Experimental Testing of Innovative High-Level-Waste Pipeline Unplugging Technologies – 14601

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ABSTRACT

Transferring high-level waste (HLW) between storage tanks or to treatment facilities is a common practice performed at the Department of Energy (DOE) sites. Changes in the chemical and/or physical properties of the HLW slurry during the transfer process may lead to the formation of blockages inside the pipelines ~~[1]~~. Current commercially available pipeline unplugging technologies do not provide a safe, cost-effective and reliable means to address the current problems ~~[1]~~. Florida International University (FIU) has continued to develop two novel unplugging technologies that have the potential to efficiently remediate cross-site line and transfer line plugging incidents: an asynchronous pulsing system (APS) and a peristaltic crawler system (PCS) ~~[2]~~. Previously, these two technologies have been evaluated and improved based on experiments using small scale testbeds. Current efforts focus on conducting and evaluating both systems on engineering scale testbeds that will bring the technologies closer to deployment.

INTRODUCTION

In this paper, details of the experiments aimed at testing the APS [1] and its functionality in a large scale pipeline is presented. The testbed consisted of two 41 m~~135 ft.~~ pipelines separated by a plug. The pipelines were instrumented with accelerometers and pressure transducers that can capture vibration and pressure data in the pipeline. Various conditions within the pipeline were evaluated including lines with and without entrained air. Studies were conducted prior to the engineering scale testing to determine how air entrainment can be mitigated. For the engineering scale testing, parametric trials were conducted using a dummy plug to determine the effects of varying static pressure, amplitude of the pulse pressure and pulse frequency. Research efforts also focused on manufacturing a plug that had the necessary material characteristics and could not be removed by static pressures less than ~~300 psi~~2068 kPa. Unplugging trials were conducted based on the results of the parametric testing and using a 3 ft kaolin plaster plug.

Results of engineering scale PCS testing is also presented in this paper. The testbed used to evaluate the PCS consisted of a ~~430 ft~~131 m pipeline with four straight sections coupled together by three 90° elbows. The tests evaluated the navigational capability of the crawler inside the pipeline and the load required for the crawler to traverse through straight sections and one 90° elbow. Finally, conclusions and recommendations for further improvements for both technologies are presented. Additionally, discussions are provided that indicate which scenarios may be optimal for each of the different technologies.

ASYNCHRONOUS PULSING SYSTEM

General Description

The asynchronous pulsing system (Figure 1) uses a hydraulic pulse generator to create pressure disturbance that dislodge blockages within the pipeline. The engineering scale test pipeline loop contains two identical ~~135-foot~~41 m pipeline sections with a ~~3-foot~~1 m plug between them. This test loop allows for control of the individual pipeline section pulse characteristics to determine how each pulse influences the total plug dynamic loading. Pressure transducers and accelerometers

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located throughout the pipeline measured the pressure pulse as it propagates through the pipeline. The pipes used for the loop are ~~3-inch~~76 mm diameter schedule-40 threaded carbon-steel pipes. The heart of the asynchronous pulsing system are two hydraulic piston pumps that are powered by the pulse generation unit which is comprised of hydraulic power unit and two electronically controlled high-speed valves.

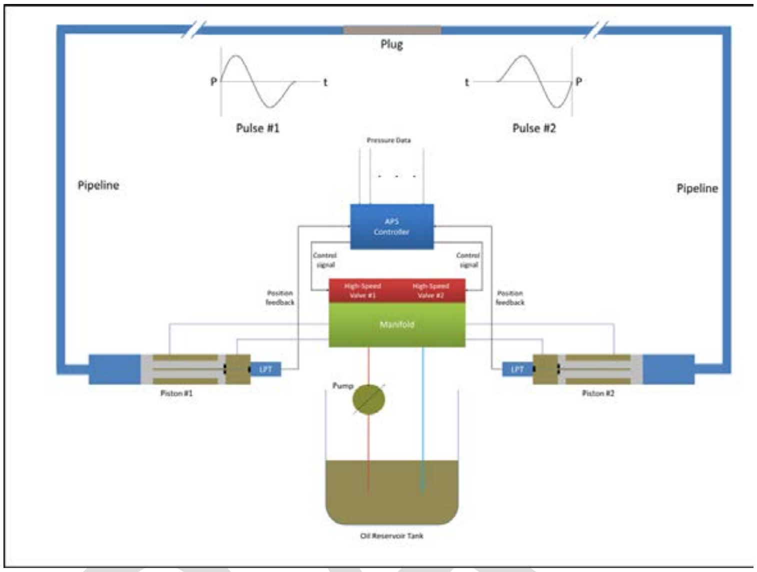


Fig.~~ure~~ 1. The asynchronous pulsing system.

