CAAP Quarterly Report

09/30/2022

Project Name: *Easy Deployed Distributed Acoustic Sensing System for Remotely Assessing Potential and Existing Risks to Pipeline Integrity*

Contract Number: *693JK3215002CAAP*

Prime University: *Colorado School of Mines*

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Reporting Period: *[7/01/2022 – 09/30/2022]*

Project Activities for Reporting Period:

The activities completed during the reporting period were all on track. These activities are summarized below:

1. Activities completed during the reported period for Tasks#1&2: Detection of Liquid Accumulation and Dynamic Intermittent (Slug) Structures
   - The clear PVC flow loop construction previously completed has now been equipped with all 5 different fiber optic cables on the testing section: external helically wrapped and straight cables, along with internal flat, thin, and thick cables.
   - Sandbags have been used to prompt the flow loop in the inclined sections to minimize the noise in the dataset as a result of the pipe vibration. Additionally, moving blankets were put in place to help protect jacket fiber cable from rough surfaces (Fig. 1a).
   - All cables were spliced together and tested with the Optical Time Domain Reflectometer (OTDR) to evaluate the integrity of the splicing and signal path along the entire length of the cables. Multiple (+9) damaged points in the helically wrapped cable were identified and fixed at various splice points, as shown in Fig. 1b. In order to avoid the deterioration of laser light through the imperfections, the order of cable connection was rearranged in order to place the helically external cable last and prevent contamination of data in the other cables. The splicing of cables has taken more time than expected due to inexperience with splicing, dust, and the complicated environment of the facility and mine.
   - DAS data has been collected without any fluid flowing through the pipe so as to further test the integrity of the cable setup. A tapping test with a video recording has been taken to evaluate the setup and identify the location of channels along the cable. The internal thin and flat cables have been identified to be broken at the location of the sealing point, as shown in Fig. 1c. The sealing has been designed to keep the pressure and fluid inside the pipe, however, it has also caused permanent damage to the two more delicate cables.

- The results from the DAS data collected using the Terra 15 interrogator clearly show the damage in the fiber optic cable corresponding closely to channel 164. A damaging reflection is observed at this location in space marked by the red color line throughout time as shown in Fig.2a. In Fig. 2a, at around 36.7 seconds, the tap is observed in the data at various channels. This is expected due to its geometry, however, after channel 164 the tap is no longer observed as the fiber is damaged.
- We plan to resplice the thin and flat cables by extracting said cables through a second hole, shown in Fig. 2b, and improving the seal so as to maintain the integrity of the cables while keeping the fluids and pressure inside the pipe.
- We also conducted preliminary experimental studies using two different gas flow rates without liquid accumulation, and the results are shown in Fig. 3. The data were acquired from external wrapped fiber, internal thick fiber, and external straight fiber, from the bottom to top, respectively. One can clear notice the different signals for different flow rates. The frequency spectrum of the data from the internal thick cable shown in Fig. 4, further demonstrates the significantly stronger amplitude of cable vibration at higher flow rates. This implies the potential of DAS to estimate the flow rate.

Fig. 1. (a) Photograph of the clear PVC section for Tasks#1 & 2 with hellically wrapped cable (yellow) and straight cable covered by blue tape. Sand bags and moving blanckets are used to prevent vibration and protect cable. (b) Photograph of a splice at a damaged point in the helically wrapped fiber. (c) Photograph of the sealing for internal cable deployment located at the entrance of the Orica drift in Edgar Mine. All cables are permanently deployed using epoxy compound. Flat and thin cables are damaged at this location.

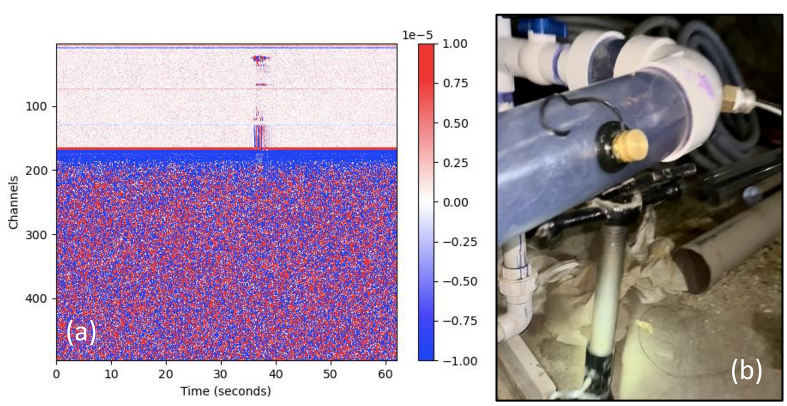


Fig. 2. (a) Waterfall plot of the DAS data collected during a tap test along the helically wrapped cable. After Channel 164 data is only showing noise as the fiber is damaged and no longer sensing the strain from the taps. (b) Photograph of second hole initially created for water inlet; now to be repurposed for extracting thin and flat damaged cables to be respliced.

