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NuVision Engineering Power Fluidics™ System: Improving the Efficiency of Enhanced Chemical Cleaning

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ABSTRACT

Millions of gallons of high level waste are stored in underground tanks across the United States. In recent years, the radioactive waste threatens to leak from the aged tanks, which poses a tremendous risk to surrounding soil and groundwater. The United States Department of Energy (DOE) has taken decisive measures to transport this waste into more secure double-shelled tanks by way of a pipeline. While the liquid waste is easily transported, it is the hard salt-cake heel concentrated at the bottom of these tanks that poses an engineering challenge. The Savannah River Site (SRS) is currently in pursuit of dilute-chemical acid cleaning of high level waste tanks in preparation of final tank closure. Active circulation is required to promote a fresh boundary layer between the heel and the oxalic acid. Standard slurry mixer pumps cease operation when the tank's liquid level drops below approximately 30 inches. NuVision Engineering Inc.'s Power Fluidics™ pulse jet mixers are capable of operating at 1 to 2 inches above the tank floor. The objective of NVE's FY09 work is to demonstrate that the Power Fluidics™ technology is a viable option for this mixing duty. The demonstration was conducted in a temporary tank that replicates the bottom of a Type-I tank at an 80% scale. In the demonstration, Power Fluidics™ equipment included a valve/jet pump skid, charge vessels located outside the tank, and two nozzles. Adjustable parameters included fluid level, nozzle direction, nozzle height, and drive pressure. Thermal flow meters were used to record scalar velocities that must achieve a minimum of 0.2 ft/s as set by site representatives. The Power Fluidics™ system was able to achieve 0.2 ft/s in many areas across the tank and was dependent on the direction of the nozzles [4]. This report details the work performed by DOE Fellow, Lee Brady, during his summer internship assignment at NuVision Engineering Inc (a DOE contractor).

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1. INTRODUCTION

The Savannah River Site (SRS), located in South Carolina, has a total of twelve 750,000-gallon-capacity tanks, numbered 1-12. These tanks were built in the 1950's and are located in the H and F tank farms. The tank farms are located below the water table. The tanks are primarily carbon steel shelled and rest in a carbon steel pan that extends 5 ft up the tank sidewall. The tanks are 75 ft in diameter and approximately 25 ft high. The tanks are densely populated with horizontal and vertical cooling coils as well as columns. The aging tanks show signs of leaks, which threaten surrounding soil and groundwater. A cross section of a Type-I tank is shown below in Figure 1.

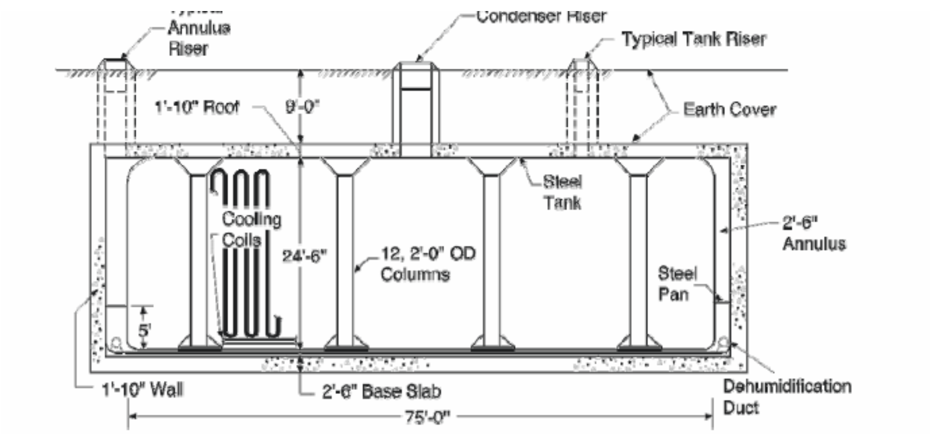

Figure 1: Type-I tank cross-section.

In preparation of final tank closures, SRS is pursuing dilute-chemical acid cleaning of high level waste (HLW) tanks. The enhanced chemical cleaning (ECC) process aims to reduce oxalate loading and total volume of cleaning solution in comparison to previous methods. The ECC process uses a 1-wt% oxalic acid with a depth of 12 to 24 inches. Active circulation is necessary to promote a fresh boundary layer between the oxalic acid and the hard salt-cake heel that has formed at the bottom of the tank. Due to the low liquid levels and the tank's obstructions, the circulation of these fluids has become an engineering challenge of its own. NuVision Engineering (NVE) demonstrated how their Power Fluidic™ technology is a viable option for the mixing duty.

Power Fluidics™ pulse jet mixers (PJM's) use a clean medium in the form of compressed air to move radioactive fluids and are maintanence free as they have few to no moving components in contact with the fluids.

The demonstration was conducted in a temporary tank that approximated the bottom of a Tank-I at an 80% linear scale. The scaled tank is 60 feet in diameter, and water will be used to simulate liquid mixing. The purpose of the demonstration was to determine the effectiveness of Power Fluidics™ pulse jet mixing in achieving the required velocity throughout the tank when constrained by available tank riser positions. According to SRS scientists, the specified mixing velocity is 0.2 ft/s or greater throughout the tank. It is not necessary to maintain the target velocity at all times or at all locations simultaneously [4].