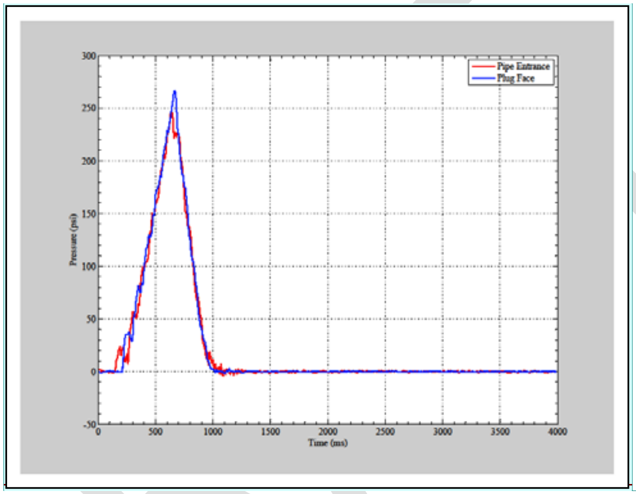
Experimental Testing

As can be seen in Figure 2, an outdoor site was cleared and leveled and pipeline supports were fabricated and anchored to the ground. The elevations of the pipeline supports were surveyed and adjusted to provide a pipeline slope of 0.25 %. In addition, the hydraulic power unit was placed inside a shed to protect it from the rain.

Fig.~~ure~~ 2. Engineering scale testbed images for asynchronous pulsing system.

Pulse Testing

Initial tests were single pressure pulse tests using a solid aluminum shaft to emulate a plug. These tests were intended to obtain a better understanding of the responses of the system to various operating parameters. Tests were conducted at both 0 and ~~50 psi~~345 kPa static pressures. As can be seen in Figure 3, a ~~30 psi~~207 kPa pressure amplification was observed with a ~~270 psi~~1861 kPa max pressure when the static pressure was set to zero. However when the static pressure was increased to ~~50 psi~~345 kPa, as shown in Figure 4, only a ~~20 psi~~138 kPa pressure amplification is obtained but the max pressure increased to ~~390 psi~~2689 kPa. This is due to the air in the pipeline being compressed. As observed in the previous tests, when the air is compressed, the damping effect of the air is minimized and thus the higher pressure pulse is obtained.



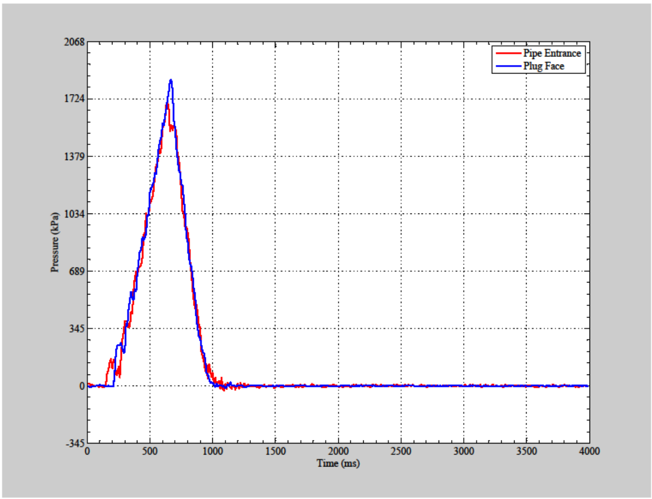


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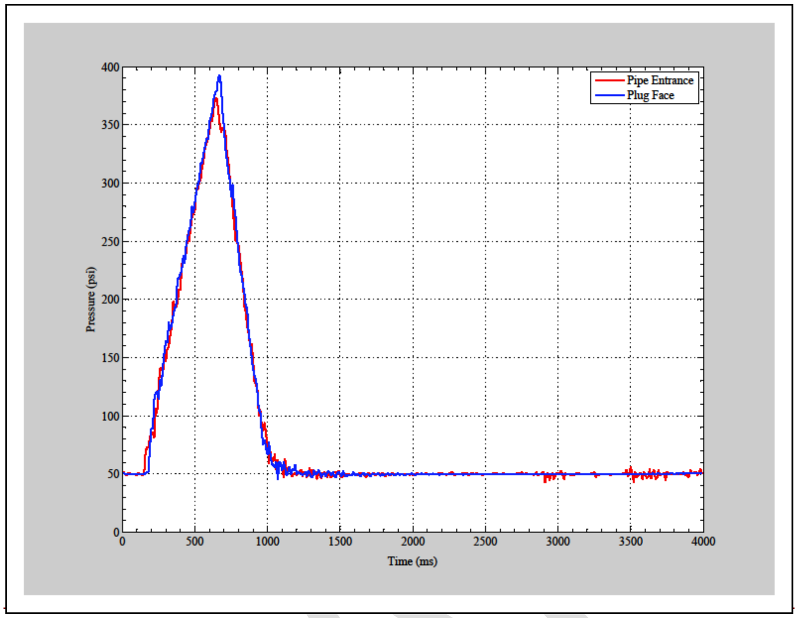
Fig.~~ure~~ 3. Single pressure pulse results with a 0 ~~psi~~ Kpa static pressure.



