Evaluation of Innovative High-Level Waste Pipeline Unplugging Technologies - 9477

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ABSTRACT

In this paper, we review the pipeline unplugging methods that have been evaluated at Florida International University (FIU) since 2000 and present the results from recent tests in 2008. Pipelines of various lengths and configurations were constructed at FIU and used to simulate the Department of Energy, (DOE) waste transfer lines and plugging scenarios which were generated by inserting plugged pipe sections at various locations along the pipelines. A total of 8 different unplugging methods were tested from 2000 to 2002 using various blockage materials that were selected according to their physical and chemical properties that simulated the plugs that are observed in DOE transfer lines. In 2007 and 2008, two of the most promising technologies for removing plugs thousands of feet from the few access points in transfer lines were tested more rigorously with guidance from DOE site engineers.

INTRODUCTION

Over the past 50 years, some of the pipelines [1] at Department of Energy (DOE) sites have plugged during high-level radioactive waste (HLW) transfers. These have resulted in costly schedule delays and increased costs in some cases to replace plugged sections [1, 2]. The HLW pipelines were built many decades ago and are too costly to replace. They are two and three inches in diameter and many of the lines are not heat traced. The pipelines can potentially have many sharp 90° bends which can present challenges for unplugging technologies. In addition, plugs are typically caused by the accumulation of solids, chemical crystallization (phosphate crystals), or chemical gelation. The successful demonstration of a suite of commercially available pipeline unplugging technologies/tools is crucial to ensure cost-effective operation of the waste transfers and to ensure tank farm cleanup milestones are met.

In 2000, Florida International University (FIU) solicited from across the world the best demonstrated pipeline unplugging technologies. One of the unplugging technologies tested was the mechanical snake systems that have typically failed after two or three 90° bends. Three other technologies tested at FIU in 2001 were able to unplug various types of plugs through a pipeline with multiple 90° bends and with over 1000 feet from access to the pipeline to the plug. These included a patented wave erosion technology that was not fully commercially available, a sonic wave technology (commercially available but whose working principles were not well understood), and a low volume, high pressure water jet technology.

In 2007, FIU again looked at technologies from across the world and found that no new technologies were available for the diameter and length of HLW pipelines. While the 2001 testing was focused upon showing that the technologies could unplug lines, the testing program for 2007 and 2008 was designed to: understand the working principles of the technologies; evaluate the effect of technology parameters on erosion rates; and allow scaling of the technology performance to distances several thousand feet from line access to plug.

In this paper, a synopsis of the previous testing conducted at FIU will be provided. General results from FIU's 2007-2008 experimental testing will be presented. The intent is to provide an overview of the state-of-the-art for HLW pipeline unplugging technologies. The outline of the paper is as follows; First, unplugging principles tested since 2000 are summarized and the pros and cons of technologies are presented. Next, the experiments conducted during 2007 an 2008 are described. Finally, the results of recent tests are presented along with conclusions of the relevance to DOE HLW line unplugging.

SUMMARY OF UNPLUGGING PRINCIPLES TESTED

Roto-rooter® Technology Demonstration

In 2000 Roto-rooter® Services Company demonstrated two technologies at FIU's test site for unplugging pipelines. One of the two technologies demonstrated was a high-pressure water jet technology manufactured by Harben, Inc. and shall be referred to in this report as Harben Jet. The technology is trailer-mounted and consists of a water tank and approximately 152.4 m (500 ft) of high-pressure water hose (see Fig. 1(a)). A "jet head" or nozzle is attached to the end of the hose and acts as both the propulsion system and the cleaning tool.

There are many choices of nozzles available for the operator. Based on experience, the operator chooses which nozzle is most appropriate for the job. An operator may go through many different nozzles in order to find the best "compromise" for moving through and cleaning the pipeline. The nozzles are made in different sizes and have different water jet orientations. The nozzles have holes located in the rear and/or on the tip (facing forward) of the nozzle. The rear facing jets provide forward thrust and propel the hose though the pipeline. The jets located at the tip of the nozzle are used to clean or blast away the obstruction in the pipeline.

The Harben Jet equipment can produce up to 27.58 MPa (4,000 psi) of water pressure while using up to 0.0606 m^3/min (16 gpm). The system was also equipped with Harben's Jump Jet Pulsation System, which vibrates the water hose and nozzle to assist the system in making its way around obstacles such as elbows.

The other technology demonstrated was Ridgid Snake, manufactured by Ridgid Tool Company. The Ridgid Snake technology consists of an approximately 45.72 m (150 ft) long semi-flexible steel rod with a cutting blade tip that is inserted inside the pipeline for cleaning blockages. The snake is housed inside a rotating drum, which is used to feed and retract the snake from the pipeline (see Fig. 1(b)).).

(a)

(b)

Fig. 1. (a) Harben Jet being inserted into test bed #2 by Roto-rooter. (b) Ridgid Snake technology being inserted into test bed #2 by Roto-rooter.

Characteristics of blockages

Two blockages were tested on test bed #1 for demonstration of the unplugging and pipeline navigation technology by Roto-rooter. Both tested blockages were 1.524 m (5 ft) long, epoxy-sand mixtures that produced a hard, adherent coating on the inside surface of the pipe. These blockages are only partial blockages and are hollow through their centers. The blockages simulate a hard buildup of material on the sidewall of the pipeline.

A total of two, 1.524 m (5 ft) long blockages were tested on test bed #2. These blockages were made from two different blockage materials and placed at different locations.

The percentage (by weight) of the blockage removed is determined by weighing the pipeline sections with a blockage before and after the demonstrations. A removal effectiveness of 100% would indicate the technology was completely successful in removing the plug. However, partial removal and/or dislodging of the plug were recorded, as partially successful.

Table I. Benefits and limitations of Roto-Rooter Technology

	Harben Jet Technology	Ridgid Snake Technology
Benefits	• Short mobilization and demobilization time • Commercially available • Relatively low cost	• Extremely short mobilization and demobilization time • Commercially available • Low cost • Self-propelled
Limitations	• Although technology is self-propelled, it’s still very labor-intensive. • Water is not contained or recycled. • Water overflows toward the operator. • High water usage • Effectiveness depends on test bed configuration	• Reaching is limited to 45.72 m (150 ft). • Limited effectiveness on both test beds • The snake can break if the plug has a hard composition • Due to its geometric configuration, the blades cannot remove all the blockages in the 3-in pipe.