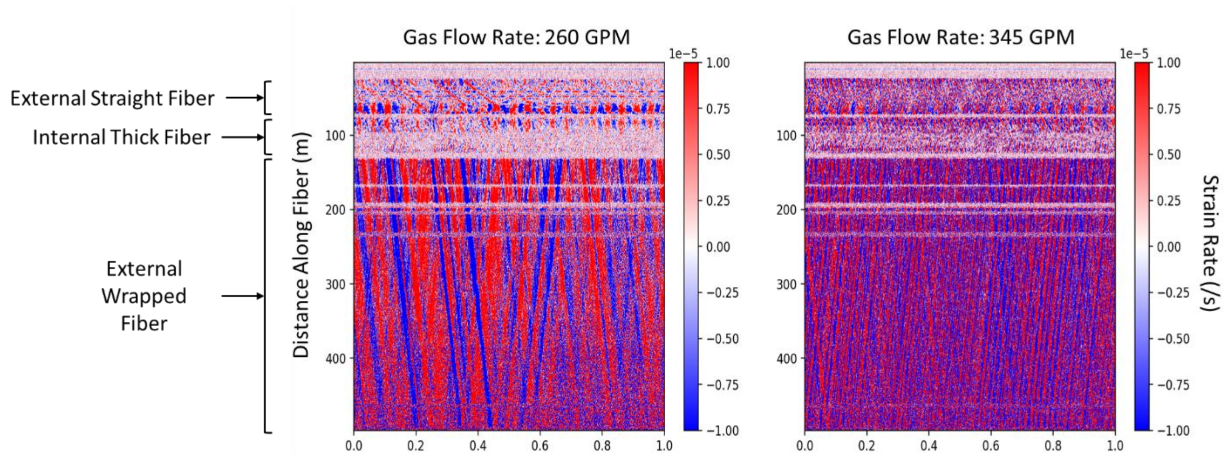


Fig. 3. Processed DAS signals from preliminary single phase gas flow tests with two different flow rates

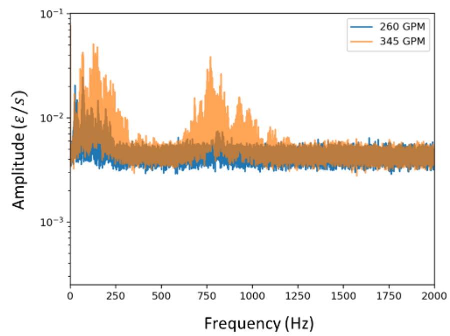


Fig. 4. Frequency spectrum of internal thick cable recording for the two different gas flow rates

2. Activities completed during the reported period for Tasks#3-6: Detection of Corroded Spots, Deformation, Infrastructure Damage, and Leakage.
   - The steel pipeline sections previously received have now been connected and supported for Tasks#3-6. A gap between the two sections is left for the 1 m test section to be installed later based on the Task addressed (Fig. 5).

Fig. 5. Photograph of the steel pipeline section connected and supported

   - Another seven steel pipe sections (1 m long) have been ordered and received to cover Tasks#3-6.

- Lab tests have been conducted to test different options to accelerate corrosion for corroded surface preparation for Task#3. Details are given in the next subsection.

3. Activities completed during the reported period for lab tests in Task#3:
   - The objective of the lab tests conducted during the reported period is to test different options helping with increasing the corrosion rates and generating corroded surface inside the 1 m test section more effectively in terms of time. Below discusses the materials and methods, the results, and the future plan.
   - Materials and Methods:
     - We consulted some experts in the Metallurgical Department at Colorado School of Mines, and decided to use a heating system to increase the temperature of the acid deployed inside the testing rings to achieve a higher corrosion rate as recommended.
     - The system includes an electrical heating tape to heat the steel pipe, a thermocouple to detect the system temperature, and a temperature controller to maintain the system temperature steady at the desired value (Fig. 6). Fiberglass was used for insulation.
     - Since the temperature ranges of the previously used pipe plugs are below the tested values, new sealing plugs were purchased and modeled to fit the requirements of our experiments. The natural rubber is the sealing component and is proven resistant to the hydrochloric acid used. High temperature silicone was used to cover the stainless steel plate exposed to the acid. A hole was drilled to allow the deployment of the thermocouple inside the pipe for temperature control purposes, as discussed before (Fig. 7).