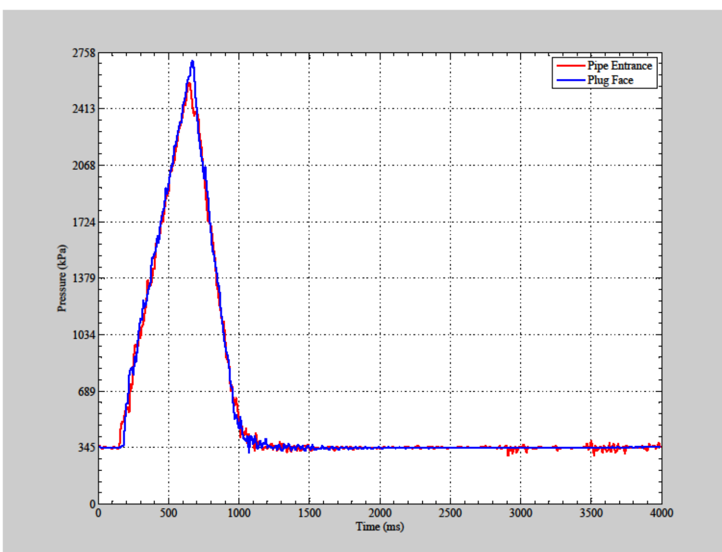


Fig.~~ure~~ 4. Single pressure pulse results with a ~~50 psi~~345 kPa static pressure.

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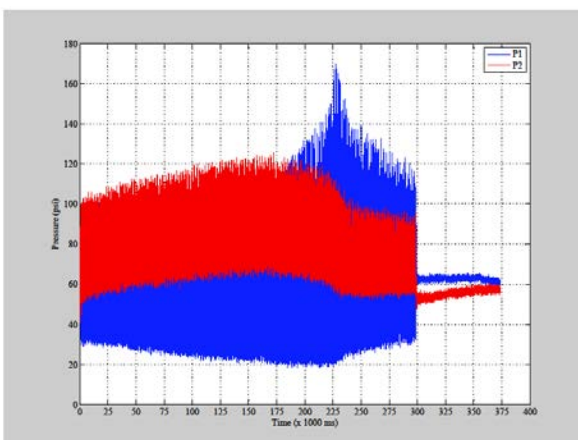
Unplugging Tests

The next phase of tests involved the actual unplugging of ~~3-ft~~1 m kaolin-plaster plugs. Figure 5 shows examples of kaolin-plaster plugs prior to testing and after unplugging.

Fig.~~ure~~ 5. A kaolin-plaster plug before and after unplugging.

Figure 6 shows the pressure data from an unplugging of a ~~3-ft~~1 m kaolin-plaster plug. P1 and P2 represent the pressures on each side of the plug face. For these tests, a static pressure of approximately ~~55 psi~~379 kPa was utilized. The majority of air was removed from the pipeline, with residual amounts remaining due to limitations created by the plug. Frequencies were varied from 0.5 to 2 Hz, however, transducer issues arose at 2 Hz. Resulting pulse amplitudes were dependent on valve opening, frequency/piston speed and air entrainment. After analyzing the data it was observed that P2 had a smaller pressure range than P1 for the 1.5 Hz trial. This is believed to be due to the P2 side of the pipe loop containing more air than the P1 side. Another observation was that just before unplugging occurred P1 started to increase as P2 was decreasing. This is due to water starting to leak past the plug from the P2 side to the P1 side. The decrease in the water volume from one side will cause the pressure per stroke to decrease while the increase of water volume on the other side will cause the pressure per stroke to increase.



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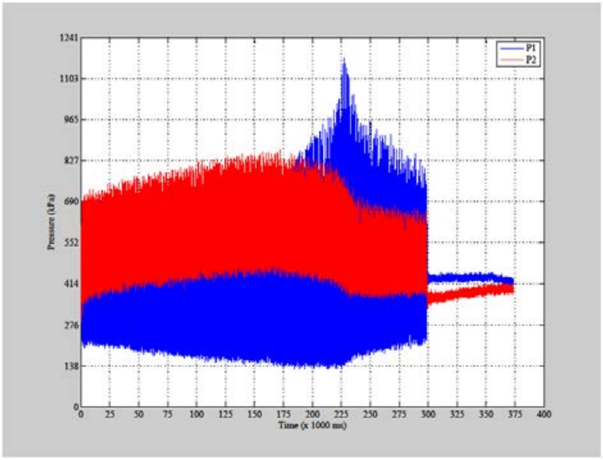
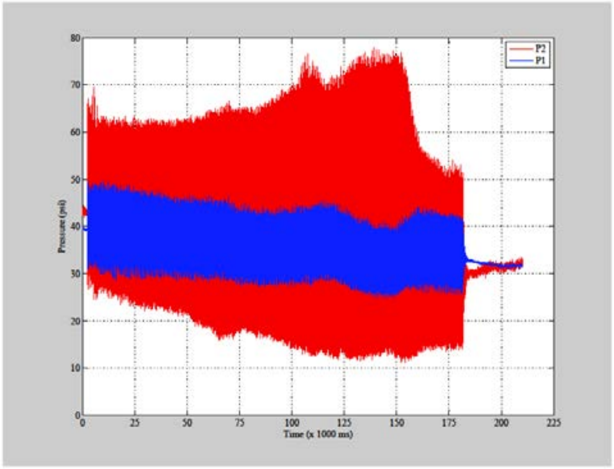


Fig.~~ure~~ 6. Pressure data from an unplugging of a kaolin-plaster plug at 1.5 Hz.

Figure 7 shows the pressures for a 0.5 Hz trial. As with the previous test, P2 had a larger pressure range than P1. This is also believed to be due to air still remaining in the P1 side of the loop. Also in this test, water started to leak past the plug from the P1 side to the P2 side which resulted in P2 starting to increase as P1 was decreasing~~-~~ just before unplugging occurred.



