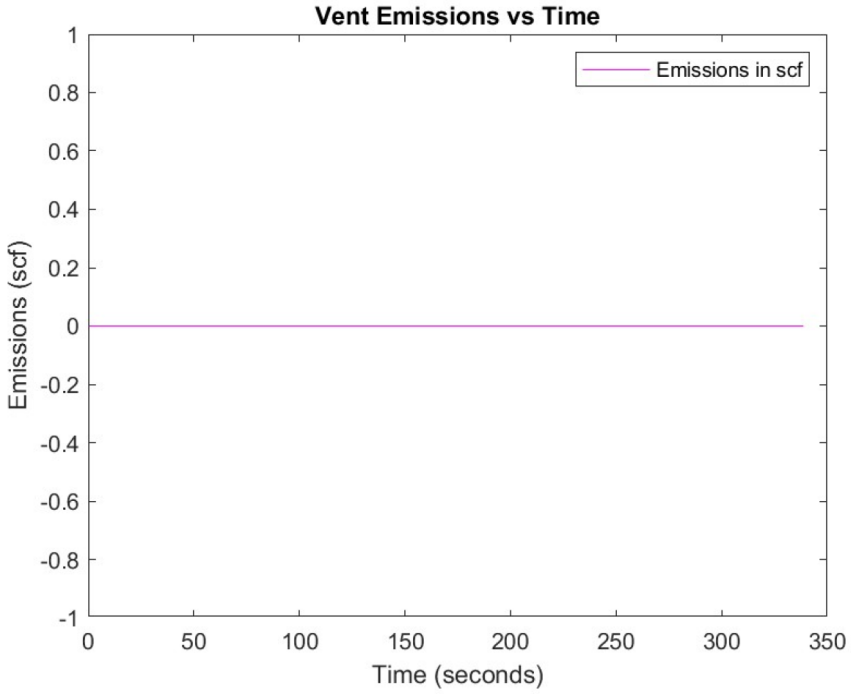




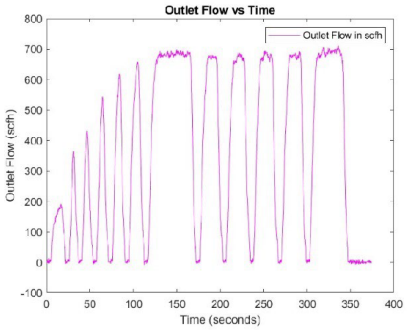
- 222489-053_BV
  The volume of total emissions in 338.79 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.

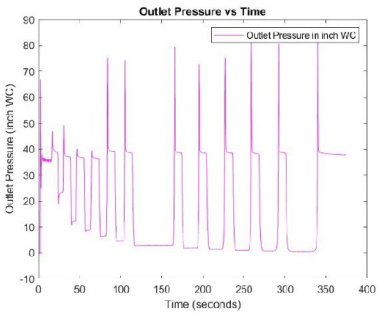


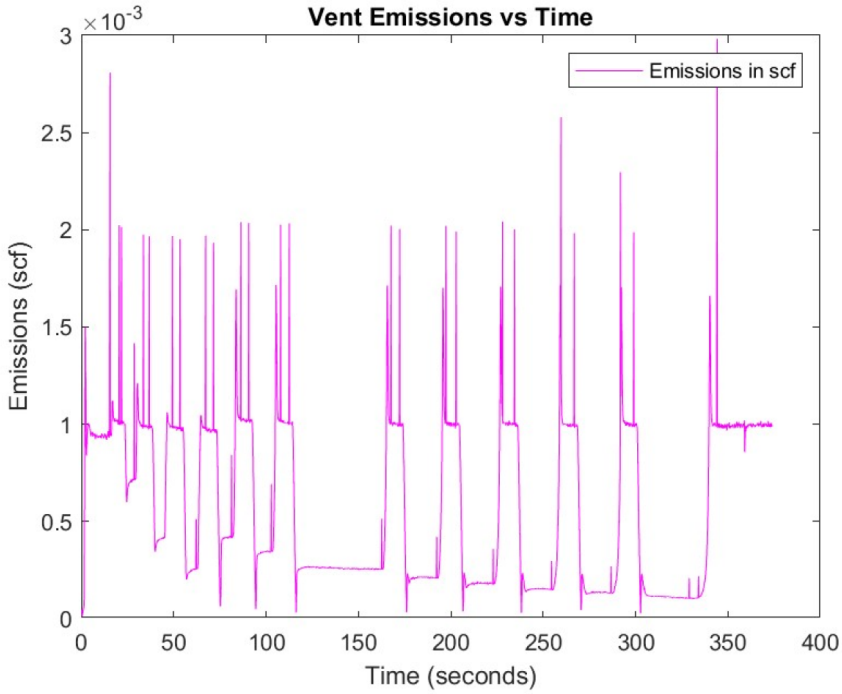




- 222489-053_DT
  The volume of total emissions in 374.07 seconds is 2.0418 scf.
  The flow rate of emissions is 19.6498 scfh.

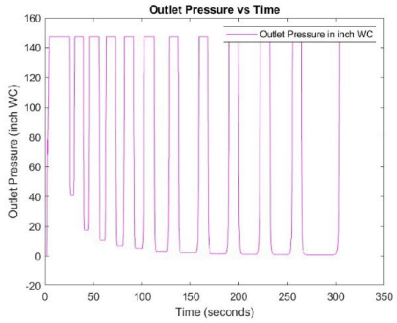


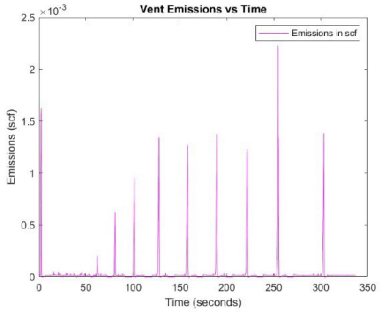


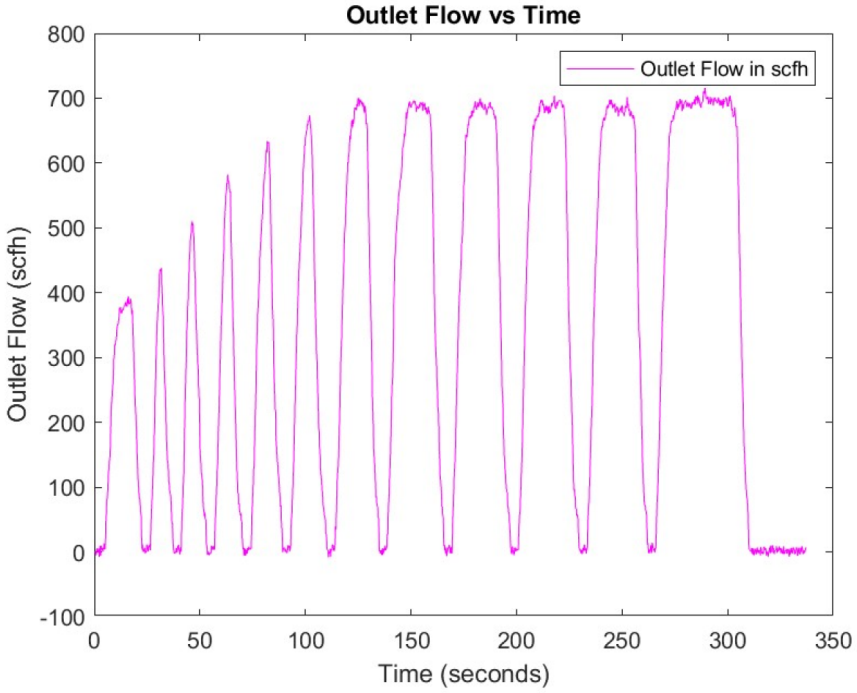


GTI ENERGY

- 222489-053_LD
  The volume of total emissions in 337.06 seconds is 0.1280 scf.
  The flow rate of emissions is 1.3669 scfh.





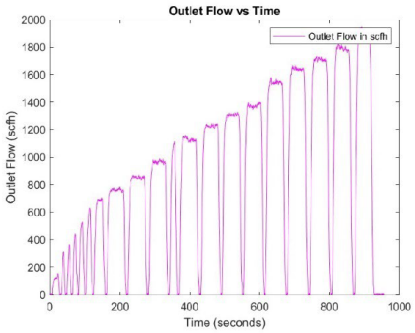


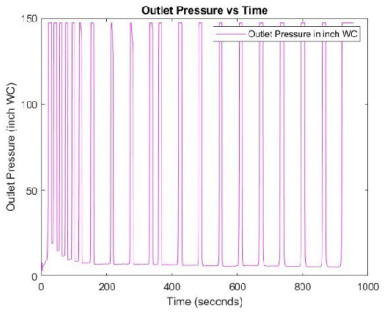
7” WC Outlet, 60-psig Inlet

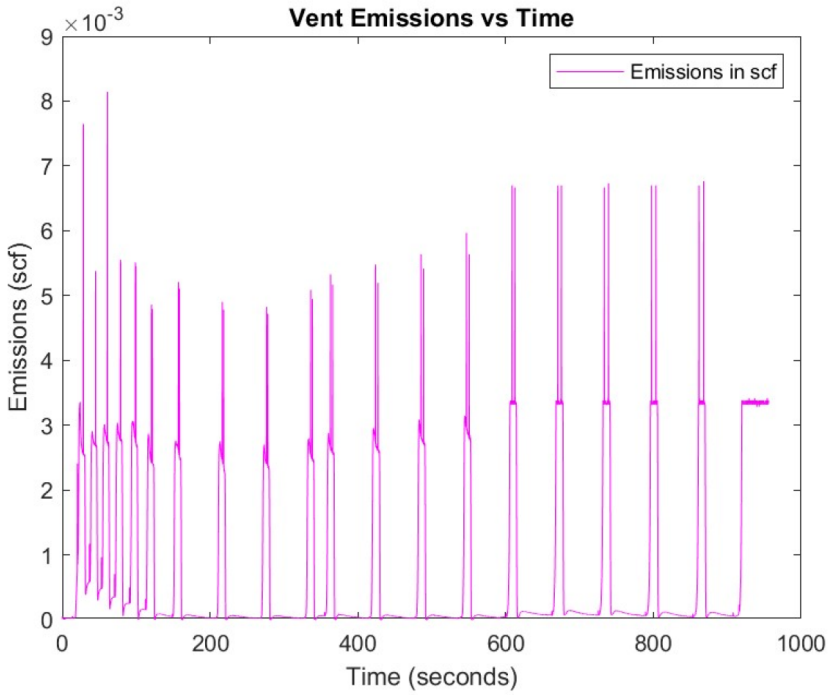
- 222489-051 (1/2” ori)

  The volume of total emissions in 955.84 seconds is 6.8169 scf.

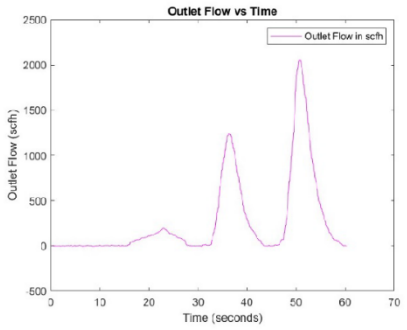
  The flow rate of emissions is 25.6747 scfh.

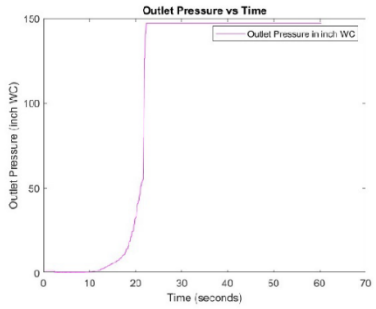


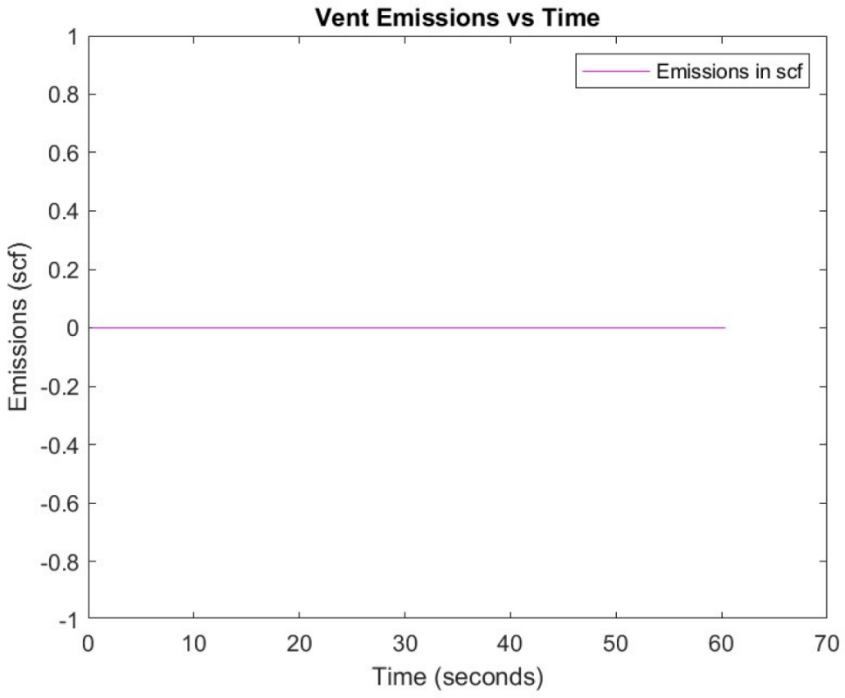




- 222489-051_BV (1/2" ori)
  The volume of total emissions in 60.34 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.

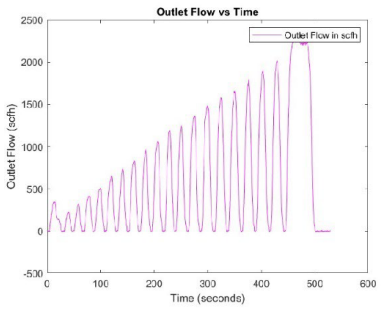


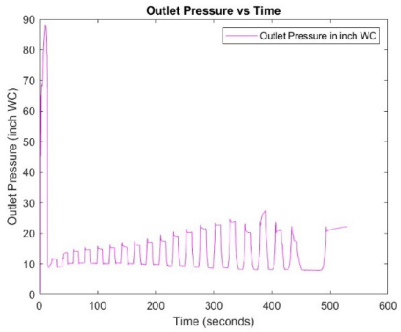


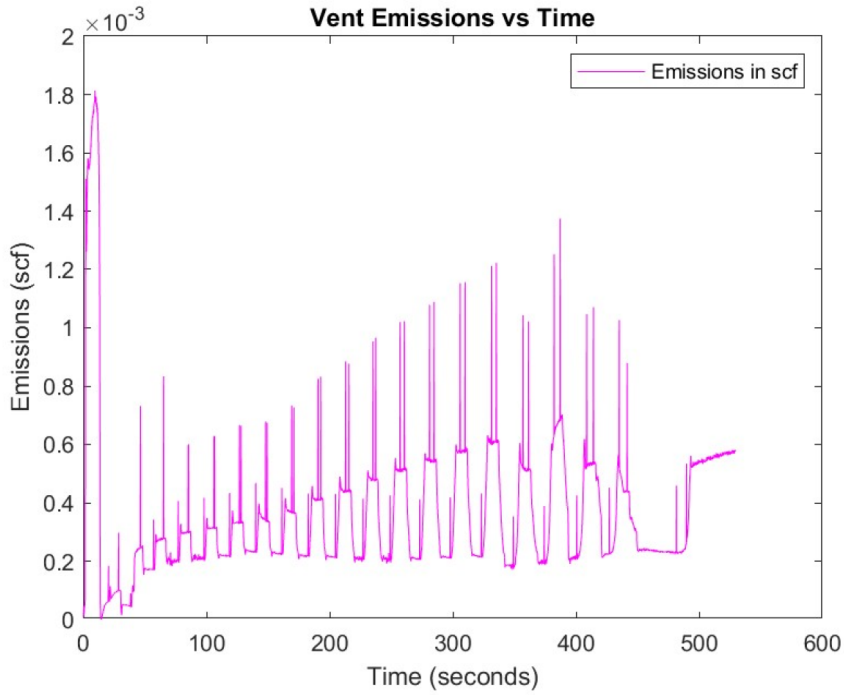


GTI ENERGY

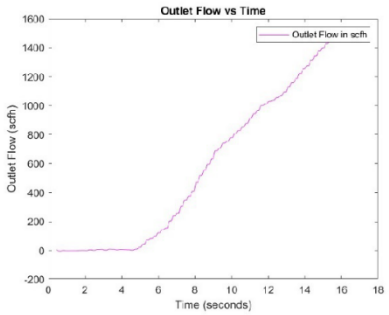
- 222489-051_DT (1/2" ori)
  The volume of total emissions in 529.59 seconds is 1.8015 scf.
  The flow rate of emissions is 12.2458 scfh.

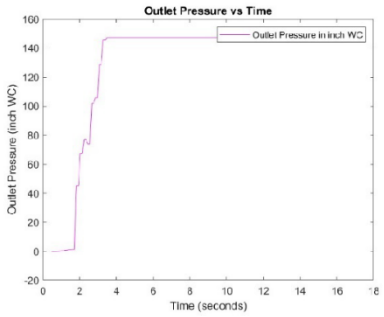


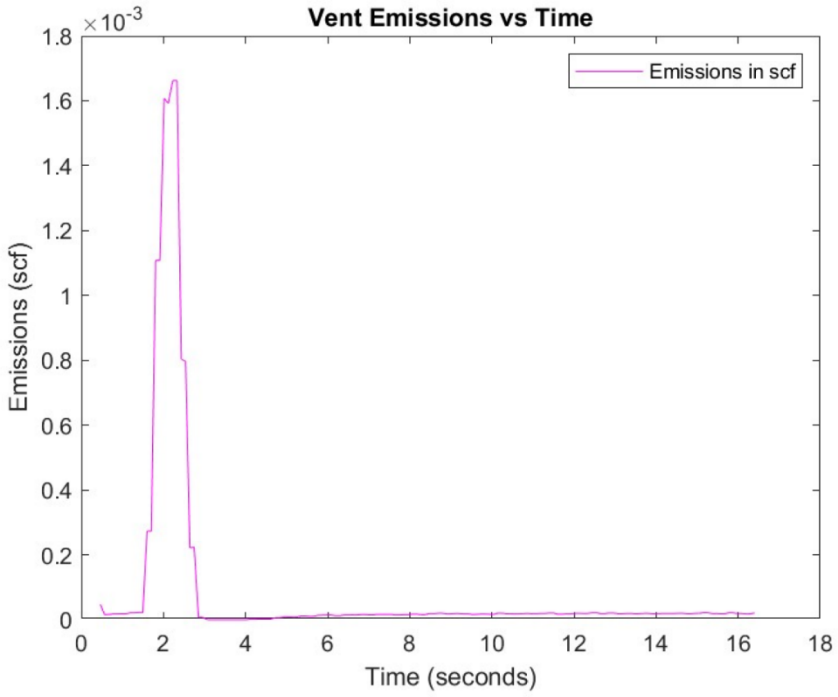




- 222489-051_LD (1/2" ori)
  The volume of total emissions in 16.40 seconds is 0.0136 scf.
  The flow rate of emissions is 2.9753 scfh.

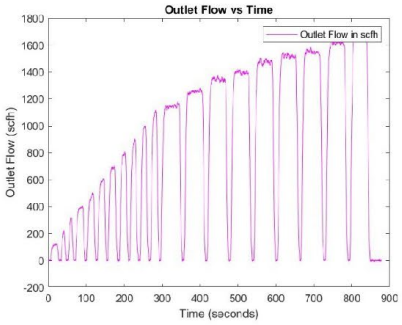


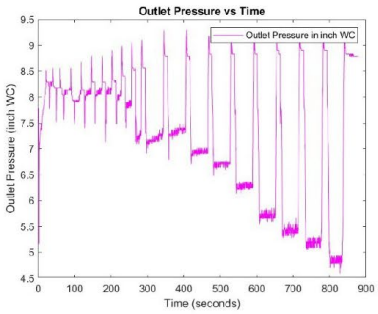


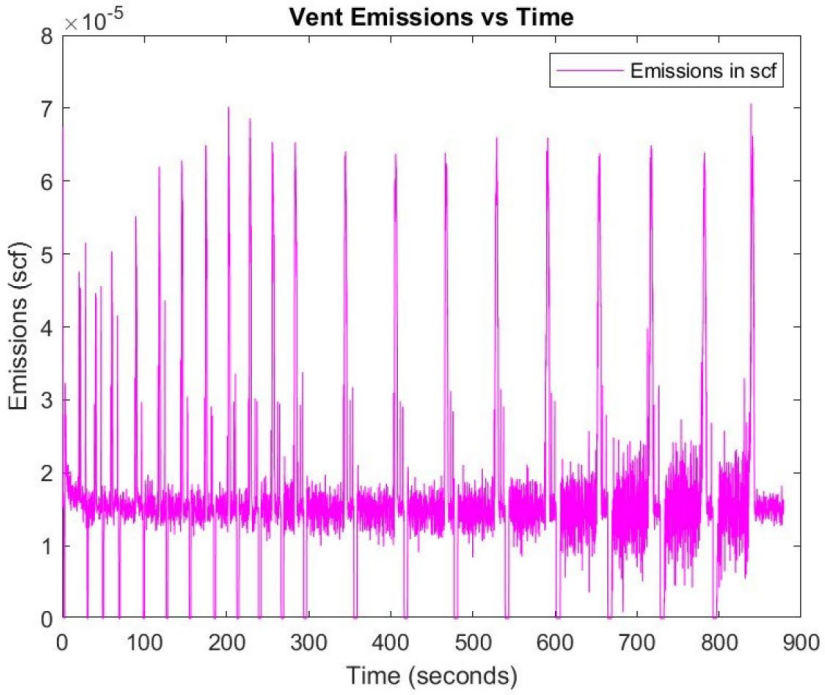


GTI ENERGY

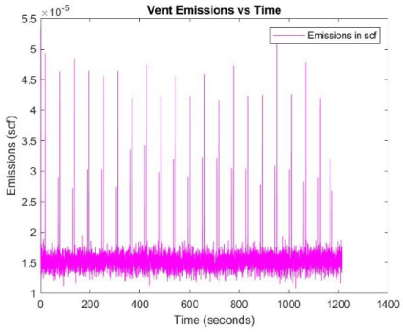
- 222489-052
  The volume of total emissions in 878.80 seconds is 0.1402 scf.
  The flow rate of emissions is 0.5742 scfh.

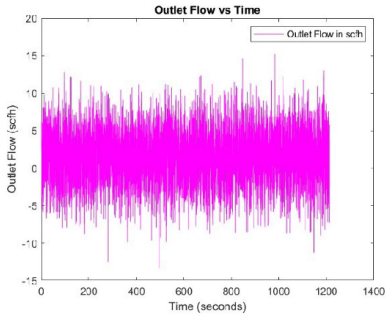


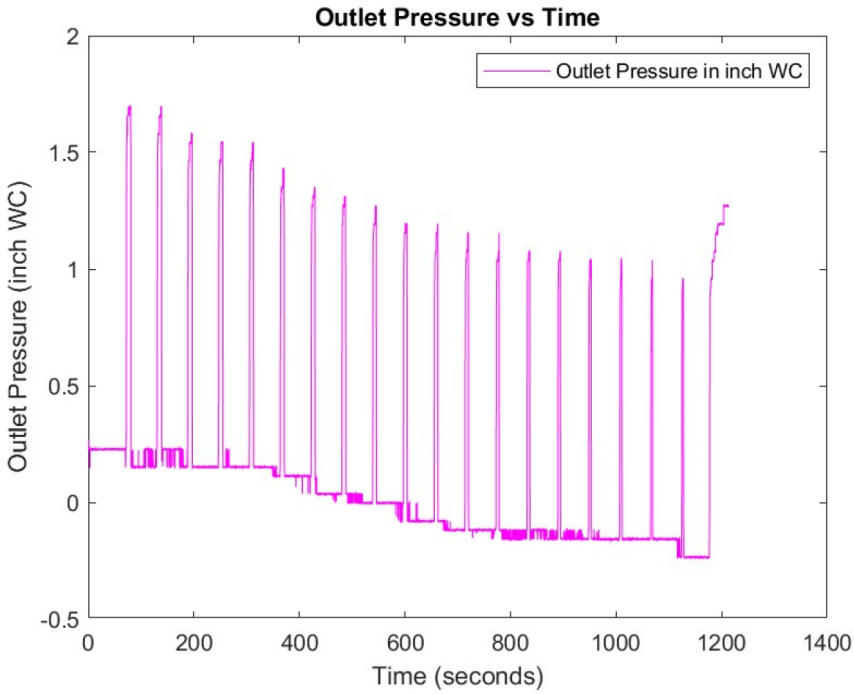




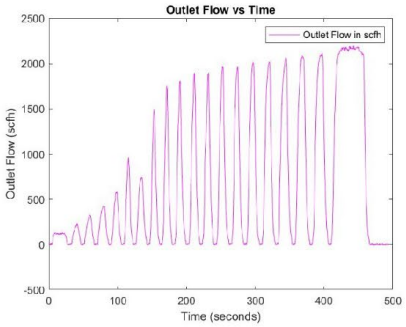
- 222489-052_BV
  The volume of total emissions in 1213.34 seconds is 0.1773 scf.
  The flow rate of emissions is 0.5259 scfh.

