Design and Fabrication of Test Facilities for the Demonstration of Jet Mixer Performance in the Hanford Double Shell Tanks – 11241

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ABSTRACT

The ability to effectively mix, sample, certify, and deliver consistent batches of High Level Waste (HLW) feed from the Hanford Double Shell Tanks (DST) to the Waste Treatment Plant (WTP) presents a significant mission risk with potential to impact mission length and the quantity of HLW glass produced. At the end of 2009 DOE's Tank Operations Contractor, Washington River Protection Solutions (WRPS), awarded a contract to Energy*Solutions* to design, fabricate and operate a mixing demonstration platform to generate tank mixing performance data at two different scales. These data are being used to examine the particulate distribution in a tank mixed by rotating jet mixer pumps, and provide scale up information to predict full scale operational performance. This information will then in turn be used to define the position of the tank discharge pump suction such that consistent batch feed delivery to WTP can be achieved.

The Small Scale Mixing Demonstration (SSMD) platform consists of 110 cm (43.2)" and 305 cm (120") diameter clear acrylic test vessels, each equipped with two scaled jet mixer pump assemblies, and all supporting vessels, controls, services, and simulant make up facilities. All tank internals have been modeled including the air lift circulators (ALCs), the steam heating coil, and the radius between the wall and floor. The test vessels are heavily instrumented such that 3-dimensional solids distribution can be measured and recorded in real time while mixing is occurring. Instrumentation includes Acoustic Doppler Velocimeters (ADVs)[1], Electro Resistance Tomography (ERT), Focused Beam Reflectance Measurement (FBRM®) and Coriolis mass flow measurements, and a detailed discussion of the novel application of this instrumentation is presented in a separate paper [10]. The test platform was fabricated in several modular skids, and was installed and began operating in July 2010.

INTRODUCTION

The SSMD program is focused on the portion of the River Protection Project (RPP) mission where the HLW waste is delivered from the tank farms DSTs to the WTP. The HLW feed will be staged in DSTs that contain up to 178 cm (70") (~720,000 liters) of settled solids on the bottom of the tank with the remaining tank volume (up to 3,407,000 liters) filled with liquid supernate. Prior to feed delivery the solids will be mixed with the supernate to create an HLW feed slurry. There is some uncertainty surrounding the ability of the baseline DST mixer pump

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[1] FBRM® is a registered trademark of Mettler-Toledo Inc., 1900 Polaris Parkway, Columbus, OH 43240

system to adequately suspend and homogenously distribute the HLW solid particles within a million gallon tank. Homogenous, as used here, should be interpreted as the same concentration and makeup of solid particles occur at any point and time within the volume of the mixed tank such that a sample taken from one location would be representative of the entire tank contents. The WTP design basis assumes each staged HLW feed tank is homogenously mixed and delivered in consistent feed delivery batches of 570,000 liters (150,000 gallons) (see Fig. 1.). Consistent, as used here, is intended to mean that the first 570,000 liter batch has the same solids composition as the last 570,000 liter batch.