A-to-Z Plumbing and Environmental Services Technology

In 2000, A-to-Z demonstrated a high-pressure water jet technology manufactured by Harben, Inc., referred to in this document as the Harben Jet. This is the same technology as demonstrated by Roto-rooter.

The technology is trailer-mounted and consists of a water tank and approximately 152.4 m (500 ft) of high pressure water hose. A “jet head” or nozzle is attached to the end of the hose and acts as both the propulsion system and the cleaning tool. There are many choices of nozzles available for the operator. Based on experience, the operator chooses which head is most appropriate for the job. An operator may go though many different nozzles in order to find the best “compromise” for moving through and cleaning the pipeline. The nozzles are made in different sizes and have different water jet orientations. The nozzles have holes located in the rear and/or on the tip (facing forward) of the nozzle. The rear-facing jets provide forward thrust and propel the hose though the pipeline. The jets located at the tip of the nozzle are used to clean or blast away the obstruction in the pipeline.

The Harben Jet equipment can produce up to 27.58 MPa (4,000 psi) of water pressure while using up to 0.0606 m^3/min (16 gpm). The system was also equipped with Harben's Jump Jet Pulsation System, which vibrates the water hose and nozzle to assist the system in making its way around obstacles such as elbows.

Benefits of A-to-Z Plumbing are:

- short mobilization and demobilization time,
- being commercially available,
- relatively low cost.

Limitations included:

- Although technology is self-propelled, it's still very labor-intensive,
- Effectiveness may drop depending on test bed configuration,
- Water is not contained or recycled,
- Water overflows toward the operator, and
- High amount of water usage.

Characteristics of blockages

An epoxy-sand blockage was tested on test bed #1 for demonstration of the unplugging and pipeline navigation technology. The blockage tested on test bed #1 was a 1.524 m (5 ft) long, epoxy-sand mixture that produces a hard, adherent coating on the inside surface of the pipe. This plug is only a partial blockage and is hollow through its center. The blockage represents a hard buildup of material on the sidewall of the pipeline. A 1.524 m (5 ft) Bentonite-sand blockage was tested on test bed #2.

Carolina Equipment & Supply's Aqua Miser

FIU coordinated the pipeline unplugging technology demonstrations by Carolina Equipment & Supply during the third week of June 2001. The Aqua Miser line of water blasting equipment combines 103.42 MPa (15,000 psi) to 275.79 MPa (40,000 psi) water injection technology at very low volumes to unplug pipelines. The Aqua Miser also has the capability to use different abrasives that loosen the blockage. This innovative line of equipment offers a wide array of capabilities including the following: quick and effective degreasing and cleaning, stripping paint from surfaces layer by layer, removing heavy corrosion from surfaces, and achieving a white metal surface similar to sandblasting. The Aqua Miser has the potential to be efficient, effective, and economical in providing a solution in various heavy-duty cleaning or blasting situations, and their systems are currently being used in military and commercial aviation, transportation, and pulp and paper mill industries.

One 1.524 m (5 ft) section of epoxy-sand (40 wt% - 60 wt%) blockage was tested on Test Bed #1 (Gravity Drain Line). On Test Bed #2 (Horizontal Long Pipeline), a total of three blockages ranging from 1.524 m (5 ft) to 2.048 m (10 ft) sections of Bentonite-sand (30 wt% - 30 wt%) and also three blockages ranging from 1.524 m (5 ft) to 3.048 m (10 ft) sections of K-Mag-Water (90 wt% - 10 wt%) were tested. Due to the pressure loss experienced on every 15.24 m (50 ft) of pressure hoses, the Aqua Miser had difficulty negotiating more than two elbows, usually starting from 60.96 m (200 ft) away from the entry point. The Aqua Miser has a pressure drop of 8.618 MPa (1250 psi) per 15.24 m (50 ft) of hoses. Consequently, there is little thrust remaining to propel the nozzle head beyond 60.96 m (200 ft) into the pipeline to negotiate any elbows on the FIU Test Bed #2. The water pressure used during the demonstration was between 68.947 MPa (10,000 psi) and 165.474 MPa (24,000 psi), and that was 3 to 5 times higher than that of Roto-Rooter and A-to-Z Environmental Services during their technology demonstrations performed in 2000.

The technology is trailer-mounted and consists of a water tank and approximately 121.92 m (400 ft) of high-pressure water hose. However, the Aqua Miser can reach beyond 121.92 m (400 ft) given a pipeline with no elbows. A jet head or nozzle (water jet orientations: 45° angle forward and 45° backward, 30° perpendicular angle) is attached to the end of the hose and acts as both the propulsion system and the cleaning method. There are many choices of nozzles available for the operator. Based on experience, the operator chooses which head is most appropriate for the job. An operator may go through many different nozzles in order to find the best “compromise” for moving through and cleaning the pipeline. The nozzles are made in different sizes and have different water jet orientations. The nozzles have holes located in the rear and/or on the tip (facing forward) of the nozzle. The rear-facing jets provide forward thrust and propel the hose though the pipeline. The jets located at the tip of the nozzle are used to clean or blast away the obstruction in the pipeline.

Benefits of the technology include:

- The Aqua Miser has the potential to be more effective on the Gravity Drain Line Test Bed than Roto-Rooter Plumbers and A-to-Z technology,
- Low water usage,
- Short mobilization and demobilization time,
- Being commercially available,
- Relatively low cost, and
- Capability to gain access through the 1-inch access port if necessary.

Limitations of the technology include:

- Although technology is self-propelled, it is labor intensive,
- Technology is unable to negotiate more than two elbows,
- Technology is unable to flush out the blockages completely,
- Water is not contained or recycled,
- Water drains toward the operator, and
- Limited effectiveness on Test Bed #1 based upon the nozzle heads available during the demonstration.