2. EXECUTIVE SUMMARY

This research work has been supported by the DOE/FIU Science & Technology Workforce Initiative, an innovative program developed by the US Department of Energy's Environmental Management (DOE-EM) and Florida International University's Applied Research Center (FIU-ARC). During the summer of 2009, DOE Fellow (Lee Brady) spent 10 weeks doing a summer internship at NuVision Engineering Inc., located in Mooresville, N.C., under the supervision and guidance of Mr. Ethan King and Mr. Patrick Nevins. The intern's project was initiated on May 25, 2009, and continued through July 31, 2009, with the objective of being a test-engineering intern and commissioning an 80% scaled Type-I high level waste tank. The objective was to demonstrate that Nuvision's Power Fluidics™ technology is a viable option for the low level mixing duty needed for the Savannah River Site's dilute-chemical cleaning process. The intern was advised by the lead CE&I (control, electrical & instrumentation) lead mechanical engineer, and project manager. The test engineer intern engaged in the commissioning of the equipment in the test facility. The intern conducted tests to characterize the performance of a single nozzle plume, validate the performance of a two nozzle system acting to create tank wide convection cells, and validate the performance of a two nozzle system converging on specific locations. The intern's duties during the conduction tests included: operating the equipment, maintaining logbooks, recording data, compiling test records, conducting regular walk downs of the facility, summarizing data, and analyzing results. The intern worked closely with lead engineers to evaluate the performance during testing and modify the methods, parameters, and procedures as required to demonstrate a positive outcome. The intern was responsible for two independent visualization systems which included idea generation, prototyping and trials, design and implementation. The intern also significantly expanded 3D modeling and animation using SolidWorks software. The 3D modeling and animation provided visual aids to illustrate how the Power Fluidics™ system will be incorporated in high level waste tanks.

3. RESEARCH DESCRIPTIONS

3.1 SRS Tanks

The waste storage tanks in SRS, located in the F and H Area tank farms, were built from 1951 to 1981. They were built in three different sizes and four different designs. The four different designs are designated as Types I through IV. Table 1 shows a summary of the tanks located in the F and H Area tank farms [4].

Table 1. Summary of Tanks Located in F and H Area Tank Farms [4]

Tank No.	Type	Capacity (gal)	Tank Size	Cooling Coil Configuration
1-8 F	I	750,000	75ft dia. X 25ft h	36 Parallel Cooling Coils suspended from top of tank
9-12 H	I	750,000	75ft dia. X 25ft h	
13-16 H	II	1,030,000	85ft dia. X 27ft h	44 Parallel Cooling Coils suspended from top of tank
17-20 F (closed)	IV	1,300,000	85ft dia. X 34ft h	No Cooling Coils
21-24 H	IV	1,300,000	85ft dia. X 34ft h	
25-28 F	III	1,300,000	85ft dia. X 33ft h	All Type IIIA waste tanks (e.g., Tanks 38-43) have internal fixed distributed cooling coils. Type III waste tanks (e.g., Tanks 29-32) do not have internal fixed distributed cooling coils. Instead, these tanks are cooled with cooling bundles which are installed through the "B Risers" located on the tank top. Four different types of cooling bundles are installed inside Type III tanks (type of coil varies by tank): cylindrical deployable, conical deployable, heavy-duty compact and reciprocating. Tank 35 has design features of both Type III and IIIA waste tanks. However, Tank 35 has heavy-duty compact bundles installed through B risers consistent with Type III waste tank design.
29-32 H	III	1,300,000	85ft dia. X 33ft h	
33-34 F	III	1,300,000	85ft dia. X 33ft h	
35-37 H	IIIA	1,300,000	85ft dia. X 33ft h	
38-43 H	IIIA	1,300,000	85ft dia. X 33ft h	
44-47 F	IIIA	1,300,000	85ft dia. X 33ft h	
48-51 H	IIIA	1,300,000	85ft dia. X 33ft h	

The NuVision Engineering (NVE) Inc. demonstration used the Type I design as the basis of their mock-up. More specifically, the Type-I number 8 tank was modeled in the NVE facility [4].

3.2 Scaling

The fluid and operating parameters were scaled to maintain important dimensionless groups in order to maximize the realism of the model. The dimensionless groups selected as the most important were the Reynolds number (at nozzle), the Strouhal number, and the inertia/pressure force ratio (ie. the Euler number). Scaling calculations, taken from the memorandum: "Mixing Evaluation on a Type I Waste Tank" (Reference 1), were combined with Mixtran™, simulations made by NVE (References 2 and 3) to size the components of the demonstration system. Mixtran™ is a NVE proprietary software for modeling Power Fluidics™ systems [5].

From these calculations, the scaled system employed a 30.4-mm nozzle and a 3.8-m high charge vessel. For the full scale system, a 38-mm nozzle and a 6.07-m charge vessel would be used. All other components and dimensions were the same as the full-sized system [4].