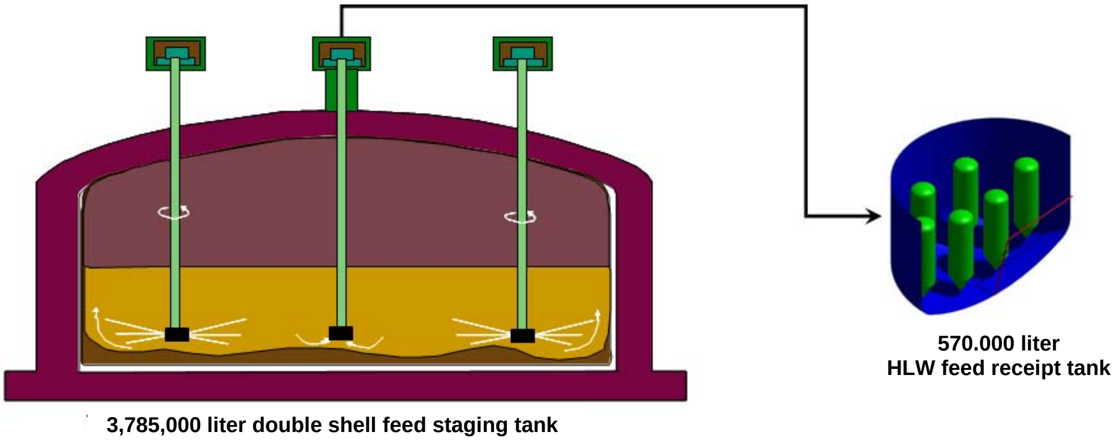

Fig. 1. Double Shell Tank and WTP Feed Receipt Tanks

There is also a sampling risk in meeting the requirement that each DST be sampled and characterized to a high degree of confidence prior to delivery to the WTP as certified feed. The number and location of sample collection events required for feed certification increases as tank heterogeneity and required confidence levels increase. The sample must be representative of each batch, which becomes problematic if there is variability between batches. It is known that the present baseline DST mixing systems will not homogeneously distribute sludges in a typical HLW feed DST, which will complicate the ability to collect samples that meet feed certification confidence requirements. Additionally, some of the WTP feed acceptance requirements are based on physical and transport properties (e.g. particle hardness, densities and critical velocity) that are not easily measured in an analytical laboratory.

This paper reviews the key parameters in the platform design which had to be prototypically scaled, and discusses the approaches used when this was not possible. Scaling up complex particulate behavior in large tanks mixed by rotating centrifugal jet pumps includes multiple parameters, many of which scale up differently. For example, it was not possible to build prototypic jet mixers similar to those proposed for the DSTs and this paper will discuss the solution and associated compromises (due to system hydraulics) in detail. This modeling problem is significantly different to conventional stirred tanks, in that mixing is achieved by fluid jets rotating through the liquid, and the jet velocity and angular rotation rate are interdependent and differ in how they scale as vessel size increases. Since one of the objectives of this platform was to define the (unknown) scaling correlations, the platform was designed to cover the full range of flows and rotational rates possible.

Separate computational fluid dynamics (CFD) modeling work is being conducted by others, and experimental data from the SSMD platform testing will be fed into this modeling with the objective of validating the use of CFD for analysis of in-tank mixing in the full scale DSTs. This paper focuses on the design, procurement, fabrication, installation, and acceptance testing of the test platform under an aggressive fast track schedule. It does not discuss the test data collected and it's application to the ongoing CFD modeling, or to the actual mixing performance in the DSTs, this being the subject of a separate paper [11].

Objectives

The primary objectives of this phase of demonstrations were to:

- Demonstrate equivalent tank mixing behavior can be achieved in the two sizes of scaled tanks. This is accomplished with the following sub elements
    - Demonstrate SSMD equipment performance and the ability of the scaled tanks to meet performance objectives
    - Demonstrate SSMD instrumentation performance and the ability to measure particulate movement within the tank
    - Collect fluid velocity measurements for input into a Computational Fluid Dynamic (CFD) model. Data will be used to calibrate and validate the model.
- Demonstrate a range of tank operating parameters that define the edges of mixing performance to include:
    - Mixer pump flow rate
    - Mixer pump rotation rate
- Provide the framework to move forward to the next phase of batch transfer and sampling testing
    - Support the batch transfer testing by identifying the range of parameters, simulants and instrumentation to be used during that testing.

EQUIPMENT OVERVIEW

The mixing and sampling demonstration program initially focuses on the first HLW planned for transfer to WTP, (AY-102) and then will apply knowledge gained to the remaining planned feed delivery DSTs. AY-102 is 22.8 m (75 ft) in diameter, has an operating liquid height of 9.25 m (364"), a total waste height of 8.71 m (343"), and a sludge height of 1.40 m (55"). The particle size range of the solids in AY-102 is of the order of 2.5 to 16.8 (99th percentile) micron and density ranges from 2.4 to 11.4 g/cm^3 [1]. The baseline configuration will include two mixer pumps, with opposing 15 cm (6") diameter nozzles that will recirculate tank waste at approximately 20,000 liters (5200 gallons) per minute per nozzle. The mixer pumps have the ability to be rotated such that the nozzles can cover a full 360° of rotation. AY-102 also contains 22 air lift circulators (ALCs) that are currently not functional. The ALCs are essentially cylindrical obstructions in the tank 0.76 m (30") in diameter that extend down to within 0.76 m (30") of the tank floor.

