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Qualification of Innovative High Level Waste Pipeline Unplugging Technologies

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ABSTRACT

In the past, some of the pipelines have plugged during high level waste (HLW) transfers resulting in schedule delays and increased costs. Furthermore, pipeline plugging has been cited by the “best and brightest” technical review as one of the major issues that can result in unplanned outages at the Waste Treatment Plant causing inconsistent operation. As the DOE moves toward a more active high level waste retrieval, the site engineers will be faced with increasing cross-site pipeline waste slurry transfers that will result in increased probability of a pipeline getting plugged. Hence, availability of a pipeline unplugging tool/technology is crucial to ensure smooth operation of the waste transfers and in ensuring tank farm cleanup milestones are met. FIU had earlier tested and evaluated various unplugging technologies through an industry call. Based on mockup testing, two technologies were identified that could withstand the rigors of operation in a radioactive environment and with the ability to handle sharp 90 elbows. We present results of the second phase of detailed testing and evaluation of pipeline unplugging technologies and the objective is to qualify these pipeline unplugging technologies for subsequent deployment at a DOE facility. The current phase of testing and qualification comprises of a heavily instrumented 3-inch diameter (full-scale) pipeline facilitating extensive data acquisition for design optimization and performance evaluation, as it applies to three types of plugs atypical of the DOE HLW waste. Furthermore, the data from testing at three different lengths of pipe in conjunction with the physics of the process will assist in modeling the unplugging phenomenon that will then be used to scale-up process parameters and system variables for longer and site typical pipe lengths, which can extend as much as up to 19,000 ft. Detailed information resulting from the testing will provide the DOE end-user with sufficient data and understanding of the technology, and its limitations to aid in the benefit-cost analysis for management decision whether to deploy the technology or to abandon the pipeline as has been done in the past.

INTRODUCTION

As Hanford moves into a more active retrieval and disposal program, the site engineers will be encountering increasing cross-site pipeline transfers with the increase in the probability of a pipeline getting plugged. In the past, some of the pipelines have plugged during waste transfers resulting in schedule delays and increased costs. Furthermore, pipeline plugging has been cited as one of the major issues that can result in unplanned outages at the Waste Treatment Plant causing inconsistent operation. As such, availability of a pipeline unplugging tool/technology is crucial to ensure smooth operation of the waste transfers and ensuring Hanford tank farm cleanup milestones. Previous studies at FIU included the testing and evaluation of unplugging technologies through an industry call. Two technologies were identified based upon the testing that could withstand the rigors of operation in a radioactive environment and in with the ability to handle sharp 90 elbows. The proposed testing and evaluation of these two technologies extends the technology validation performed earlier and will attempt to qualify pipeline unplugging technologies for deployment at the Hanford site as per the site criteria.

The testing and validation of the unplugging technology comprises of a heavily instrumented 3-inch diameter pipeline facilitating extensive data acquisition for design optimization and performance evaluation, as it applies to three types of plugs typical of the waste at Hanford. Furthermore, the data from testing at three different lengths of pipe in conjunction with the physics of the process will assist in modeling the unplugging phenomenon that will then be used to predict process parameters and system variables for longer and site typical pipe lengths, which can extend up to 19,000 ft. Detail information resulting from the testing will provide the DOE end-user with sufficient data and understanding of the technology, and its limitations so that management decisions can be made whether the technology has a reasonable chance to successfully unplug a pipeline, such as a cross-site transfer line or process transfer pipeline at the Waste Treatment Plant.

NUVISION'S UNPLUGGING PRINCIPLES

Based on pipeline unplugging technologies demonstrations conducted at FIU in FY99 to FY02, NuVision's Fluidic Wave-action Technology was one of the two most promising technologies selected for qualification testing for the Hanford site. The operating principles of these technologies are outlined in this section.

NuVision's technology is based on a fluid wave-action principle, which 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. The fluidic control system is then used to generate waves in the fluid by providing positive and negative pressures to the fluid 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 frequency and duration, as well as the pressure, 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 (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.

EROSION AND PARAMETRIC STUDY

In this section, evaluation of the erosion effect and the parametric analysis to be conducted are described.

Erosion Effect

The Fluidic Wave-action technology generates cyclic action of waves hitting the face of the blockage in the pipeline which in return can induce erosion of the blockage material. During this process the face of the blockage exposed to the wave impact is scoured and the sediments are carried away by the waves during the suction phase.

In the scientific literature, such an erosion effect has been studied mainly in the field of beach erosion due to long-term ocean wave effects or storm surge events. Among the studies on beach erosion, the most similarity with the current case can be seen in dune erosion due to wave impact. Coastal dunes constitute the defense lines against high waves and storm surges. It is of vital importance to be able to predict the impact of waves on a dune in terms of recession distance, eroded volume and probability of breaching. Several analytical and numerical models have been proposed for the purpose of predicting dune erosion. In the current study, the "wave impact theory" method developed by Fisher and Overton [1] and Nishi and Kraus [2] will be utilized, where erosion is modeled as a function of the frequency and intensity of the impacts.