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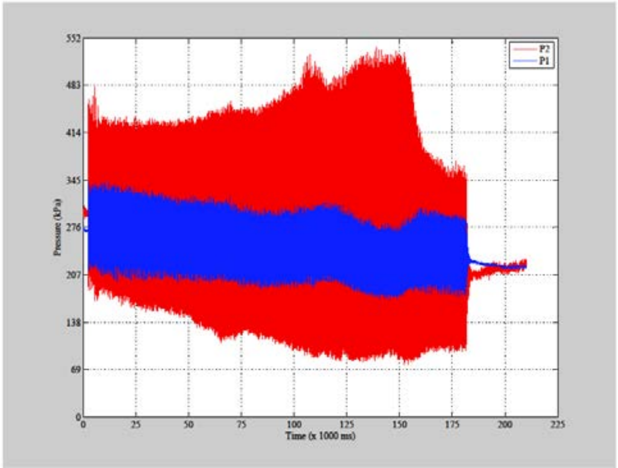

Fig.~~ure~~ 7. Pressure data from an unplugging of a kaolin-plaster plug at 0.5 Hz.

Figure 8 shows the data from the accelerometers mounted on the pipeline on both sides of the plug. As can be seen from the graph, the force applied to the pipeline started to increase as just before the plug was unplugged and reached its maximum when unplugging occurred.

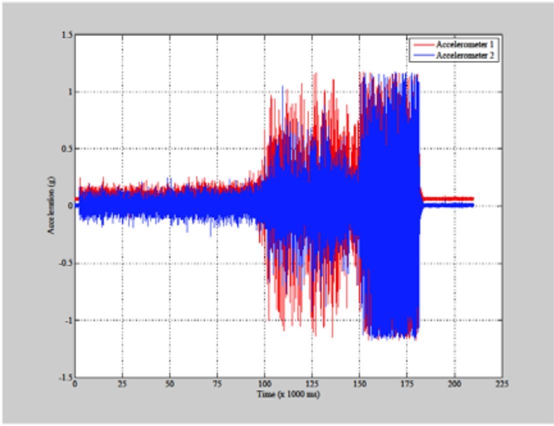

Fig.~~ure~~ 8. Pipeline accelerometer data during a 0.5 Hz. unplugging

PERISTALTIC CRAWLER SYSTEM

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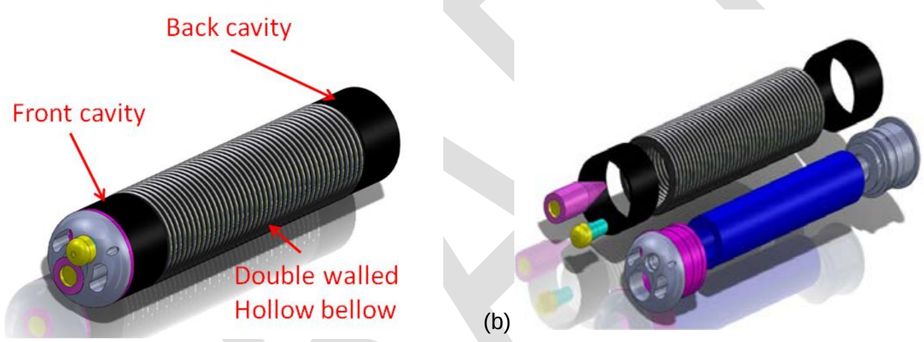
General Description

The Peristaltic Crawler System (PCS) is a pneumatic/hydraulic unit that can navigate inside a pipeline by pressurization/depressurization of flexible cavities [1]. Past efforts included the design, assembly and testing of three generations of the PCS, each one having improvements to overcome the limitations previously observed. For each generation, the tests conducted on bench-scale testbed have provided information on the navigational speed, ability to negotiate thru a 90° elbow, pulling force, and unplugging ability.

The current system consists of a crawler unit, a tether-reel assembly and a control station. The unplugging tool is attached to the front of the unit and powered by pressurized water. The crawler unit has a double walled bellow assembly and front and back rims to which flexible sleeves are clamped, forming the front and back cavities. The center of the double walled bellow assembly creates a passage that allow particles of the plug that are set loose during the unplugging process to travel to the back of the unit. Attached to the front rim is a nose cap designed to hold the unplugging tools (high pressure water nozzle) and the camera. Figure 9(a) shows a rendering of the crawler unit and Figure 9(b) shows an exploded view of the crawler assembly.



(a) (b)

Fig.~~ure~~ 9. (a) Rendering of crawler, (b) exploded view of crawler assembly [2,3].

The tether-reel assembly connects the crawler to the control station and the power supply source. The tether consists of three pneumatic lines, one hydraulic line, and one multi-conductor cable jacketed together having a total length of 152.40 m ~~500 ft~~. The reel system was designed to accommodate the tether and provides rotating connections to the pneumatic, hydraulic, and electrical lines. The control station includes the pneumatic pressure regulators, a vacuum pump, vacuum chamber and a controller box containing a programmable logic controller (PLC) that controls the position (opened/closed) pneumatic valves of the crawler unit. By programming an appropriate sequence on the PLC, the desired motion is achieved.