The main components of the platform (Figure 2) are the flush vessel (11,000 liters), test vessel TK-201 (110 cm dia., 420 liters), and test vessel TK-301 (305 cm dia., 8877 liters). A number of pumps provide the means to transfer batch material around the platform. The flush water vessel provides a bulk amount of flush water to all other vessels and pump suctions such that any blockages can be cleared (a simple connection to city water in the facility would not provide adequate flow or pressure for this duty). This is a multi-function vessel and can also be used for feed make-up as required. All mixing tank internals, pumps and associated systems are scaled prototypically where possible. Where it was not possible to do this, due to, for example, dimensions being too small, the final scaled dimensions were as close to prototypic as possible. Table I below shows the key parameters that were scaled for the design and construction of the test platform.

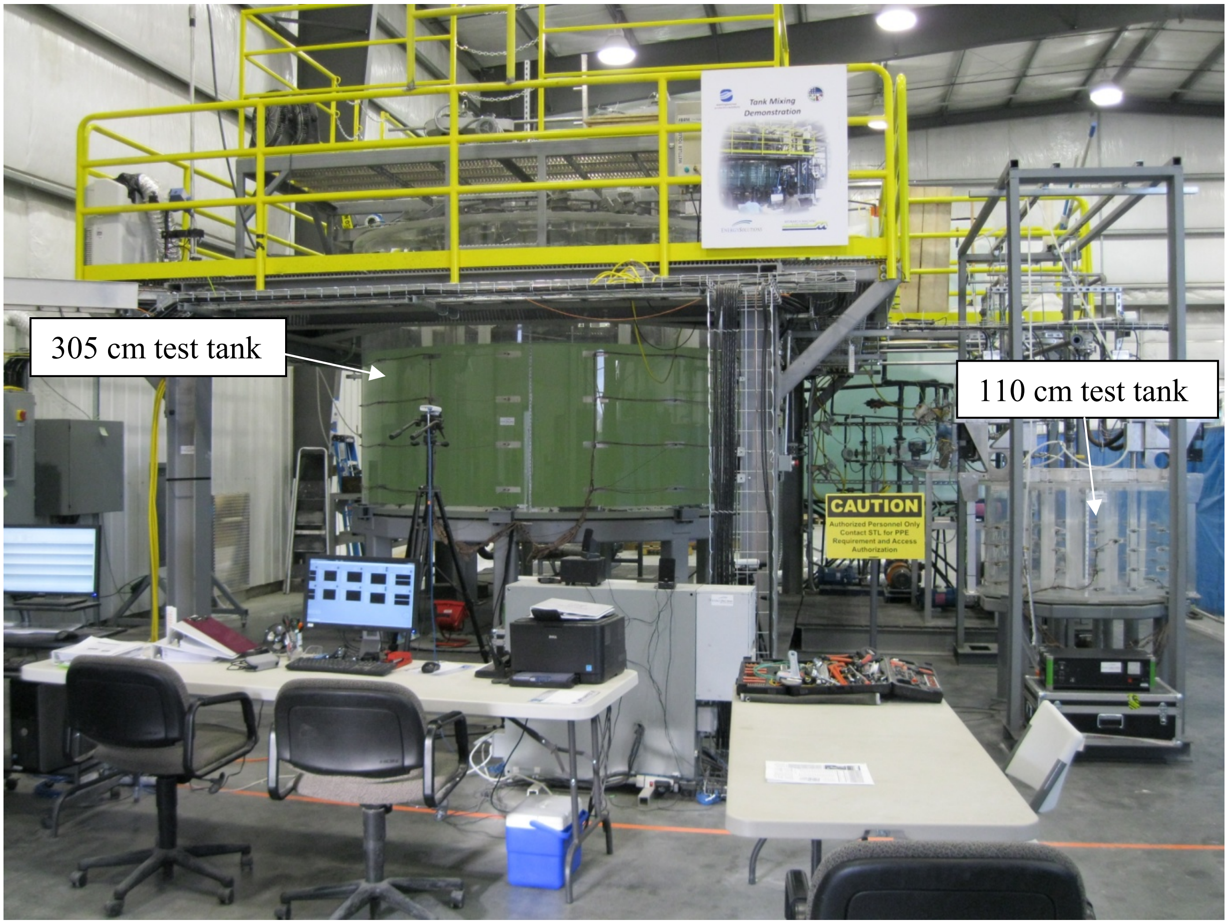

Fig. 2. SSMD Test Platform

The test vessels are fabricated out of optically clear acrylic, and mounted such that there is free access above, below and to the side for visual observation and video recording. The test vessels include all internals and obstructions to flow (e.g. air lift circulators, steam heating coil).