Characteristics of Blockages

One blockage was tested on Test Bed #1. It was a 1.524 m (5 ft) long epoxy-sand (40 wt% - 60 wt%) mixture that produced a hard, adherent coating on the inside surface of the pipe. This plug is a partial blockage and is hollow through the center. The blockage represents a hard buildup of material on the sidewall of the pipeline. Based on the nozzle heads that were available for the vendor during the demonstration, the Aqua Miser was able to unplug approximately 0.11% of the 1.524 m (5 ft) epoxy-sand blockage over a period of 2 hours and 33 minutes. However, given sufficient time and the suitable nozzle head for the epoxy-sand blockage, the Aqua Miser would be able to unblock the pipeline. A total of six blockages were tested on Test Bed #2, three of which were Bentonite-sand-water mixture (30 wt% - 30 wt% - 40 wt%). These blockages had length ranging from 5 ft to 10 ft that produced a hard and bulky plug, and the remaining three blockages were of K-Mag-Water (90 wt% - 10 wt%) ranging from 1.524 m (5 ft) to 3.048 m (10 ft) long. The Aqua Miser technology was successful in dislodging all the blockages presented by FIU on Test Bed #2. However, the Aqua Miser technology did not have the capability to flush out the dislodged blockages.

Control Devices, Inc.’s CD42-TX/CD42-R/CD42-GP Blockage Locating Technology

Control Device, Inc., (CDI) is an electronics product development company. One of the products CDI has designed for FIU is the CD42 transmitter system to track and locate blockages. The system consists of a CD42-Tx transmitter, a CD42-R receiver, and a CD42-GP antenna. The CD42’s primary purpose is to allow an operator to both track and locate a blockage. The CD42 system works on magnetic principles. A transmitter emits a pulsing magnetic field that travels through the pipeline and any groundcover and is received on the outside of the pipeline by the antenna and is displayed to the operator on the receiver's Liquid Crystal Display (LCD). The system utilizes computer-driven liquid crystal displays (LCDs) allowing interpretable output of each and every pulse. The receiving antenna is attached to the receiver display unit and is carried by the person (the operator) tracking and locating the blockage. The transmitter, once loaded with batteries, begins to generate a strong magnetic field at 1.5-second intervals. The receiving antenna detects this magnetic field, passes it to the display unit that displays it to the operator as pulses (or peaks) on the screen. The height of these pulses varies with distance from the transmitter such that the closer the receiving antenna is to the transmitter, the higher the corresponding pulse on the display.

During the demonstrations, magnetic pulsing techniques have proved to be effective when the transmitter is small enough to penetrate the pipeline. Unlike radioactive sources, pulsing magnetic transmitters penetrate the pipeline with a range that consistently reaches the blockage, and poses no health risk to the operator. Another advantage of the magnetic transmission system is that in most cases, ground cover (solid rock, soil, water, and vegetation) does not effect reception. Some exceptions are soils with high metallic content. Bridge decks, concrete roadways with reinforcement bars and other metallic structures can also inhibit magnetic pulses from penetrating fully and thus reduce the range. The CD42 system also has the advantage of being distinguishable from other signals that one may encounter in a pipeline environment.

The magnetic system employed at the FIU test site was mounted in a Jetter Snake, or with a high-pressure water jet, a receiving antenna, and a receiver display unit.

During 2001, CDI responded to a solicitation from DOE's Tank Focus Area and FIU to participate in a demonstration of pipeline blockage locating technology at the FIU demonstration site. The CD42 locating and tracking system performed a total of six demonstrations in the three test beds. In Test Beds #2 and 3, the transmitter was deployed on the end of a 121.92 m (400 ft) Water Jet hose that propelled it into the pipeline. The transmitter became lodged on both occasions in the first sharp 90° elbows in Test Bed #2 but with success in Test Bed #3. The system was unable to negotiate any of the bends; consequently, it is unknown what the CD42 locating and tracking system capabilities are in Test Bed #2. Two tests were performed in Test Bed #1 at a distance of 18.288 m (60 ft) and 22.86 m (75 ft), respectively, from the entry point. The transmitter was deployed on the end of an 25.908 m (85 ft) Jetter Snake and successfully located the blockage in the pipeline with an accuracy of ± 5.08 cm (2 inches).

Two tests were also performed in Test Bed #3 at a distance of 4.572 m (15 ft) and 8.23 m (27 ft), respectively. The jet propulsion system carried the transmitter to the blockage, and the transmitter was accurately located through the soil cover with an accuracy of ± 5.08 cm (2 inches). Thus, the system demonstrated its ability to locate the transmitter accurately through the soil cover and the steel pipeline.

Benefits of the CDI system are:

- Ground cover such as solid rock, soil water, and vegetation does not affect reception,
- The CD42 system can quickly and accurately identify the exact location of blockages and can track the physical layout of the pipeline within ± 5.08 cm (2 inches),
- Short mobilization and demobilization times,
- Commercially available,
- The operator easily distinguishes between what are true transmitter signals and what is noise produced by antenna movements or nearby metallic objects moving in the earth's magnetic field,

- When the CD42-Tx physically impacts the blockages, their location, time and date can be stored in computer's memory for viewing, report printing, and transferring to desktop PCs, and
- The receiver has a rated battery life of 40 hours with all options on.

Limitations of the CDI system are:

- The CD42 system didn't have its own delivery devices to deliver the CD42-Tx transmitter;
- Since the CD42-Tx transmitter has to physically deploy with an electrical-powered jetter snake or high-pressure water jet, the CD42 system may expose workers to large volumes of contaminated wasted or radiation fields; and
- Technology was not able to negotiate any of the sharp 90° elbows.

The Flagship Group's Enviro-Beam XL Technology

The Flagship Group demonstrated their Enviro-Beam XL non-chemical water treatment technology at FIU during the week of August 19, 2002. The Enviro-Beam XL is a non-chemical, water treatment technology that uses magnets to eliminate hard-water deposits in pipelines. The magnetic field alters the structure of the calcium carbonate found in hard water from hard rock-like scale to a soft fragile crystalline structure. The soft crystalline structure is then easily flushed through the piping system leaving the pipeline scale-free. According to the manufacturer, the technology uses the magnetic field to polarize ionic molecules in the fluid as dipoles. This polarization tends to cause the solution to become homogenous.