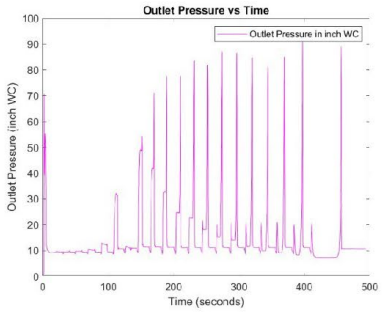


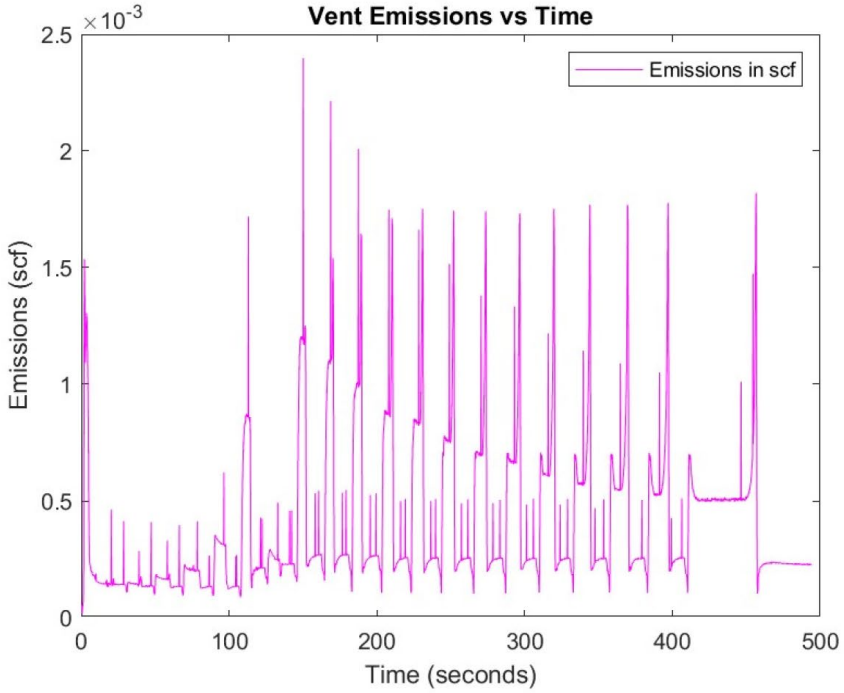




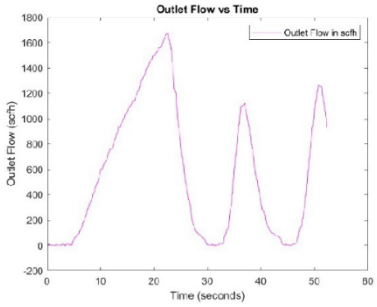
- 222489-052_DT
  The volume of total emissions in 494.33 seconds is 1.8637 scf.
  The flow rate of emissions is 13.5728 scfh.

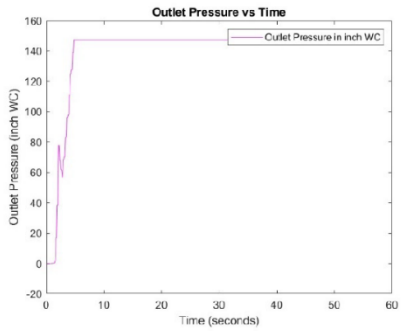


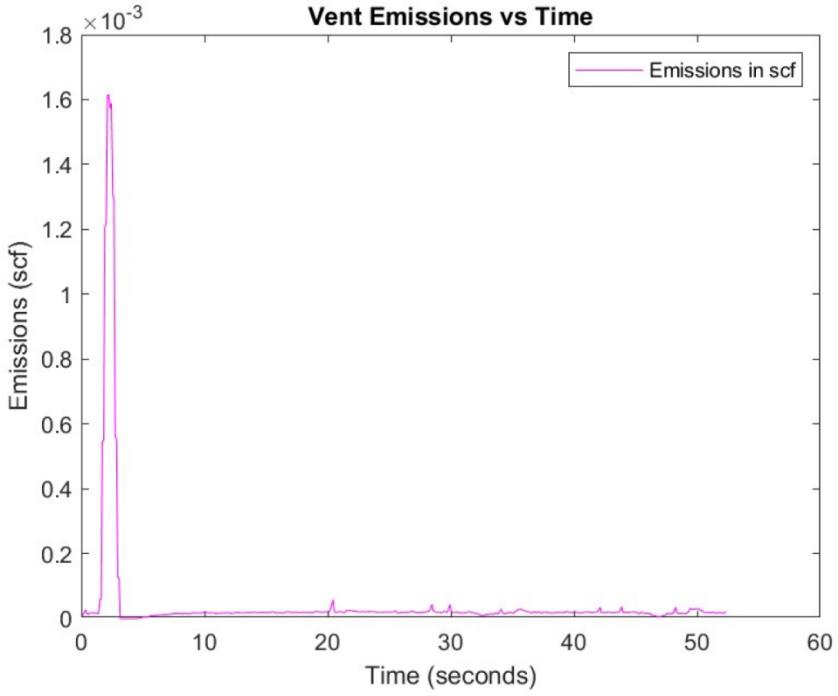




- 222489-052_LD
  The volume of total emissions in 52.34 seconds is 0.0223 scf.
  The flow rate of emissions is 1.5371 scfh.

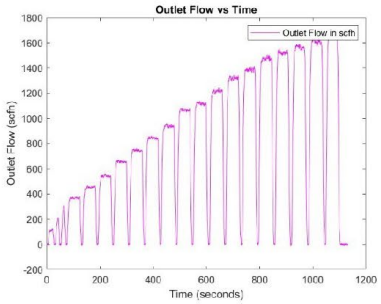


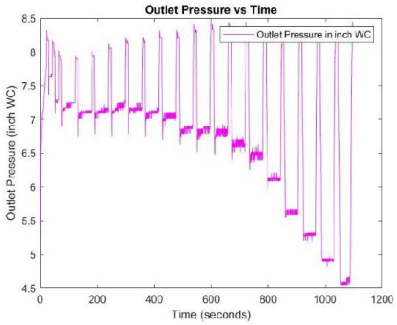


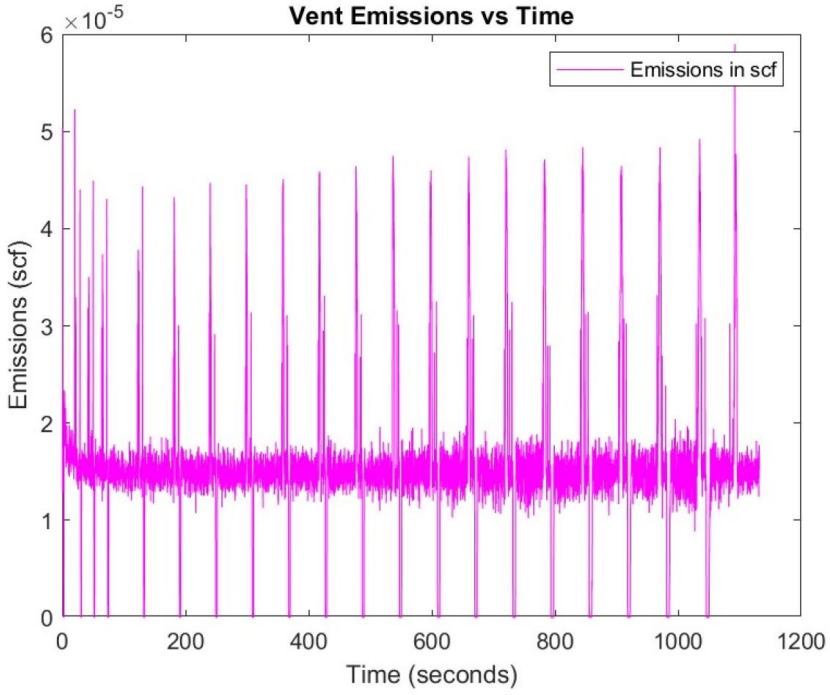


GTI ENERGY

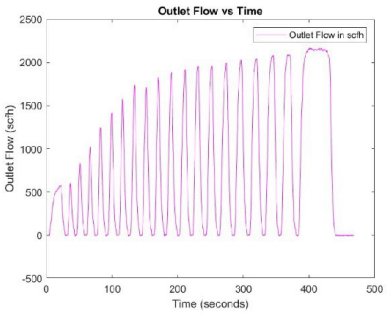
- 222489-053
  The volume of total emissions in 1132.03 seconds is 0.1679 scf.
  The flow rate of emissions is 0.5341 scfh.

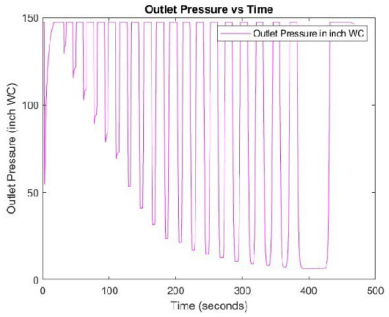


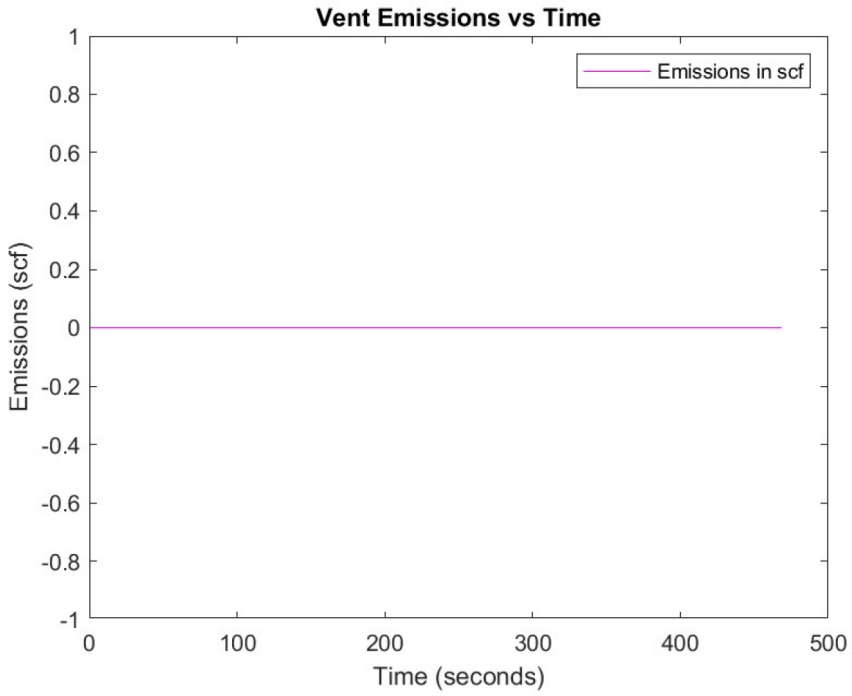




- 222489-053_BV
  The volume of total emissions in 468.45 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.

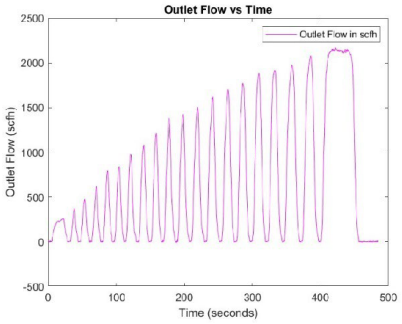


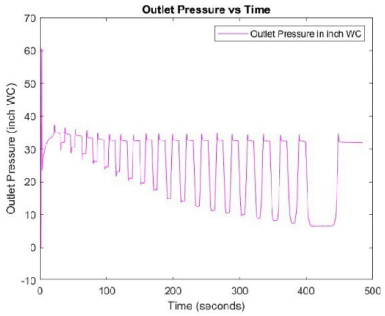


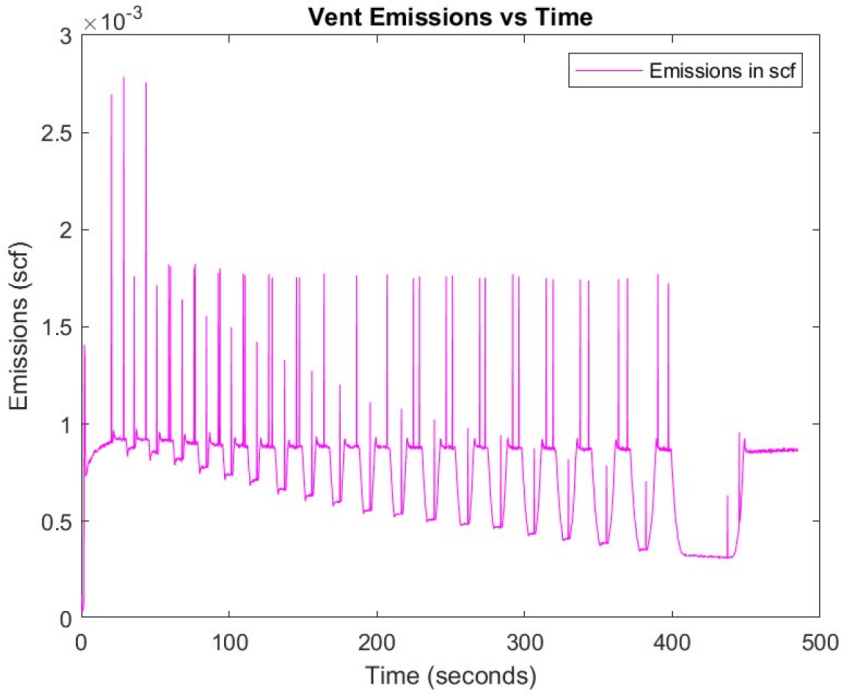


GTI ENERGY

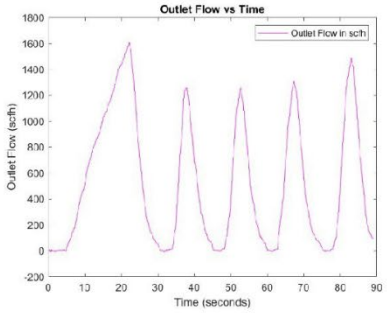
- 222489-053_DT
  The volume of total emissions in 485.23 seconds is 3.4013 scf.
  The flow rate of emissions is 25.2353 scfh.

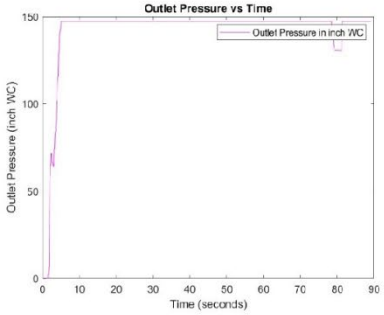


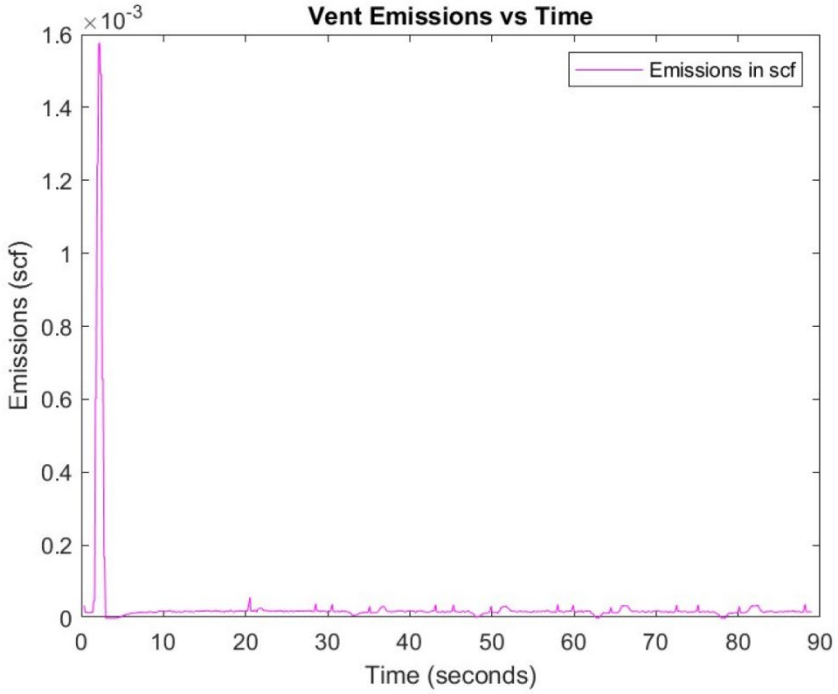




- 222489-053_LD
  The volume of total emissions in 89.00 seconds is 0.0262 scf.
  The flow rate of emissions is 1.0579 scfh.







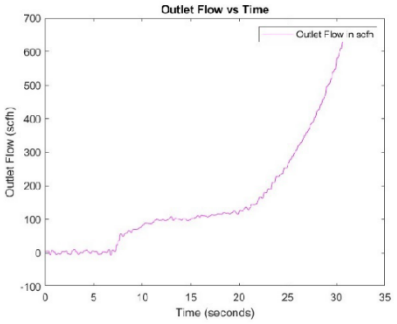
GTI ENERGY

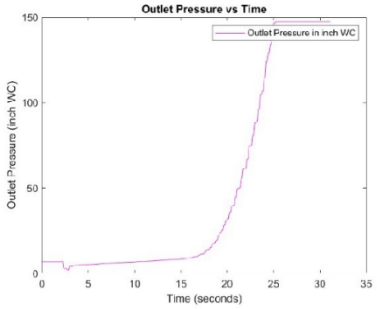
7” WC Outlet, 100-psig Inlet

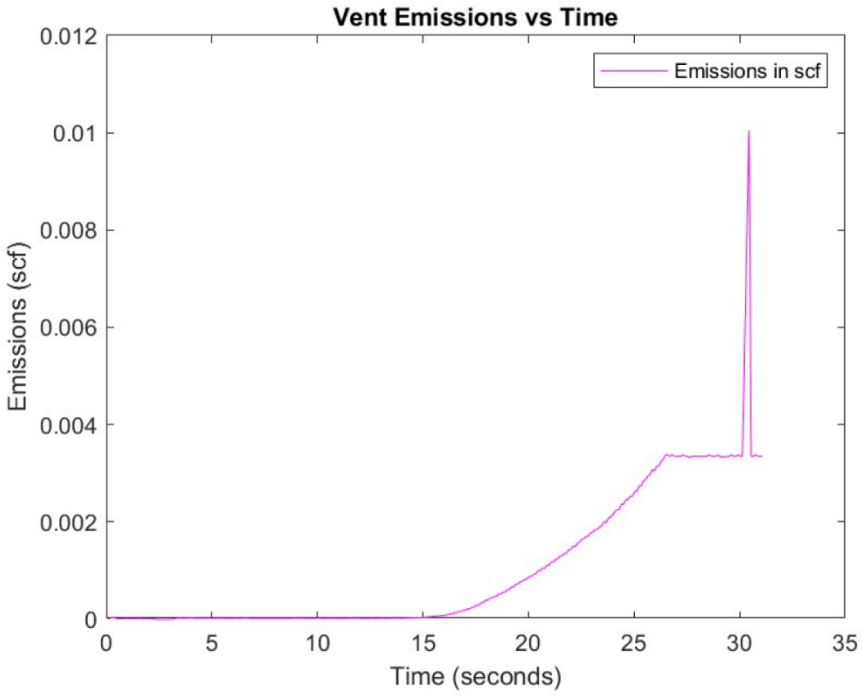
- 222489-051 (1/2” ori)

  The volume of total emissions in 31.07 seconds is 0.2895 scf.

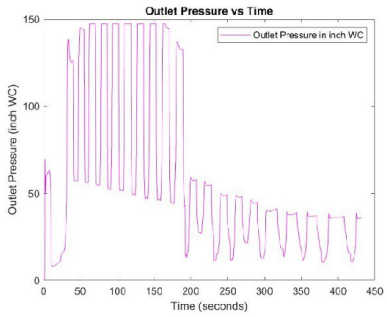
  The flow rate of emissions is 33.5460 scfh.

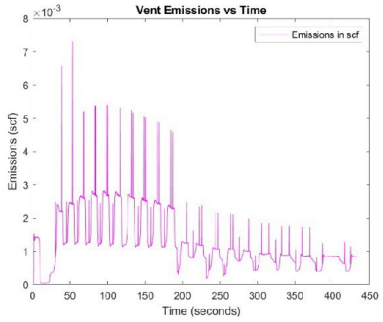


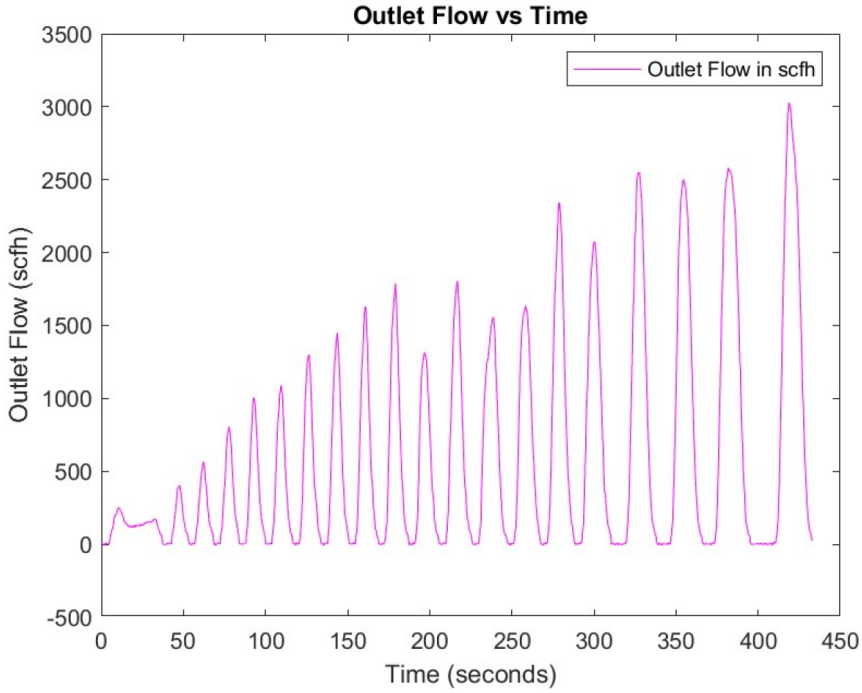




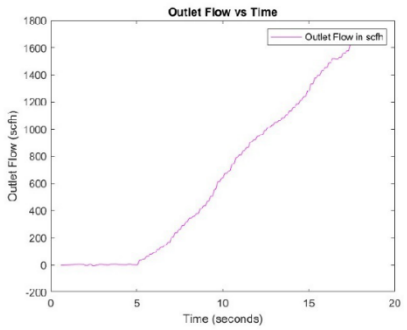
- 222489-051_DT (1/2" ori)
  The volume of total emissions in 432.94 seconds is 5.0763 scf.
  The flow rate of emissions is 42.2104 scfh.