In Fig. 1, the sketch for modeling the dune erosion due to wave impact is presented. In order to estimate the erosion the weight (ΔW) of the sediment volume eroded from the dune must be predicted. The weight of the eroded volume is given by

$$\Delta W = \Delta V \rho_s (1-p) g \qquad \text{(Eq.1)}$$

where ρ_s is the density of the sediment, p porosity, and g acceleration of gravity. The total swash force for a number of bores impacting the dune during a time period Δt is written as

$$F_o = \frac{1}{2}\rho \frac{u_o^4}{g C_u^2}\frac{\Delta t}{T} \qquad \text{(Eq.2)}$$

The average rate of dune erosion can be derived by equating the swash force (F_o) and the weight of eroded volume (ΔW),

$$\frac{\Delta V}{\Delta t} = -\frac{1}{2}\frac{C_E}{C_u^2}\frac{\rho}{\rho_s}\frac{u_o^4}{g^2 T}\frac{1}{(1-p)} \qquad \text{(Eq.3)}$$

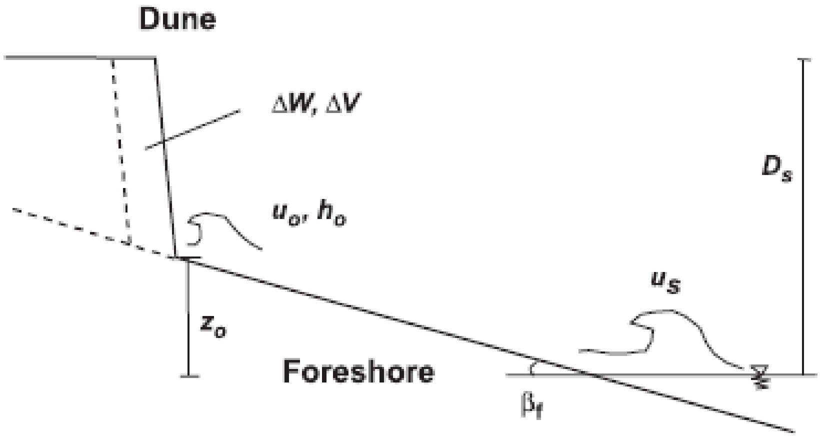


Fig. 1. Definition sketch for modeling dune erosion due to the wave impact [3].

Here C_E and C_U are empirical constants to be determined and u_o will be predicted by another model predicting the propagation of pressure pulses along the pipeline.

During the unplugging testing, a video camera was placed in front of a transparent section of the pipeline where the wave action on the plug was visible. Parameters required for the erosion model were obtained and the model results will be compared with the unplugging rates obtained from experimental results.

Parametric Study

Process variables important to this study include unplugging rates and pipeline pressure distributions (maximum pipe pressure) and their variability with respect to the equipment control parameters. The equipment control parameters, which are provided later in this article, are the parameters NuVision must select to operate their equipment. The effect of these parameters on the pipeline pressure and wave mechanics/erosion rates needs to be well understood. In addition, to qualify NuVision's technology, maximum pressures will need to be determined and compared with site safety requirements. Due to the lack of information on exactly how the NuVision's technology scales to longer pipes, we will adopt a parametric approach to evaluate the technology functionality and how it is expected to affect the process variables.

The following data was collected to provide the understanding of the technology, its capability, limitations and safety.

- Pressure profile along the test bed, time dependent pressure measurements at several pressure taps along the test bed
- Maximum pressure in the test bed pipeline during technology operation
- Temperature of the process fluid (water) in the test bed pipeline
- Atmospheric temperature and pressure
- Cycles of operation (time)
- Plug weight – before and after technology operation
- Unplugging rate
- Equipment control parameters

Other data from the test bed that will be used in the analysis include:

- Distance to the plug , distance from the test bed entry point to the plug
- Plug length
- Nature of the plug, composition of the material used to create the plug
- Number of elbows in the test bed from entry point to the plug
- Distances between pressure transducers

EXPERIMENTAL TESTING

Test Bed Details

Testing was conducted using 3 test bed lengths. The test bed lengths were selected based on the idea that testing parameters (i.e., unplugging time, erosion rates etc.) obtained at three different lengths could be used to predict the parameter at lengths up to 19,000 ft. This will be done by fitting a curve on the test data and extrapolating that to 19,000 ft. In order to predict the testing parameter at 19,000 ft, it is important to select the three lengths (L_1, L_2 and L_3) properly. Since most of the rheological data is non-linear, L_1, L_2 and L_3 can be selected according to the geometric progression, $L = ar^N$, where $N = 1,2,3\ldots$ Selecting $a = 100$ ft and $r = 1.3$, gives for $N = 4$, $L_1 = 286$ ft, $N = 7$, $L_2 = 627$ ft, $N = 11$, $L_3 = 1792$ ft and $N = 20$, $L_4 = 19005$ ft. The values of a and r were selected to match the value of 19,000 ft as a future value in the geometric series. Using a non-linear regression analysis, the measurements taken at L=286 ft, 627 ft and 1792 ft will enable us to extrapolate the performance of the technology to much longer pipes (19,000 ft).

The instrumented test bed for technology qualification was designed and constructed with the capability to evaluate the impact of a number of parameters on the technology effectiveness including; the distance to the plug, pipe layout (e.g. bends, expansions, reducers, etc.) and connection with limited accessibility (through a Hanford connector inside a pit).

Schematic diagrams of the test beds are shown in Fig. 2 and Fig. 3. The test beds are constructed from 3-inch diameter, 21 foot long, Schedule 10, carbon steel pipe sections joined by Victaulic couplings.