Table I. Parameters Associated with AY-102 and the Scaled Models

Parameter	**Units**	**AY-102 Full Scale**	**Test vessel #1 0.048 scale factor**	**Test vessel #2 0.133 scale factor**
Tank Internal Diameter[2][*]	[cm]	2286	109.7	304.8
Corner Radius between Wall and Floor[*]	[cm]	30.5	1.47	4.04
Max Tank Operating Liquid Level[*]	[cm]	941.7	45.2	125.5
Total Waste Height	[cm]	871.2	41.9	117.3
Waste Volume	[liter]	3,794,943	419.8	8,876.4
Tank riser diameter[*]	[cm]	86.4	-	-
Mixer Pump Centerline Radius from Tank Center[*]	[cm]	670.6	32.3	89.4
Pump Suction Screen to Tank Floor	[cm]	12.7±2.5	0.61±0.13	1.70±0.33
Nozzle Diameter	[cm]	15.2	0.74	2.03
Nozzle Centerline to Tank Floor (assuming 5” from screen to floor))	[cm]	45.7	2.18	6.10
Pump casing max. diameter and nozzle spacing[3][*]	[cm]	81.3	3.81[2]	10.80
Distance nozzle centerline to top of screen (to pump inlet elevation)	[cm]	21.6	1.04	2.90
Pump Design Oscillation Speed[*]	[rpm]	0.05 - 3.0	1.53	0.77
Nozzle U_0D	$[m^2/s]$	2.73	0.13	0.36
Pump Flow Rate[*]	[lpm/nzl]	19,616	45.0	348.6
Nozzle exit Velocity (equal power/vol)	[ft/s]	58.8	22.2	31.3
Pump Flow Rate (equal power/vol)	[lpm/nzl]	19,616	16.3	185.5
Design Pump Flow Rate	[lpm/nzl]	19,684	0 – 45	0 - 379
Pump Suction Inlet Area	$[cm^2]$	1226	2.84	21.68
Pump Suction Diameter	[cm]	27.9	1.35	3.73
Air Lift Recirculator Diameter (22 off)[*][4]	[cm]	76.2	3.66	10.16
Heating Coil Diameter (1 off)[*]	[cm]	102.6	4.93	13.67

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[*] driving parameter for scaled platform capabilities

[2] Height is not based on AY-102 but on maximum DST liquid level anticipated and allowing extra freeboard for safety

[3] Although the ALCs are 76.2 cm in diameter, they reduce to 15.2 cm diameter at 4.5 m above the tank base. It has been agreed that this testwork will assume the ALCs are 76.2 cm diameter for their complete length.

Parameter	**Units**	**AY-102 Full Scale**	**Test vessel #1 0.048 scale factor**	**Test vessel #2 0.133 scale factor**
Transfer Pump Inlet Diameter	[cm]	5.72	0.71	0.81
Batch Transfer Volume	[liter]	567,812	62.8	1,327.9
Batch transfer Time *(not scaled)*	[min]	1143 - 1778	8 - 14	127 - 137
Transfer Pump Flow Velocity (inlet)	[m/s]	0.67 – 1.04	0.67 – 1.04	0.67 – 1.04
Transfer Pump Flow Rate *(not scaled)*	[lpm]	340 - 530	5.3 – 8.3	6.8 – 10.6

SELECTION OF SCALE FOR TESTING

To be able to accurately predict and understand equipment performance at full scale, a minimum of two data points at smaller scales are required. There is qualitative visual observation data already in existence from the work conducted at the Savannah River National Laboratory (SRNL) on the 1/22nd scale acrylic tank, and this approximate scale was used as the starting point for the demonstration tests. Using this scale also took advantage of the existing scaled jet mixer pump design and minimizes re-engineering. It is also a good scale for simulant volumes needed (394 liters), makes chemical handling straightforward, and is large enough to accommodate instrumentation in the vessel without affecting the mixing profiles.

The selection of the second scale of test vessel was made by balancing performance, cost and risk considerations. Smaller scale usually brings with it cost and schedule savings, however, the risk in not obtaining representative data is increased. In this mixing system, prototypic representation of the jet mixer nozzles is key and this becomes increasingly difficult as the scale reduces (on the 110 cm diameter scale vessel, the mixer nozzle is already only 7 mm diameter). Therefore, after review of previous work, availability of hardware, instrumentation, and testing requirements, the second acrylic vessel was sized at 305 cm diameter (1/7.5th scale). This second scale was judged to be large enough to give well spaced data points (relative to the first scale), and still retained the advantages of being able to use acrylic as the tank material.