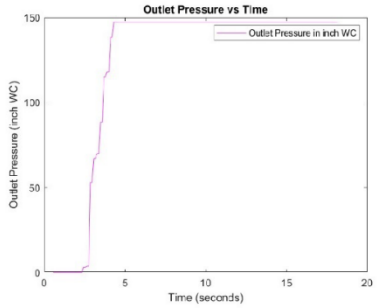


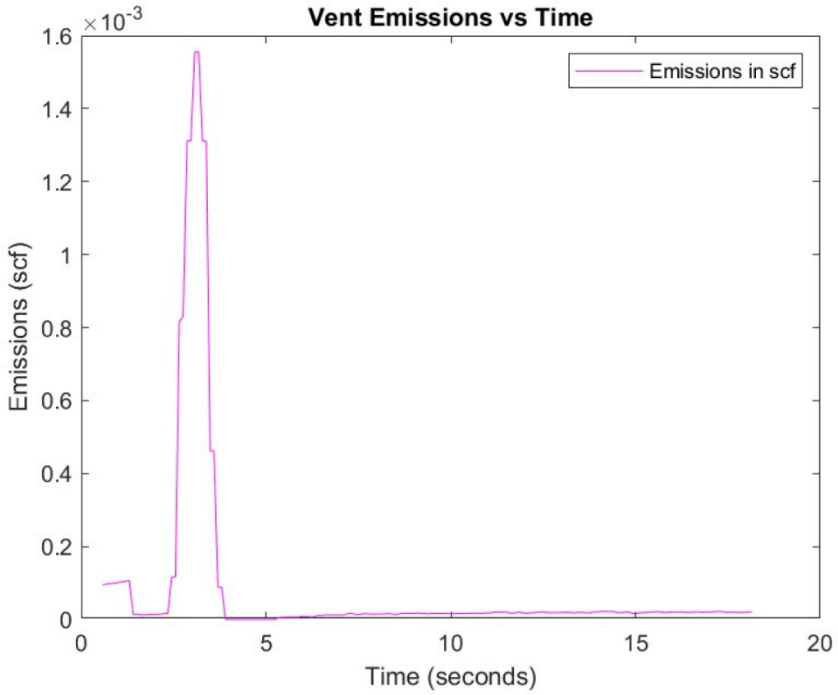




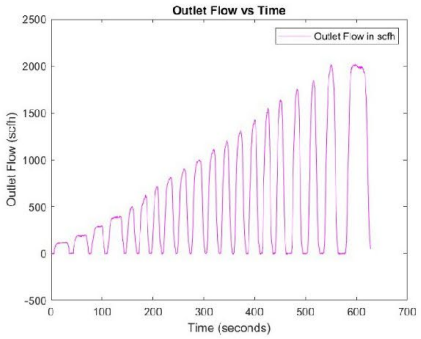
- 222489-051_LD (1/2" ori)
  The volume of total emissions in 18.15 seconds is 0.0138 scf.
  The flow rate of emissions is 2.7276 scfh.

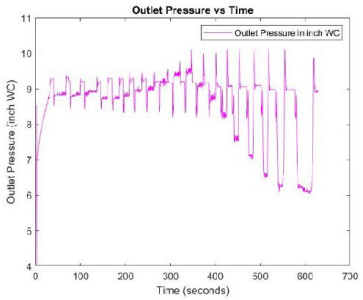


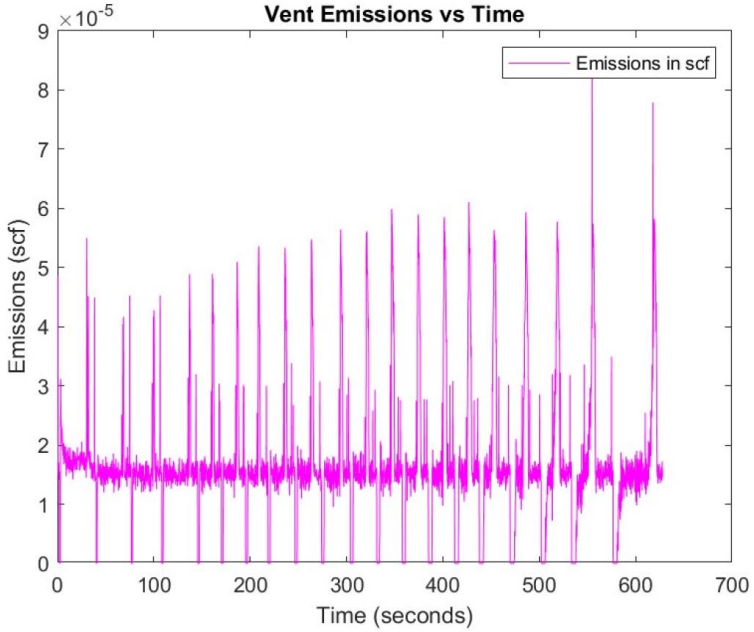




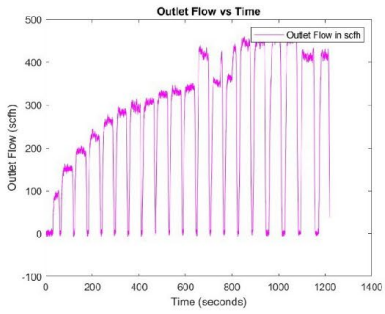
- 222489-052
  The volume of total emissions in 628.11 seconds is 0.1007 scf.
  The flow rate of emissions is 0.5770 scfh.

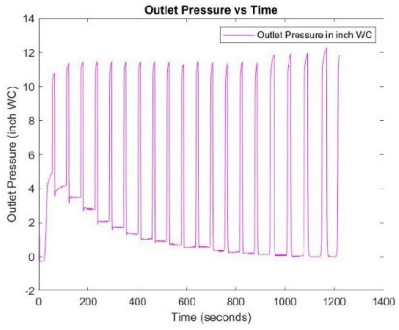


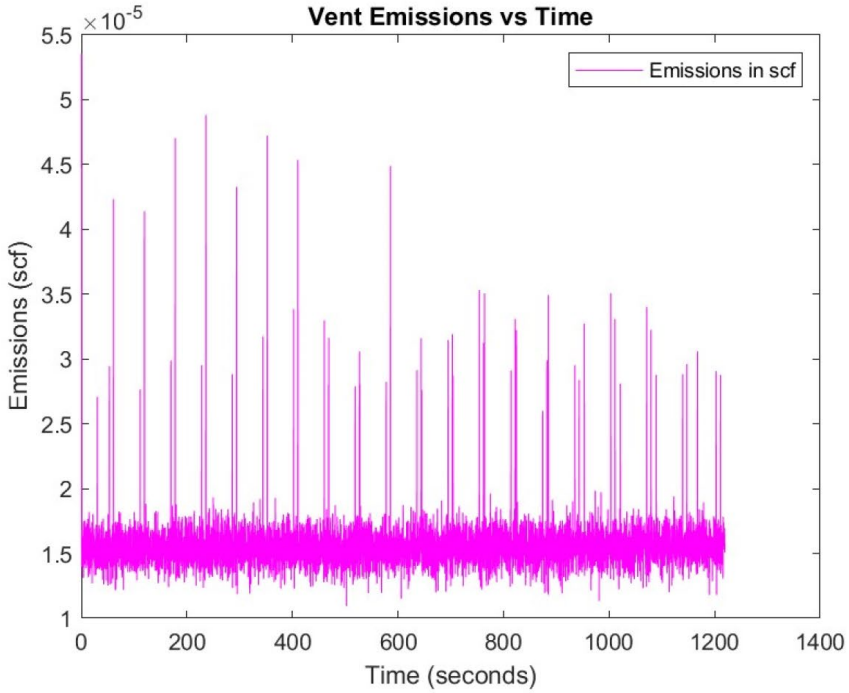




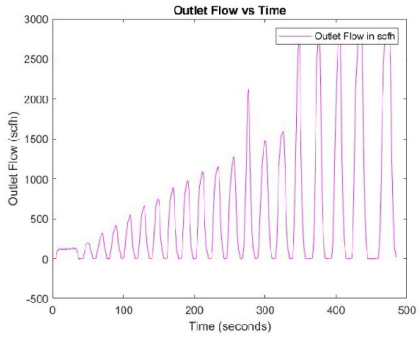
- 222489-052_BV
  The volume of total emissions in 1219.56 seconds is 0.1808 scf.
  The flow rate of emissions is 0.5336 scfh.

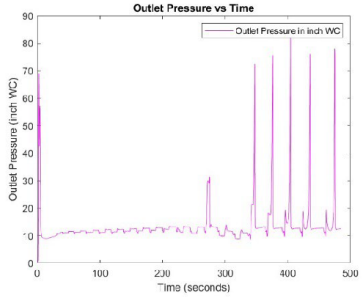


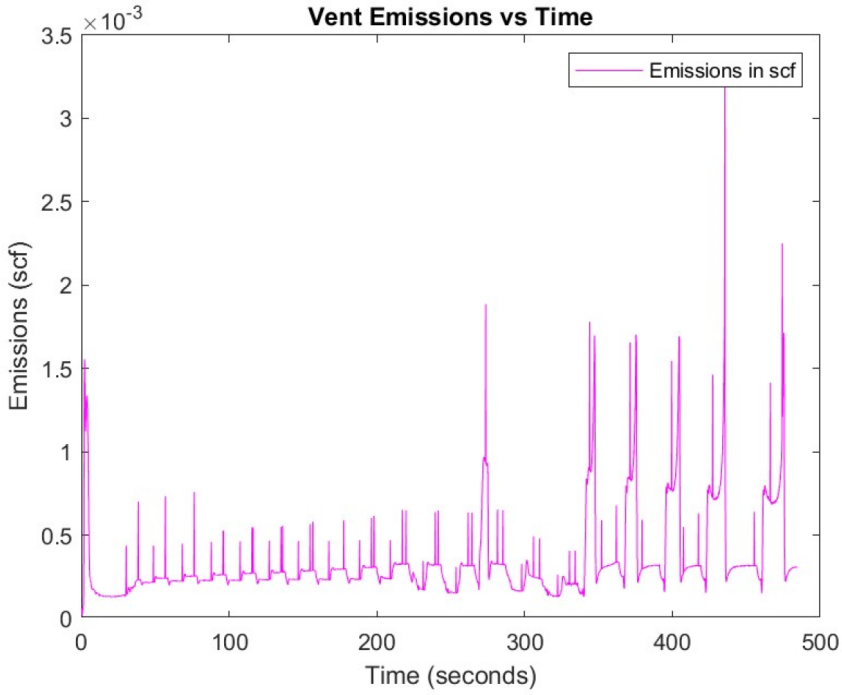




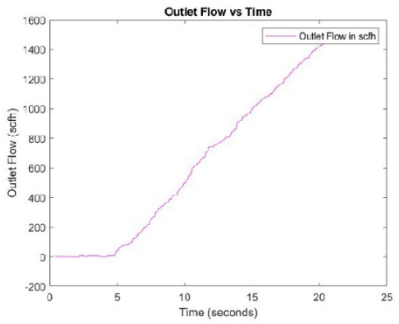
- 222489-052_DT
  The volume of total emissions in 484.35 seconds is 1.5387 scf.
  The flow rate of emissions is 11.4366 scfh.

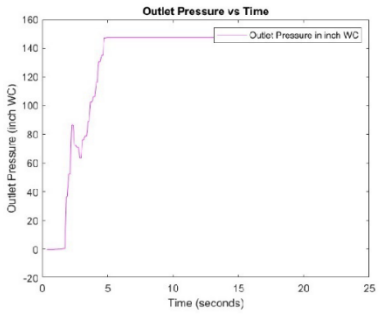


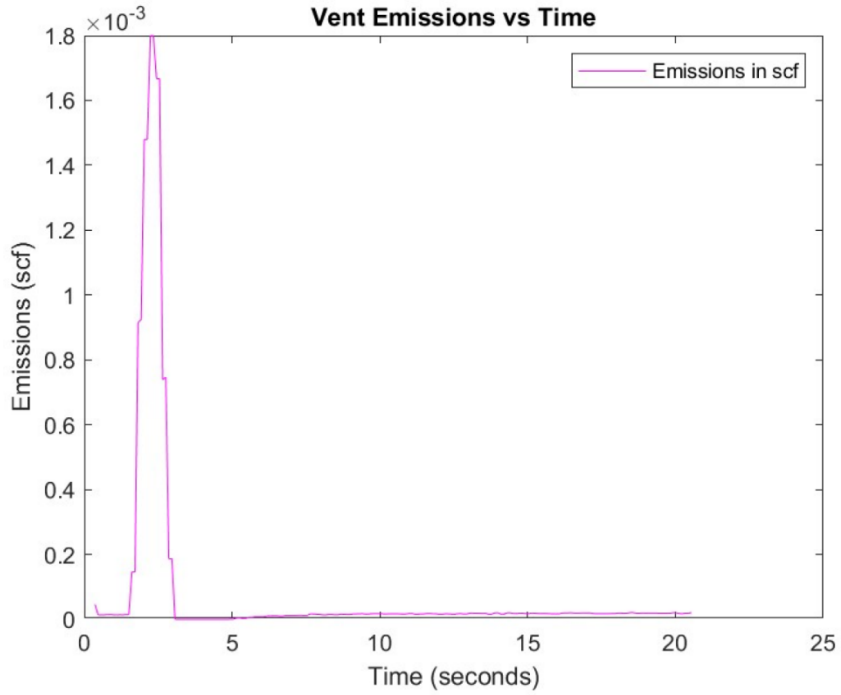




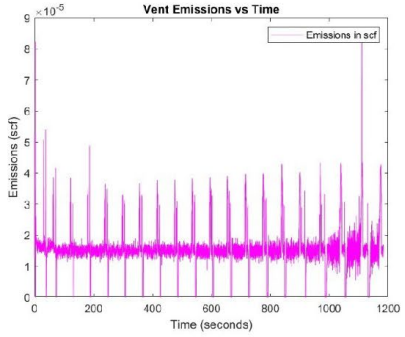
- 222489-052_LD
  The volume of total emissions in 20.55 seconds is 0.0165 scf.
  The flow rate of emissions is 2.8868 scfh.

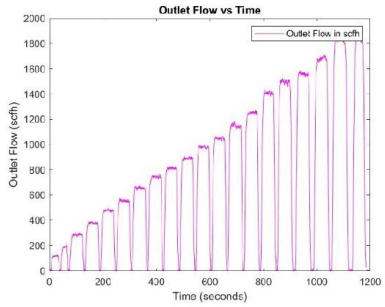


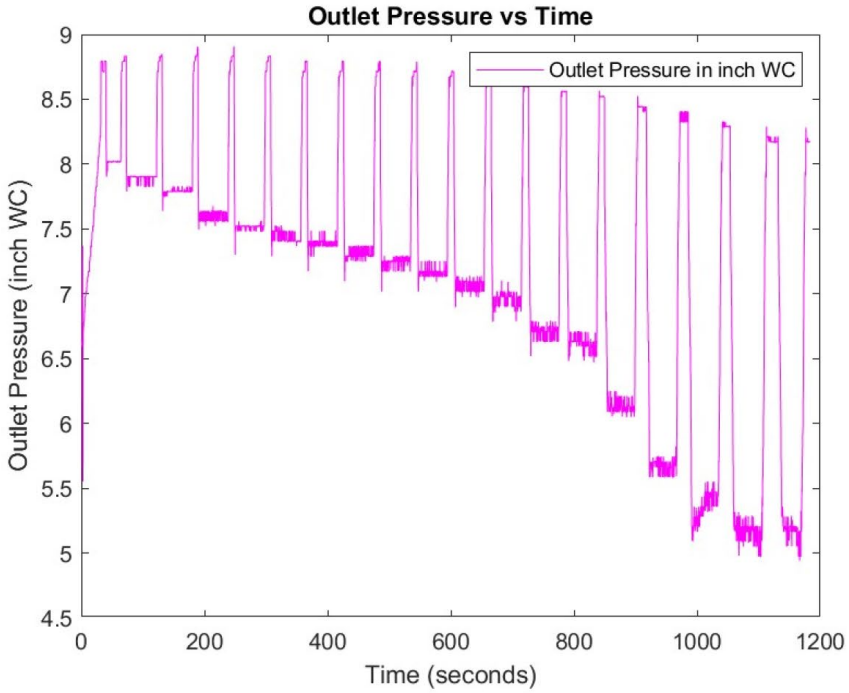




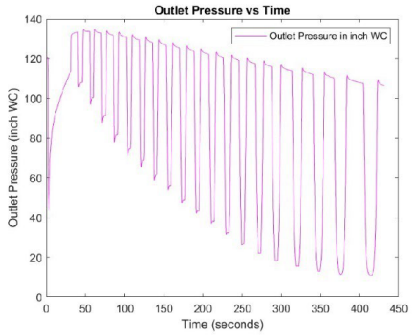
- 222489-053
  The volume of total emissions in 1183.23 seconds is 0.1752 scf.
  The flow rate of emissions is 0.5330 scfh.

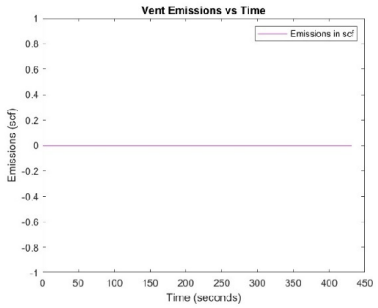


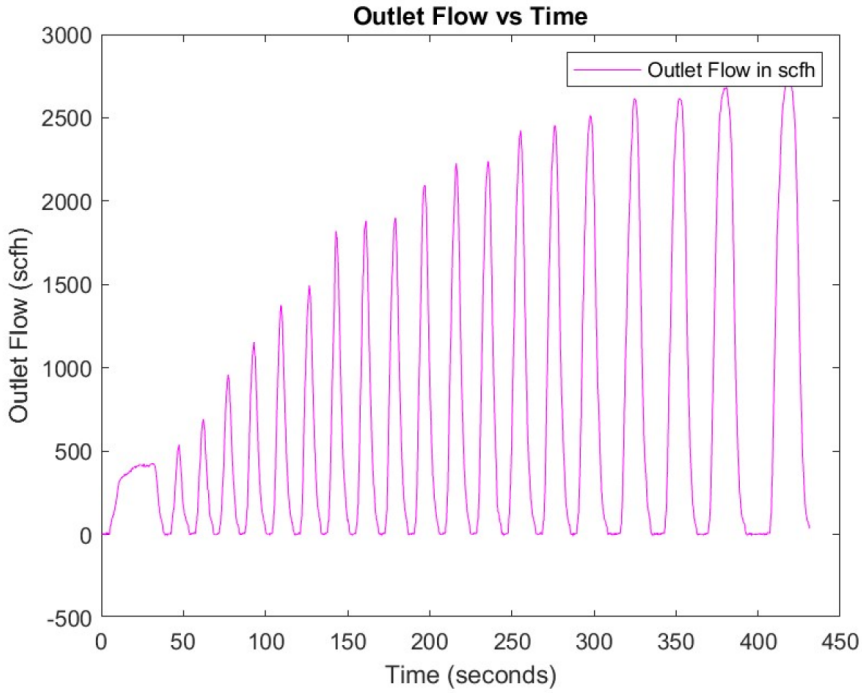




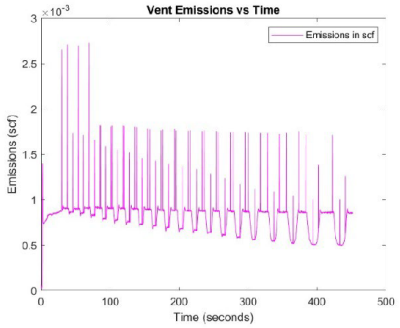
- 222489-053_BV
  The volume of total emissions in 431.40 seconds is 0.0000 scf.
  The flow rate of emissions is 0.0000 scfh.

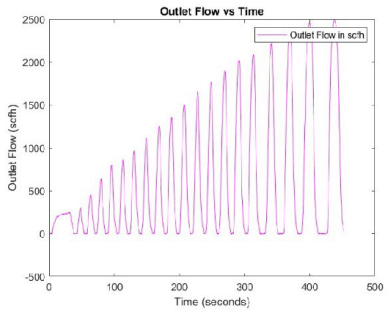


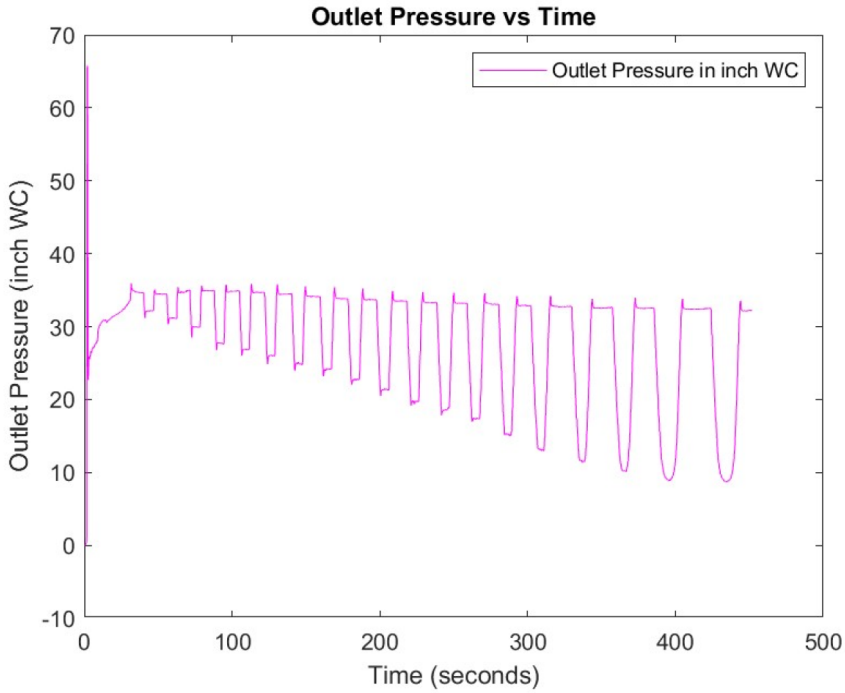




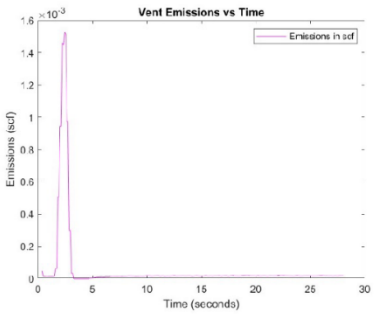
- 222489-053_DT
  The volume of total emissions in 451.94 seconds is 3.4503 scf.
  The flow rate of emissions is 27.4840 scfh.

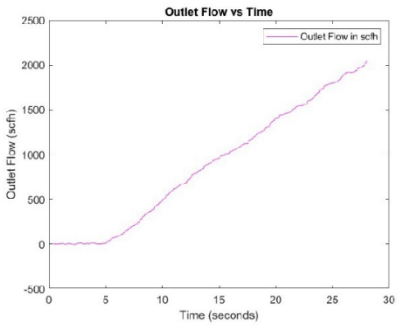


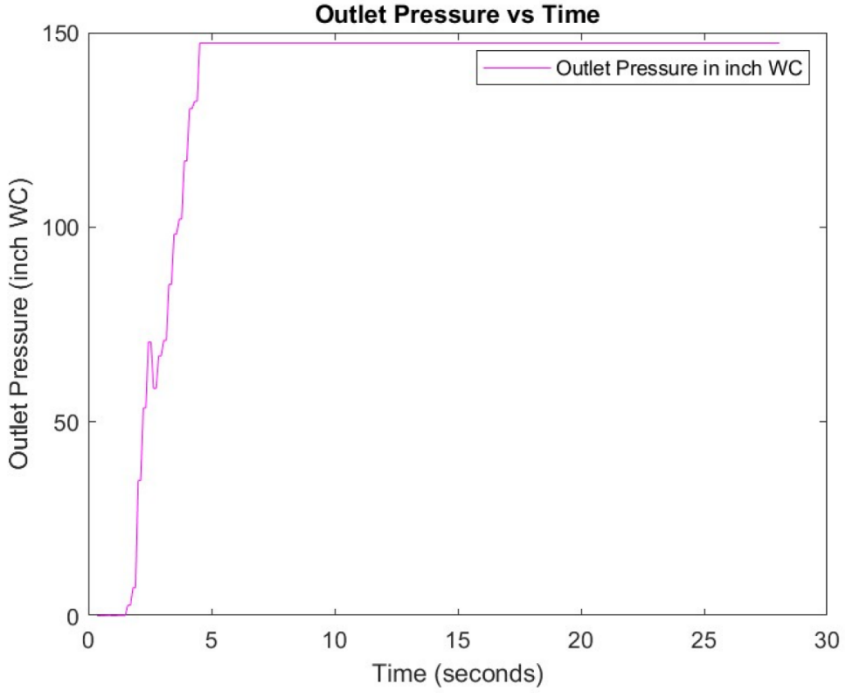




- 222489-053_LD
  The volume of total emissions in 28.07 seconds is 0.0158 scf.
  The flow rate of emissions is 2.0243 scfh.