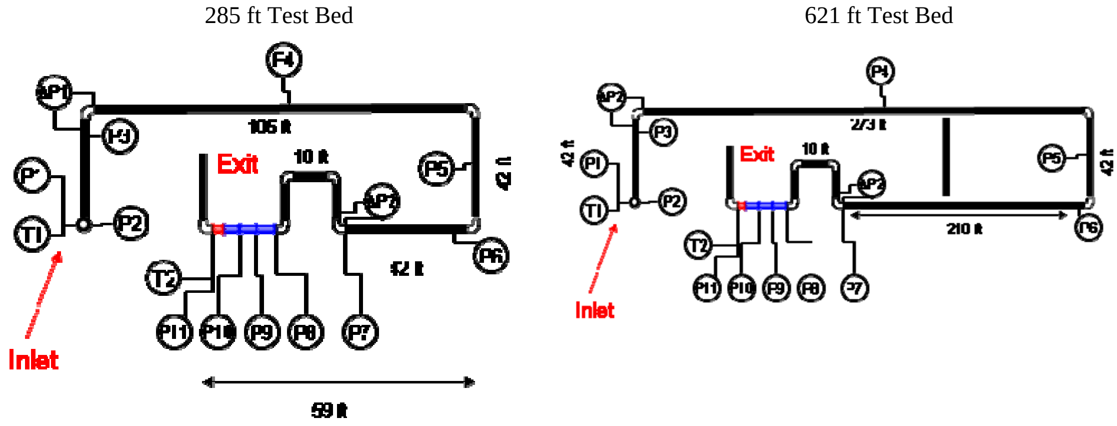


Fig. 2. Schematics of 285 ft and 621 ft test beds.

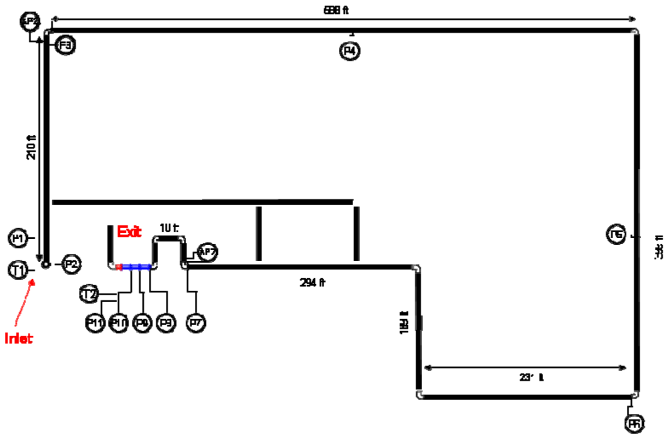


Fig. 3. Schematics of 1797 ft test bed.

The test bed is designed so that the inlet and exit sections remain in the same location for each of the three test beds. To simulate the connection to the transfer lines in a pit, the inlet section is connected vertically to the long horizontal section via sharp 90^o elbow. The test bed entry point is equipped with standard 3-inch Victaulic 741 flange. As shown in Fig. 2 and Fig. 3, pressure transducers are located throughout the test bed to provide data on pressure losses around elbows and over various pipe lengths. In addition a number of pressure transducers have been place near the blockage.

Three 8-foot clear PVC pipe sections are located upstream of the blockage. This allows for the examination of the wave as it approaches the blockage. The clear section is inclined at 1^o to simulate the site elevation. Fig. 4 provides a detailed drawing of the inclined section and blockage. The blockage is placed into a 4-foot section of clear PVC. The low coefficient of friction between the PVC and some of the plugs required that the ball valve be placed just behind the blockage. The ball valve prohibited the blockage from moving which otherwise could have been pushed out during the testing process. A 21 ft pipe section was used as the discharge section and was placed after the ball valve.

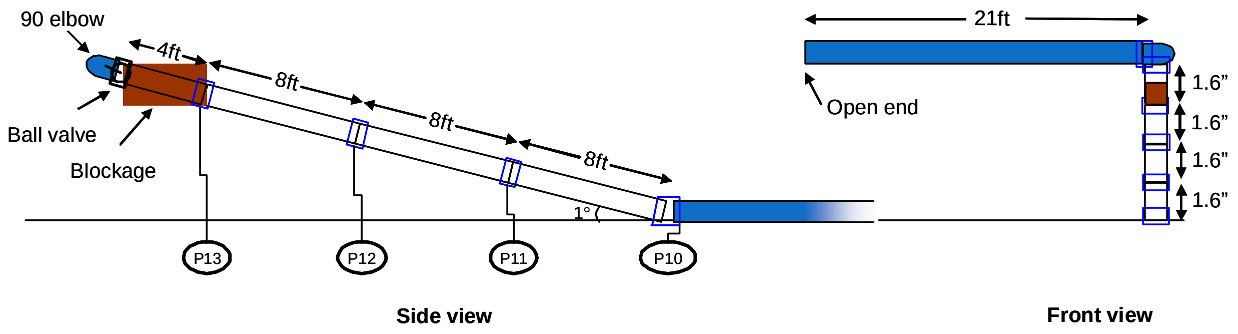


Fig. 4. Detailed drawing of the inclined section.

A pressure relief valve, rated at 150 psi, was installed upstream and adjacent to the clear inclined section. The operating pressure of the clear PVC is the test bed's limiting component - at an operation pressure of 150 psi. Also shown in the test bed drawings (Fig. 2 and Fig. 3), is a removable expansion loop located just upstream of the inclined clear section. This loop, containing 3-10 ft sections, emulates the expansion loops typical of the cross-site lines at Hanford. The expansion loop can be removed to evaluate the effectiveness of the technology with and without the loop present.