Current efforts included increasing the navigational speed of the crawler by improving the response time of the double wall bellow assembly by decreasing the outer bellow material thickness. Navigational bench scale tests conducted using the new bellow configuration yielded a straight line speed of 11.58 m~~38 ft~~/hr. Figure 10 shows the navigational speed result using previous and current bellow configurations.

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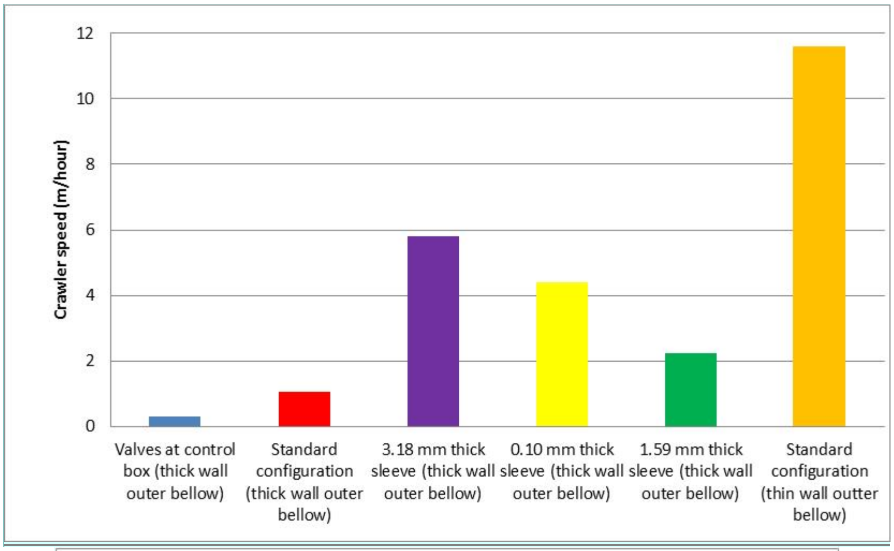

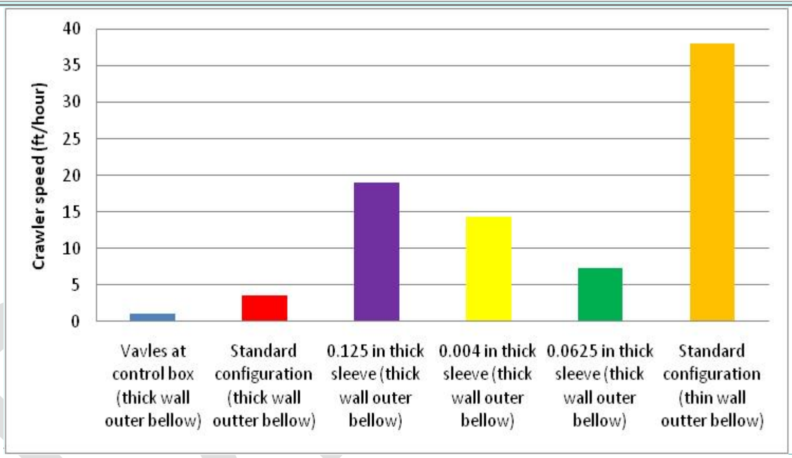

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Fig.~~ure~~ 10. Speed test using different bellow configurations.

The force generated by pressurizing the bellow assembly dictates the maximum load the crawler can pull which primarily consists of the tether. Expansion force tests using the new thin wall bellow configuration showed similar results to that of the bellow configuration previously tested. The crawler assembled using the thinner bellow configuration was provided with a maximum pressure of 345 KPa ~~50 psi~~ and generated a force of 24.29 N~~108 lb~~. For both cases, there was a liner relation between supply pressure and force generated was observed. Figure 11 shows the results of the expansion force test conducted.

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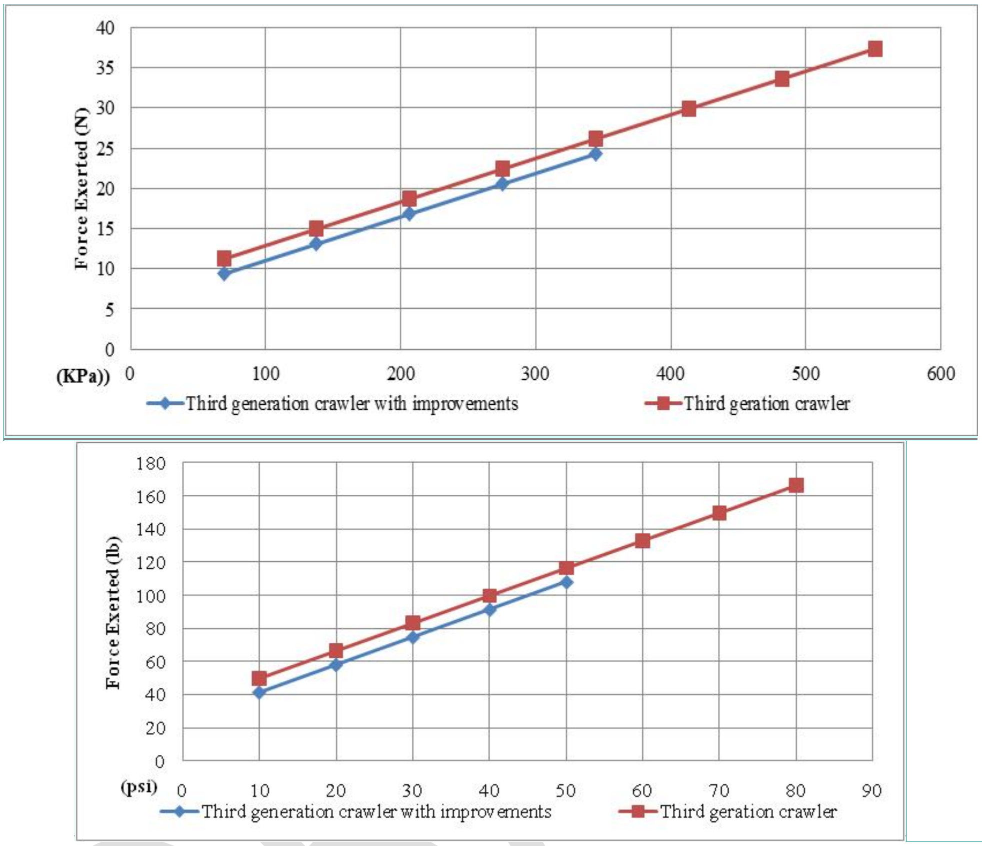