Adopting a similar approach to the advance design mixer pump (ADMP) testing for Tank 18F at Savannah River Site [2], the following dimensionless parameters were identified as a result of the scaling analysis: the jet Reynolds number, standard Froude number, the time ratio, the ratio of solids mass retrieved to initial solids mass, the ratio of retrieval line solids concentration to bulk solids concentration within the tank, and the dimensionless settling velocity. In addition, dimensionless parameters were developed for nozzle discharge velocity and ADMP angular velocity scaling. The sections below present these additional dimensionless numbers that are critical for determining the operating parameters for the scaled tests, followed by a discussion of the mixer pump inlet scaling and the transfer pump scaling.

Nozzle Velocity Scaling

Experimental data on the erosion of cohesionless materials show that the volume of scoured material is independent of the scale of the model [3]. Furthermore, the dominant dimensionless numbers for cohesionless erosion are the densimetric particle Froude number Fr_ρ and the relative downstream depth s_1 defined by

$$Fr_\rho = \frac{U}{\sqrt{g\delta_p \Delta\rho / \rho}} \qquad \text{(Eq. 1)}$$

$$s_1 = \frac{h_1}{d}$$

where

d = Nozzle diameter
δ_p = Characteristic mean particle diameter
$\Delta\rho$ = Density difference between particulate and liquid
ρ = Density of liquid
U = Jet nozzle velocity
h_1 = Initial height of liquid above the sludge level
g = Gravitational acceleration.

It is expected that the particulate of the simulant will have properties similar to those of the actual sludge in terms of cohesion characteristics, density, and particle size. Thus, it follows from Fr_ρ that the velocity in the scaled model should be the same as that in the full-scale tank.

However, if the densimetric particle Froude number is large enough, particle erosion in cohesionless sludge will take place at a high rate, resulting in complete scouring in the vicinity of the jet nozzle. In this instance, matching the densimetric Froude number in both the scaled and full-scale tanks will not be necessary. This situation is analogous to matching in the scaled and full-scale tanks a very large Reynolds number. When the densimetric Froude number is large, the relevant parameter that must be matched is the standard Froude number, in which a modification to the vertical length scale is made to account for the settled solids layer. The Froude number is

$$Fr = \frac{U^2}{g\left[\phi h_2 + (1-\phi)h_1\right]} \qquad \text{(Eq. 2)}$$

where

h_2 = Initial height of sludge level
φ = Mass fraction of solids in the heel.

Assuming that there is geometric scaling between the model (indicated by the subscript S) and the prototype (denoted by the subscript F), the nozzle velocity in the scaled tank U_S is given by

$$U_S = \sqrt{\frac{\phi_S h_{2S} + (1-\phi_S)h_{1S}}{\phi_F h_{2F} + (1-\phi_F)h_{1F}}}\,U_F \qquad \text{(Eq. 3)}$$

110 cm vessel:

$$\text{if } \phi_S = \phi_F \text{ and } \frac{h_{2F}}{h_{2S}} = \frac{h_{1F}}{h_{1S}} = 21.3 \text{ then } U_S = \frac{U_F}{\sqrt{21.3}} = 0.22U_F \qquad \text{(Eq. 4)}$$

305 cm vessel:

$$\text{if } \phi_S = \phi_F \text{ and } \frac{h_{2F}}{h_{2S}} = \frac{h_{1F}}{h_{1S}} = 7.5 \text{ then } U_S = \frac{U_F}{\sqrt{7.5}} = 0.37U_F \qquad \text{(Eq. 5)}$$

This approach is supported by the results of the qualitative testing conducted at SRNL [4, 5].

An alternative approach to jet scaling is to model the power input per unit volume to the system. This is believed to be more appropriate, however testing at the two different scales will define the correct scaling factor to use. The test platform was designed to be capable of the full jet velocity. Using the power per unit volume approach and iterating to find velocity gives the values shown in Table II below.