A removable reducer to 2-inch pipe with subsequent expansion back to 3-inch was used to evaluate its effects on the technologies effectiveness. The reducer was installed on the 285 foot test bed upstream of the expansion loop.

The transducers were connected to a data acquisition system for simultaneous recording of pressure along the test bed during the unplugging tests. Such pressure profiling allows extrapolation of technology performance to longer pipeline distances based on curve fitting of pressure profiles. Time histories of pressure at different tap locations along the test bed will also allow measurement and subsequent extrapolation of pressure waves in the pipeline. In addition to the pressure transducers, one thermocouple was installed in the test bed to monitor the temperature during the unplugging process.

The various lengths of the test beds will be used to evaluate how the effectiveness of the unplugging technology is impacted by the distance to the blockages as well as pipe layout (bends, expansions, reducers, and elevation changes before and after the plug). Evaluation of unplugging efficiency at different distances from the test bed entry point will also allow a projection of how the technology would perform at longer distances (e.g. 19,000 ft for the cross-site transfer line).

Blockage Materials

In order to evaluate how the effectiveness of the unplugging technology is impacted by the character of the plug, three blockage materials were used. Kaolin clay water mixture was used to emulate settled sludge and phosphate and aluminum gel was used to emulate crystallized salt plug.

Literature suggests that the most relevant blockage material property with respect to conveyance system potential of plugging, choking, and slugging is cohesiveness [4, 5]. Cohesiveness characterizes the tendency of the material to adhere to itself and to conveyance system equipment. For many sludge-like materials, the expected cohesiveness is a function of the shear strength [5]. Kaolin clay water mixture was recommended as a sludge simulant by Golcar et al. [4] and Powell et al. [5] because its shear strength, cohesiveness, particle size distribution, and density (for 66-67 wt% kaolin in water) are similar to those of tank sludge. Comparison of material properties of kaolin water mixture with those of Hanford tank sludge is given in Table 1. The data in this table is extracted from graphs contained in Powell et al. [5]. Detailed comparisons are also available in Powell [6] and Powell et al. [5]. FIU-ARC also conducted shear strength, tensile strength, and stickiness measurements of kaolin clay water mixtures to verify that kaolin obtained by FIU-ARC is similar to that used by Powell et al. The result of this characterization is presented in Fig. 5 and Fig. 6. It is seen from these figures that shear and tensile strength of kaolin-water mixtures studied by Powell et al. [5] and by FIU-ARC are similar to each other.

Table 1. Comparison of Material Properties of Kaolin Water Mixture with Hanford Tank Sludge

	Mean Particle Diam, µm	Shear Strength, kPa	Density, g/cm^3
Kaolin water mixture (66 wt% kaolin in water)	1.02	3.5	1.65
Tank Sludge	1.2	0 to 5	1 to 2

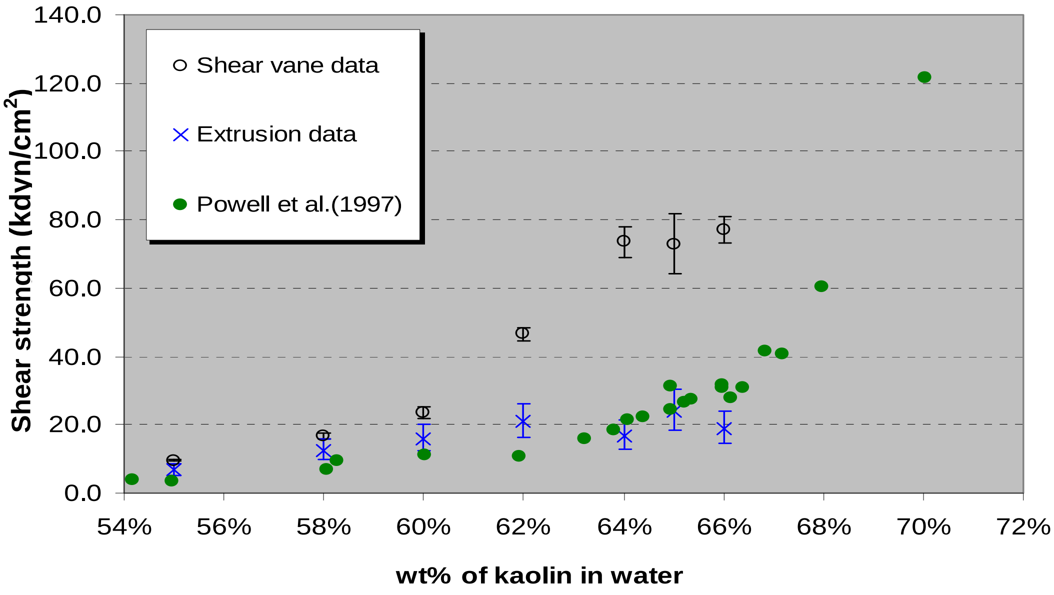


Fig. 5. Shear strength of kaolin-water mixture as a function of the wt% of kaolin in water.