3.3 Demo Tank Components

The scaled demonstration was constructed in the NVE facility located in Mooresville, NC. The 80% scaled tank measured 60 feet in diameter. The demonstration tank was capable of a maximum depth of 3 feet and had a 55,000 gallon capacity. Figure 2 below shows that it was made from wood with a PVC liner.

Figure 2: PVC lined tank.

Having a tank holding thousands of gallons poses a risk of leaks and flooding to surrounding businesses as well as water damage to the NVE facility. A leak detection system was installed to provide warning of any leaks. Leak detection cables ran around the circumference of the tank. If the leak detection cables sensed moisture, it would trigger alarms as well as start a Vacuboom annulus system, illustrated in Figure 3 below.

Figure 3: Preliminary Vacuboom testing.

Figure 3 shows the preliminary testing of a Vacuboom system. When the tank was filled with water, the hoses of the Vacuboom stretched around the tank. Figure 3 shows how successful the Vacuboom was in preventing the water from leaking beyond the boundaries of the hose.

The obstructions in the mock-up were built to reflect what existed in Tank 8. It was fitted with horizontal and vertical cooling coils made from PVC pipe. The columns were simulated by blue barrels. Figure 4 illustrates the final assembly of all obstructions in the tank.

Figure 4: Complete demo tank with obstructions.

Visualization components were also inserted into the tank as seen in Figure 5 below. Flow streamers and bobbers were assembled in order to indicate flow patterns across the tank. The intern was responsible for two independent visualization systems which included prototyping, design and implementation.

Also, two overhead cameras were used to give the overall view of the entire tank while testing was in progress.

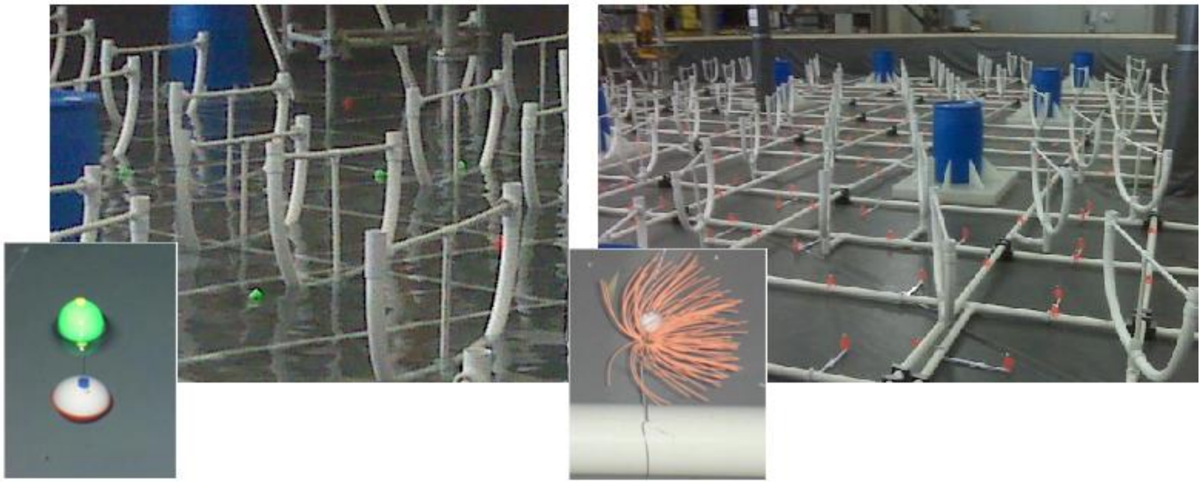

Figure 5: Visualization components.

3.4 System Components

For this demonstration, the fluidic mixing system was based on two pulse jet mixers (PJMs), each comprising of a horizontal nozzle, a charge vessel, a jet pump pair, and associated valves and controls. For the demonstration, NVE used two mixer charge vessels, two pulse jet nozzles (including supports and means for rotation), a jet pump/valve skid, a controller, and interconnecting hoses [4].

A deployable system would include an off-gas skid and up to four mixer charge vessels. The charge vessels and, potentially, jet pump pairs would be inside the tank [4].

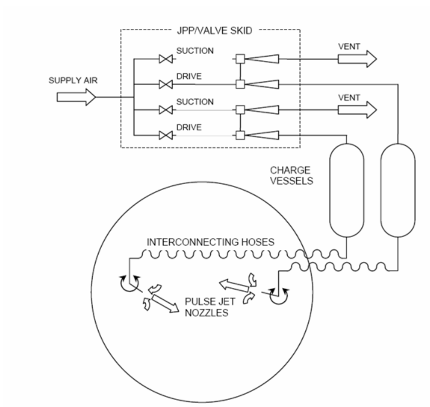

Figure 6: Power Fluidics™ main components. [4]

The following describes NVE's patented process. Taking a look at Figure 6, compressed air is supplied across the valve skid. In this case, the valve skid consists of two jet pump pairs. One side of the jet pump pair allows air to vent to the atmosphere while the other goes to the charge vessel. NuVision Engineering's patented Power Fluidics™ systems operate in three phases: suction, drive, and a vent phase.

Figure 7 illustrates what takes place in the jet pump pair while in the suction phase. The valve on the drive input side of the jet pump is closed while the valve at the suction input side of the jet pump is open. As compressed air rushes through the jet pump and out to the atmosphere, it creates a vacuum that sucks liquid into the charged vessel.