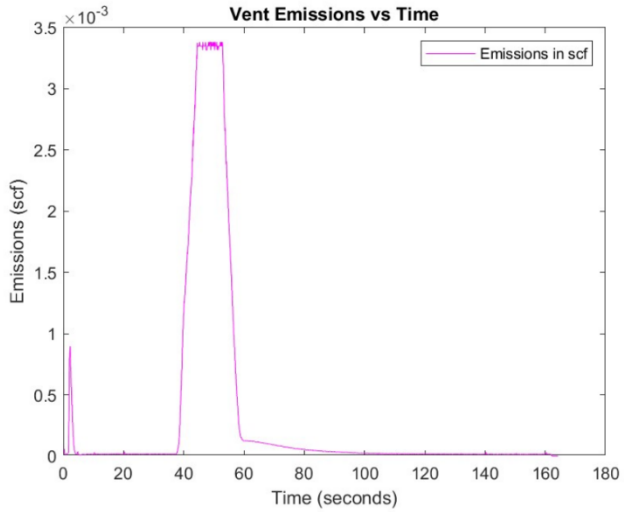


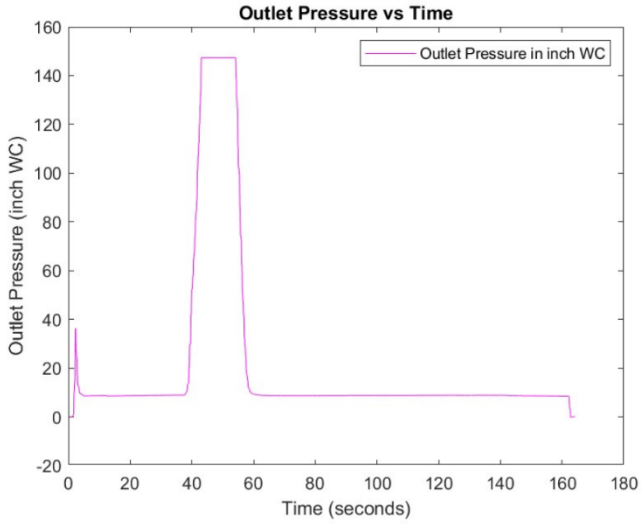


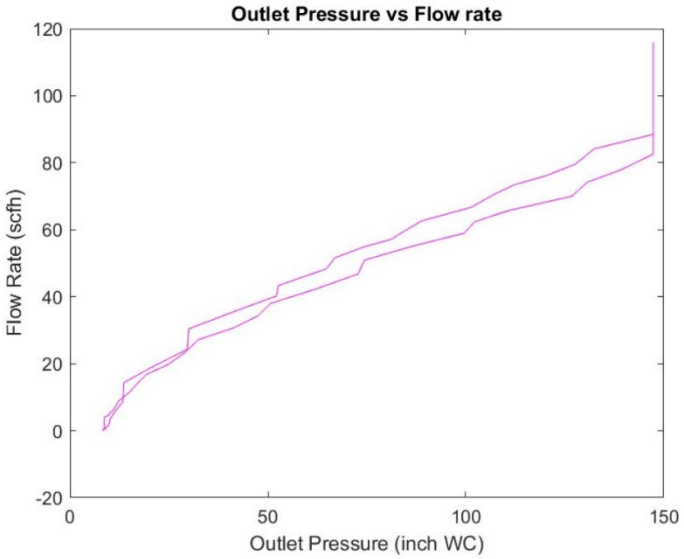
Relief Tests

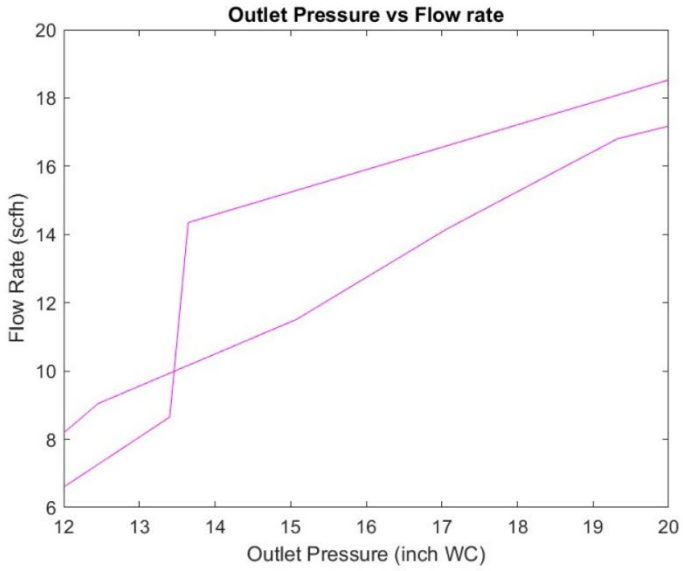
7" WC Outlet, 10-psig Inlet

- 222489-051 (1/2" ori)
  The volume of total emissions in 164.23 seconds is 0.5078 scf.
  The average flow rate of emissions at 18 inches WC is 14.15 scfh.

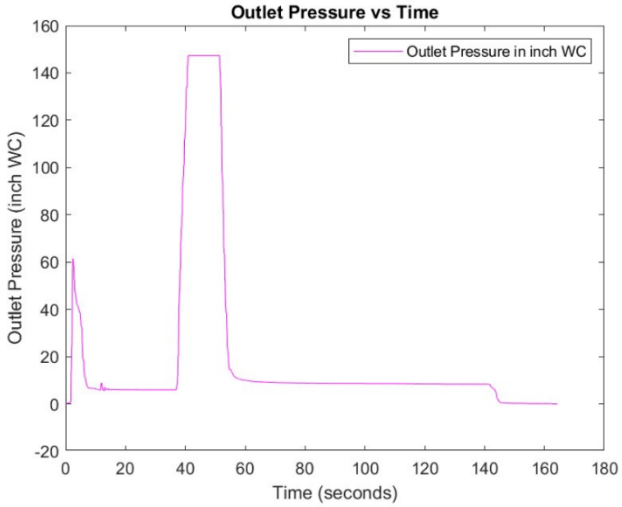


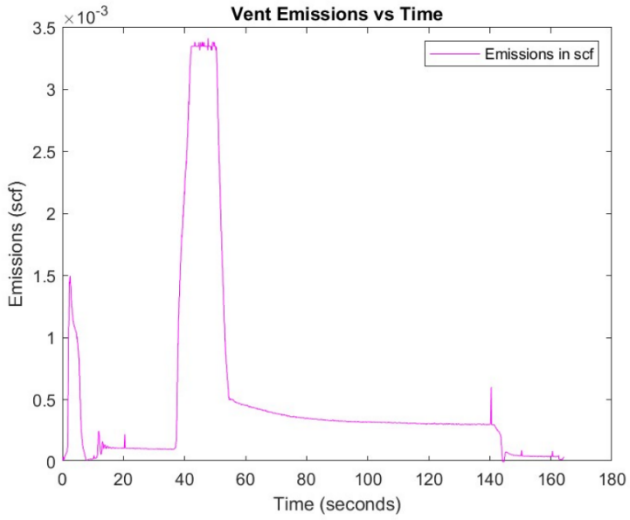


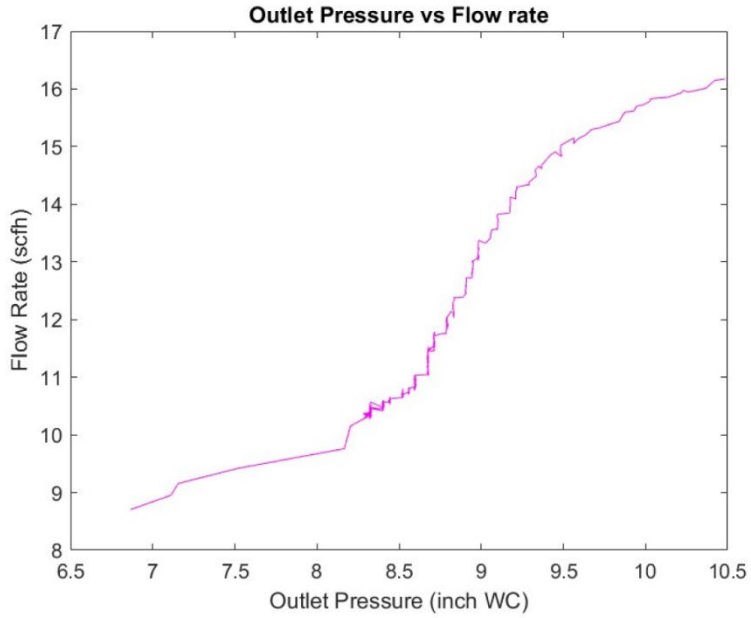

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
120
100
80
60
40
20
0
-20
0
50
100
150

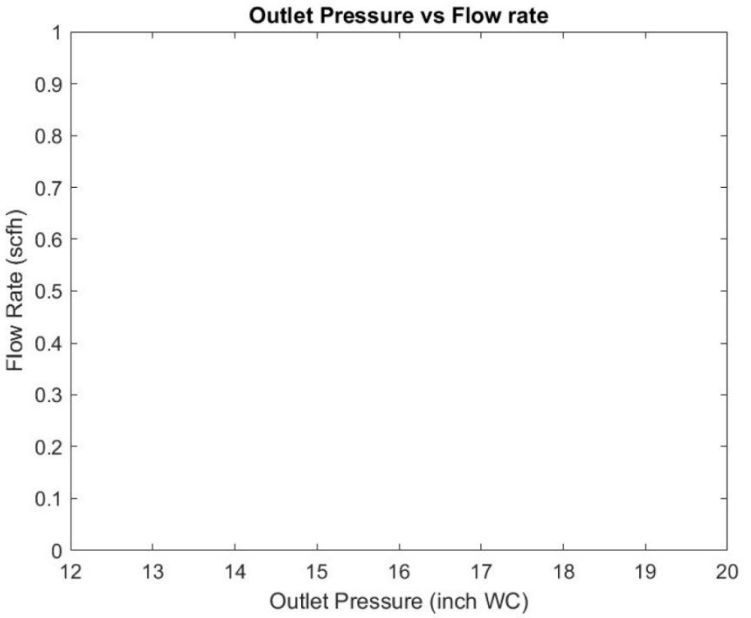

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
20
18
16
14
12
10
8
6
12
13
14
15
16
17
18
19
20

- 222489-051_DT (1/2" ori)
  The volume of total emissions in 164.30 seconds is 0.7993 scf.
  The average flow rate of emissions at 18 inches WC is 11.70 scfh.

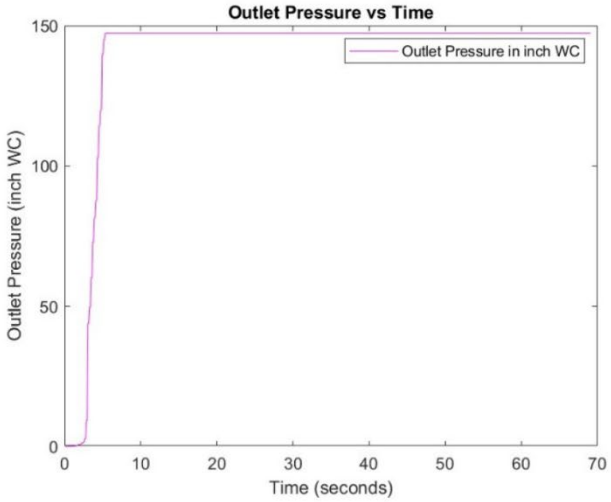


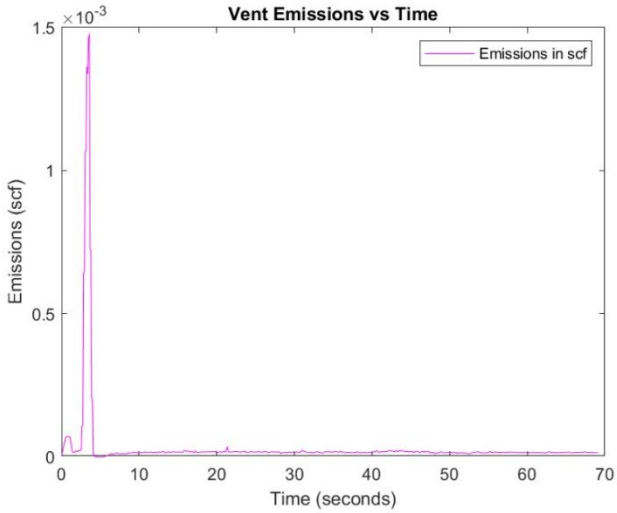



Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
17
16
15
14
13
12
11
10
9
8
6.5
7
7.5
8
8.5
9
9.5
10
10.5

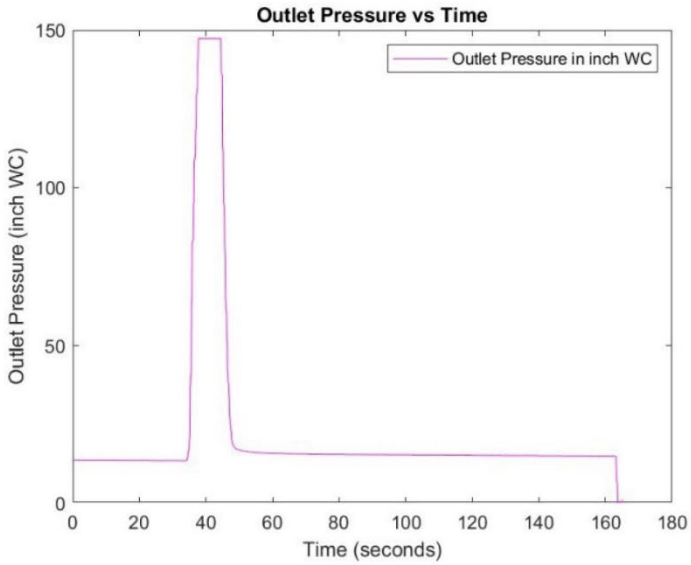

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
12
13
14
15
16
17
18
19
20

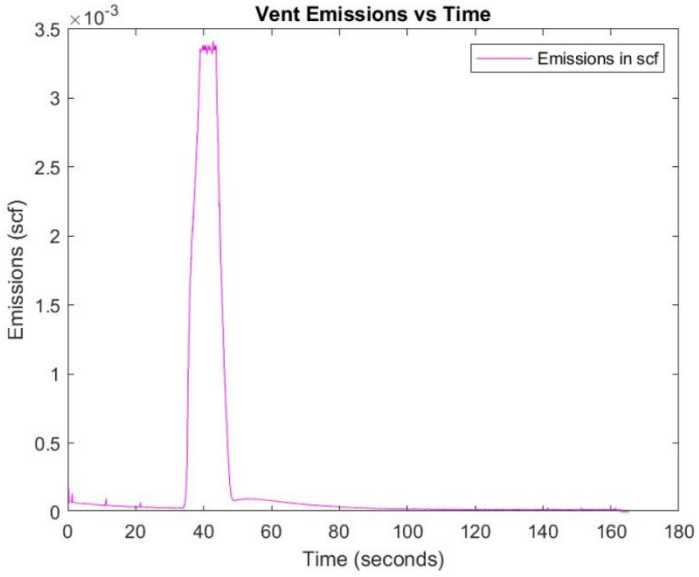
- 222489-051_LD (1/2" ori)
  The volume of total emissions in 69.08 seconds is 0.0212 scf.

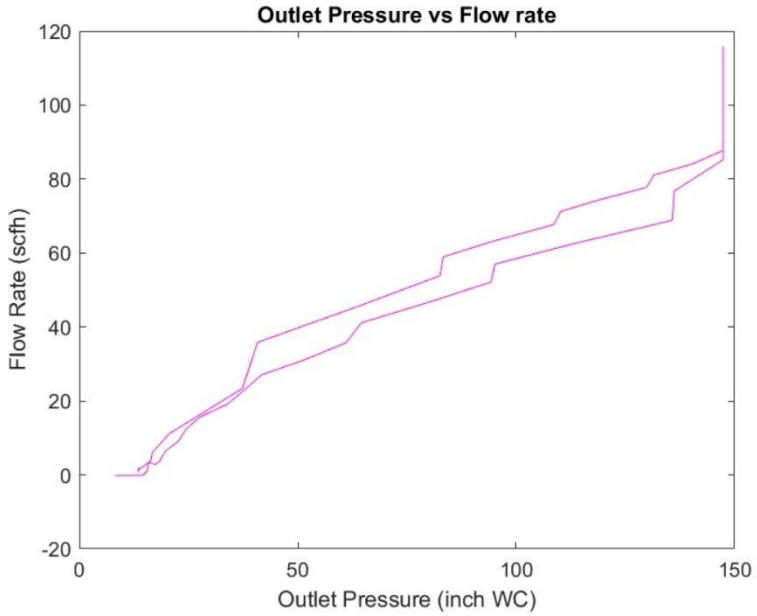


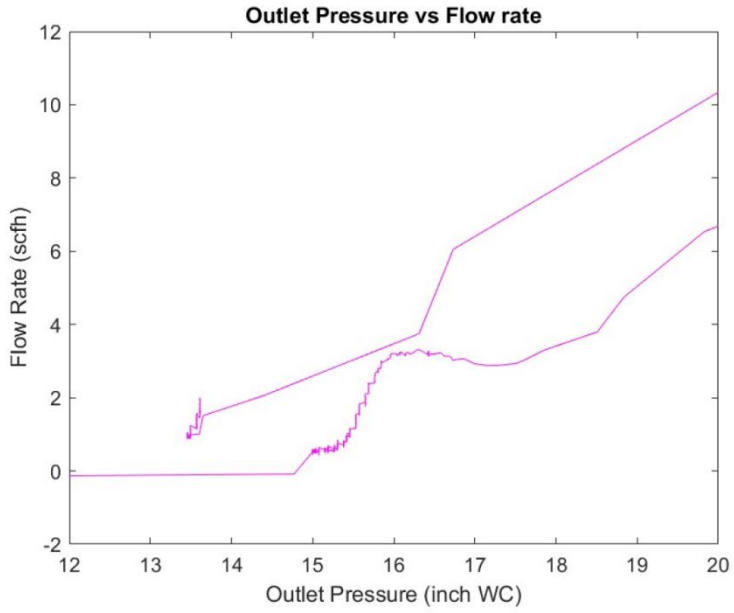


- 222489-052 (3/16" ori)
  The volume of total emissions in 165.26 seconds is 0.3394 scf.
  The average flow rate of emissions at 18 inches WC is 3.30 scfh.

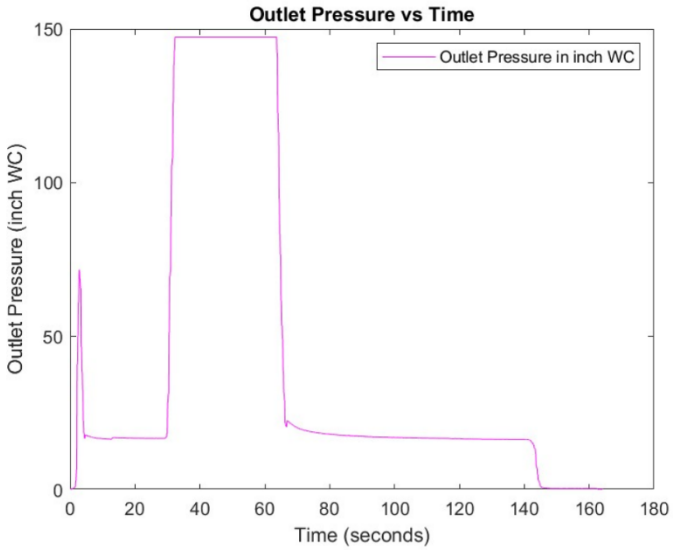


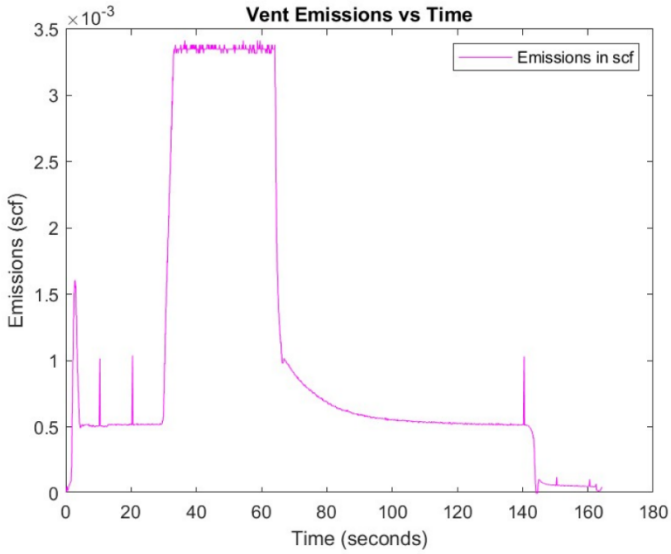


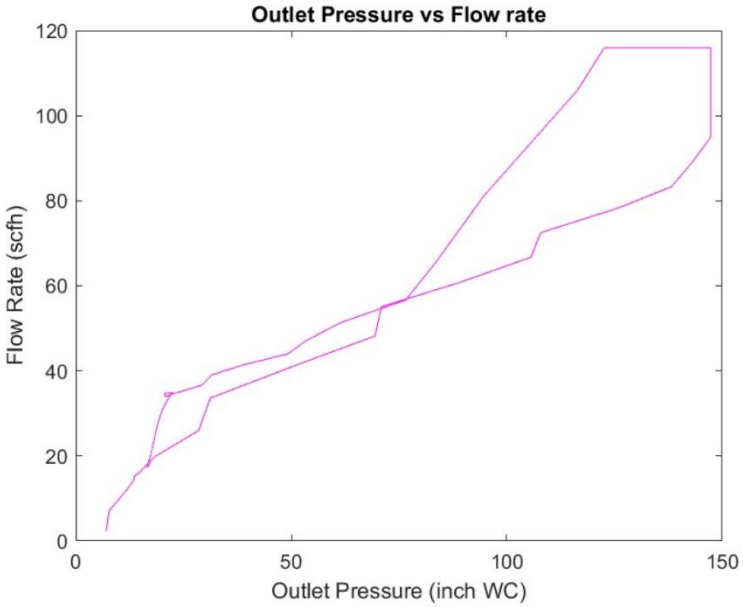

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
120
100
80
60
40
20
0
-20
0
50
100
150

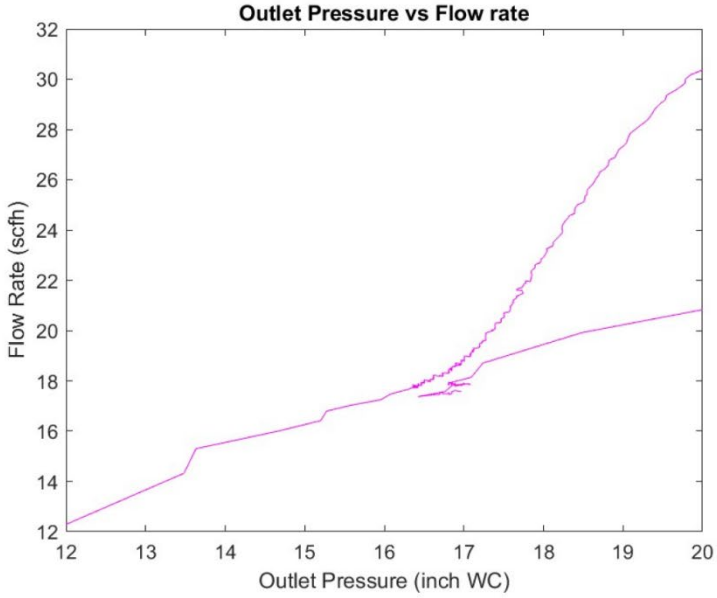

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
12
10
8
6
4
2
0
-2
12
13
14
15
16
17
18
19
20

- 222489-052_DT (3/16" ori)
  The volume of total emissions in 164.30 seconds is 1.7040 scf.
  The average flow rate of emissions at 18 inches WC is 22.13 scfh.