Fig.~~ure~~ 11. Force tests results.

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Engineering Scale Tests

To evaluate the performance of the PCS on longer pipelines, an engineering scale testbed was assembled. The engineering scale experimental testbed consists of 24 straight sections and three 90° elbows assembled with couplings. The pipes sections used are grade 10 carbon steel pipes and have an inner diameter of 82.80 mm~~3.26 inches~~. The total length of the pipeline was 131.06 m~~430 ft~~ which was designed based on the length of tether available. The control station, air compressor, vacuum pump, tether-reel assembly, and feed-back camera monitor were placed in a container for easy deployment. Figure 12 shows the testbed layout and system configuration.

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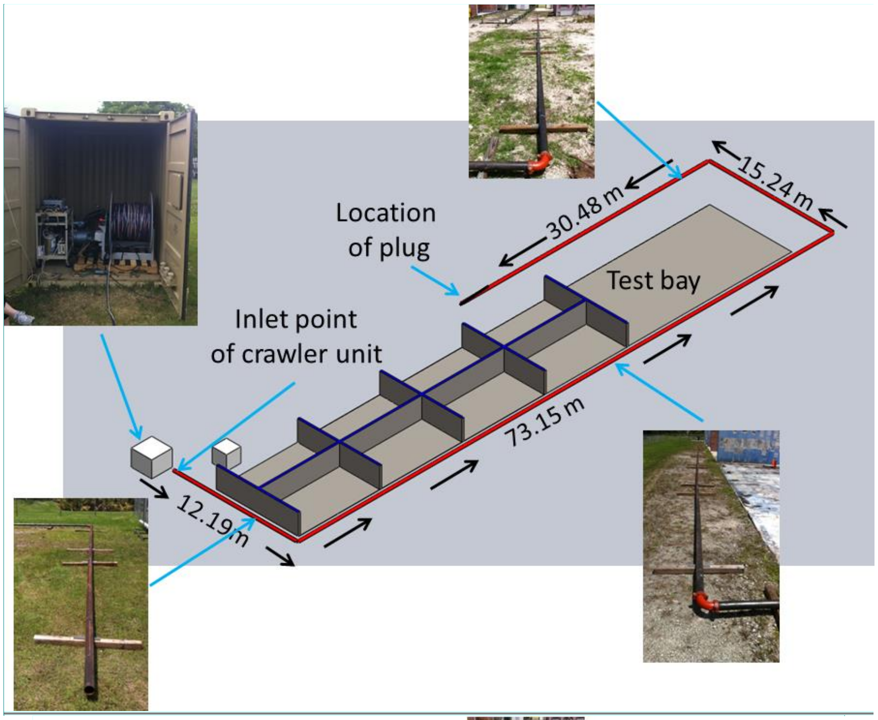