Table II. Nozzle Velocity at Equal Power per Unit Volume

	Formula	**AY-102**	**110 cm Vessel**	**305 cm Vessel**	**Units**
Nozzle Diameter (D)	Input	15.2	0.71	2.0	cm
Tank Volume	Input	3,794,943	394.4	8,876.4	liters
Fluid Density[1]	Input	1150	1000	1000	kg/m^3
Power[2]	0.5 * volumetric flow*density*velocity^2	60,065	6.241	140.494	W
Power per Unit Volume	Power / Volume	15.83	15.83	15.83	W/m3
Nozzle velocity		17.9	6.8	9.5	m/s
Volumetric Flowrate		19,616	16.1	185.5	lpm/nzl

[1] Fluid density is weighted density of liquid plus the solids in the slurry. For this calculation water only has been assumed for the simulants as a conservative basis

[2] Volumetric flowrate = Pi * D^2/4 * velocity

Demonstration testing initially started using the flow values specified in Table II, and was adjusted during the preliminary mono-disperse simulant testing in order to achieve equivalent concentration profiles in both test scales.

Angular Velocity Scaling

Specifications for the full scale mixer pump were taken from RPP-SPEC-43262, Rev. 0 [6]. This gives the following specification for flowrate:

"*The design flow for each nozzle shall be approximately 19684 lpm (5,200 gpm) at 100% design speed, such that the product of the nozzle diameter and the average nozzle exit velocity (ft/sec) (UoD) of 2.73 m^2/sec (29.4 ft2/sec) is achieved.*"

The specification for the pump oscillation/rotation is stated as follows:

"*Two methods of rotation shall be incorporated into the design:*

1. *Oscillation: The turntable assembly shall oscillate through a 95*^{o} *clockwise rotation and return to 0*^{o}*, and 95*^{o} *counter-clockwise rotation and return to 0*^{o} *in a continuous repetitive oscillation.*
2. *360*^{o} *Rotation: The turntable assembly shall be capable of 360*^{o} *full circle rotation.*

Drive Motor: The drive motor shall be rated for use with a VFD, and be continuously adjustable for an MP rotational speed range of 0.05 to 3.0 rpm. The design shall be capable of operation in both a clockwise and counterclockwise direction."

Although the range specified above is 0.05 to 3 rpm, the full scale rotation rate was assumed to be 0.2 rpm (based on previous Hanford operating experience). Demonstration testing initially assumed the scaling of rotational rate was based on constant power number, and the jet velocity was adjusted during preliminary mono-disperse simulant testing to achieve equivalent concentration profiles in both test vessels.

When scaling rotational rate with geometric scaling, it can be shown that

$$\frac{\Omega_S}{\Omega_L} = SF\left(\frac{u_s}{u_L}\right) = SF * SF^{-n} = SF^{1-n} \qquad \text{(Eq. 6)}$$

where

Ω_S = nozzle rotational rate at small scale
Ω_L = nozzle rotational rate at full scale
SF = geometric scaling factor from model to full scale

Whilst the objective of this work was to define the correct exponent n, it is known that it will be in the range of 0 - 0.5, where
n = 1/2 corresponds to scaling based on constant Froude number (based on vessel length scale),
n = 1/3 corresponds to scaling based on constant power number (power per unit volume)
n = 0 corresponds to a constant velocity ratio (the jet velocities are the same in the model and the full scale) and provides a bounding case

Table III. Nozzle Rotational Velocity vs Scaling Basis

		n	**0**	**1/2**	**1/3**	**1**
	SF	**Units**				
AY-102	1	[rpm]	-	-	-	0.2
Test Vessel #1	20.8	[rpm]	4.17	0.91	1.51	-
Test Vessel #2	7.5	[rpm]	1.5	0.55	0.77	-

Jet Mixer Pump Inlet Scaling

The specification for the mixer pumps [6] specifies only the pump flow and U_0D requirements. This sets the nozzle diameter, but not the pump suction diameter. In order to proceed with a scaled model therefore, this diameter had to be assumed. Ref. 2 gives the dimensions for the jet mixer pump to be deployed in SRS Tank 18F, and this was used as the basis for the AY-102 jet mixer pump suction inlet sizing used in this study. The Tank 18F pump has two 15.2 cm (6") nozzles, and runs at the same jet velocity, thus the suction inlet cross sectional area was assumed to be the same as that for the Hanford pumps. The suction cross sectional area is given as 613 cm^2. This equates to an inlet diameter of 27.9 cm, and this value was used as the basis for this test work.