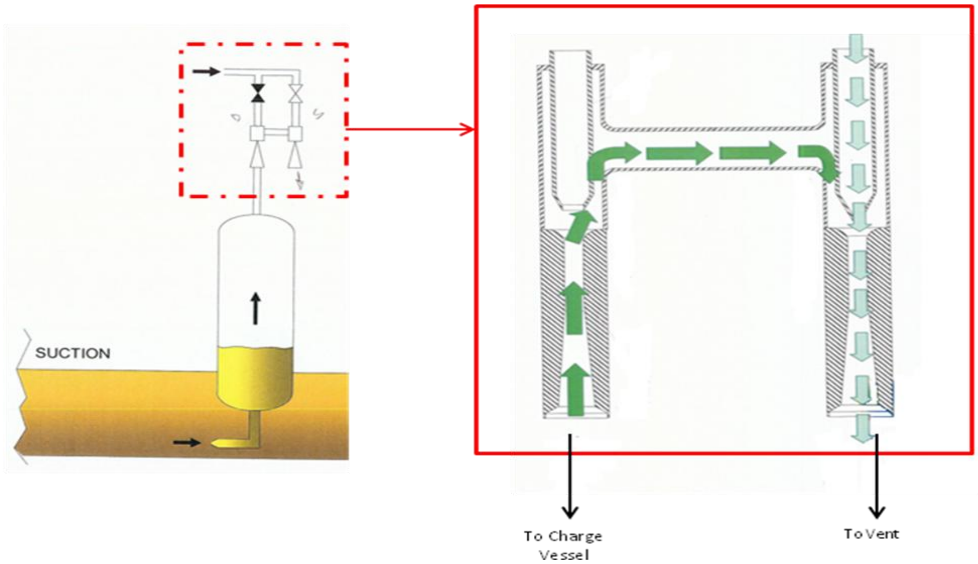

Figure 7: Jet pump pair - suction phase.

The second phase, illustrated in Figure 8, is the drive phase. In this case, the suction input valve is closed, and the valve at the drive input side of the jet pump is now open. This allows compressed air to rush into the charge vessel and expel the liquid, returning it to the tank to mix. (A small amount of air bleeds out the vent to atmosphere.).

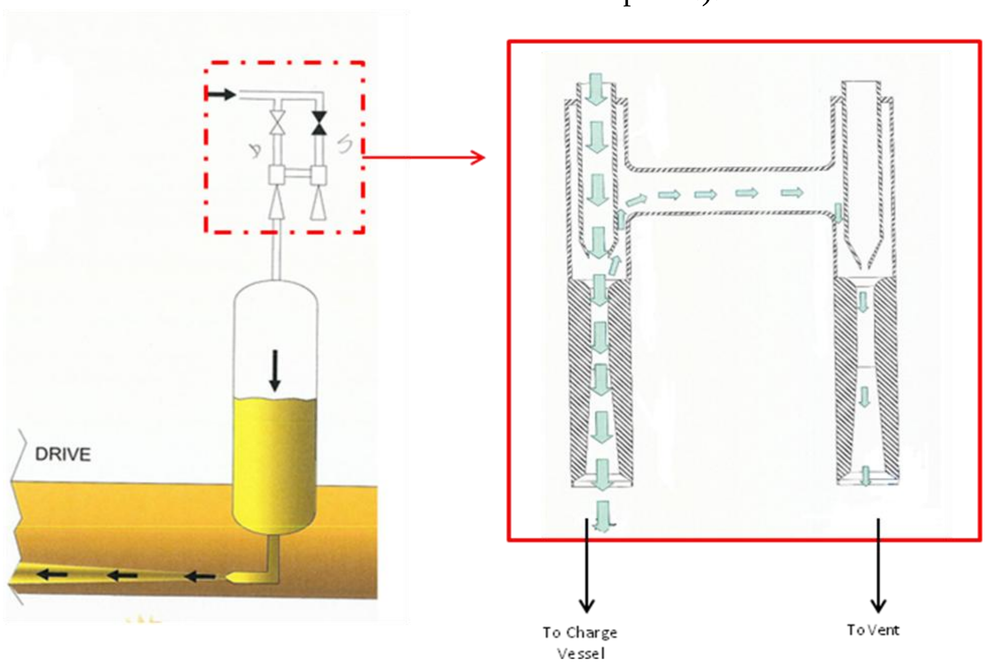

Figure 8: Jet pump pair - drive phase

The third and final phase is called a vent phase and is illustrated in Figure 9. In the vent phase, the two input valves are closed, and the charge vessel and jet pump pair are returned to equilibrium to start the three-phase cycle again.