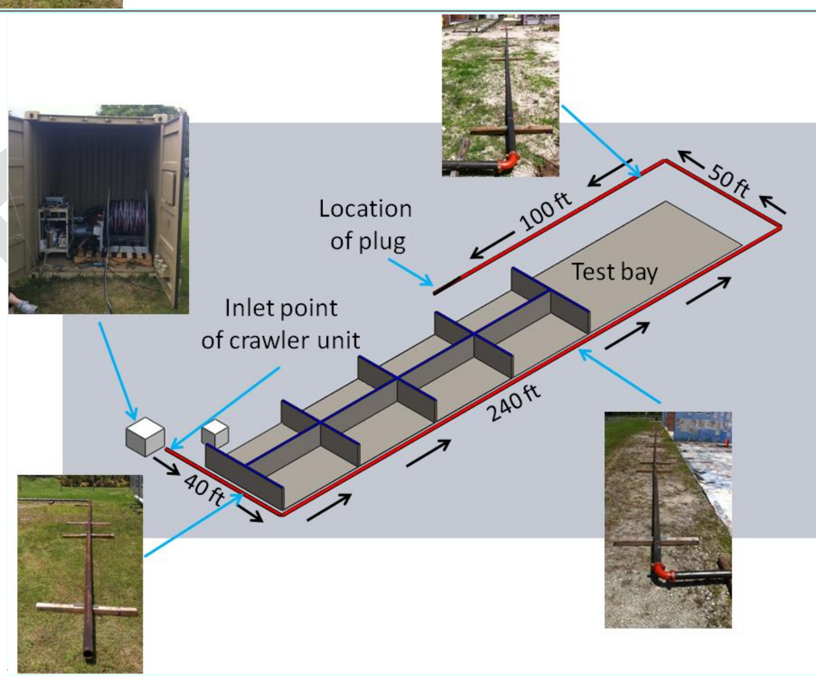

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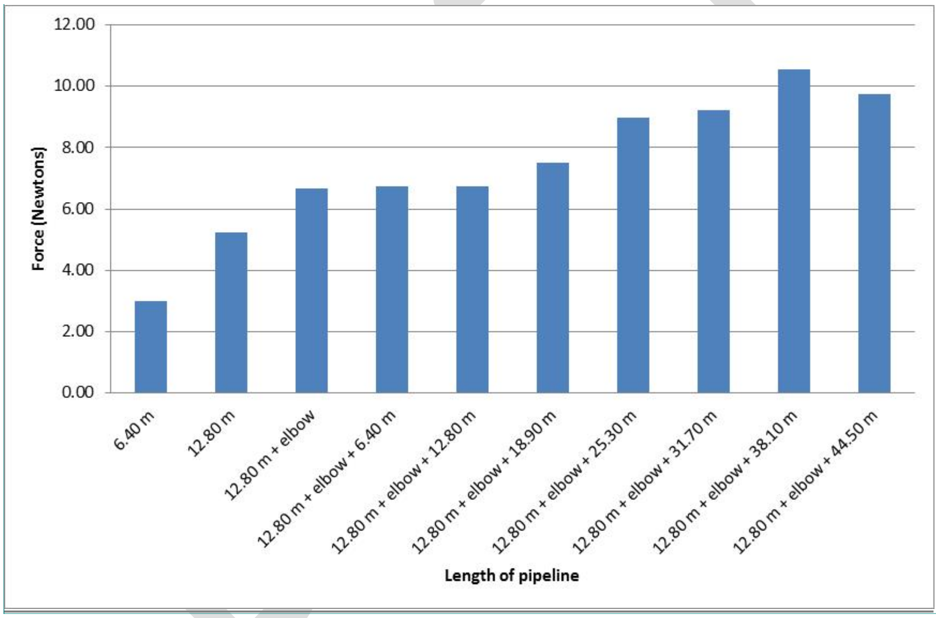
Fig.~~ure~~ 12. Engineering scale testbed configuration.

Pull Force Tests

Using the engineering scale testbed, tests were conducted to determine the pulling force required to carry the tether through the pipeline. The tests consisted on manually pulling the tether and recording the pulling force using a spring scale at various locations in the pipeline. The force recorded to pull the tether in a 6.40 m~~21 ft~~ straight pipe section was 4.05 N~~18 lb~~. The force required to pull the tether increased significantly, however, once the tether was routed through a straight pipe coupled to a 90° elbow. This large force requirement would hinder the crawler unit from successfully navigating longer distances. In order to decrease the fiction force and also reducing the contact area between the tether and the pipeline, a 1.30 mm~~0.051 in~~ stainless steel wire was coiled onto the tether. Pulling force tests conducted using this configuration showed that the force required to pull the tether using a 6.40 m~~21 ft~~ section was reduced to 3.00~~13~~ N ~~lb~~. The force required to pull the tether inside a pipeline of 57.30 m~~188 ft in~~ length having a 90° elbow located 12.80 m~~42 ft~~ from the inlet point was 9.74 N~~43 lb~~, approximately. Figure 13 shows the results for the manual pull force tests conducted.



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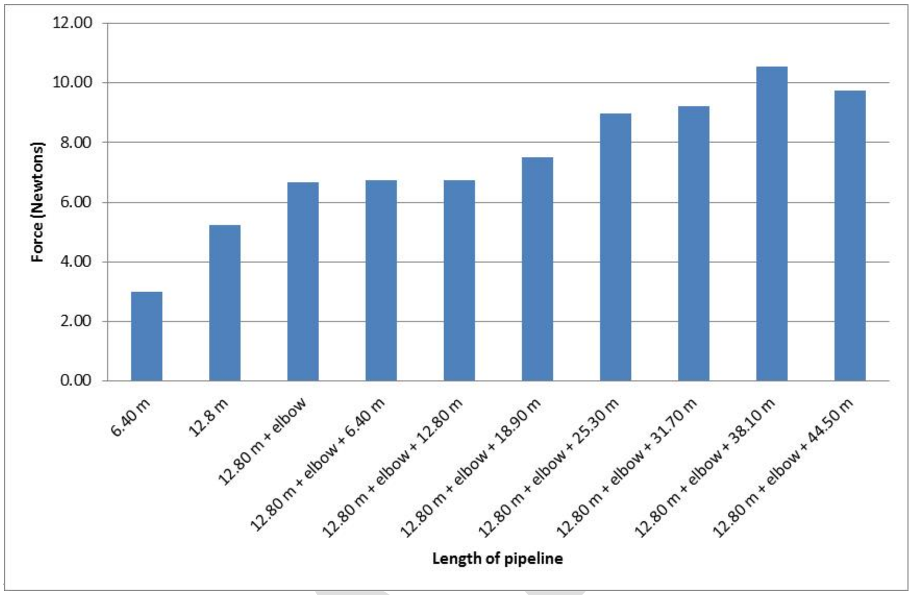

Fig.~~ure~~ 13. Manual tether pull force for different pipeline lengths.