Each unit consists of four magnets encased in stainless steel (see Fig. 2). Each of the four individual magnets has a strength of 6700 Gauss. The unit assembly focuses the magnetic flux into the center of the unit with a maximum reading of 10 Gauss at 6 in from the surface of the closed assembly.

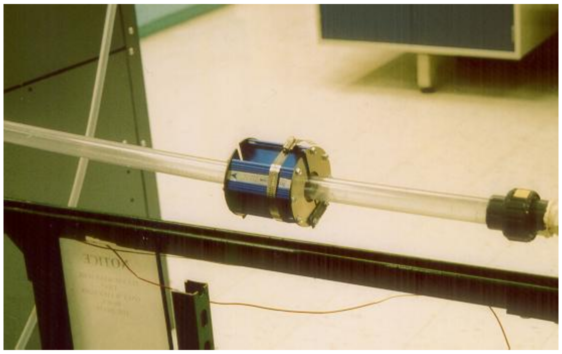


Fig. 2. Enviro-beam XL unit.

Each magnet unit is easily and quickly installed and removed from the tubing or pipe due to stainless steel half-moon plates attached to each side of the unit. The plates hold and space the individual magnets to enable the unit to be opened and closed to clamp around the tubing or piping, (see Fig. 2).

An existing flow loop used for the Solids Formation and Feed Stability During Waste Slurry Transfer Project was used for the technology demonstration. The same solid-forming simulant, X1 (3M NaOH + 0.2M NaF + 0.6M Na_3PO_4), used for the Solids Formation and Feed Stability Project, was also used. This recipe was approved by the Hanford Office of River Protection as a simplified simulant for the actual saltcake blockage material found at the Hanford site. The technology was evaluated based on its ability to prevent solids from forming in the loop. The simulant forms white, discrete, small particles that do not stick together and have a relatively fast settling rate. The substance also easily goes into suspension when stirred or shaken.

The important components of the loop for the Enviro-Beam XL technology evaluation were as follows:

- Feed Tank: The simulant and water were poured into the tank and introduced into the pipeline.
- Valve Pit: The valve pit consists of transparent sections of PVC horizontal and vertical 90^o bends. The valve pit section is immersed in a temperature-controlled bath (fish tank). The bath was set to 15 °C. Based on 2001 testing, a greater amount of solids formed at a faster rate at the 15 °C temperature in comparison to higher fish tank temperatures.
- Sampling Port: Two sampling ports located after the valve pit were used for sample collection.
- Incline Section: The inclined section having a 5.08 cm (2 inch) elevation over 2.743 m (9 ft) of pipe is made of 2.54 cm (1 inch) diameter transparent PVC pipe.

FIU performed preliminary testing of the Enviro-Beam XL, a magnetic water treatment technology from The Flagship Group, on Hanford salt waste simulant using a flow loop that had been used for Hanford waste salt crystallization studies. Comparison of the baseline tests (without magnetic units) to that of The Flagship Group tests (with magnetic units) revealed that the test runs with the magnet units had consistently higher percent solids (by weight) than the runs without the units. Whether or not this reduces the chance of plugging was not determined. In addition, due to the test's limited scope, the performance of neither the magnet technology nor the data gathered was validated due to the limited number of test runs and limited sampling capability. An experiment specifically designed to quantify the results would have to be conducted to prove the extent to which the Enviro-Beam XL would be effective in hazardous waste blockage prevention or mitigation.

The manufacturer requested a flow rate of 2.134 m/s (7 ft/s) for the tests performed at FIU. This does not represent the low-flow salt well pumping operations at Hanford but reflects conditions expected for delivery of waste to the vitrification facility. The Enviro-Beam XL, in actual field usage by the manufacturer, is installed and left on the piping system to be cleaned for several days. The validation experiments should also repeat this same practice to have a better understanding of the relationship between time and solid formation or prevention. Each Flagship Group test, as well as baseline test, should be performed at least three times to verify repeatability.

The data collected during validation testing should include solid formation or prevention vs. time as well as the particle distribution along pipe cross-section with and without magnet units. Additional data that can be collected include the maximum length of pipe one magnet unit can serve and the minimum amount of time required for magnet units to 'clean' fouled pipeline as well as the length of the zone of influence.

Baseline tests for The Flagship Group's technology evaluation were performed in August 2002. Baseline tests (BT) consist of BT#2, BT#3, BT#4, and BT#5. BT#1 was disregarded due to changes made to the sample collection procedure after the first baseline test run. The baseline tests were conducted under the same conditions as The Flagship Group tests (FGT) but without the use of the magnets and represent the normal condition data for the amount of solids that typically form in the loop with the use of the X1 simulant. Tests were conducted at 1.524 m/s (5 ft/s) and 2.134 m/s (7 ft/s) flow velocities with samples taken every hour for a duration of four hours for measurement of solid concentration (by weight). Both flow velocities showed an increase in solid formation through time. At 1.524 m/s (5 ft/s), a slightly greater percent solid concentration was observed than at 2.134 m/s (7 ft/s). The greater concentration may be due to the longer duration of the simulant in the chilled valve pit area and less dilution of the solids in the water due to the slower flow velocity. From previous testing conducted for the Solids Formation and Feed Stability project, it was observed that solid formation increased as the simulant temperature decreased. One baseline test, BT#4, was run at 1.524 m/s (5 ft/s) without chilled water in the fish tank. As expected, the percent solid was lower than the runs with chilled water.