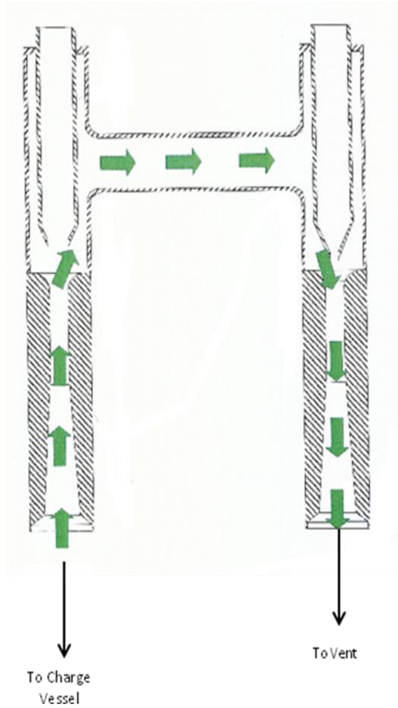

Figure 9: Jet pump pair - vent phase.

The Power Fluidic™ System is controlled by a Prescon™ controller (Figure 10).

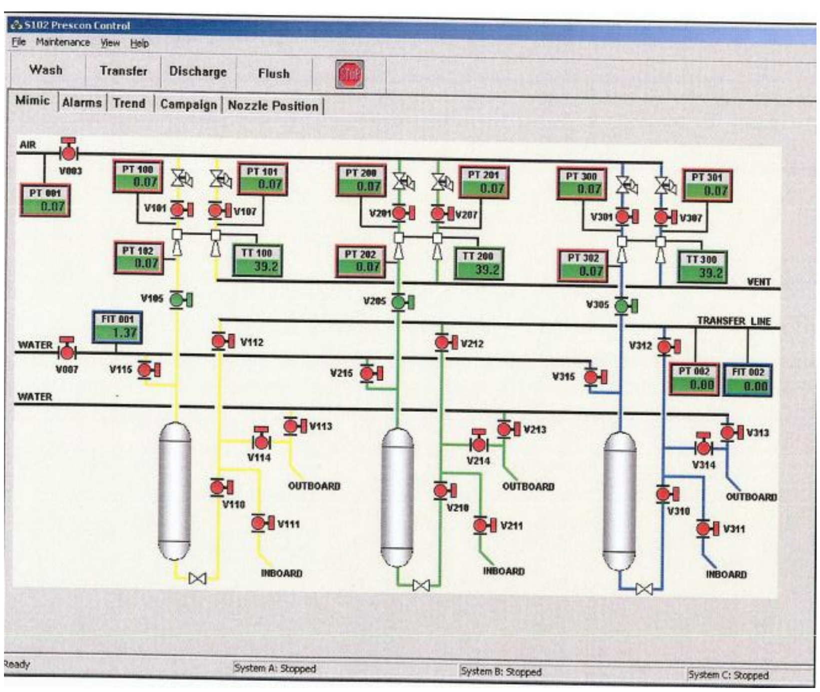

Figure 10: Prescon™ controls. [2]

Prescon™ Controls allow the user to view and control many system parameters.

3.5 Adjustable Parameters

Adjustable parameters for the demonstration included the fluid level in the tank which can range from 12” to 36”. The nozzle direction can be manually adjusted to various clock positions. The nozzle height can be adjusted to various heights above the tank floor. The input drive pressure can also vary to affect the nozzle discharge. In the demonstration, 3 bar and 5 bar pressures were used [4].

3.6 Demo Campaigns [4]

Campaign #1

- Single nozzle plume, far wall
- Objective was ≥ 0.2 ft/sec

Campaign #2

- Two nozzles, coordinated target
- Objective was ≥ 0.2 ft/sec

Campaign #3

- Two nozzles, tangential orientation, circulating tank
- Objective was ≥ 0.2 ft/sec

3.7 Data logging

Data logging was automatically performed by the Prescon™ controls. When the system started, the Prescon™ controls immediately began logging the parameters of the system. The most important parameter was velocity. Velocity was measured by the use of thermal flow meters.

Thermal flow meters were used because they can measure flow coming from many directions. Common types of flow meters, such as magnetic flow meters, are dependent on flow direction and cannot be used in an open tank environment. The thermal flow meter used for this experiment was from Fluid Components International (FCI) as seen in Figure 11.

Figure 11: FCI flow meter.

The FCI flow meter consists of two pins at the end, just like a thermal couple. One pin is heated while the other is a sensing pin that measures the temperature drop between the two.

The difference in temperature is then given in volts. For a given fluid, a higher velocity will correlate to a higher conduction rate [4].

A test rig was set-up in order to correlate a velocity to the voltage readings (Figure 12). The FCI flow meter output was not supplied with calibration due to time constraints. Therefore, data analysis was needed in order to correlate voltage output to velocity of the water. The equipment consisted of a pump located in a 500-gallon water tote. The pump discharges through a gate valve into a 3" diameter clear pipe. The straight section is over 10 diameters long and on a slight incline. The magnetic flow meter was used as the reference flow meter. Once the flow rate was read by the magnetic flow meter it was dumped into the larger diameter PVC pipe, seen in Figure 12. The mass flow rate is constant in the system and therefore the velocity of the water can be found in the larger pipe.

Figure 12: Test Rig.

The orientation of the FCI flow meter was changed in 45 degree increments and ranged from 0 to 270 degrees. Markings were made to illustrate the increment on the white PVC pipe, shown in Figure 13. With the pump engaged, the gate valve was used to set the flow rates thus, changing velocity. Data was collected at a sample rate of 2 Hz, at various velocities, as well as, FCI orientations using a sweep method.

