CAAP Quarterly Report

06/30/2022

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: *[4/01/2022 – 06/30/2022]*

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
   - Overall, the flow loop construction has been completed as planned.
   - The clear PVC pipes have been fully assembled and connected to the existing main flow loop, as shown in Figure 1. The pipe has a valley configuration, with a total length of around 150 ft. The tailored V-section has been connected 43 ft from the start of the clear PVC section.
   - The external cable, a singled mode jacket cable, has been wrapped around the outside of the clear PVC pipes in a helical shape. For every 10 ft of pipe, 100 ft of cable was used, yielding a spacing of 3 cm in between each wrap (Figure 2). Tension and duct tape were used to hold the cable in place.
   - Three internal cables (thin, thick, and flat) were deployed inside the PVC pipes as proposed. They are freely sitting in the clear PVC pipeline. The internal cables exit the pipe through specially tailored sealings at the opposing ends of the clear PVC section. The sealing uses rubber and poxy to withstand pressures of 40 psi as shown in Figure 3. Also shown in Figure 3 are the two ends of the internally deployed cables.

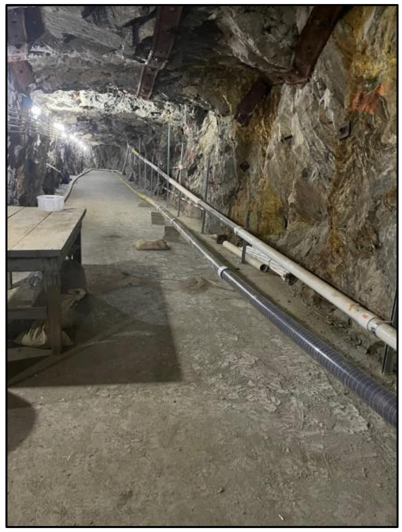

Figure 1. Photograph of the clear PVC section for Tasks#1 & 2 (the blue one at the bottom)

Figure 2. Photograph of section of clear PVC pipe with wrapped cable (yellow) and 3 cm of spacing in between.

Figure 3. Photographs, left, Sealing using for internal cables at the end of the PVC section. Right, sealing for internal cable at the entrance of PVC test section.

2. Activities completed during the reported period for Tasks#3-6: Detection of Corroded Spots, Deformation, Infrastructure Damage, and Leakage
   - The API 5L, schedule 40 NPS 4-in, grade X65 carbon steel seamless pipes have been received at Colorado School of Mines Edgar Experimental Mine as shown in Figure 4 (left). The test pipeline will consist of four 5-m sections and one replaceable 1-m test section. Now, we have four 5-m sections and five 1-m sections.
   - The four 5-m sections and five 1-m sections have been threaded to make the test pipeline inside Edgar Mine. The 1-m sections will be replaced with the corresponding deformations being tested (corrosion, leak, or dent)
   - Couplings with the threading have been received to connect different sections on site (Figure 4, right).

Figure 4. Left, Photograph of carbon steel pipes in Edgar Mine (API 5L X65 schedule 40 4-in, 5 m long each); Right, Photograph of 1-m section of steel pipe with a coupling at the top to connect in the middle of the pipeline

   - Lab tests have been conducted to determine the procedure to create the corroded surface in the 1-m test section, which is discussed in detail below.
3. Activities completed during the reported period for lab tests in Task#3:
   - The objective of the lab tests is to determine the acid type, concentration, and the procedure to prepare the corroded surface in the 1-m test section, using small pieces of specimen first. Below discusses the materials and methods, the results, and the future plan. During the last period, the students have also completed all laboratory safety training required for acid handling.
   - Materials and Methods:
     - We used test rings with the same specifications as the steel pipe to be tested in Edgar Mine for the optimized corrosion methods. The carbon steel rings have the following dimensions: 15 cm in length, 4 in. inner diameter, and 4.5 in. outer

diameter. The acid used is a 12M hydrochloric acid. The experiments are run in the FAST lab (Fracturing, Acidizing, Stimulation Technology) equipped with all required materials for safety (PPE, Fume Hood…etc.)

- To create the internal pipeline corrosion, 4-in Pipe plugs (Figure 5) were purchased to allow the deployment of the acid only internally inside the pipe. The plugs seal off the pipe from the inside, as the rubber expands. The plate is plastic, and the natural sealing rubber is proven to be resistant and does not react with the hydrochloric acid used.

Figure 5. Picture of expansion plugs (natural rubber and plastic plate)

- As a first attempt, the internal corrosion was created at the 6 o'clock position, as shown in Figure 6. The ring was first rinsed in acetone and distilled water and dried. Then, it was plugged from one side, and the 100 ml volume of 12 M Hydrochloric acid was introduced. Afterward, the ring was plugged from the other side using the plug mentioned above. A hole was drilled at the top to prevent pressure buildup following the chemical reaction of the hydrochloric acid and the steel pipe (Figure 7).

Figure 6. Photographs of 6 o'clock position (left) and cleaned ring (right)

Figure 7. Photographs of pressure relief hole (left) and Plugged ring (right)

- The tested ring was pre-weighted, and the acid was set inside for *t* hours. After *t* hours, the ring was rinsed in acetone and distilled water, dried, and weighed again.
- The corrosion rate is calculated as follows: corrosion rate = $(w_1 - w_2)/(A \times t)$, where w_1 is the initial weight and w_2 is the ring's weight after exposure to acid. A is the exposed surface area, and t is the exposure time. The corroded depth can be estimated from the weight loss using the carbon steel density. A caliper was used for confirmation.