Table B12(a-i) contains each test's condition and data. Analyses of that data reveal the following observations:

- Runs with magnets have consistently higher percent solids than the runs without the magnets. For example, the percent solid range for the 2.134 m/s (7 ft/s) runs with magnets were from 18% - 19%, and the percent solids for the 2.134 m/s (7 ft/s) runs without the magnets were from 16% - 18.5%. The same was observed for 1.524 m/s (5 ft/s) but with higher percentages.
- One run (FGT#2) was run with 3 magnetic units installed on the loop. This run showed an overall higher percent solid than the other runs. The first sample had a high percent solid concentration of 21.8% that stabilized to the range of 19.7%-19.4% after the first hour.
- Another magnet run (FGT#5) was done with the magnetic unit installed for the first 15 minutes only. This run showed an initial percent solid of 18% (taken when magnet removed) and a decrease in percent solid (15.9%-16.38%) every hour after that. It fell into the range of the baseline tests.
- In another run with the magnets (FGT#3), samples were taken every 15 minutes in the first hour and then every hour after that. The percent solids recorded showed that from the initial sample taken in the first 15 minutes, the range fell in the 20% concentration with a dip to 19.5% in the third hour.
- In the baseline tests, the percent solid recorded every hour had a more distinct increase (i.e., 16% - 17% - 18% - 19%) than the runs with the magnets. This was not observed for the baseline test run without the chilled fish tank. This run (BT#5) ranged from 15.2% - 14.8%, which is more representative of the magnet runs that had a more consistent percent solid every sample.

The dry filter samples and stored wet samples collected from both the baseline tests and Flagship Group tests were also inspected using a microscope set to 100X magnification. There was no observable difference between any of the samples. Two crystal formations were apparent in all the samples, wet or dry. One formation was spherical in shape, and the other formation was long and thin. Some of the needle-like crystals appeared broken. This could be due to the fast flow velocity of the simulant as it passed through the pump.

Pump data were also recorded every hour samples were taken. In reviewing the pump information, no patterns were observed. In fact, the flow rate is not a linear correlation to the % solids as was expected. In other words, a greater solid concentration did not mean a slower simulant flow rate.

It must be noted that the technology demonstration does not prove whether the Enviro-Beam XL does or does not prevent blockage formation. Nor does it show if the particles are kept in suspension as the manufacturer claims. The technology evaluation was performed only to determine if any changes would occur with the magnets versus the baseline tests. No conclusions can be made as to why they happened or if they would consistently repeat. Not enough tests were run, and the margin of error is too large to state that the above observations are scientifically valid. A much more complex test setup would be required to validate the technology.

Precautions need to be taken to maintain the magnetic units closed or properly stored to avoid over-exposure due to the large magnetic flux emitted from the exposed face of each individual magnet.

NuVision (former AEAT) Wave-Action Technology

In September 2000, NuVision Engineering Inc. demonstrated the technology based on a fluid erosive wave-action principle on a capped pipeline, which operates much like ocean wave-action on beach erosion. The system consists of a water/solvent tank, pressurized/vacuum vessel, fluidic control unit, vacuum finishing pump, and an air-operated jet pump eductor.

NuVision’s technology operates much like ocean wave-action on beach erosion, possibly aided by use of a solvent, coupled with positive and negative pressure pulses that tend to loosen the blockage. It can operate on a long pipeline that has drained down below a blockage. The system consists of a water/solvent tank, a pressurize/vacuum vessel (charge vessel), a portable air compressor, jet pump pair and valve manifold, a fluidic control unit, a vacuum finishing pump, a system controller, and a system module. First, a vacuum pump is used to evacuate a majority of the air in the pipeline below the blockage in elevation. Once a partial vacuum has been established, a ball valve is opened, and the fluid is allowed to back fill the pipeline. Since a portion of the air remains, a cavity forms near the elevated blockage which is inserted at the end of the pipeline. The fluidic control system is then used to create waves in the pipeline by providing positive and negative pressures at the inlet of the pipeline in a cyclic manner. A cycle consists of three phases; a suction phase, a drive phase and a vent phase. During the suction phase the fluid is pulled back into the charge vessel. The fluid is quickly expelled during the drive phase, creating a wave in the cavity near the blockage. In the vent phase, the system is vented to atmosphere, allowing the fluid to settle. This process is repeated numerous times until the blockage is removed.

The duration and pressure level of each cycle can be controlled via the fluidic control unit. This coupled with the dissolving action of a selected solvent and the physical action of the vacuum and pressure cycles works to both erode and loosen the blockage.

Benefits of NuVision's technology include:

- Short mobilization and demobilization time possible with an adaptive jumper.
- Can be used to deliver chemical solvent to the blockage where a solvent may be of assistance in loosening a blockage.
- Can be applied to the section of the pipeline that has drained down below the elevation of the blockage.
- System works under relatively low drive pressures (0.689 MPa (100 psi) tested.)
- Technology can negotiate many elbows.
- Technology can be operated remotely.
- No water discharged until the blockage is cleared - minimizing the amount of liquid added.
- Relative location of the blockage can be determined by the amount of water required to back-fill the pipeline.

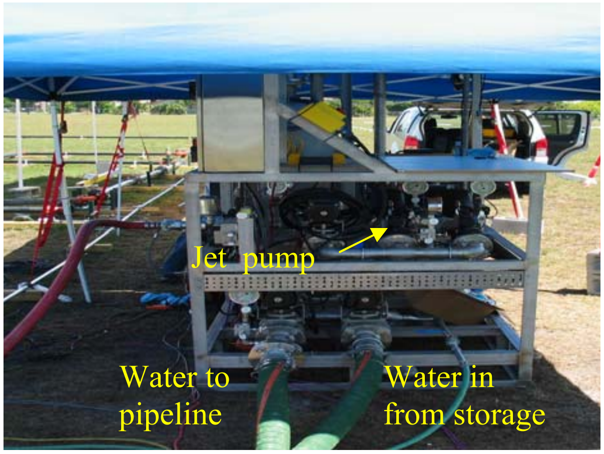
Limitations of NuVision's technology include:

- Length of reach in an empty pipeline is limited by the strength of the vacuum pump.
- Unplugging times are relatively long.

Characteristics of blockages

A total of 12, 0.305 m (1 ft) long, blockages were tested on test bed # 2. Blockages were made from a variety of materials (see Table 1) and placed at two different locations. Eleven blockages were tested at a distance of approximately 77.724 m (255 ft) from the access port, and one blockage was tested at the end of the 537.97 m (1765 ft) pipeline. In order to best demonstrate the technology, Test Bed #2 was modified upon agreement by AEAT, DOE-TFA, NETL, and FIU. The 1.524 m (5 ft) test section of the pipeline was tilted up at 76.2 m (250 ft) from the access port approximately 5° with respect to the ground to simulate a graded pipeline that has drained down below a blockage. In order to observe and measure the rate at which a blockage is being physically eroded, a section of clear PVC pipe containing the blockage was attached to the pipeline. The test section was capped due to the inability of short (one-foot-long) test blockages to adequately hold a vacuum against the NuVision system.