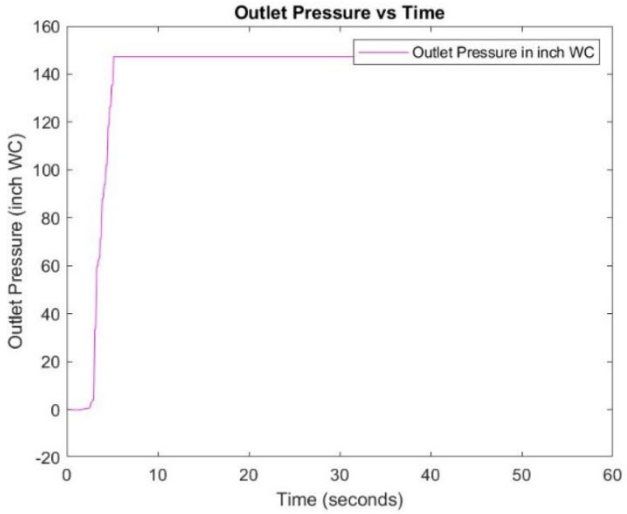


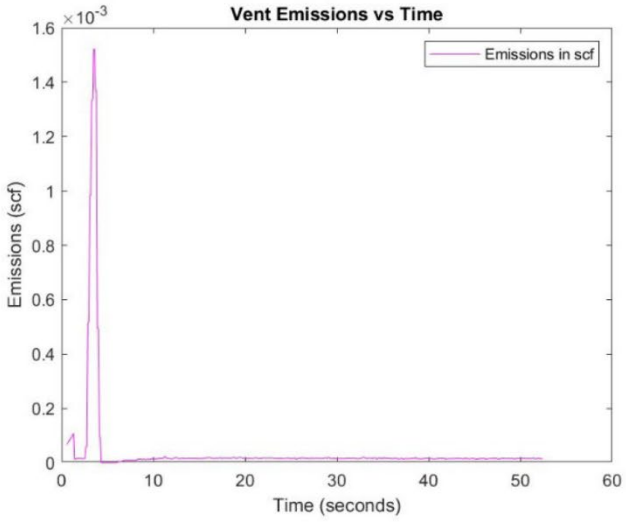



Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
20
40
60
80
100
120
0
50
100
150

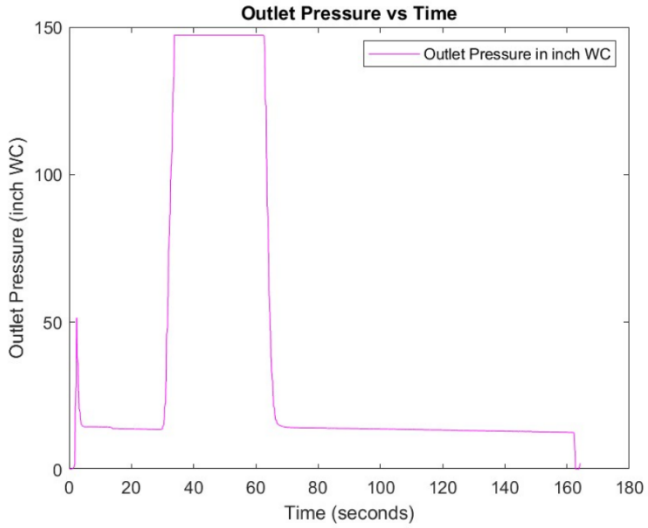

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
12
14
16
18
20
22
24
26
28
30
32
12
13
14
15
16
17
18
19
20

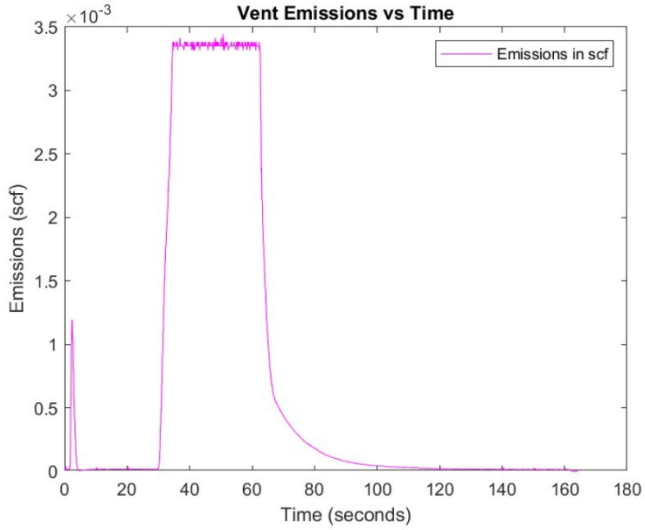
- 222489-052_LD
  The volume of total emissions in 52.42 seconds is 0.0201 scf.

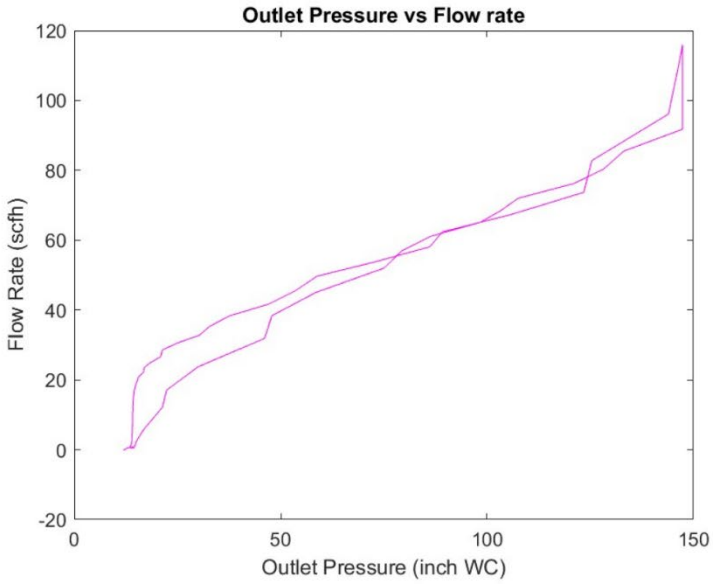


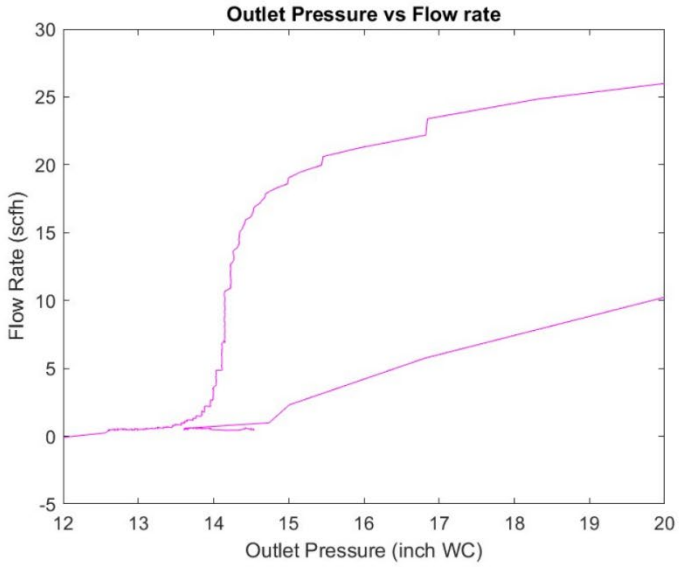


- 222489-053
  The volume of total emissions in 164.26 seconds is 1.1167 scf.
  The average flow rate of emissions at 18 inches WC is 24.84 scfh.

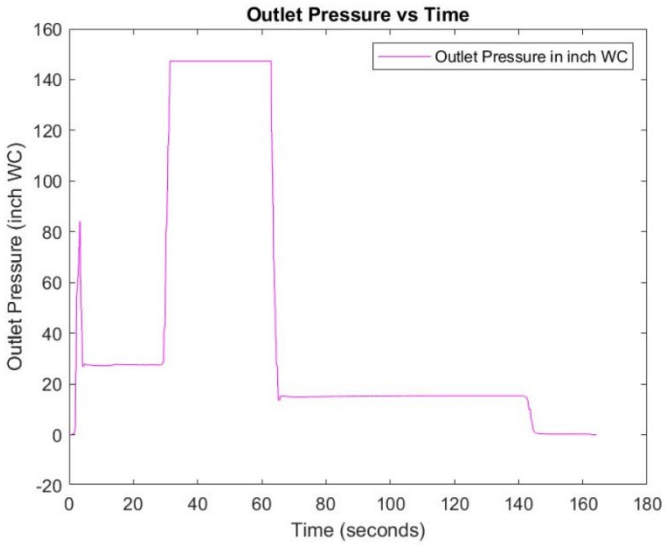


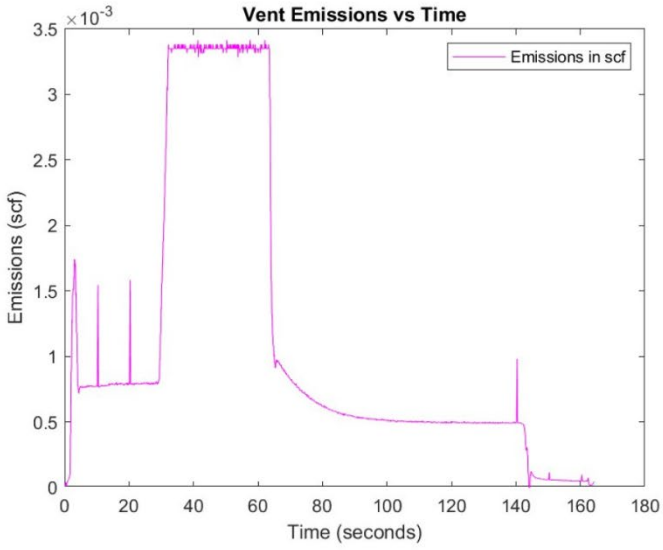



Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
120
100
80
60
40
20
0
-20
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
30
25
20
15
10
5
0
-5
12
13
14
15
16
17
18
19
20

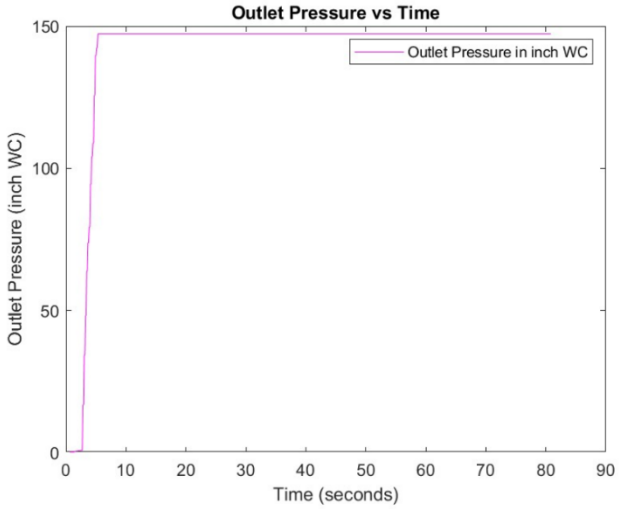
- 222489-053_DT
  The volume of total emissions in 164.23 seconds is 1.7439 scf.

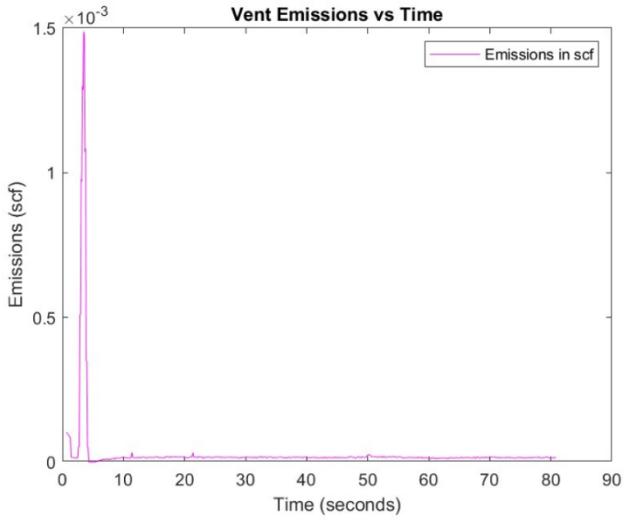




GTI ENERGY

- 222489-053_LD
  The volume of total emissions in 80.83 seconds is 0.0234 scf.



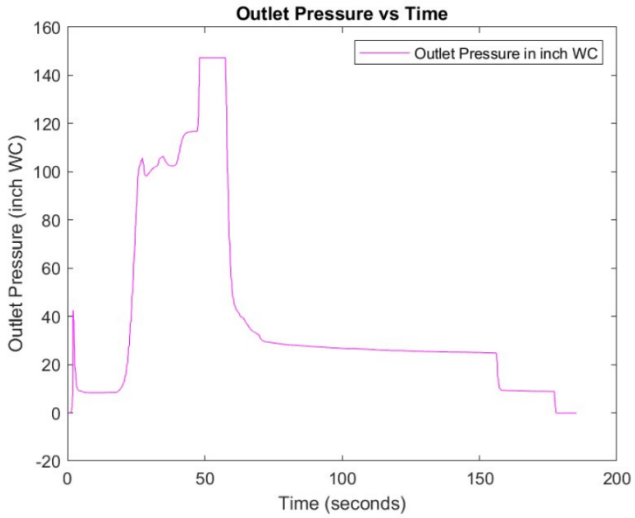


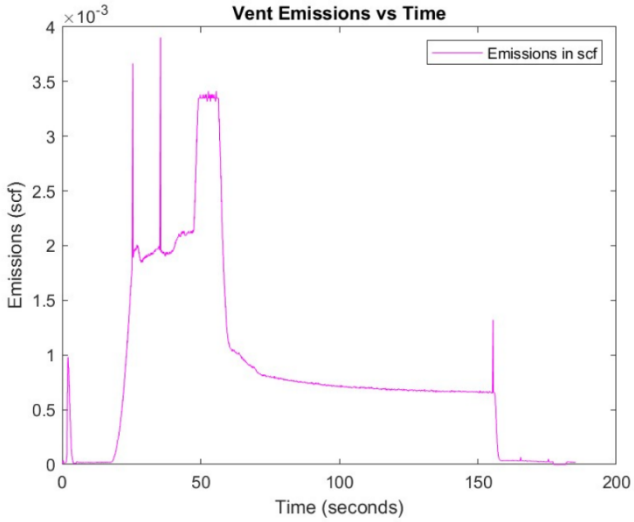
7” WC Outlet, 60-psig Inlet

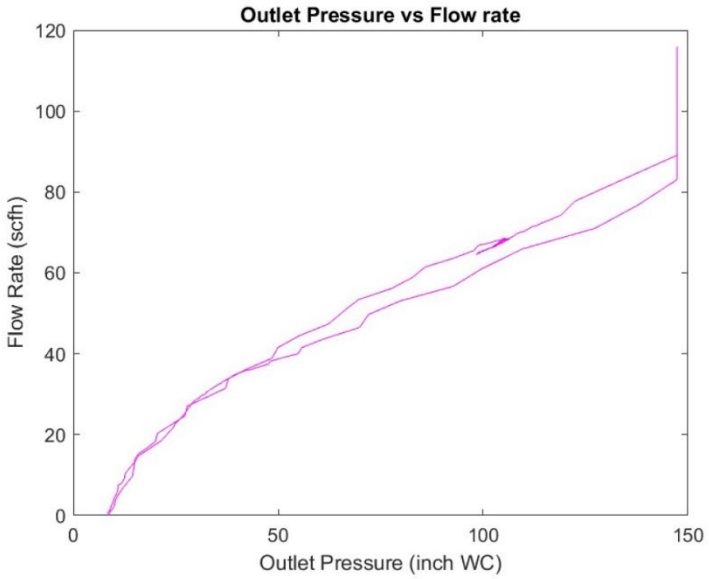
- 222489-051 (1/2” ori)

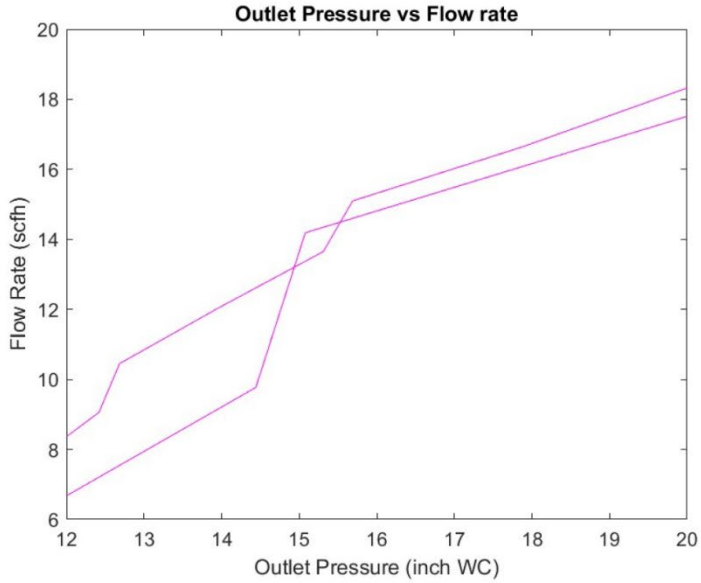
  The volume of total emissions in 185.28 seconds is 1.5188 scf.

  The average flow rate of emissions at 18 inches WC is 16.62 scfh.



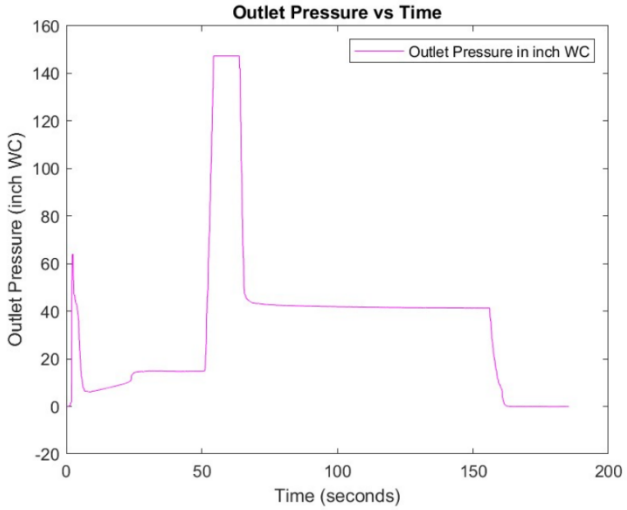


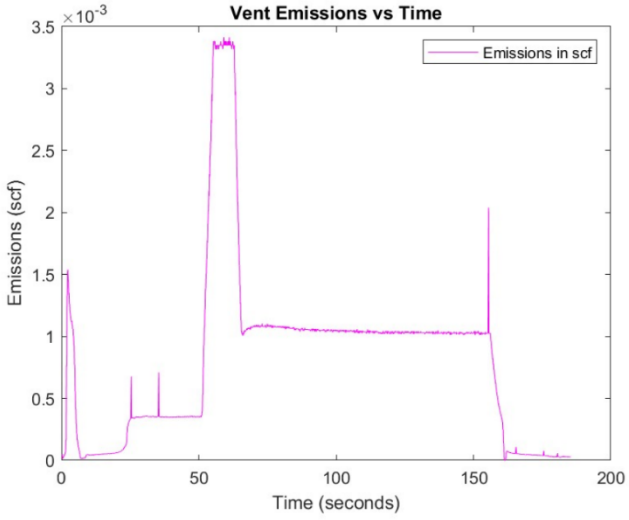

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
20
40
60
80
100
120
0
50
100
150

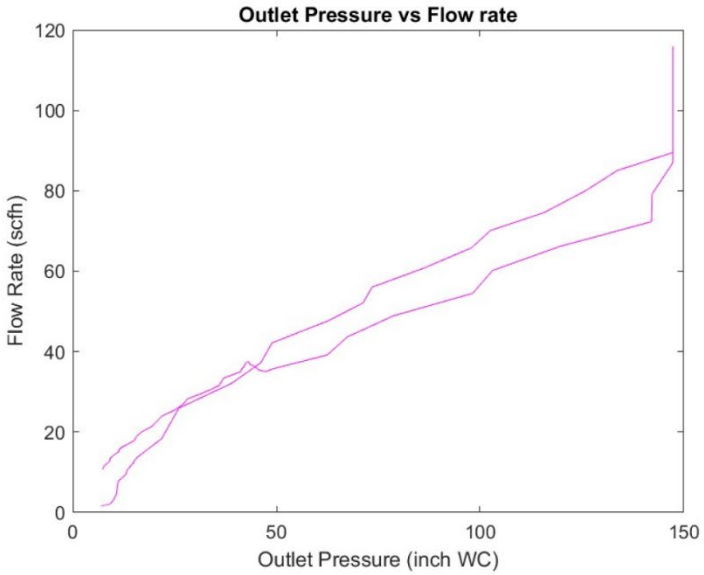

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
6
8
10
12
14
16
18
20
12
13
14
15
16
17
18
19
20

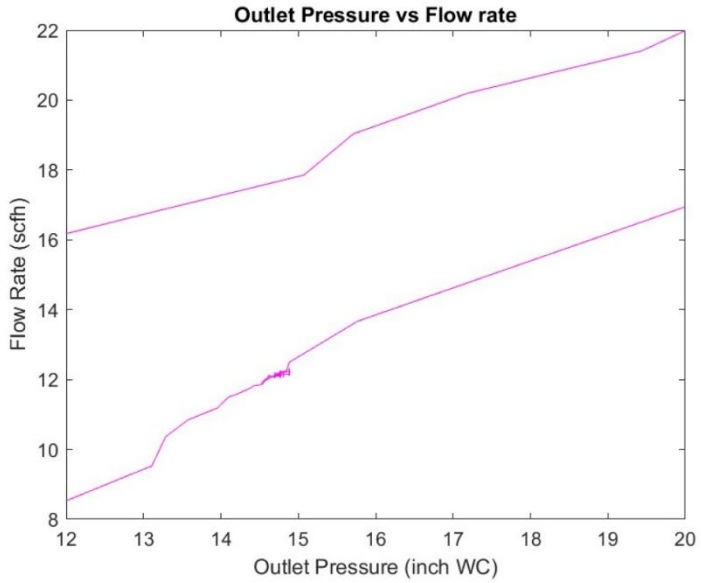
GTI ENERGY

- 222489-051_DT (1/2" ori)
  The volume of total emissions in 185.37 seconds is 1.4552 scf.
  The average flow rate of emissions at 18 inches WC is 20.20 scfh.



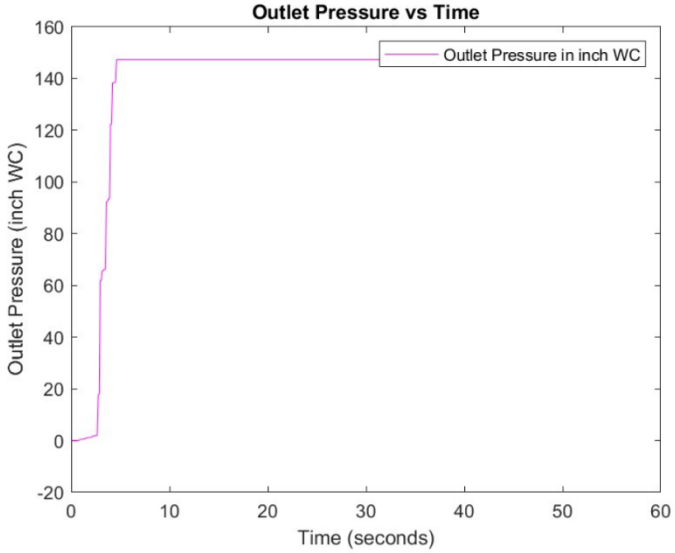


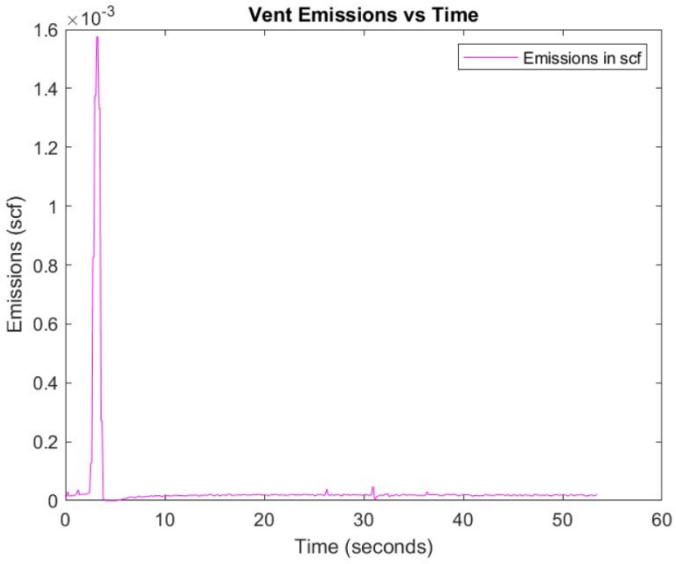

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
20
40
60
80
100
120
0
50
100
150

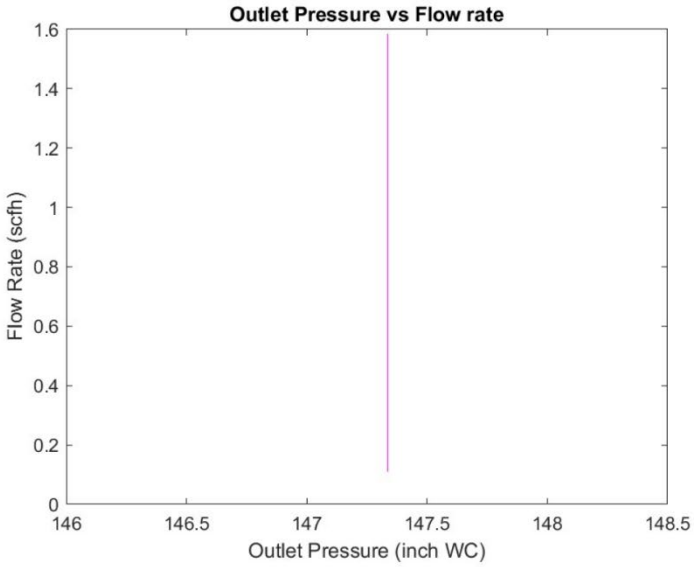

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
8
10
12
14
16
18
20
22
12
13
14
15
16
17
18
19
20

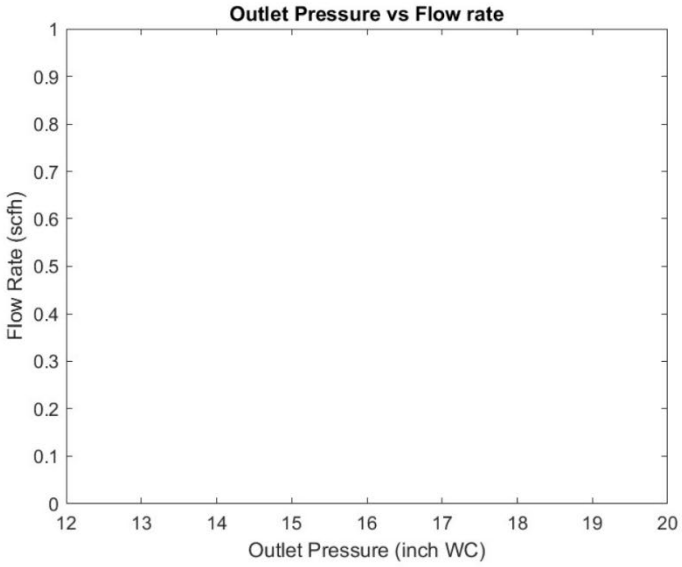
GTI ENERGY

- 222489-051_LD (1/2" ori)
  The volume of total emissions in 53.49 seconds is 0.0197 scf.
  The average flow rate of emissions at 18 inches WC is 28.54 scfh.