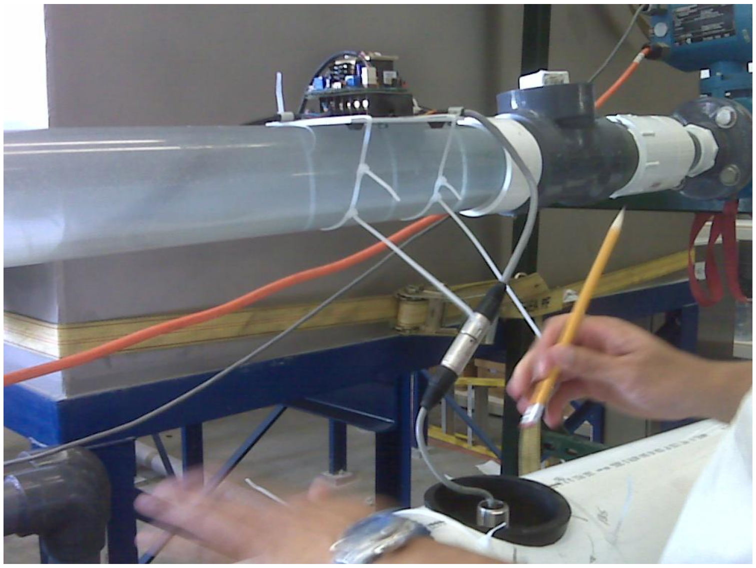

Figure 13: FCI orientation.

The sweep procedure was conducted on all six flow meters. The procedure was repeated for each meter, across a range of 0 to 270 degrees. The intent of the procedure was to continuously transition the flow rate through a full range while recording data. Figure 14 shows the typical sweeping profile of flow rate with time.

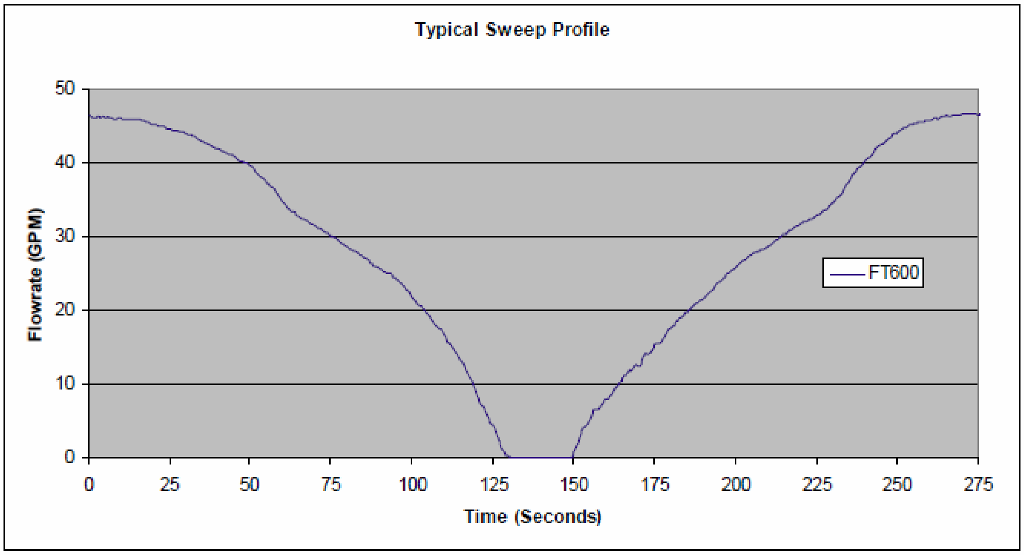

Figure 14: Typical sweep profile. [4]

A total of 6 flow meters were used to measure velocities in the tank. Because 6 data points are not nearly enough, the flow meters were moved to different areas across the tank to attain more data points. After the system was run for 10 cycles, the system was stopped. The meters were then moved and the system was started again for a 10 cycle duration.

3.8 3D Modeling and Animation

The main purpose for providing 3D modeling and animation was to better illustrate how NVE components will be implemented in the real application at SRS. The main component to be illustrated that differs from the demonstration is the fact that the charge vessels will be inserted into the high level waste tanks at SRS rather than being outside the tank. Figure 15 shows one snapshot of the charge vessels inside the tank.

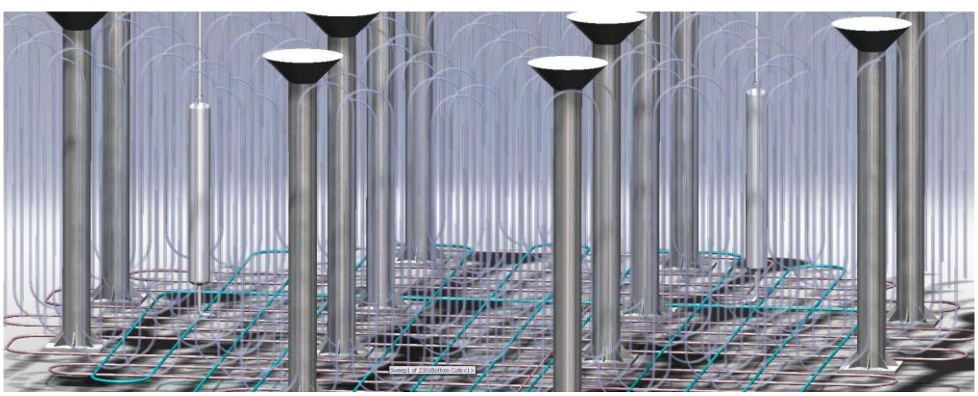

Figure 15: 3D modeling.