In 2007, another set of experiments were conducted using the NuVision's Wave-Erosion Method at three different pipeline set ups with total lengths of 86.868 m (285 ft), 189.281 m (621 ft) and 547.726 m (1797 ft). The test beds were instrumented with pressure transducers at several locations in order to understand the variation of pressure magnitude in the pipe during an unplugging operation of the technology. Since the technology requires an air cavity prior to the plug, the plug section, which is placed at the end of the pipeline, was tilted at an angle of 1°. This allowed most of the air in the pipeline to be collected at the highest point, which is the plug section when the system is flooded with water.



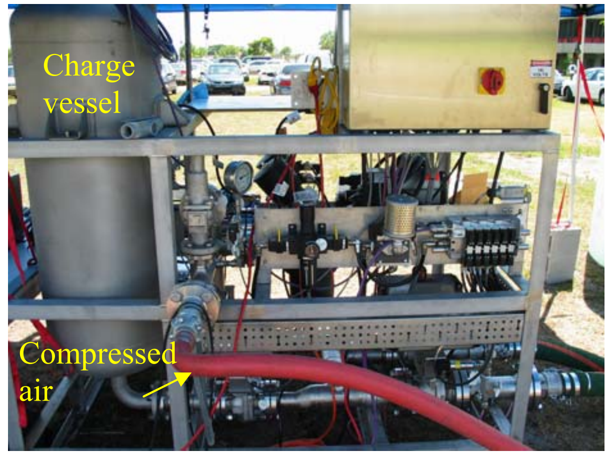


Fig. 3. NuVision Engineering pipeline unplugging skid used in 2007.

The plug sections were manufactured out of 1.22 m (4 ft) PVC 3 inch pipes with flanges attached at the ends. The transparent PVC pipes had a pressure rating of 1.034 MPa (150 psi) which reduced the pressure limit NuVision could operate at, however, they were instrumental in visual observation of the erosion mechanism during the experiments. Actually, the 7.32 m (24 ft) section right before the plug was also made of transparent PVC pipes which helped to understand the behavior of the air bubble and water wave during the suction and drive cycles caused by the technology.

Three different plug materials were manufactured for the tests conducted with NuVision in 2007, which were Kaolin clay/water mixture, Phosphate based chemical plug and Aluminum based gel plug. The recipes of the plugs were recommended by DOE in order to simulate various sludge and plugs that are formed due to crystallization. The ability of the technology to push the plugs out of the plug section was inhibited using a closed ball valve after the plug and concentration was given to the erosion capability of the technology.

It was observed that the fastest eroding plug was the Phosphate based chemical plug which almost dissolved directly as soon as the water wave hit it. The rate of erosion was 9.5 kg/hr at 86.868 m (285 ft), 10.32 kg/hr at 189.28 m (621 ft) and 9.9 kg/ hr. The other two plugs demonstrated to have similar erosion rates which were 0.476 kg/hr and 0.698 kg/hr at 86.868 m (285 ft) for Kaolin and Al-gel respectively and 0.6 kg/hr, 0.478 kg/hr at 189.28 m (621 ft) and 0.214 kg/hr and 0.146 kg/hr at 547.73 m (1797 ft).

Extrapolation of NuVision's capability to remove plugs over 609.6 m (2000 ft) from access points was not possible due to: limitation of current vacuum pump and variation of results with temperature. The influence of environmental conditions (diurnal heating of pipeline) on the air cavity size and test results was significant. The environmental variability noted in our testing would not be an issue at the cross-site lines at Hanford since they are buried and have little temperature cycling during the day. Further testing is needed to eliminate the environmental parameters from influencing the test results.

The Atlantic Group Technology

In FY00, FY01, and FY02, The Atlantic Group demonstrated AIMM Technologies' Hydrokinetic™ Technology for cleaning fouled and completely blocked pipes, heat exchanger tubes, and furnaces. In FY01, The Atlantic Group demonstrated the technology on longer and multiple blockages in Test Bed #2.

For FY02, the vendor demonstrated for the first time to FIU their new computer controller, which semi-automates the Hydrokinetic™ process by controlling the water and air valves located at the system's manifold.

The Hydrokinetic™ process is based on the induction of sonic resonance within a cleaning water stream. This sonic resonance travels through the water stream and transfers vibration to both the pipe and the blockage. Because of the different compositions of the pipe wall and the blockage material, the blockage and the pipe wall vibrate at different frequencies, thus breaking the cohesive bond between them and allowing the blockage to be expelled from the pipe.

By amplifying the pulsation with a high-pressure plunger pump, the water stream accelerates to achieve a velocity of 640.08 m/s (2,100 ft/s). The generation of the sonic vibration takes a few milliseconds to complete, and the tube or pipe being cleared is exposed to the sonic wave for only a fraction of the process time. A maximum frequency of 11,250 vibrations per minute can be achieved, far below the number of cycles per second needed to cause metal fatigue in even soft metals such as copper-nickel alloys or copper.[1]

Pigs were also used during the demonstrations to aid in the cleaning process. The pigs were placed in the test bed inlet and propelled through the pipeline with either water or compressed air. After applying the Hydrokinetic™ process on the blocked pipeline, a bare foam pig would be sent into the line. The physical condition of the expelled foam pig dictates to what degree the line has been cleaned and how hard the blockage material is. If the blockage material is extremely hard, such as the case with the epoxy blockage, then a steel bristle pig would be sent in to aid in the cleaning process.