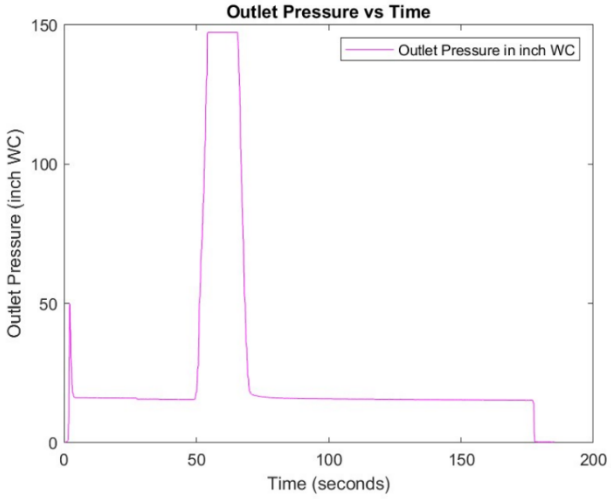


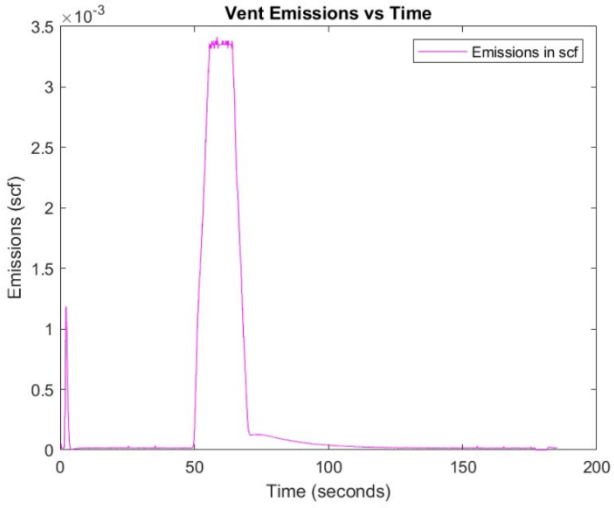


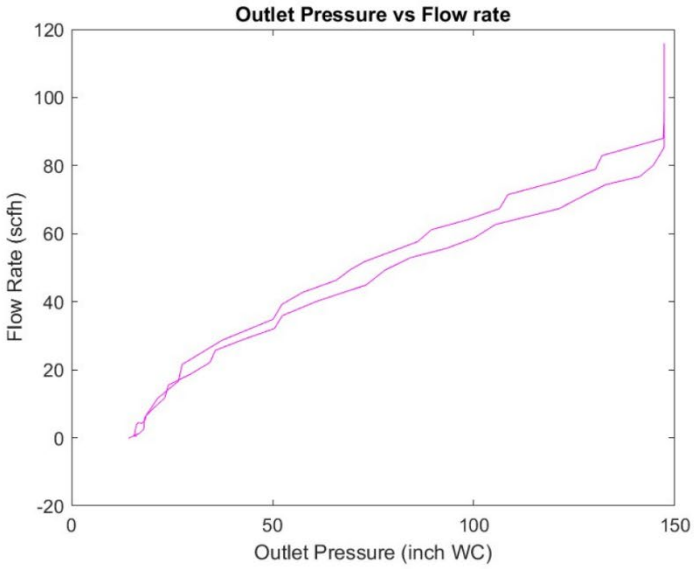

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
146
146.5
147
147.5
148
148.5

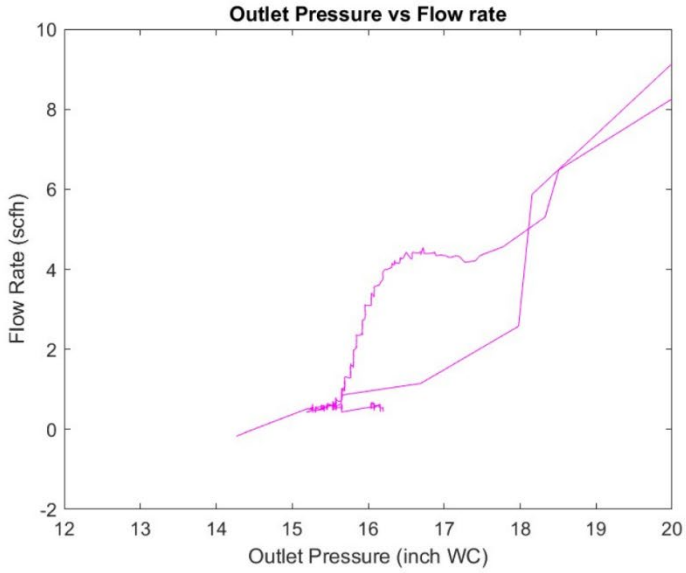

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
12
13
14
15
16
17
18
19
20

- 222489-052
  The volume of total emissions in 185.34 seconds is 0.5231 scf.
  The average flow rate of emissions at 18 inches WC is 4.59 scfh.

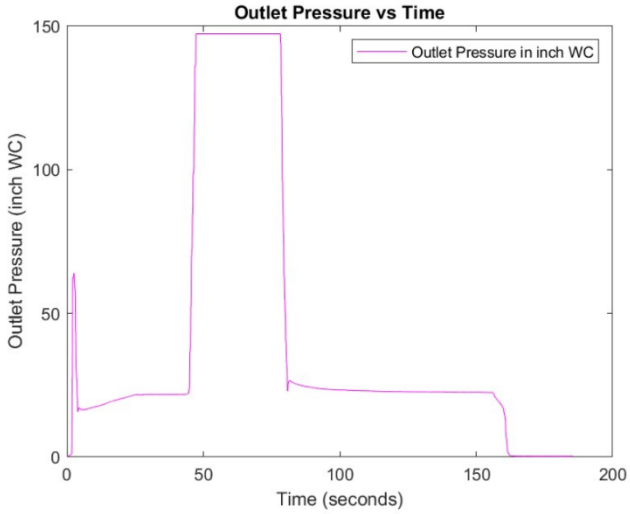


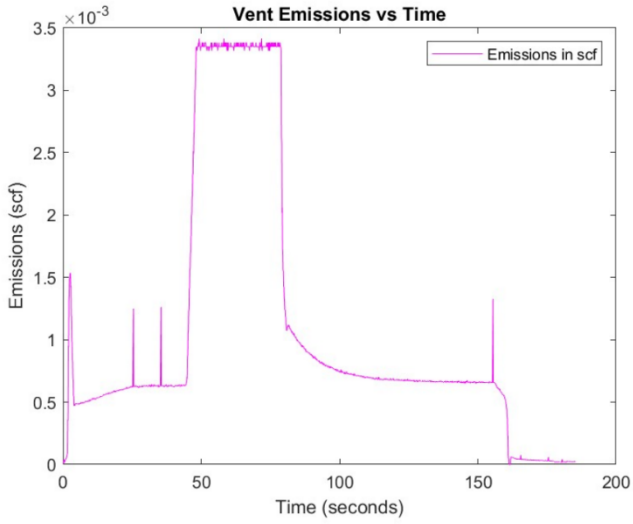


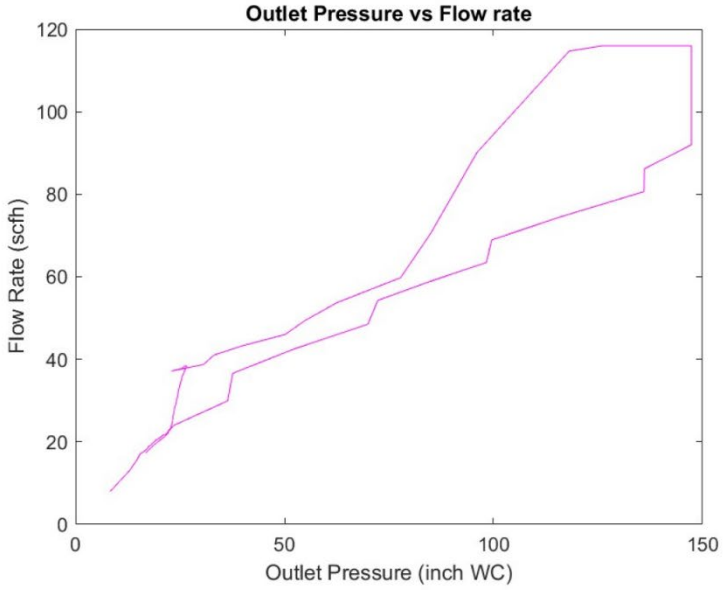

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
120
100
80
60
40
20
0
-20
0
50
100
150

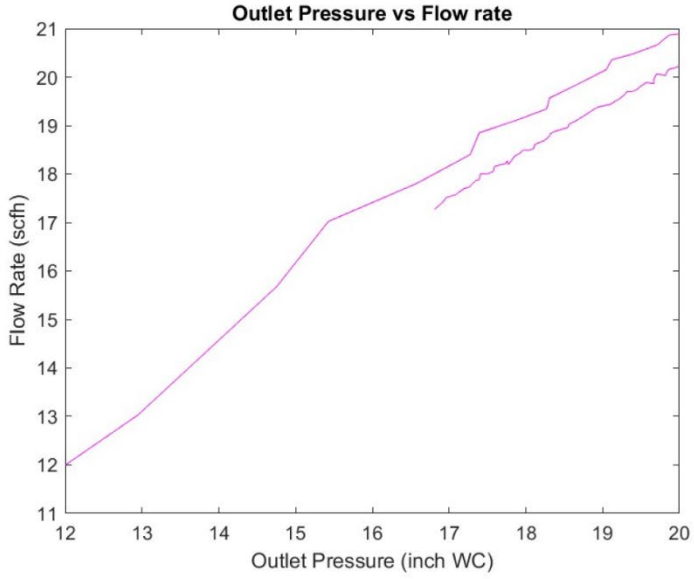

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
10
8
6
4
2
0
-2
12
13
14
15
16
17
18
19
20

- 222489-052_DT
  The volume of total emissions in 185.36 seconds is 1.9009 scf.
  The average flow rate of emissions at 18 inches WC is 18.57 scfh.

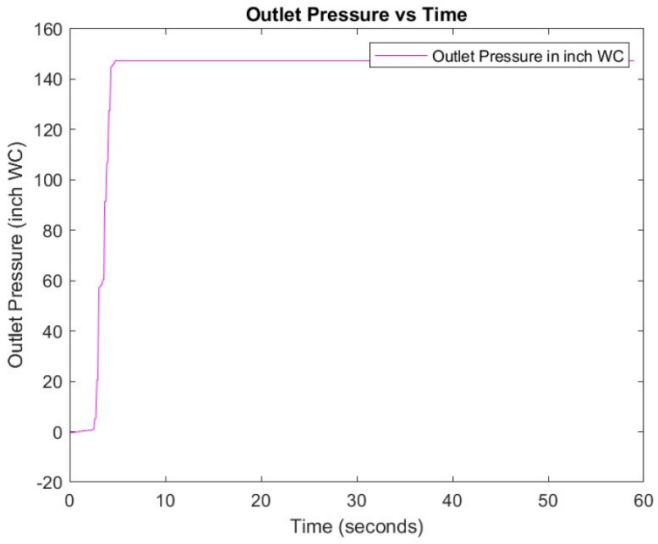


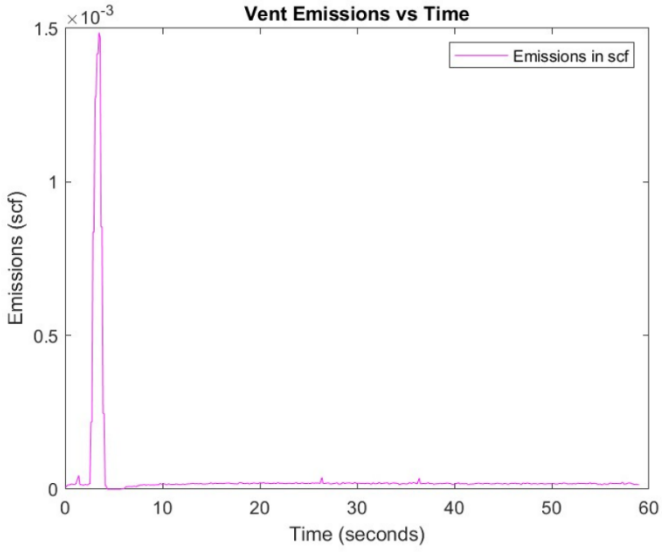



Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
20
40
60
80
100
120
0
50
100
150

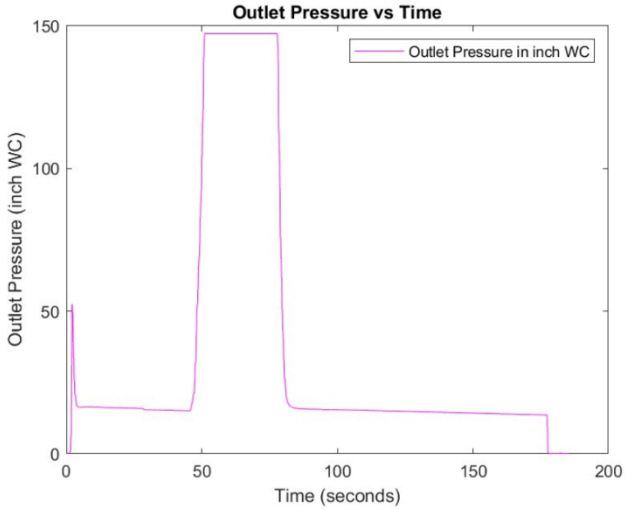

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
11
12
13
14
15
16
17
18
19
20
21
12
13
14
15
16
17
18
19
20

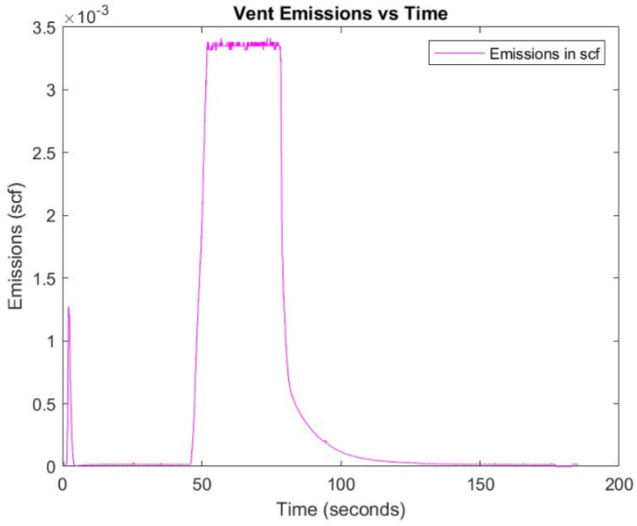
- 222489-052_LD
  The volume of total emissions in 58.99 seconds is 0.0219 scf.

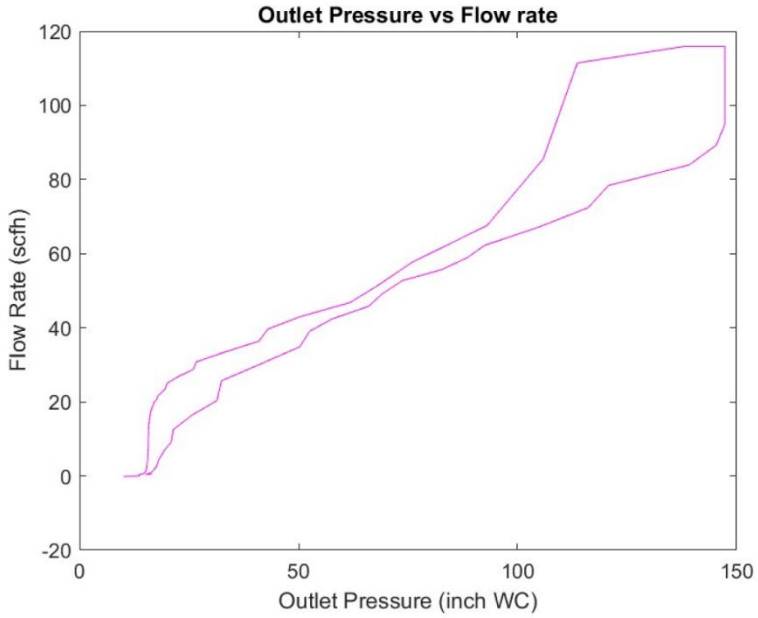


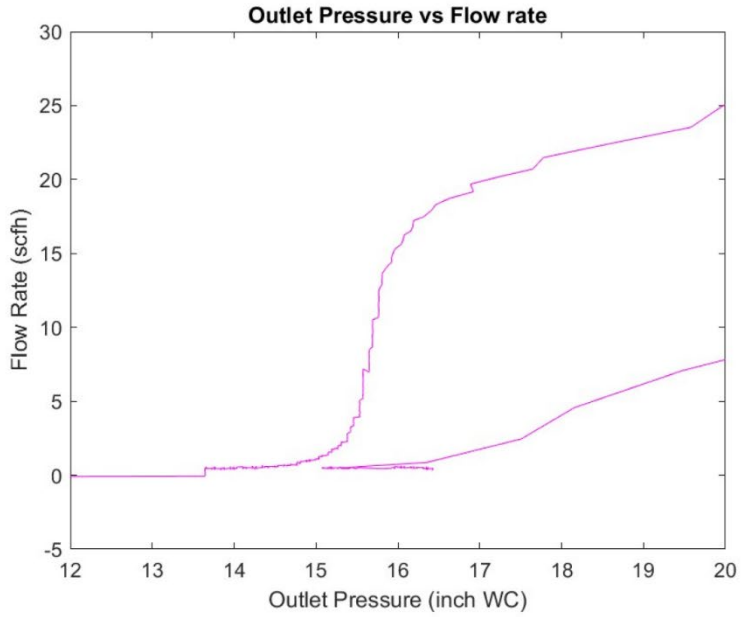


- 222489-053
  The volume of total emissions in 185.35 seconds is 1.0665 scf.
  The average flow rate of emissions at 18 inches WC is 4.10 scfh.

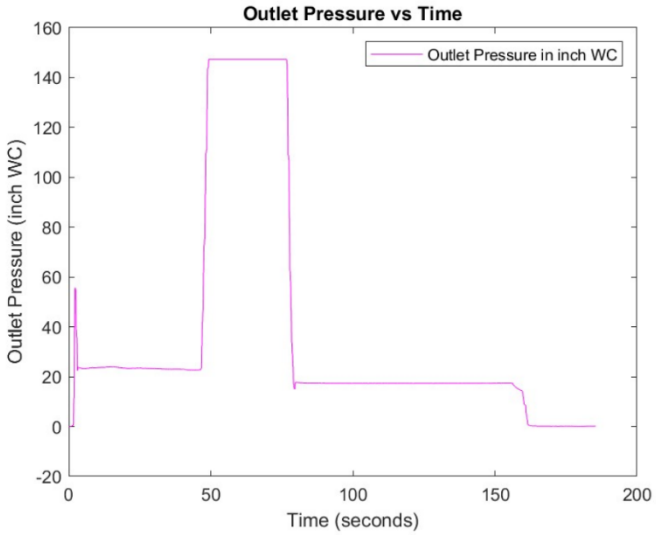


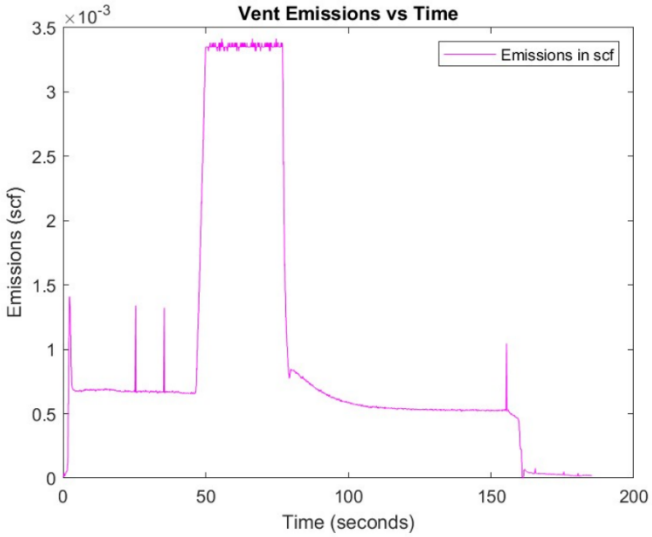


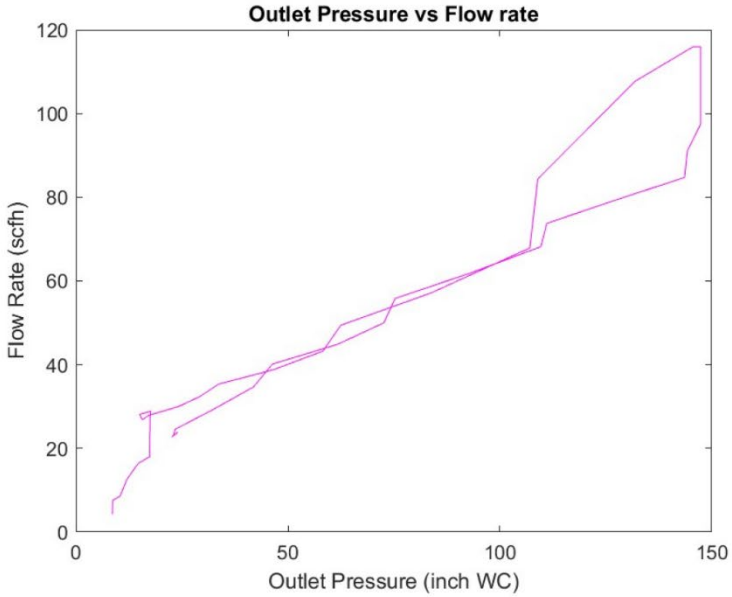

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
120
100
80
60
40
20
0
-20
0
50
100
150

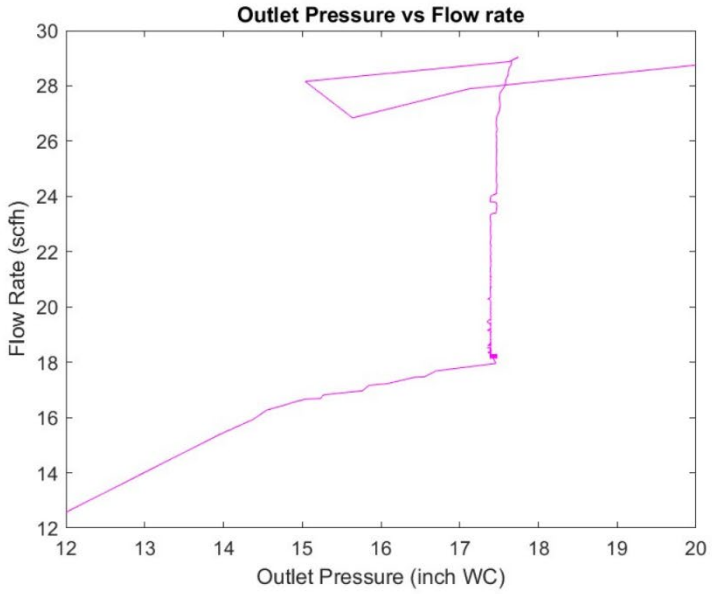

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
30
25
20
15
10
5
0
-5
12
13
14
15
16
17
18
19
20

- 222489-053_DT
  The volume of total emissions in 185.42 seconds is 1.7177 scf.
  The average flow rate of emissions at 18 inches WC is 20.07 scfh.