4. DATA AND RESULTS

4.1 FCI Flow Meter Analysis

The objective of the sweep procedure was to generate curve fits that could be used to transform voltage into velocity during the Power Fluidics™ demonstration. The sweep trials resulted in 30 data sets, one for each flow meter in each orientation. Figure 16, shows one such sweep, notice that the trend is exponential [4].

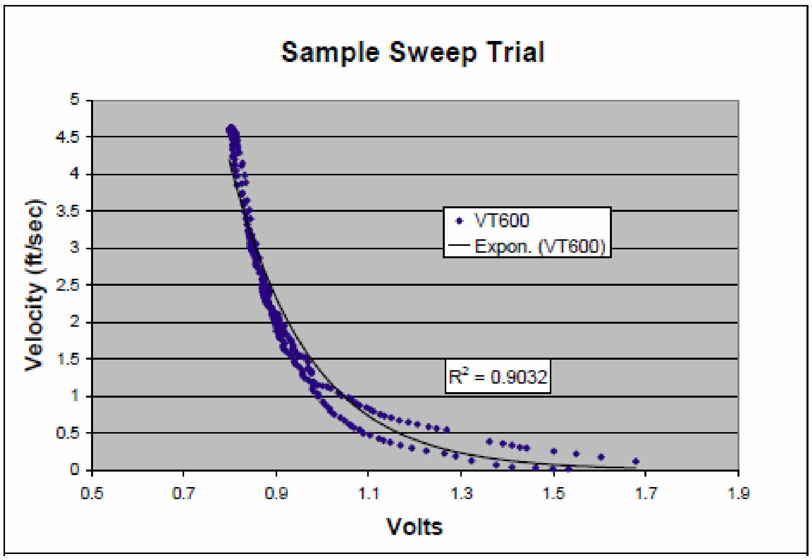

Figure 16: Sample sweep trial. [4]

"The relationship between sensor output (voltage) and fluid velocity is best evaluated on a linear-logarithmic scale" [4]. Figure 17 shows the relationship is nearly linear when plotted on this semi-logarithmic scale.

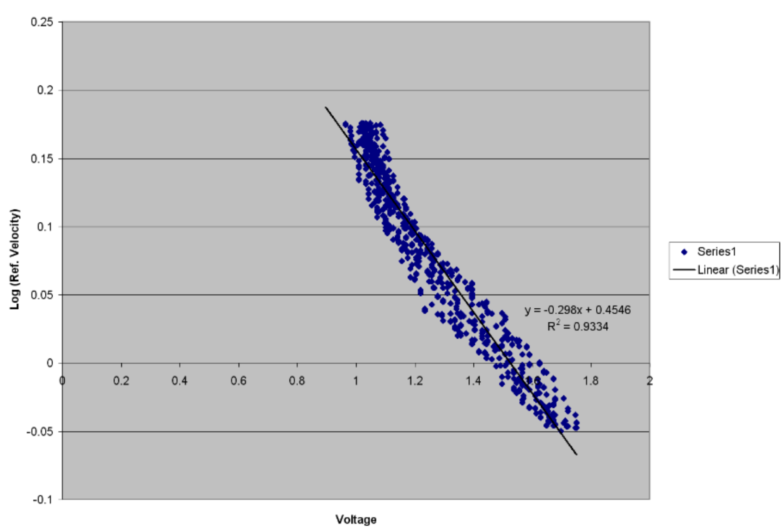

Figure 17: Log(Ref. Velocity) vs. Voltage.

The selected curve fits shown in Table 2, were used to transform the output voltage signal to a velocity measurement for each of the six flow meters. Exponential curve fits were chosen. Flow meter VT-305 was calibrated by FCI and the remaining flow meters were calibrated using the sweep method [4].

Form: $F_1(x) = A_1 e^{B_1 x}$; where $F_1(x)$ = Velocity (ft/sec), x = Volts (V)

Inst #	Serial Number	Coefficients		Source	Cable Length	R^2
		A_1	B_1			
VT-300	307340	477.87	-4.762	Sweep	100 ft	0.85
VT-301	307339	258.20	-4.586	Sweep	100 ft	0.83
VT-302	307336	100.41	-4.238	Sweep	100 ft	0.82
VT-303	307338	48.424	-3.909	Sweep	100 ft	0.89
VT-304	307337	208.35	-4.385	Sweep	75 ft	0.84
VT-305	307341	507.09	-5.710	FCI	25 ft	0.95

Table 2: Flow meter selected fits [4]

Figure 18 shows the curve fits for the six flow meters respectively.