Fatigue Tests

Previous bench scale navigational tests were performed using PVC pipe sections. The inner diameter of these PVC pipes is 73.66 mm~~2.9 inches~~. The carbon steel schedule 10 pipes used in the engineer~~-~~ing scale testbed have a larger inner diameter of 82.80 mm~~3.26 inches~~. The increase in the distance between the crawler and the pipeline wall requires the front and back cavities to expand further in order to anchor the crawler unit to the pipeline. During the navigational tests performed, this additional expansion caused the cavities to prematurely rupture after the crawler had traveled minimal distances in the pipeline. Based on the projected displacement of the crawler per cycle, it is estimated that total of 3,600 cycles will be required for the unit to navigate a 152.40 m~~500 ft~~ pipeline. For all tests, the rupture occurred at the stress risers created at the clamps edges. In an attempt to eliminate the failure of the cavities, different materials, configurations, and clamping pressures were tested. The largest number of cycles recorded without failure was 1,260 using a Kevlar gasket placed between the clamps and the flexible cavity.

Bench Scale Tests

An alternative approach to reach the 3,600 cycles without failure was to increase the distance between the clamps. This increase provides additional available material that can expand to reach the inner pipeline wall. An experimental fixture having the same outer diameter as the back rim was assembled and tests were performed in a schedule 10 pipeline section. Two tests were performed: one having a distance between clamps of 44.45 mm~~1.75 in~~ and the other having a distance of 25.40 mm~~1 inch~~. The test for the 44.45 mm~~1.75 in~~ provided a total of over 14,000 cycles with no evidence of failure. The test for the 25.40 mm~~1 inch~~ clamp distance held a total of over 15,000 cycles prior to failure. Figure 14(a) shows the experimental fixture and Figure 14(b) shows the test conducted using the 1 inch clamp distance.

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(a)  (b) 

Fig.~~ure~~ 14. (a) Experimental fixture and (b) experimental fixture inside pipeline section.

Using the experimental result from the fixture, prototypes of the rims having an additional length of 12.70 mm~~0.5 in~~ to provide 31.75 mm~~1.25 in~~ of distance between clamps were prototyped and the crawler was then assembled. A pull test in a 90° elbow was conducted by routing a wire through the crawler and attaching it to the rear rim. Tests showed that the increased length of the rims caused the crawler to wedge against the inner surfaces of the elbow preventing it from turning. A second set of rims having ~~0.25 in~~6.35 mm of additional length (25.40~~1~~ mm~~ in~~ of distance between clamps) were prototyped and tested using the same procedure. Using these rims, the crawler was able to successfully navigate through a 90° elbow with a pull force of 53.38 N~~12 lb~~.

CONCLUSIONS AND FUTURE WORK

After analyzing the data from asynchronous pulsing system test runs, it was observed that the system is capable of unplugging long pipelines. However, just as in the smaller test loops, air entrapment in the pipeline hinders the asynchronous pulsing system performance due to the system's fixed volume piston pumps. Though just like in the smaller loops, increasing the static pressure in the pipeline mitigates the effects of the air. The next phase of work will utilize the data obtained from the experimental testing to develop a numerical analysis model that will be capable of predicting the system's performance on any length pipeline with any amount of entrapped air.

For the PCS, tests showed that the improvements in the double bellow configuration have a significant effect on its navigational performance. Using a thinner wall bellow, the crawler had a navigational speed of 11.58 ~~38 ft~~m/hr. The force tests conducted showed that the thick wall and thin wall bellow have a similar response to forces generated from the supplied air pressure. Additionally, the use of the 1.30 mm~~0.051 in~~ stainless steel wire wounded around the tether significantly reduced the pulling force required to route the tether through the pipeline. Passing the tether through an elbow increased the force by 33%.

The difference in inner pipe wall diameter between the PVC pipe sections and schedule 10 pipe sections (~~2.9 in~~73.66 mm and 82.80~~3.26~~ mm~~in~~ respectively) had a significant effect on the life of the rim cavities. Tests showed that a distance between clamps of at least 25.40~~1~~ mm~~in~~ is required to provide 14,000 cycles with no failure. The use of gaskets to decrease the stress rises at the clamps locations was not sufficient to prevent failure above acceptable limits (3,600 cycles). The prototype having a 6.35 mm~~0.25 in~~ longer rim provides a clamps distance of 25.40 mm~~1~~ in and does not increase the force required for the crawler to navigate through an elbow. Future efforts will include manufacturing a stainless steel crawler with the dimensions of the prototype. The system will then be tested in the engineering testbed (~~430 ft~~131.06 m).

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~~4.~~3. Pribanic, T., Awwad, A., Varona, J., McDaniel, D., Gokaltun, S., Crespo, J. (2013). "Design Optimization of Innovative High-Level Waste Pipeline Unplugging Technologies." In Proceedings of Waste Management Symposia, Phoenix AZ.

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