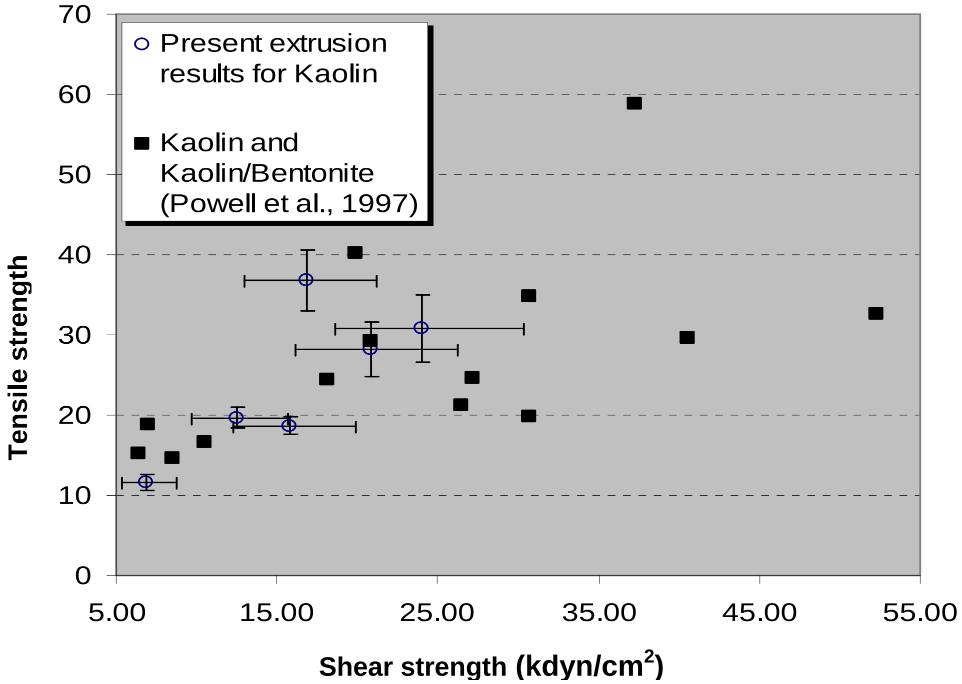


Fig. 6. Tensile strength versus shear strength for kaolin-water mixture.

Hanford and WTP engineers recommended that phosphate and aluminum gel should be used as crystallized salt blockage simulants. This type of plug may form in a pipeline due to precipitation of waste salts caused by temperature changes or supersaturation due to mixing of different waste types. Composition of the phosphate simulant is given in the Table 2 and was obtained from a master thesis at Mississippi State University [7]. This simulant is expected to gel.

Table 2. Compositions of Phosphate Blockage Simulant

Component	Molarity
$NaAlO_2$	1
NaOH	2
Na_2CO_3	0.1
$NaNO_3$	7
Na_3PO_4 $12H_2O$	0.3

The recipe for the aluminum gel is provided by the WTP. Beaker testing was performed at FIU and gelling was observed. The aluminum nitrate is dissolved in water separately to prepare the matrix solution. Sodium hydroxide and sodium carbonate are dissolved in a separate cup to prepare the gelling solution. Finally the gelling solution is added to the matrix solution to get the final Al-OH gel. The compositions of the ingredients are given in Table 3.

Table 3. Composition of aluminum Blockage Simulant

Component	Molarity
Al(NO3)3 9H2O	1.0
NaOH	3.0
Na2CO3	0.5

The plugs were created in 4-foot pipe lengths. They were weighed before and after an unplugging test to determine the weight of removed plug material and effective unplugging rates.

NuVision Equipment

To create the fluidic-wave action, NuVision uses a complex pneumatic pumping system, shown in Fig. 7. Water is stored in a 1000 gallon storage tank and enters the pumping skid as indicated in Fig. 7. Water can be allowed to flow directly into the pipe test bed or it can be used to fill the 40 gallon charge vessel. An air compressor, not shown in the figure, provides compressed air at 140 psi. The compressed air, shown entering the skid in the red pipe, is passed through a jet pump which can provide a vacuum and pull water from the pipeline into the charge vessel (suction phase) or it can be used to provide a positive air pressure and drive the water from the charge vessel. Prior to flooding the pipeline, the jet pump is used to pull a vacuum in the pipeline. A vacuum pump is then used to achieve the pressure needed, with the quality of vacuum pull dictating the size of the air cavity. With the low pressure established in the pipeline, the water storage tank is used to flood the pipeline.