- Results and future plan:
  - Based on the literature and the published work, most of the hydrochloric acid concentrations used for the corrosion of carbon steel are relatively low and produce corrosion rates that represent field applications but do not fall in the range of our targeted results. Since no lab work has been done previously using the exact specifications as our steel pipe, we establish our methodology and guidelines for our experiments, using the literature as reference.
  - The table below shows the weight loss and corrosion rates obtained for different exposure times, as well as the estimated corroded depth, assuming a uniform corroded surface without roughness.

Time (Days)	Weight Loss (g)	Estimated Corroded Depth (mm)	Corrosion Rate (g/cm^2-day)
1	4.7	0.05	0.039
2	8.2	0.09	0.034
10	16.7	0.18	0.014
13	29.8	0.32	0.019

  - When the acid was left for ten days inside the coupons. A green product (Figure 8, left) was formed, coating the surface, and preventing further corrosion from happening. Therefore, based on the preliminary results shown in the table above, the fastest corrosion can be obtained when the acid is changed frequently (on daily basis). Scratches were also considered to accelerate the corrosion, however, no big changes were observed.

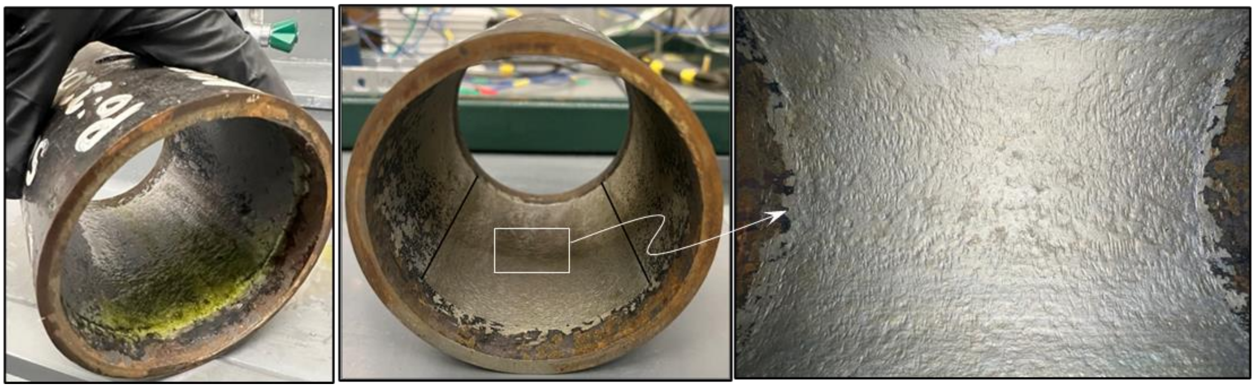

Figure 8. Left, Photograph of the product of the reaction of HCL and steel (after 10 days); Middle, Corroded surface area at 6 o'clock position; Right, closer look of the corroded surface

- Even with the largest corrosion rate, it may require around 20 days to corrode 1-mm steel. Our future plan is to test other options that can accelerate the corrosion and reduce the time required to generate desired corroded depth, such as heating using externally employed hot wires with current acid, and agitation to enhance the chemical reactions, or artificially creating rough surface using mechanical tools.
- Depending on the results, we will use the same procedure and method to prepare the corroded surface in the 1-m test sections.

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:

Same as the previous quarterly report.

Future Project Work:

The table on the next page lists the subtasks for each task, as well as the proposed timeline. To avoid frequent change 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, we propose to do the tests by installation method instead of the task, i.e., we propose to finish all the proposed experiments for the unburied pipe first, followed by densely and sparsely supported pipe, and the buried pipe at the last. The timeline for the next two quarters remains the same as the previous, while it is adjusted for the remaining tasks based on the pipeline installation method, as shown in the table.

In the next 30 days, we will:

1. Test other different options to accelerate correlation or generate a rough surface as discussed before.
2. Start Task#1.2 as planned.
3. Start to connect the steel pipes for Tasks#3-6.

In the next 60-90 days, we will:

1. Continue Tasks#1.2 as planned.
2. Start to prepare the corroded internal surface in the 1-m test sections.
3. Start Tasks#3.4 as planned.

Tasks	Year 1				Year 2				Year 3			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
	2021	2022				2023				2024		
	O-D	J-M	A-J	J-S	O-D	J-M	A-J	J-S	O-D	J-M	A-J	J-S
Task#1. Detection of Liquid Accumulation at Pipeline Lower Spots												
1.1 Facility modification and preparation												
1.2 Flow loop test without liquid accumulation												
1.3 Flow loop tests with liquid accumulation												
Task#2. Detection of Dynamic Intermittent (Slug) Structure												
2.1 Flow loop tests with Intermittent Structure												
Task#3. Detection of Corroded Spots on Pipeline Interior												
3.1 Facility modification and preparation												
3.2 Lab tests of corrosion using specimen to determine acid type, concentration, and corrosion rate												
3.3 Flow loop test in buried pipe												
3.4 Flow loop test in unburied pipe												
3.5 Flow loop test in densely supported pipe												
3.6 Flow loop test in sparsely supported pipe												
Task#4. Detection of Dent/Deformation on Pipeline												
4.1 Flow loop test in buried pipe												
4.2 Flow loop test in sparsely supported pipe												
Task#5. Detection of Infrastructure Damage												
5.1 Flow loop test in densely supported pipe												
5.2 Flow loop test in sparsely supported pipe												
Task#6. Detection of Leakage												
6.1 Flow loop test in buried pipe												
6.2 Flow loop test in sparsely supported pipe												

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.