The Hydrokinetic™ system demonstrated at FIU consisted of a mechanical control unit, which was replaced by a computer controller in FY02, that regulated the water pressure and compressed air inside a manifold (see Figures 17a and 17b). The manifold supplied high-pressure water and compressed air to the Hydrokinetic™ inlet nozzle that was connected to the fouled pipeline. The high-pressure water pump has a pressure rating of 68.947 MPa (10,000 psi) with a flow rate of 0.0757 m^3/min (20 gpm). During the demonstrations at FIU, the water pressures recorded at the manifold for filling the pipe ranged from 0.689 MPa (100 psi) to 2.758 MPa (400 psi) and the pressures for pulsating ranged up to 16.547 MPa (2400 psi). The air compressor had a pressure rating of 0.827 MPa (120 psi).

Benefits of the Hydrokinetic™ system include:

- Short mobilization and demobilization time;
- Commercially available;
- Water is discharged away from the operator;
- Quick unplugging time;
- Can negotiate many elbows before and after the blockage;
- Easily reached and expelled the plug through the 1500 ft of pipeline available;
- Can be operated remotely; and
- According to the vendor, the length of pipeline the system can reach is virtually unlimited. However, due to physical restrictions of our test site, this claim could not be verified.

Limitations of the Hydrokinetic™ system include:

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[1] Technical description is based in part on literature provided by the vendor.

- Water is not contained or recycled, although under actual conditions, the water would be discharged at the final destination of the pipeline (i.e., storage tank);
- High amount of water usage; and
- Technology was not able to gain access through the 1-in access port on Test Bed#1.

The manifold consists of a high-pressure water inlet and outlet, bypass valve, compressed air inlet, and pressure gauge. The manifold connects the high-pressure water from the plunger pump and the compressed air from the air compressor and delivers it to the inlet nozzle based on the signals it receives from the computer controller. The high-pressure water pulsations are controlled by opening and closing the valves in the manifold.

The nozzle is attached to the inlet of the pipe to be cleaned. The high-pressure water outlet and compressed air from the manifold are connected to the nozzle. The compressed air hose can be disconnected and the connection valve used as a manual purge to relieve pressure inside the pipeline.

In previous years, the operator controlled the manifold valves, and, hence, the water pressure at the manifold that is introduced into the pipeline, by pressing a series of buttons on the mechanical control unit. For FY02, the system demonstrated was upgraded with a computer controller that semi-automated the process. The system regulates the open/close sequence for the water and air valves. This sequence is what produces the high-pressure water pulsations that create the sonic resonance. The water pressure the system delivers is based on the initial pipeline design parameters inputted by the operator into the computer program. It must be noted that the system is designed for welded pipes and cannot take into account the grooved pipes and couplings of the FIU test beds. In automatic mode, the computer signals the manifold to induce the pulsations once it reads that the pressure in the manifold is increasing, signaling that the pipeline is filled with water. In manual mode, the operator controls the water pressure and pulsations induced at the manifold. The blockage is known to be dislodged once the pressure readings displayed on the controller from the manifold begin to lower.

During FY00, The Atlantic Group responded to a solicitation in collaboration with DOE-TFA and FIU to participate in a demonstration of pipeline unblocking technologies at the FIU test beds. The Hydrokinetic™ Technology proved capable of dislodging all tested blockages. In Test Bed #1, the technology was able to dislodge approximately 75% of the first 1.524 m (5 ft) epoxy-sand partial blockage and 100% of the second identical blockage. The partial blockages are applied approximately 1-in thick from the inside wall of the 2-in diameter pipe. In Test Bed #2, the technology was tested on several 1.524 m (5 ft) Kaolin clay-sand and Bentonite-sand blockages located at various places along the first 457.2 m (1,500 ft) of pipeline and was capable of completely clearing all blockages from the nine tests. The technology's effectiveness or performance was unaffected by the presence of 5 elbows along the 457.2 m (1,500 ft) pipe run. For both test beds and all blockages, the cleaning process was aided by the use of a wire bristle pig. It was concluded that, though the Hydrokinetic™ Technology demonstrated its versatility, it warranted further investigation to refine the operating parameters. Modifications to the initial testing parameters (blockage type, length, and locations) could better define the limits of the technology.

In FY01, The Atlantic Group returned to demonstrate the Hydrokinetic™ Technology on longer and multiple blockages in Test Beds #1 and #2. A single epoxy blockage was tested on Test Bed #1, and a total of 5 Bentonite and K-mag blockages were tested on Test Bed #2. Blockage combinations were arranged in different configurations for each test. Figure 21 shows the blockage locations for the various tests on Test Bed #2.

The one blockage tested on Test Bed #1 was a 6.096 m (20 ft) long partial epoxy-sand blockage. The blockages tested on Test Bed #2 included a 1.524 m (5 ft), 3.048 m (10 ft), 4.572 m (15 ft), and 6.096 m (20 ft) long K-mag and a 6.096 m (20 ft) long Bentonite-sand blockage. The technology was capable of removing 100% of the blockages from the pipeline in four of the five tests done on this test bed. However, the Hydrokinetic™ Technology was unable to unplug the 6.096 m (20 ft) K-mag blockage in Test Bed #2 and the 6.096 m (20 ft) epoxy-sand blockage in Test Bed #1. In Test Bed #2, it was able to dislodge the K-mag blockage from its original location; however, the blockage ultimately lodged again 30.48 m (100 ft) downline. When the pipe sections were removed, the blockage had been severely compressed and hardened from the over-pressurization of the blockage.

It is believed that due to the thin pipeline walls (3/32 inches), pipe section grooves, and the external gasket coupling connectors, the Hydrokinetics™ process was unable to maintain a constant force on the plug required to move the 6.096 m (20 ft) blockage without over-pressuring the system. In Test Bed #1, a plastic pig was inserted to aid in the removal of the 6.096 m (20 ft) epoxy-sand blockage, which was installed approximately 19.812 m (65 ft) from entry point. The adjoining pipe sections at the blockage locations separated approximately 1 minute after the process started. Removal of the plugged section of piping showed no dislodging of the blockage. The wire bristle pig had worked its way approximately 6 in into the blockage; however, there was no blockage removed or dislodged.