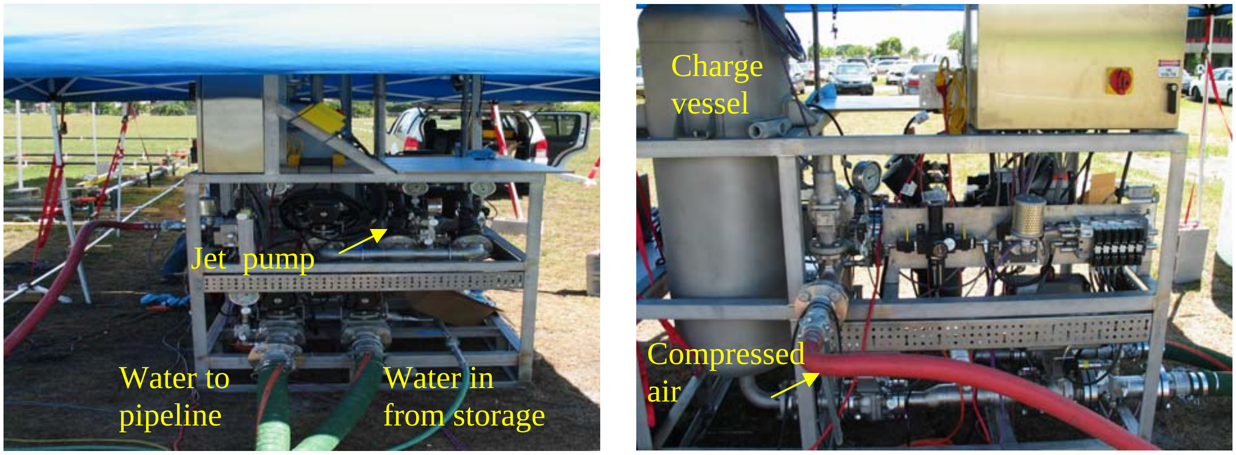


Fig. 7. NuVision Engineering pipeline unplugging skid.

After the pipeline is flooded, the equipment is used in a three phase cycle that is continuously repeated to remove the blockage. Prior to operating the equipment, NuVision has to set the equipment control parameters. These parameters define how the equipment will operate and ultimately the type of wave that is produced near the blockage. The equipment control parameters are: vacuum level, drive pressure, suction time, drive time and vent time. Optimizing these parameters to provide a wave that does not exceed our 150 psi limit is a non-trivial task. Part of the goal of this study is to provide an understanding of how each of these parameters affects the erosion wave and resulting pipe pressures.

Test Plan

The test plan for NuVision’s unplugging technology is provided in Table 4. Sixteen trials were completed including 6 on the 285 ft. pipeline, 5 on the 621 ft. pipeline and 5 on the 1797 ft. pipeline. As mentioned previously, three different blockages were used on each of the pipeline lengths. The blockages were placed into a 4 ft. clear PVC section. Due to the low coefficient of friction between the blockages and the clear PVC, a ball valve was place behind the blockage to keep it from being pushed out during the drive phase. Although, pushing the blockage out is a viable method for unplugging, it was not considered in this study since we did not believe that appropriate coefficient of frictions could be established. We, therefore, are only considering erosion and dissolution as methods for unplugging.

The test plan also shows that an expansion loop was used in the baseline test bed for all plug types and all pipe lengths. (The number 1 in the test plan indicates that it was used in the trial and the number 0 indicates that it was not used in the trial.) For each length one trial was conducted without the expansion loop using a kaolin blockage to determine the effects of the expansion loop on the unplugging rates. For the 285 ft. test bed, a 3” to 2” reducer was added just upstream of the expansion loop to see what effects it may have on the pipeline pressures and unplugging rates. In addition, blind flange testing (no plug) was conducted in which the drive pressures, drive times and suction times were varied to analyze their effects on the wave mechanics and resulting pressures.

Prior to each test bed length, NuVision conducted equipment control parameter tests to determine the optimal settings for the test bed. This primarily consisted of varying 3 of the 5 parameters: drive pressure, drive time and suction time. The vent time appeared to play a less significant role on the wave mechanics and it was not practical to vary the vacuum level.

Table 4. Test Plan for NuVision’s Unplugging Technology

Trial #	Reducer	Expansion Loop	Blockage Type	Distance to Blockage
1	0	1	Kaolin	285 ft
2	0	1	Phosphate	285 ft
3	0	1	Al-gel	285 ft
4	1	1	Kaolin	285 ft
5	0	0	Kaolin	285 ft
6	0	1	Blind Flange	285 ft
7	0	1	Kaolin	621 ft
8	0	1	Phosphate	621 ft
9	0	1	Al-gel	621 ft
10	0	0	Kaolin	621 ft
11	0	1	Blind Flange	621 ft
12	0	1	Kaolin	1797 ft
13	0	1	Phosphate	1797 ft
14	0	1	Al-gel	1797 ft
15	0	0	Kaolin	1797 ft
16	0	1	Blind Flange	1797 ft

RESULTS AND OBSERVATIONS

Unplugging Rates

Unplugging rates for various blockages and test bed configurations are shown in Table 5. Blockages were typically eroded between 25 to 50% of the original mass with the exception of the phosphate blockage which was completely dissolved/eroded at each test bed length. In general, the aluminum gel blockages produced unplugging rates similar to those produced by the kaolin blockages. The trials without the expansion loops were unpredictable. For the 285 ft. test bed, the unplugging rate of the kaolin was significantly higher when the loop was removed. This was not the case for the longer runs. In the 1797 ft. trial without the expansion loop, an extremely low rate was observed (*). This was due, in part, to the fact that the kaolin near the wave did not erode easily, but water did manage to penetrate into the plug.

When weighing the blockage to determine the percentage of erosion, the additional water retained by the plug may have skewed the final calculated rate, indicating a less effective unplugging rate than what actually occurred.