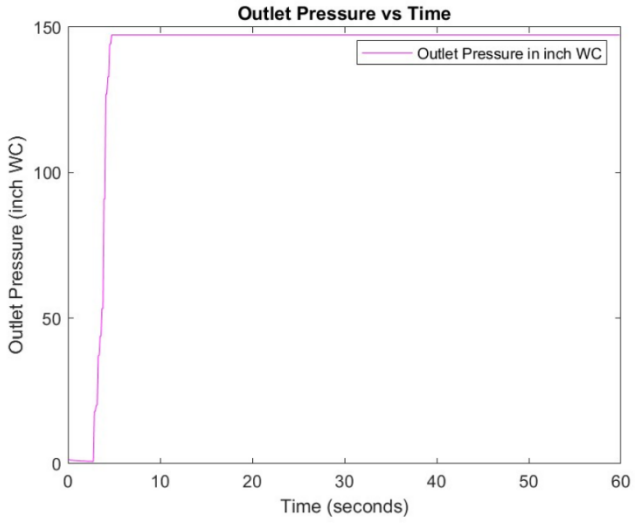


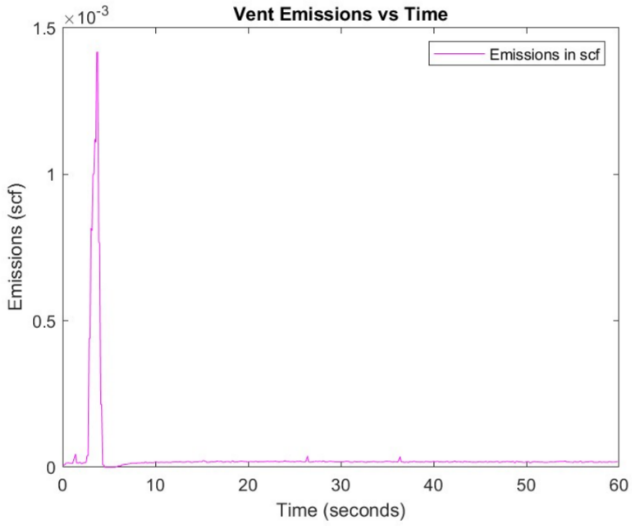


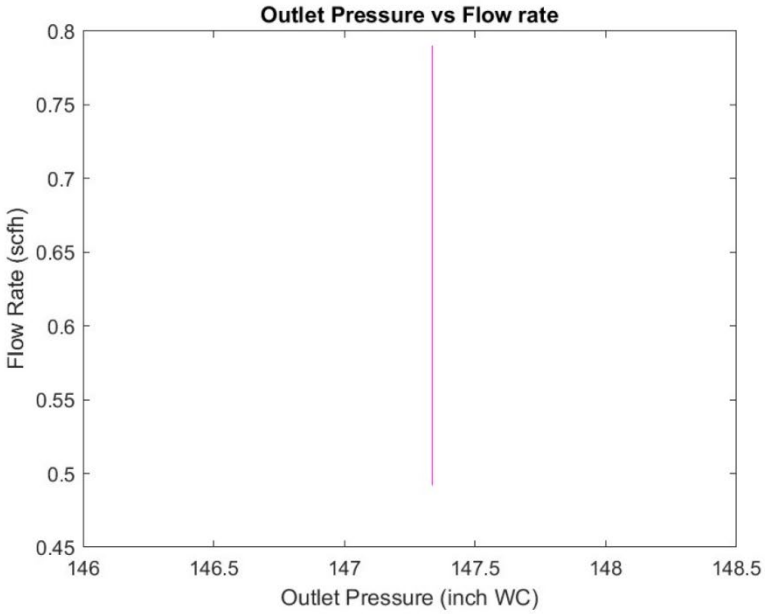

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
20
40
60
80
100
120
0
50
100
150

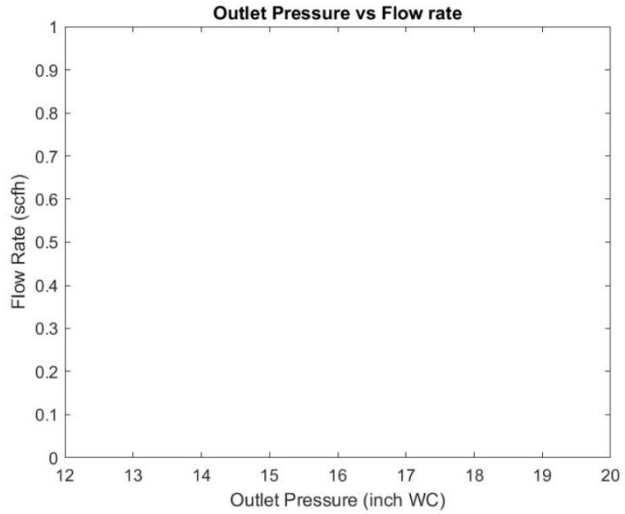

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
12
14
16
18
20
22
24
26
28
30
12
13
14
15
16
17
18
19
20

- 222489-053_LD
  The volume of total emissions in 59.84 seconds is 0.0213 scf.
  The average flow rate of emissions at 18 inches WC is 15.37 scfh.






Outlet Pressure vs Flow rate
Flow Rate (scfh)
0.8
0.75
0.7
0.65
0.6
0.55
0.5
0.45
146
146.5
147
147.5
148
148.5
Outlet Pressure (inch WC)


Outlet Pressure vs Flow rate
Flow Rate (scfh)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
12
13
14
15
16
17
18
19
20
Outlet Pressure (inch WC)

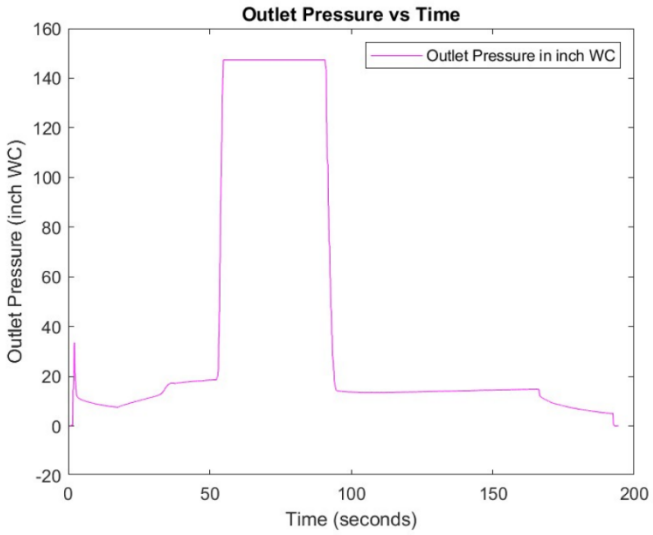
GTI ENERGY

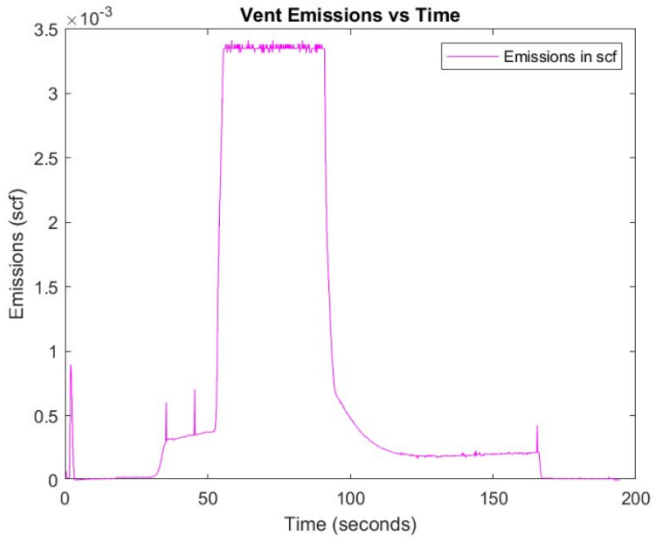
7” WC Outlet, 100-psig Inlet

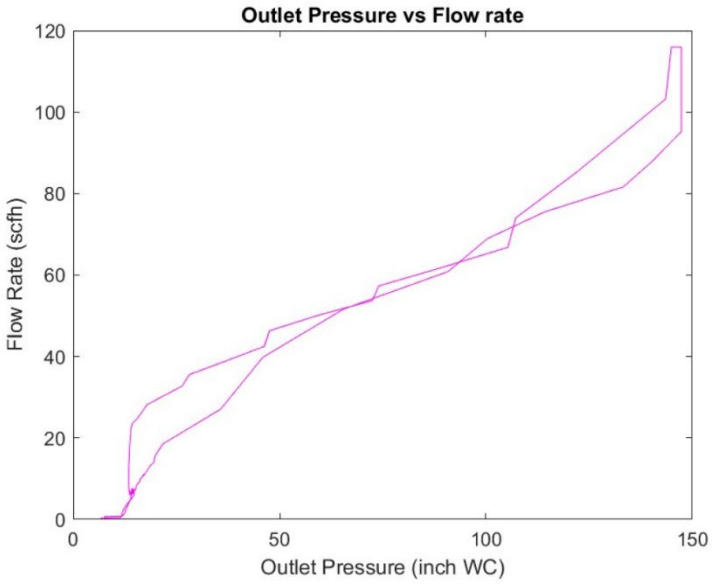
- 222489-051 (1/2” ori)

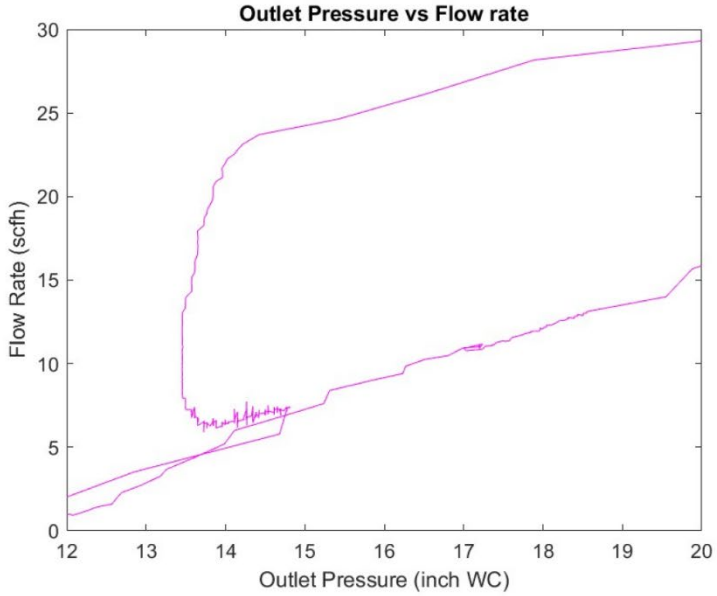
  The volume of total emissions in 194.45 seconds is 1.4949 scf.

  The average flow rate of emissions at 18 inches WC is 12.91 scfh.

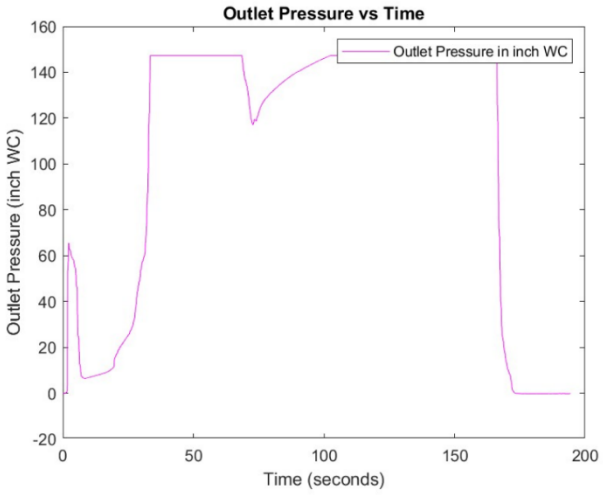


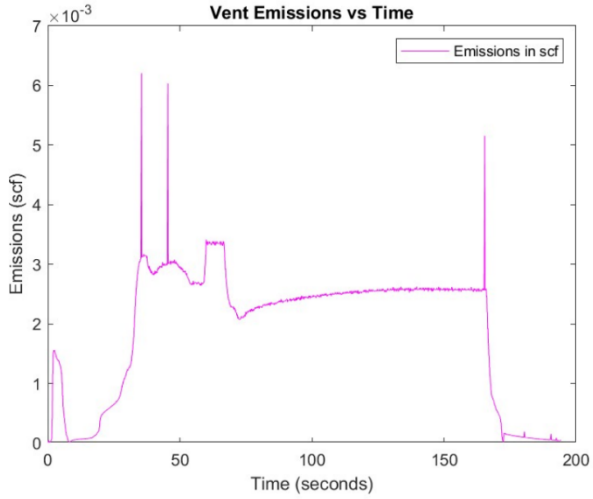


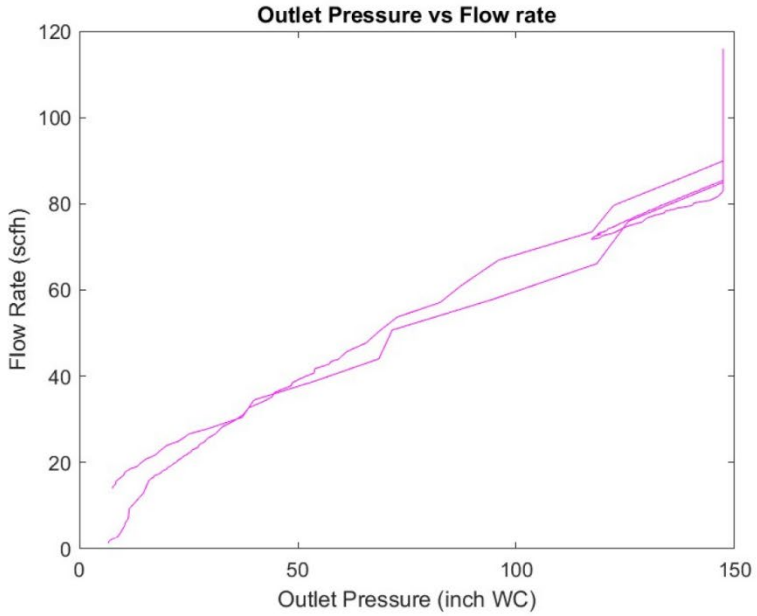

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
20
40
60
80
100
120
0
50
100
150

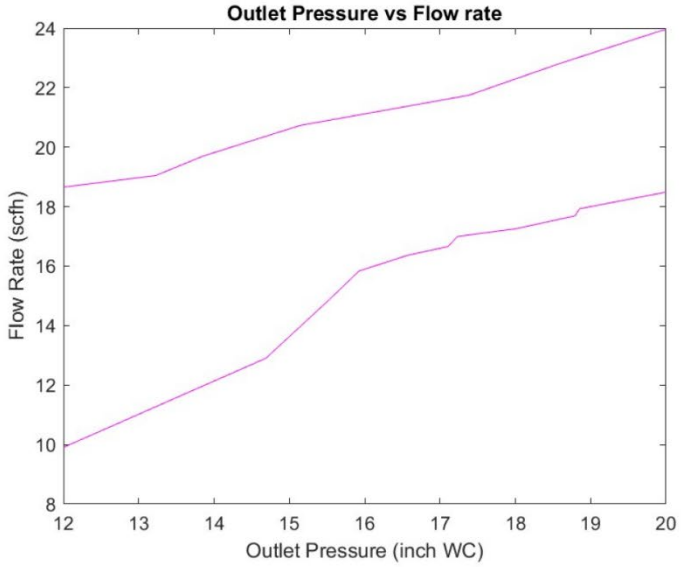

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
5
10
15
20
25
30
12
13
14
15
16
17
18
19
20

- 222489-051_DT (1/2" ori)
  The volume of total emissions in 194.37 seconds is 3.5798 scf.
  The average flow rate of emissions at 18 inches WC is 15.86 scfh.





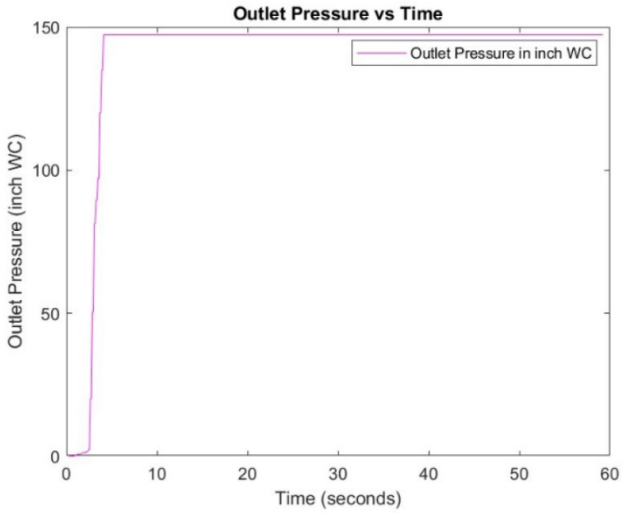


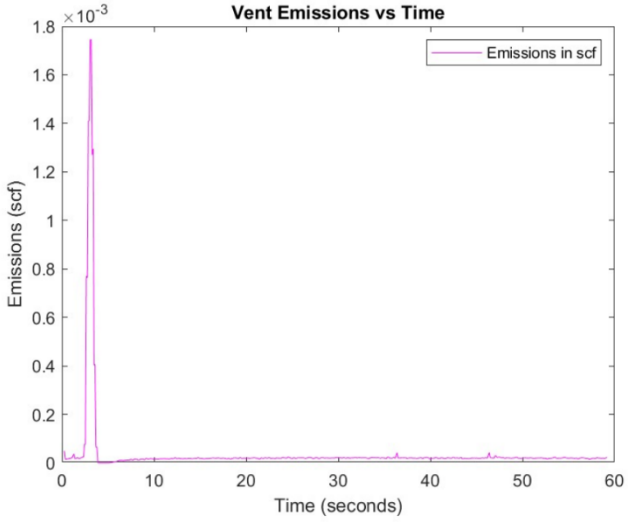


75

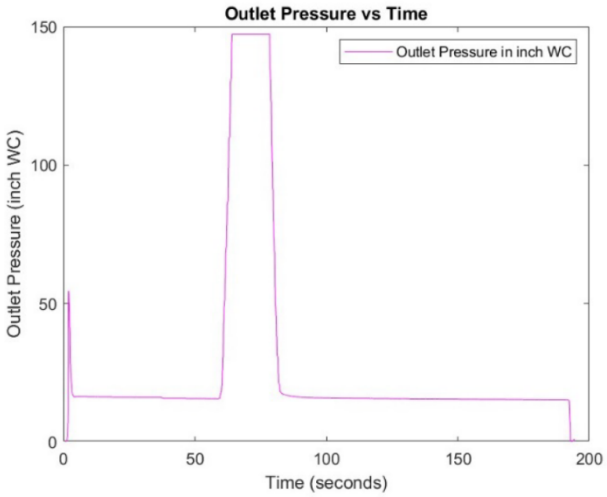
GTI ENERGY

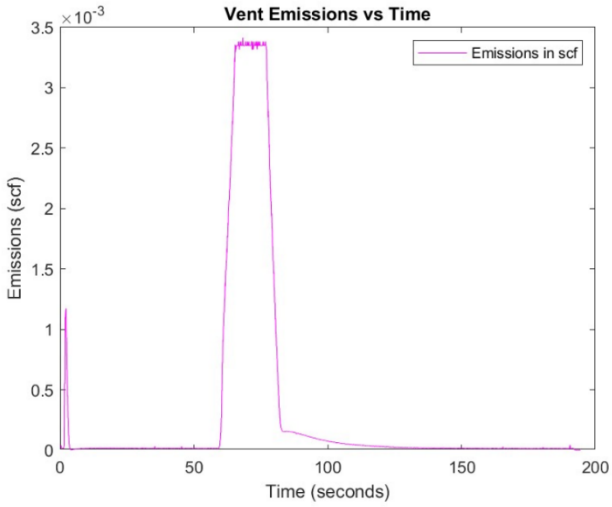
- 222489-051_LD (1/2" ori)
  The volume of total emissions in 59.20 seconds is 0.0218 scf.

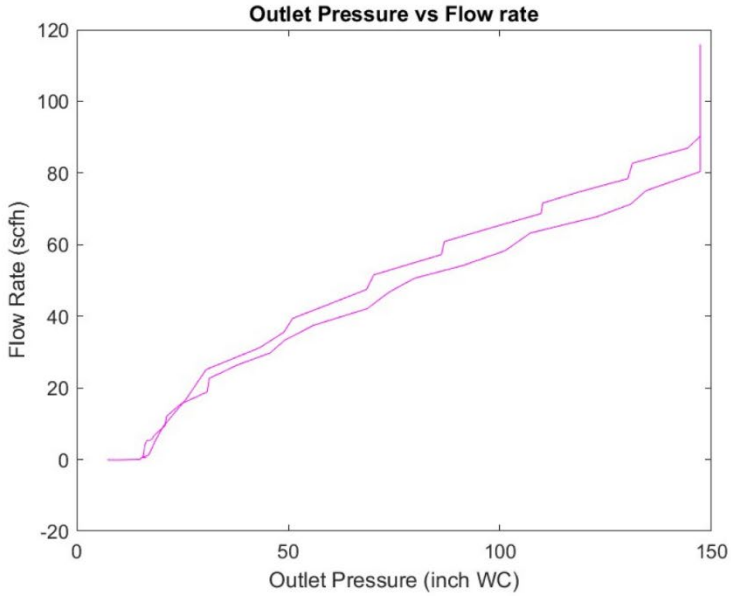


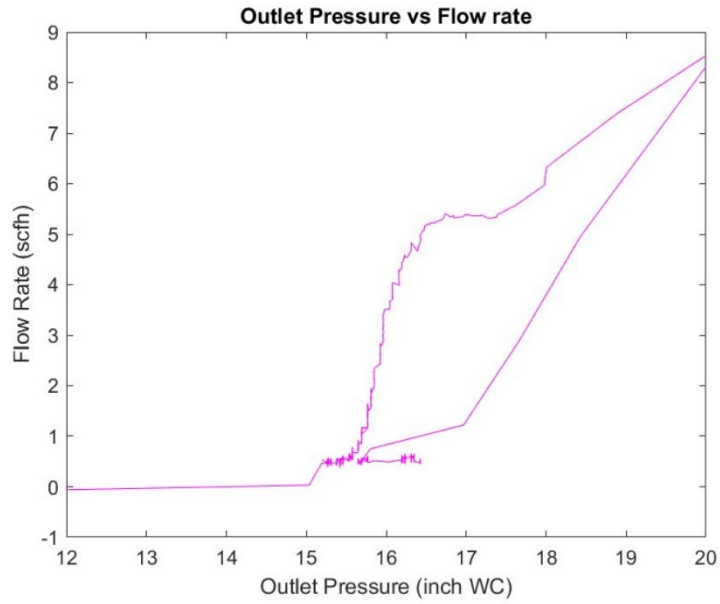


- 222489-052
  The volume of total emissions in 194.44 seconds is 0.6111 scf.
  The average flow rate of emissions at 18 inches WC is 5.51 scfh.