Fig. 6. Photograph of the heating system

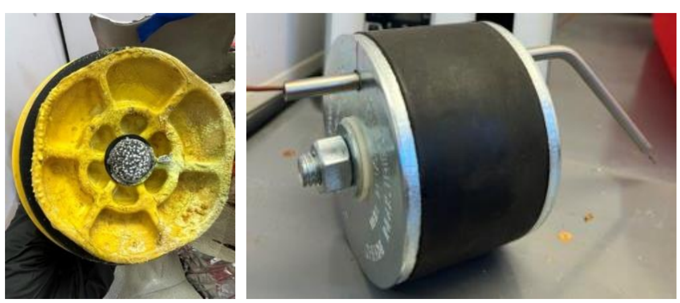


Fig. 7. Photograph of the pipe plugs (left) the previously used plug with a plastic plate deformation with heat (right) the newly modeled pipe plug

- Results and future plan:
  - The temperature increase applied to the lab tests significantly increased the weight loss and corrosion rates, as shown in Table 1. At 65°C, the weight loss was ten times higher than the reported results at room temperature (Fig. 8).

Time (hours)	Temperature (Cesius)	Weight Loss (gram)	Corrosion Rate ($g/cm^2.day$)
24	As room	4.7	0.04
24	45	24.6	0.21
24	65	50.3	0.42
24	75	36.6	0.31

Table 1. Weight loss and corrosion rate associated with testing temperatures

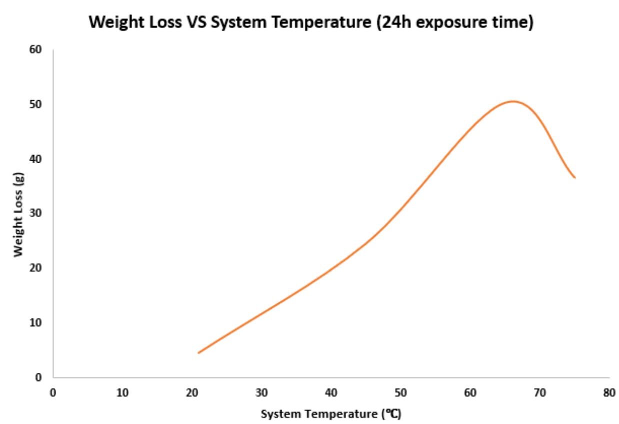


Fig. 8. Plot of weight loss vs. testing temperature for a 24 hour long test

  - It was noticed that the acid evaporates with time. At 65°C, and after 24h, only 50% of the introduced acid volume remained (Fig. 9), and for the same period, all the volume evaporated at 75°C (the acid volume evaporated faster). Therefore, the corrosion rate is shown to be lower for 75°C. 65°C is the system temperature selected for the 1 m test section.
  - Currently, the same methodology, materials, and experimental setup are used to create the corrosion inside the 1 m test section (Fig. 9).

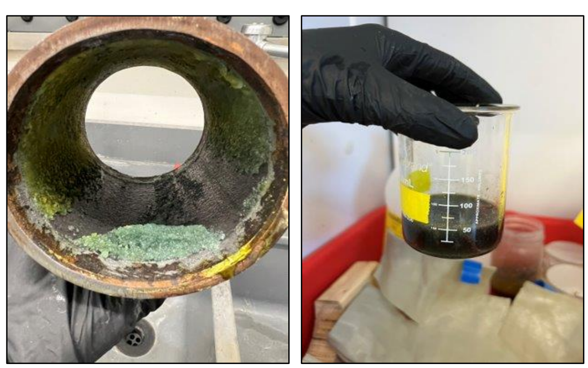


Fig. 9. Photograph of corrosion products (left) and the remaining volume of hydraulic acid (right) at 65 °C during a 24 hours test

- 400 ml of hydrochloric acid will be used and replaced every 24 hours to create corrosion inside the 1 m test section at the 6 O'clock position. Currently, we are planning to create a corroded surface of 3 mm depth and 2 ft long inside the 1 m test section for preliminary test. We will test different depths and lengths as the task moves forward.
- A general corroded depth will be generated, and mechanical griding will be used to create scratches along the same surface, increasing the wall roughness.

Project Activities with Cost Share Partners:

The cost shares are the AY efforts of the PI and co-PIs. Activities are the same as above.

Project Activities with External Partners:

No external partners.

Potential Project Risks:

In addition to the risks mentioned in the previous report, there is another factor that may potentially lead to the delay of the activities because of the broken fiber cables. The internal thin cable will be used as a reference to be compared with the results from the thick cable that is more suitable for field applications, because the thin cable theoretically can provide stronger signals due to its better response to the fluid flow inside the pipeline. However, the thin cable is fragile and has a higher risk to be broken. It will take some time to find and fix the broken points or replace the cable. Because the cable is internally deployed, it makes the repair more difficult. The flat cable is stronger than the thin cable, however, it may break at the sealing point (Fig. 1c). It will also take some time to repair the cable and the seal if it happens again in the future. Fortunately, the thick cable, which is more suitable for actual field applications, is working fine based on our preliminary tests.