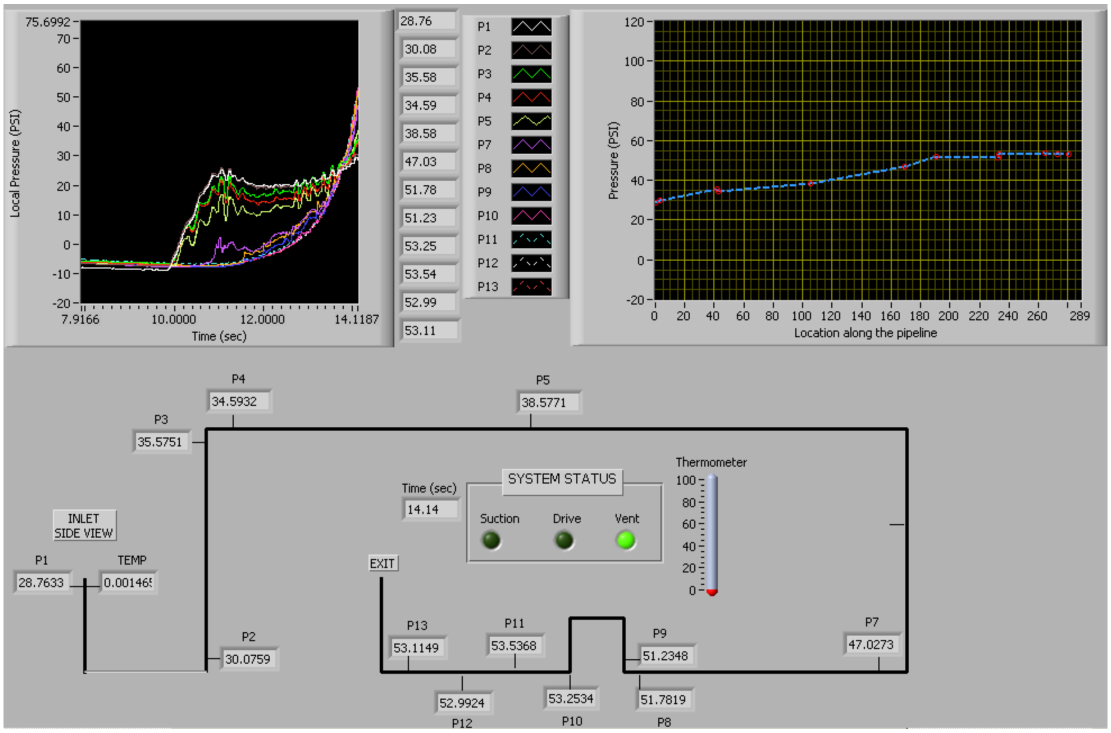
Unplugging rates for the longest pipeline length were lower than the rates for the other two lengths, as expected. However, there was not a pattern for the unplugging rates between the 285 ft. and 621 ft. test beds.

Table 5. Unplugging Rates

Pipeline Length	Blockage Type	Unplugging Rate (kg/hour)
285 ft	Kaolin	0.476
285 ft	Phosphate	9.500
285 ft	Aluminum Gel	0.698
285 ft	Kaolin w/o exp. loop	0.902
621 ft	Kaolin	0.600
621 ft	Phosphate	10.32
621 ft	Aluminum Gel	0.478
621 ft	Kaolin w/o exp. loop	0.282
1797 ft	Kaolin	0.214
1797 ft	Phosphate	9.900
1797 ft	Aluminum Gel	0.146
1797 ft	Kaolin w/o exp. loop	0.088*

Pressure Data

The pressure and wave data from the testing are currently being analyzed. Plots of the pressure during the drive and suction phases are shown in Fig. 8. These plots represent virtual simulations of the pipeline pressures during testing. The graph in the upper left corner shows the pressure readings at every transducer location along the pipeline as a function of time. The graph in the right corner provides a snapshot of all the pressure transducers at the last data point in the left graph. A schematic of the pipeline is also provided showing the location of the pressure transducers and their corresponding values at the same time used in the right graph.