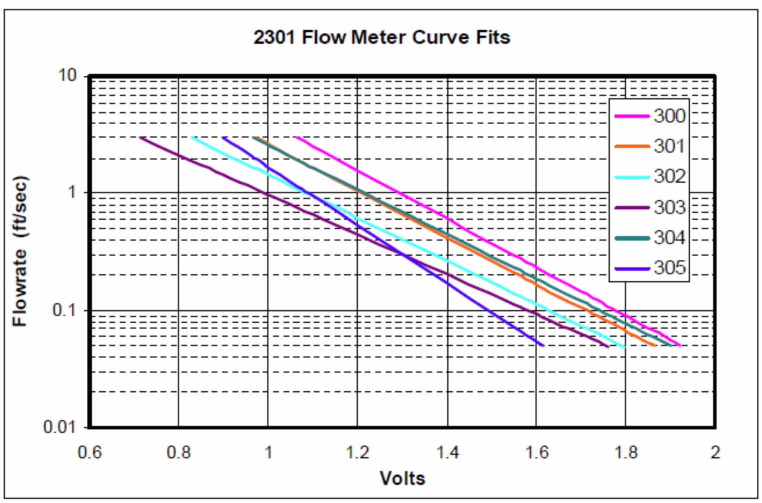

Figure 18: Flow meter curve fits. [4]

Error is defined by the difference between source data and the forecasted velocity. The standard deviation of the error is presented in Table 3. "Assuming normal distribution, the accuracy within a specific range will be plus/minus two standard deviations of the error with a 95 % confidence level." Since meters 300 through 304 were characterized and analyzed by the sweep method the accuracy will rely on the worst case from the group. Since meter 305 was characterized differently it will be treated independently [4].

Standard Deviation of Error			
Meter	Range (ft/sec)		
	0.05 to 1.0	0.05 to 2.0	0.05 to 3.0
300	0.222	0.238	0.305
301	0.241	0.241	0.312
302	0.247	0.323	0.385
303	0.081	0.162	0.398
304	0.242	0.242	0.293
305	0.098	0.119	0.278

Table 3: Standard deviation of error [4]

The resulting meter accuracy (velocity) is shown in Table 4

Flow Meter Accuracy			
Meter	Up to 1 ft/sec	Up to 2 ft/sec	Full Range
300	±0.49 ft/sec	±0.65 ft/sec	±0.80 ft/sec
301			
302			
303			
304			
305	±0.20 ft/sec	±0.24 ft/sec	±0.56 ft/sec

Table 4: Flow meter accuracy

The data in Table 4 falls short of NVE's expectations. The poor results are due to the characterization process. "The characterization process used to date does not properly account for the time constant of the sensor" [4].

4.2 Demo Results and Analysis

Each flow meter had a specific equation that was used to correlate its voltage reading to velocities in feet per second. "Sensitivity, repeatability, and accuracy are each different characteristics of any instrument. Zero instrument error does not exist. The goal is to balance the expected range of error with the range of measured values and the desired accuracy. NVE was not quite satisfied with the balance achieved", according to project manager Ethan King.

From initial test results, the Power Fluidics™ system was able to obtain velocities far beyond 0.2 ft/s and extended past the error factor in many locations in the tank. Other locations seemed to be more stagnant. Results were dependent on nozzle direction. Final data and results are being reported in NVE's Test Report 2301-4-002.

5. CONCLUSION

NuVision Engineering's Power Fluidics™ technology is definitely a viable option in handling low level mixing. From the initial results, even with the FCI flow meter error, the Power Fluidics™ system proved to be a viable source of mixing in a heavily obstructed tank and can reach the required velocity of 0.2 ft/s. Many areas in the tank achieved velocities up to 2 ft/sec in some locations. However, some areas were more stagnant. Some of the conclusions provided by Nuvision included the following:

"NVE has demonstrated a system that exceeds the key performance criteria set out by SRR/DOE while satisfying the design constraints of the number (two), size (24" diameter), and location of available risers.

The system capabilities satisfy these statements:

1. The system is capable of exceeding the primary criterion to achieve a 0.2 ft/s velocity at any location in the tank.
2. The system is marginally capable of meeting the "stretch" criterion to achieve a 2 ft/s velocity at any location in the tank" [4].

6. REFERENCES

1. Memorandum: “Mixing Evaluation on a Type I Waste Tank,” August 6, 2008, T. Caldwell, Liquid Waste Operations Division, Engineering Department, Technology Development Group; Washington Savannah River.

2. Project Technical Plan: “Demonstration of Power Fluidics™ Mixing Technology to Enhance Chemical Cleaning Operations in High Level Waste Tanks,” PTP Number: DOE/2301-6-001/01/v1.

3. Interim Report: “Initial Concept Description and Modeling,” NVE Document Number 2301-4-001.

4. Test Report: “Demonstration of Power Fluidic ™ Mixing Technology to Enhance Chemical Cleaning Operations in High Level Waste Tanks,” NVE Document Number 2302-4-002.

5. Summary Test Plan: “Demonstration of Power Fluidics™ Mixing Technology to Enhance Chemical Cleaning Operations in High Level Waste Tanks,” PTP Number: DOE/2301-6-008 Rev 0.