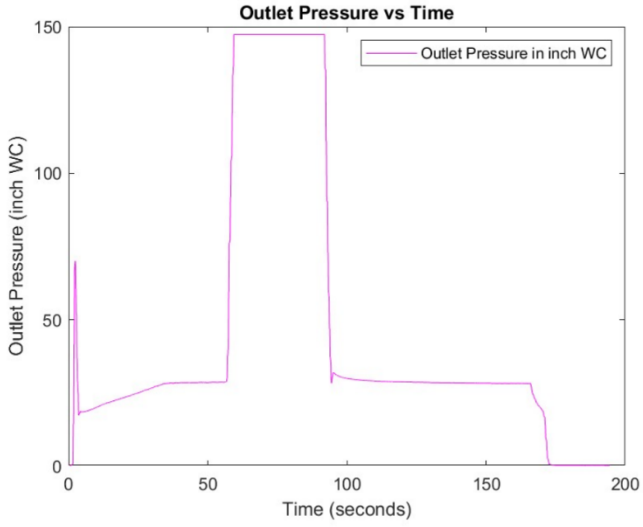


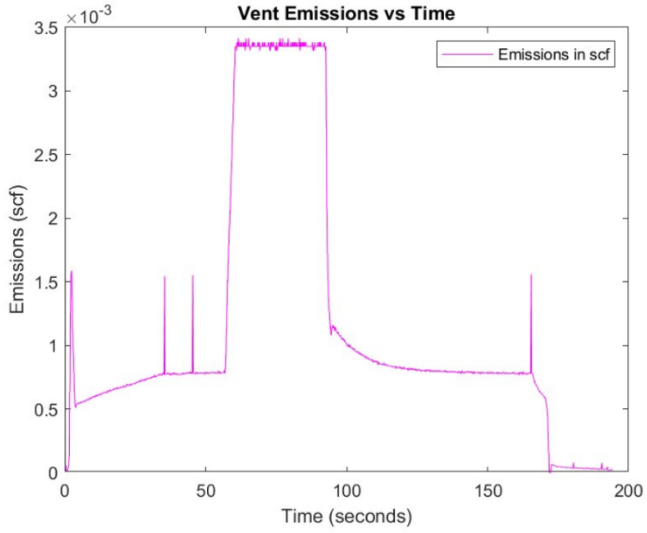


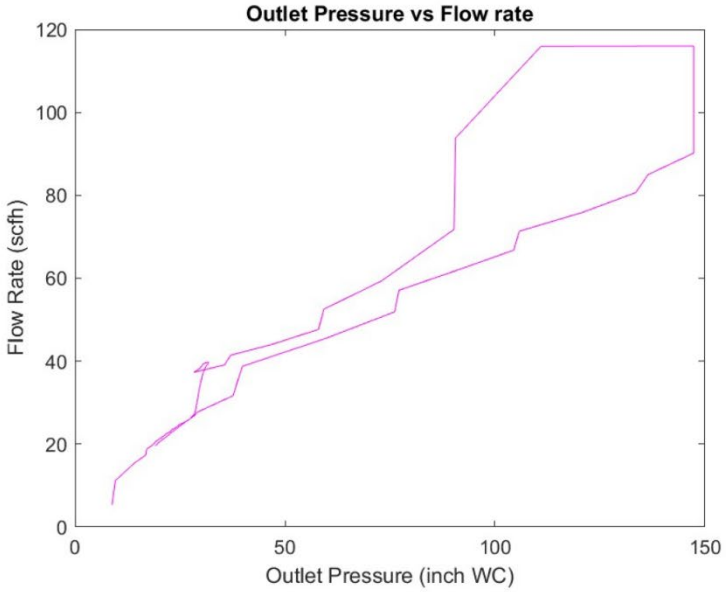
78

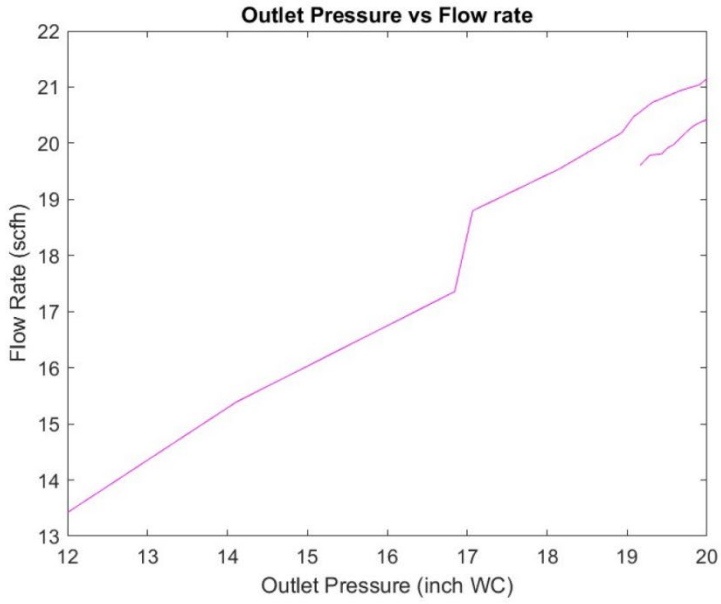
GTI ENERGY

- 222489-052_DT
  The volume of total emissions in 194.44 seconds is 2.1400 scf.
  The average flow rate of emissions at 18 inches WC is 18.55 scfh.

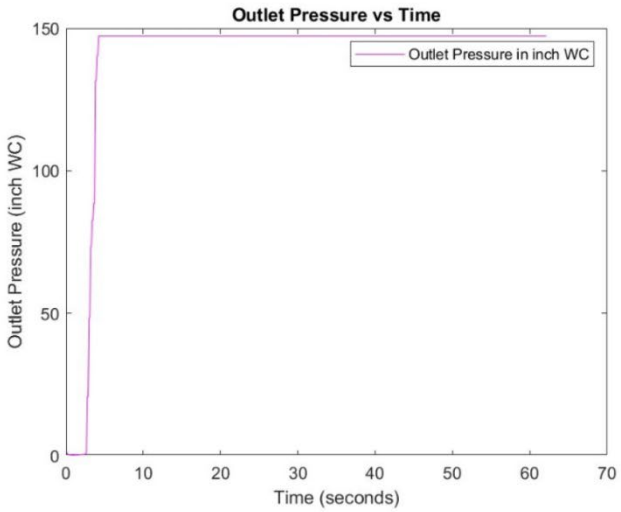


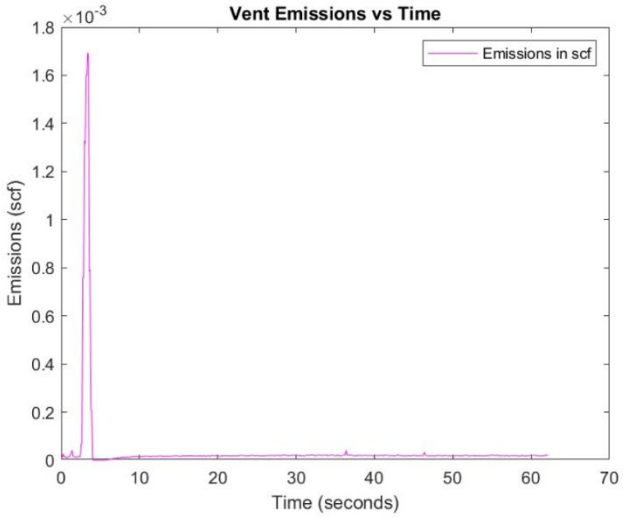



Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
20
40
60
80
100
120
0
50
100
150

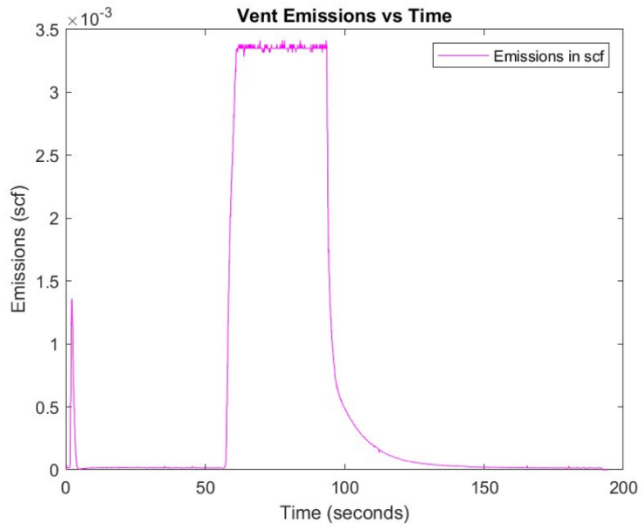

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
13
14
15
16
17
18
19
20
21
22
12
13
14
15
16
17
18
19
20

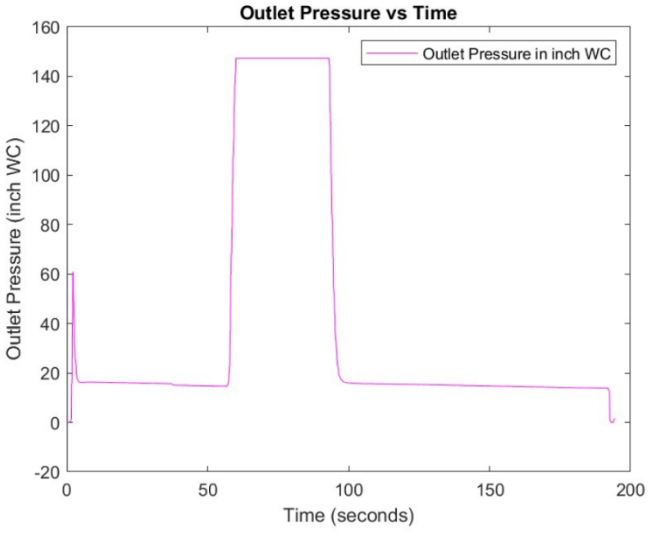
- 222489-052_LD
  The volume of total emissions in 62.13 seconds is 0.0232 scf.

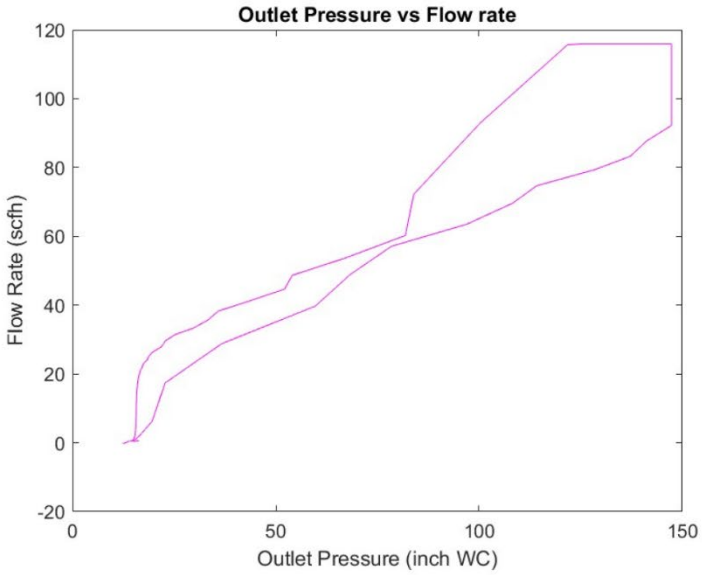


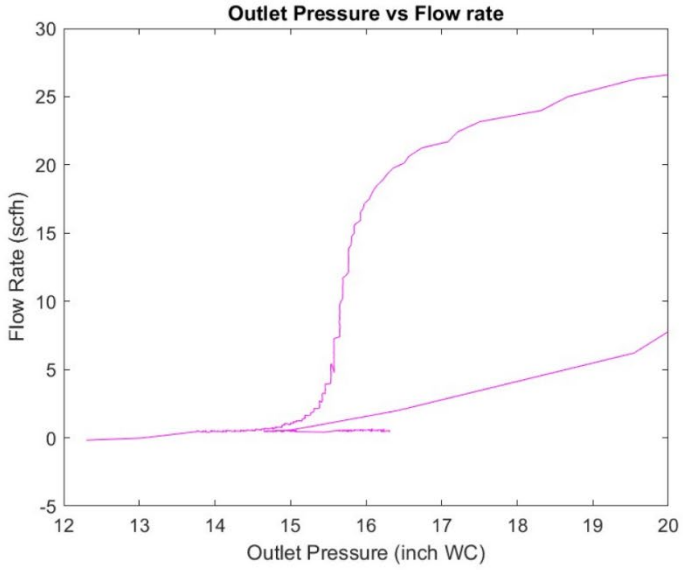


- 222489-053
  The volume of total emissions in 194.35 seconds is 1.2593 scf.
  The average flow rate of emissions at 18 inches WC is 17.44 scfh.

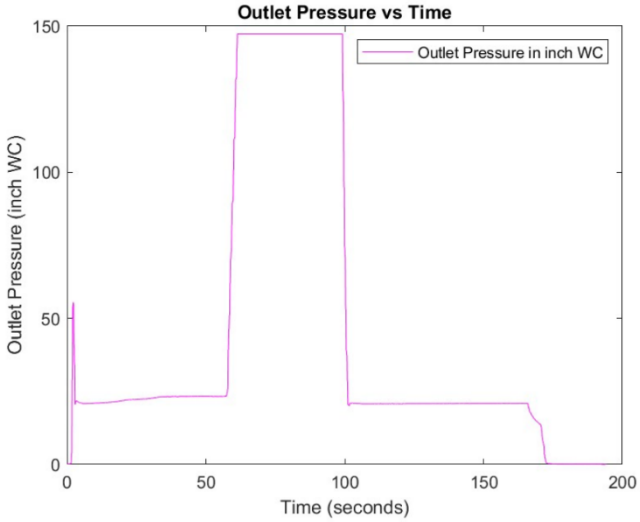


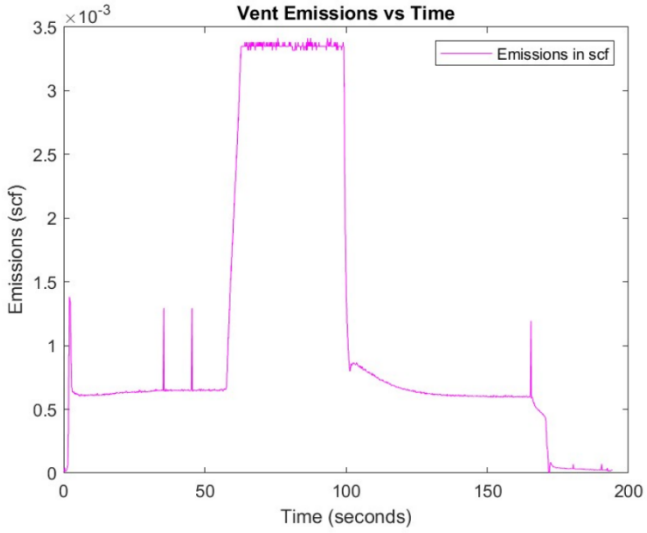


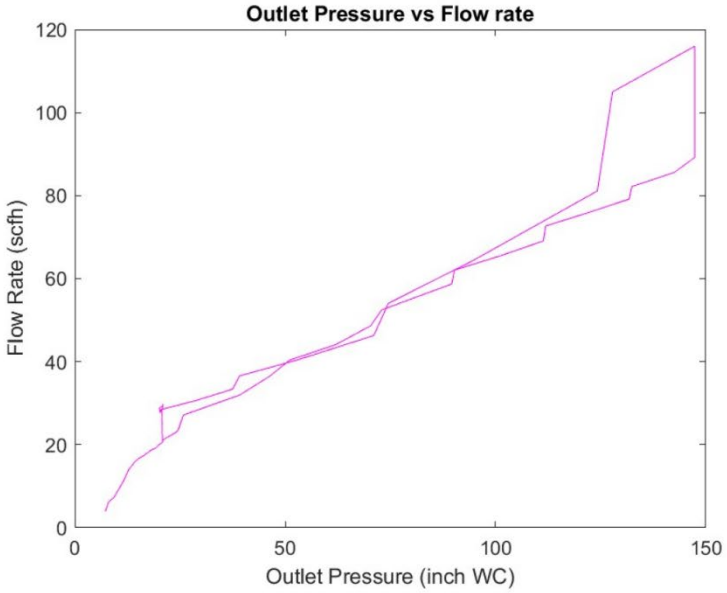

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
120
100
80
60
40
20
0
-20
0
50
100
150

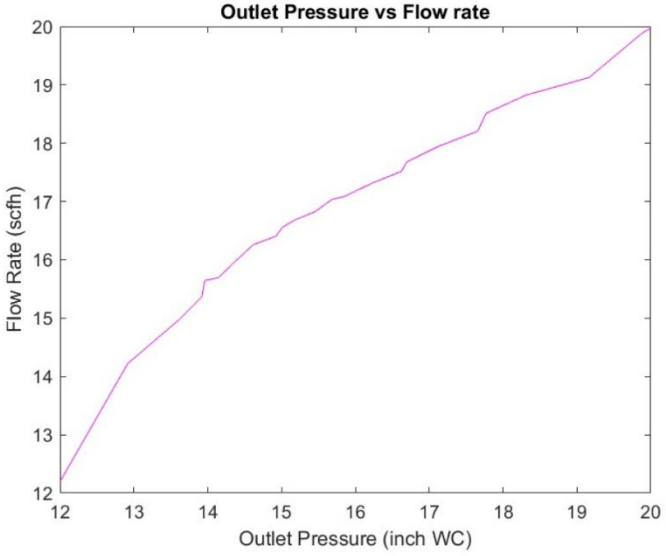

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
30
25
20
15
10
5
0
-5
12
13
14
15
16
17
18
19
20

- 222489-053_DT
  The volume of total emissions in 194.30 seconds is 2.0884 scf.
  The average flow rate of emissions at 18 inches WC is 18.37 scfh.



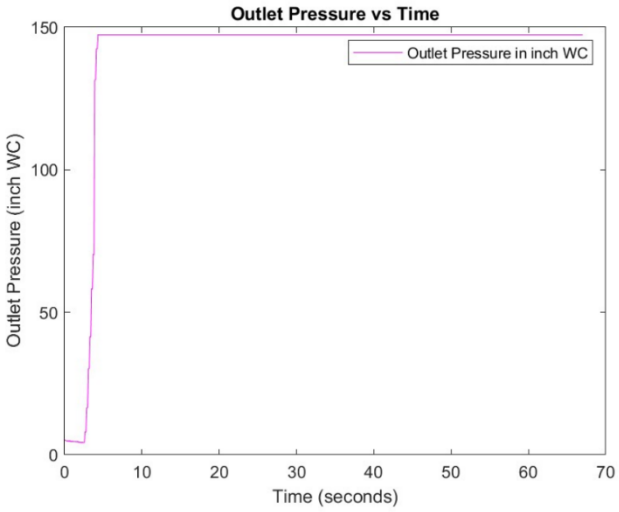


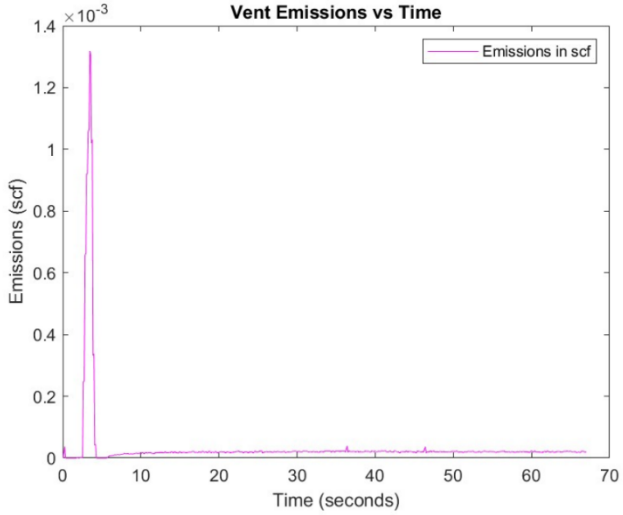

Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
0
20
40
60
80
100
120
0
50
100
150


Outlet Pressure vs Flow rate
Flow Rate (scfh)
Outlet Pressure (inch WC)
12
13
14
15
16
17
18
19
20

GTI ENERGY

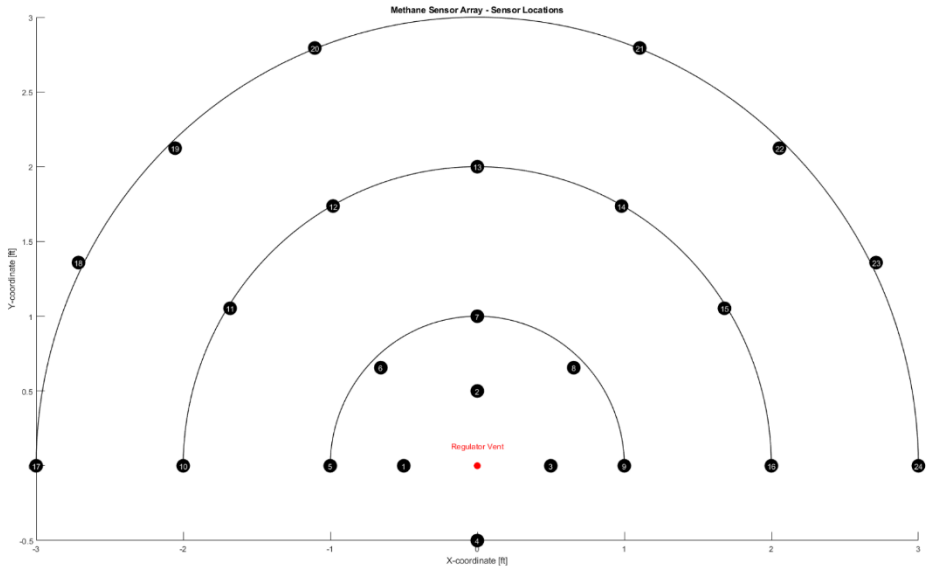
- 222489-053_LD
  The volume of total emissions in 67.01 seconds is 0.0226 scf.





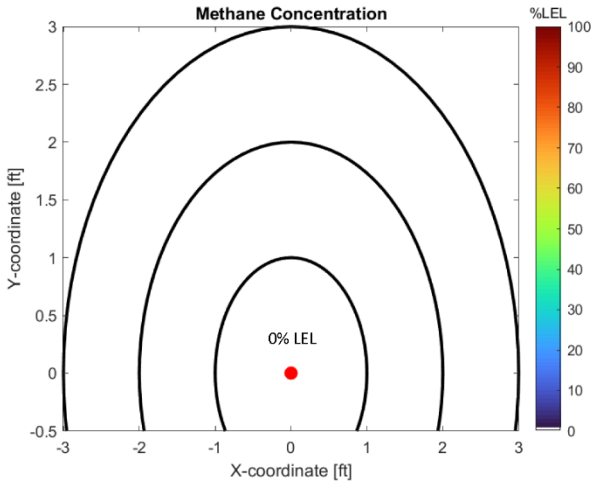
Methane Concentration Maps

Sensor Locations



7” WC

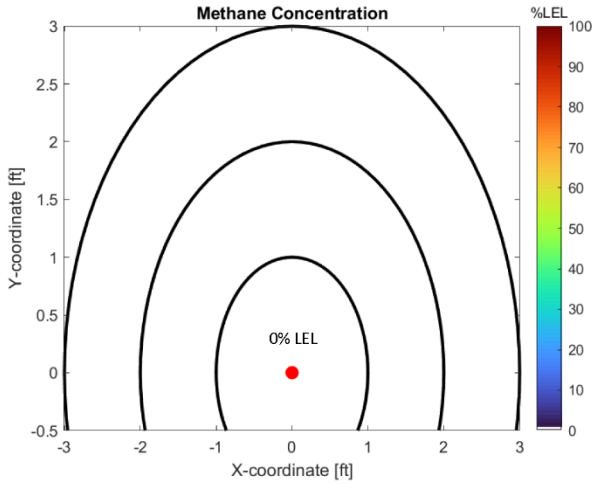
	7 In-WC	222489-052_multi lockup_sensor1 6in	Sigma = .3
IRV4	Normal Condition – Multi Lockup	Standard Array Configuration	6 in from vent



88

GTI ENERGY

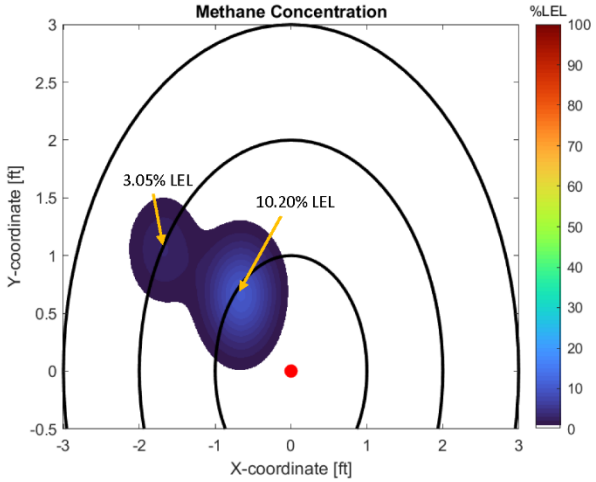
	7 In-WC	222489-052_multi lockup_sensor1 next to vent	Sigma = .3
IRV4	Normal Condition – Multi Lockup	Standard Array Configuration	1 in from vent



89

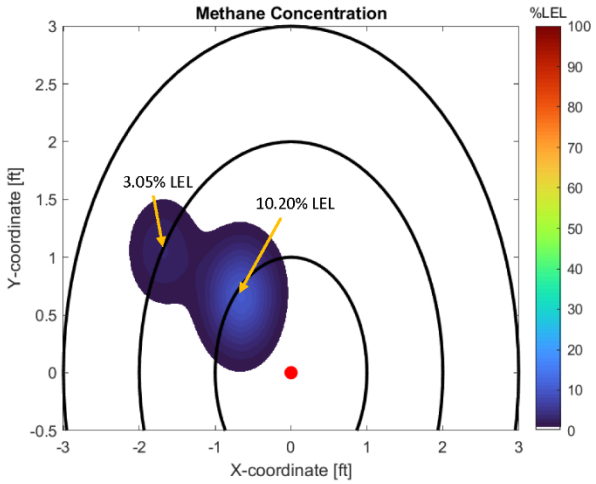
GTI ENERGY

	7 In-WC	222489-052_single lockup_sensor1 6in	Sigma = .3
IRV4	Normal Condition – Single Lockup	Standard Array Configuration	6 in from vent



90

	7 In-WC	222489-052_single lockup_sensor1 next to vent	Sigma = .3
IRV4	Normal Condition – Single Lockup	Standard Array Configuration	1 in from vent



91

GTI ENERGY

END OF REPORT