P1	28.76
P2	30.08
P3	35.58
P4	34.59
P5	38.58
P7	47.03
P8	51.78
P9	51.23
P10	53.25
P11	53.54
P12	52.99
P13	53.11

P4 34.5932

P5 38.5771

P3 35.5751

Time (sec) 14.14

P1 28.7633

TEMP 0.00146

P2 30.0759

P13 53.1149

P11 53.5368

P9 51.2348

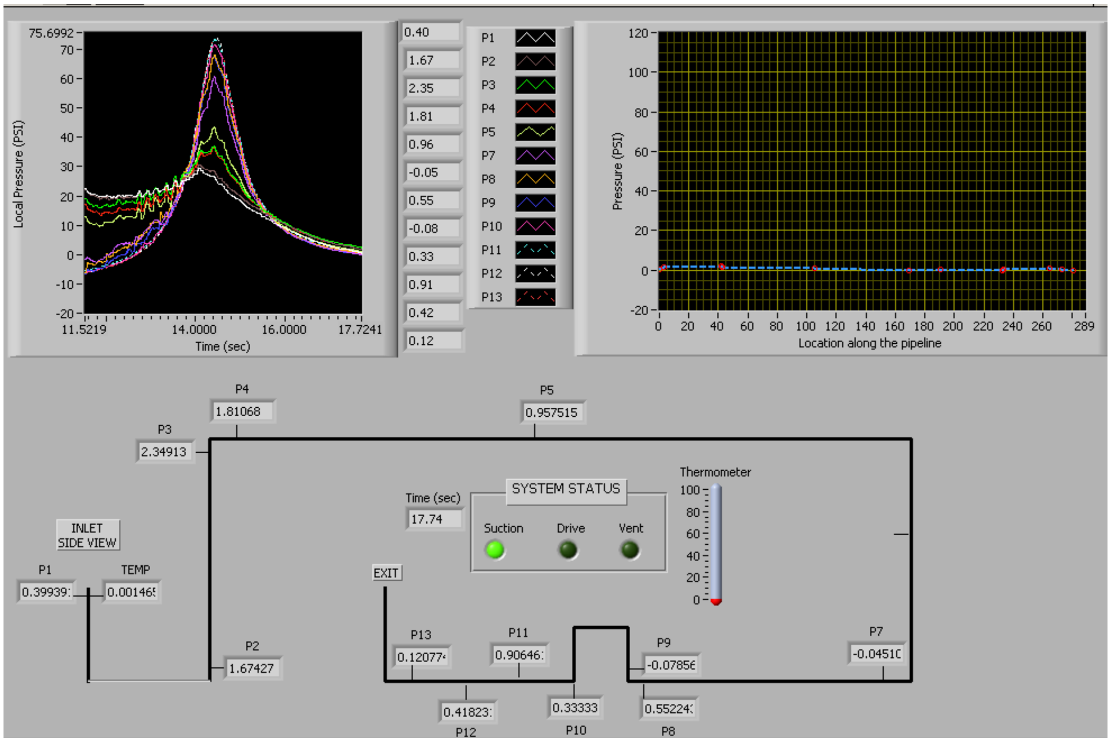
P7 47.0273

P12 52.9924

P10 53.2534

P8 51.7819

(a) Pressure distribution during the drive phase



P1	0.40
P2	1.67
P3	2.35
P4	1.81
P5	0.96
P7	-0.05
P8	0.55
P9	-0.08
P10	0.33
P11	0.91
P12	0.42
P13	0.12

P4 1.81068

P5 0.957515

P3 2.34913

Time (sec) 17.74

P1 0.39939

TEMP 0.00146

P2 1.67427

P13 0.12077

P11 0.90646

P9 -0.07856

P7 -0.0451

P12 0.41823

P10 0.33333

P8 0.55224

(b) Pressure distribution during the following suction phase

Fig. 8. Virtual simulation of pipeline at 285 ft using a blind flange.

These figures demonstrate that the inlet pressure is amplified significantly when compared to the resulting pressure at the exit. The amplification factor, which is defined by the exit pressure divided by the inlet pressure, can be obtained by determining the inlet pressure from Fig. 8a and the exit pressure from Fig. 8b. For this trial, the amplification factor is approximately 75/25 or 3. Understanding this amplification of the pressure is key in qualifying NuVision's technology.

Observations

During the testing a number of observations were made that will provide assistance in determining how the data can be used for qualifying the technology at Hanford.

The amplification of the drive pressure near the blockage appears to be due to the increased momentum of the fluid in the pipeline. If the drive pressure/drive time is too low, losses in the pipeline will slow the momentum to the point that a wave is not produced in the air cavity and there is little amplification of the drive pressure. If the drive pressure/time is too high, the resulting exit pressure can easily surpass the relief valve pressure rating.

During the suction phase of each of the test beds, the air cavity was pulled back into the expansion loop which is relatively flat. This means there is additional two-phase flow in our test bed that would not be present on the cross-site lines at Hanford. The energy losses of the unplugging wave are more significant when there is an increased two-phase flow regime.

Testing demonstrated that under the initial vacuum, some blockages were pulled apart with portions being slightly moved upstream. The kaolin blockages were particularly susceptible to this due to the low coefficient of friction between the kaolin and the clear PVC. Typically, the blockage would break into 2 or 3 sections and the most forward section would move a foot or so upstream. In some cases the portion of the blockage that moved upstream would move back to its original position after the first drive phase. This did not appear to have an effect on the general unplugging rates.

In addition, testing also demonstrated that environmental conditions could affect the results adversely. On the longer test bed lengths, the identical vacuums pulled on the pipeline did not necessarily produce the same cavity size. This required an unexpected change in the equipment system parameters.

Plan for Analysis

As mentioned previously, data evaluation is under way. Currently, our plan for data analysis includes:

1) Evaluation of the equipment control parameters and how they affect the wave mechanics and pipeline pressure distribution
2) Determining the effect of elbows, pipe lengths, reducers, and the expansion loop on flow momentum loss and pressure distributions
3) Characterizing the unplugging wave – use a Matlab edge detection routine to study video – obtain wave speed and correlate with pipeline pressure and equipment control parameters
4) Correlating unplugging rates with wave mechanics and pipeline pressures
5) Propagating system variables (unplugging rate and max pressure) to longer pipe lengths - try to establish a bound on these variables
6) Propagating equipment control parameters to longer pipe lengths

CONCLUSIONS

The ultimate objective of this study is to qualify NuVision's unplugging technology for use at Hanford. Experimental testing has been conducted using three pipeline lengths and three types of blockages. Erosion rates have been obtained and pressure data is being analyzed. An amplification of the inlet pressure has been observed along the pipeline and is the key to determining up to what pipe lengths the technology can be used without surpassing the site pressure limit. In addition, we will attempt to establish what the expected unplugging rates will be at the longer pipe lengths for each of the three blockages tested. Detailed information resulting from the testing will provide the DOE end-user with sufficient data and understanding of the technology, and its limitations so that management decisions can be made whether the technology has a reasonable chance to successfully unplug a pipeline, such as a cross site transfer line or process transfer pipeline at the Waste Treatment Plant.

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