Besides, one of the Ph.D. students involved in this project has an injury in her ankle just recently which will take sometime for recovery. This potentially increase the risk of delay in the experimental work. In this case, the other student and the PIs will take more responsiblities in the experimental work, hoping to decrease its impact on the project schedule.

Future Project Work:

In the next 30 days, we will:

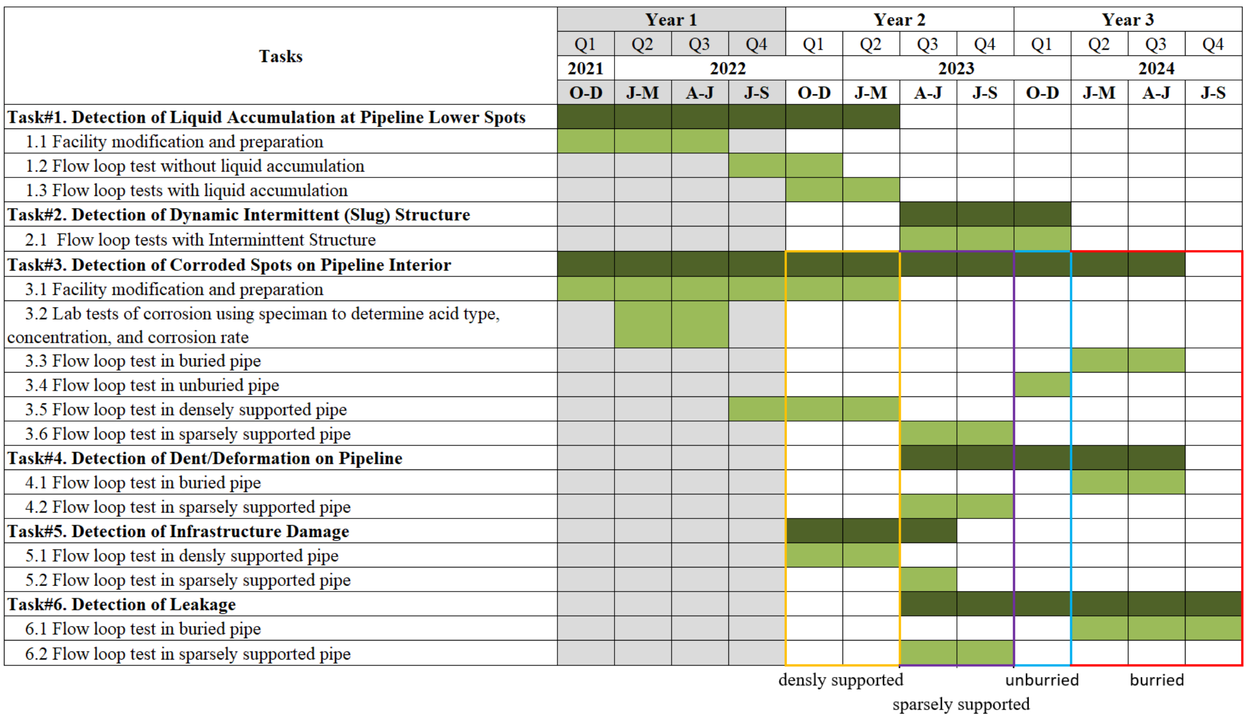
1. Continue Tasks#1.2 as planned.
2. Continue preparing the corroded internal surface in the 1 m test sections.
3. Start Tasks#5.1.

In the next 60-90 days, we will:

1. Continue Tasks#1.2 as planned.
2. Start Tasks#1.3 as planned.

3. Continue Tasks#5.1.
4. Continue Tasks#3.5.

To avoid frequent changes in the pipeline installation method ("buried", "unburied", "densely supported", or "sparsely supported") that requires a lot of human effort and may also lead to some other uncertainties and safety concerns, in our last quarterly report, we proposed to do the tests by installation method instead of the task, i.e., in the order of "unburied" – "densely supported" – "sparsely supported" – “buried". Our current setup for the steel pipeline is "supported" as shown in Fig. 5, to ease the flow loop construction. To minimize the efforts of changing installation methods that may lead to other uncertainties or safety concerns, we propose to start the tasks with the "supported" configuration first, followed by "unburied" and "buried". Specifically, we will do the tasks with the installation methods in the order of "densely supported" – "sparsely supported" – "unburied" – “buried". The modified timeline is shown in the figure below.



Potential Impacts to Pipeline Safety:

Tasks#1 and #2 can potentially help identify and characterize the possible liquid accumulation in a gas gathering or transmission pipeline using DAS, while Tasks#3-6 will potentially help detect the internally corroded surface, deformation, infrastructure damage, and leakage in a gas pipeline.