For FY02, The Atlantic Group demonstrated for the first time to FIU AIMM Technologies' new computer controller. The controller automates the Hydrokinetic™ process by controlling the water and air valves located at the manifold. When running in fully automatic mode, the controller determines when the pipeline is filled with water and when pulsating should commence. The controller also determines at what water pressure to operate based on the pipe design parameters input by the operator. It should be noted that the system does not recognize the coupling design of the FIU test beds. Although it does recognize different pipe materials, it assumes that pipe sections are joined by welds. The controller also only reads the water pressure at the manifold and is unable to determine the water pressure in the pipeline.

FY02's demonstration consisted of two epoxy blockage tests in Test Bed #1 and four K-mag blockage tests in Test Bed #2. In Test Bed #1, the Hydrokinetic™ Technology was unable to remove the 3.05 m (10 ft) epoxy blockage from the first test. It was, however, able to remove approximately 90% of the 1.524 m (5 ft) epoxy blockage from the second test. In Test Bed #2, the technology was successful in removing 100% of the 1.524 m (5 ft) and 3.048 m (10 ft) K-mag blockages associated with Tests #1 through #3.

Recently in 2008, AIMM's technology was evaluated using a similar testbed that was used in 2007 for NuVision Engineering. One difference included the addition of a pressure relief valve that forced AIMMs to operate under 2.068 MPa (300 psi), a pressure limit provided by the DOE. The testbed was instrumented with 6 static and 6 dynamic pressure transducers, 2 accelerometers and two thermocouples. In order to capture the high speed pulsations caused by the AIMM's control unit, data is recorded at a high speed using LabView FPA data acquisition system. The pressure sensors are distributed along the pipeline at various locations in order to provide the pressure variation along the pipeline, provide information about pressure losses across tee-sections and elbows and expansion loops. At every point where the pressure value is measured, one static and one dynamic pressure sensor was placed in order to capture the high frequency fluctuations in the pressure. The accelerometers are placed at the inlet and outlet sections of the pipeline to evaluate the vibration characteristics of the pipeline under the effect of pulsations caused by the AIMM's control unit.

Various blockage materials were manufactured for the testings conducted with AIMM's Technology in 2008. These were Bentonite/ Water mixture (68% by weight), Kmag/Water mixture (90% by weight) and a Sodium Aluminum Nitrate (SAN) plug which was recommended by the Waste Treatment Plant (WTP). Most of the blockages were manufactured in 1.22 m (4 ft) pipes although some Kmag plugs were made in 0.61 m (2 ft) sections as well. We also evaluated the effect of the length of Bentonite blockages by combining 1.22 m (4 ft) sections in order to make 2.44 m (8 ft) and 3.66 m (12 ft) long blockage sections.

Before utilizing the blockages during the unplugging trials, we evaluated the maximum water pressure required to force the plugs out by using a hand pump supplied with an analog pressure gauge. This was done to establish whether the plugs could be removed with simple over pressurization during the unplugging trials. The results showed that in order to remove a 1.22 m (4 ft) Bentonite plug, the minimum required pressure was about 1.172 MPa (170 psi). A similar value of 2.068 MPa (300 psi) was obtained for the 2.44 m (8 ft) plug. The 1.22 m (4 ft) Kmag plug was able to hold 4.482 MPa (650 psi) of pressure applied for about 15 mins without any water breaking through. However, the 0.61 m (2 ft) Kmag plug started leaking at 2.068 MPa (300 psi) and held pressure up to 3.103 MPa (450 psi) before a significant amount of water broke through. The pressure required to remove the 1.22 m (4 ft) SAN plug was found to be 3.447 MPa (500 psi).

During commissioning, a number of test plugs were installed to assist in the design of the test matrix. At the 94.488 m (310 ft) pipe length, AIMMs was able to remove a 1.22 m (4 ft) Bentonite plug and a 0.61 m (2 ft) Kmag plug. They were not able to remove the 1.22 m (4 ft) Kmag plug at this pipe length. At the 196.9 m (646 ft) pipe length, they were successful in removing a 1.22 m (4 ft) Bentonite, 1.22 m (4 ft) SAN, 2.44 m (8 ft) Bentonite and 0.61 m (2 ft) Kmag plugs. At the 555.346 m (1822 ft) pipeline length, they were able to remove a 1.22 m (4 ft) Bentonite plug but were unable to remove an 2.44 m (8 ft) Bentonite plug.

During the unplugging trials with AIMM Technologies, it was observed that they were unsuccessful in unplugging the 1.22 m (4 ft) Kmag, the 1.22 m (4 ft) WTP plug and the 2.44 m (8 ft) Bentonite plug at 555.346 m (1822 ft) pipeline, the 1.22 m (4 ft) WTP plug, the 1.22 m (4 ft) Kmag plug at 196.9 m (646 ft) pipeline and the 1.22 m (4 ft) WTP plug at 94.488 m (310 ft) pipeline. On the other hand, they were able to remove the 3.66 m (12 ft) Bentonite at 555.346 m (1822 ft) pipeline, the 3.66 m (12 ft) and the 2.44 m (8 ft) Bentonite plugs at 196.9 m (646 ft) and at 94.488 m (310 ft) pipelines and the 1.22 m (4 ft) Kmag plug at 94.488 m (310 ft) pipeline.

CONCLUSIONS

The objective of this study was to present the unplugging technologies that were evaluated at FIU for their ability to unplug plugged lines at various lengths and configurations. It was observed that most of the technologies evaluated , excluding NuVision Engineering Inc. and AIMM Technologies Inc., could not negotiate the large number of elbows in the pipeline which reduced the effectiveness of the methods for long pipelines. In addition, water usage was an issue with these technologies since water was not contained or recycled in the system. NuVision and AIMM's technologies were found to be more promising compared to other methods and further analysis showed that these methods could be implemented at DOE sites without requiring much modification to their systems. NuVision's technology needs an air gap before the blockage section so it is not clear whether the technology can work for negative sloping pipelines or vertical pipelines. Additional testing in a control environmental set up would be necessary in the future in order to extrapolate the technologies performance. AIMM's technology was able to remove sludge-based plugs effectively but had difficulty removing the chemical and crystallized plugs. However, the theory behind the vibration characteristics of the pipe line still needs to be analyzed. Data analysis for the AIMM's testing will be conducted in early 2009.

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