Jet Mixer Pump Nozzle Locations

The final jet mixer pump design has not been performed yet, however a similar pump has been previously tested in AZ-101 [7] and the specification for the AY-102 pumps has been recently issued [6]. By referring to these two documents, the following enabling assumptions were made about the design of the jet mixer pump:

- Nozzle configuration is 180^o diametrically opposed (not tangential)
- Nozzle centerline is maximum of 45.7 cm above the tank floor (the AZ-101 JMP was installed with nozzle centerline 43.2 cm above tank floor, and could be moved in the range 30.5 – 45.7 cm)
- Pump casing, and hence nozzle spacing, will be 81.3 cm to allow it to pass through an 86.4 cm diameter riser.

One key difference between the full scale jet mixers and the scaled models is that the impeller for the full scale pump is submerged at the end of the support shaft and pulls the suction directly from the inlet, and discharges directly through the nozzles, see Figure 3.

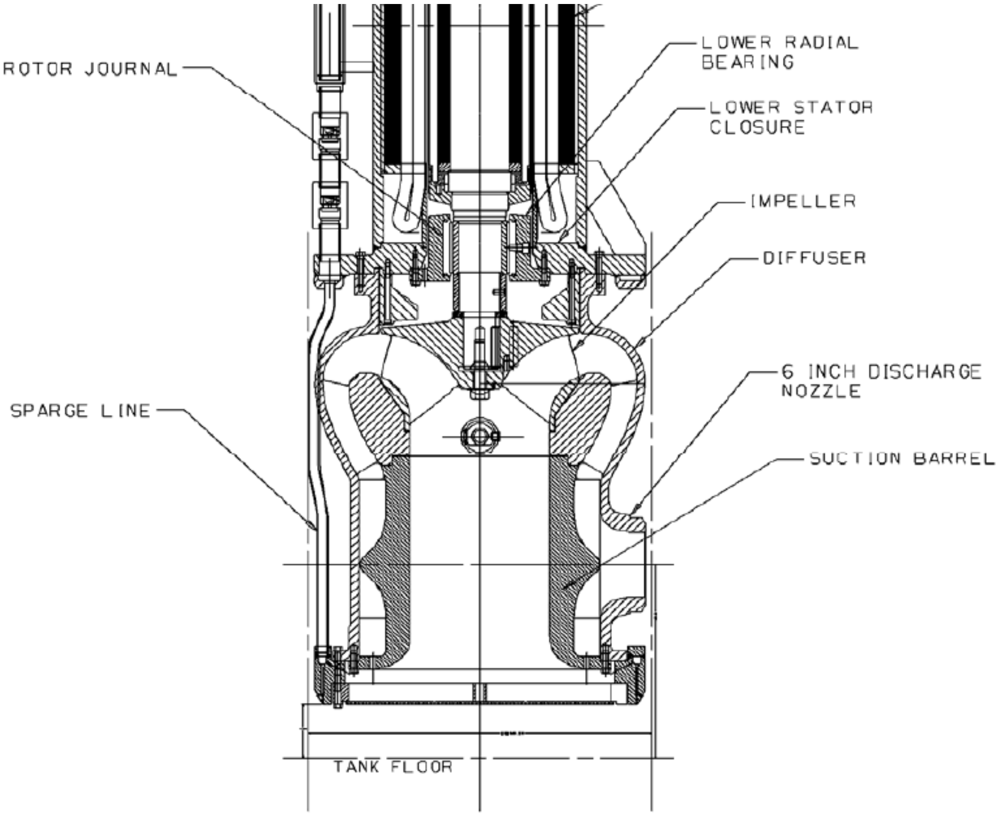

Figure 3: Conceptual Hanford Jet Mixer Pump Cross Section

The basis for the scaled jet mixer design for this demonstration platform was that used at Savannah River Site, see Figure 4, due to the prohibitive cost and schedule for custom fabricating a scaled version of the above. The scaled jet mixer consists of a suction inlet to a pump located outside the test vessel, and returning via a concentric annulus to the two nozzles. This introduces significant frictional losses on the pump suction and thereby limits the minimum suction diameter to achieve the required flow (the maximum of which is equivalent to a nozzle exit velocity of 17.9 m/s). The scaled pump suction diameter for the 110 cm vessel was 1.34 cm, and 3.73 cm for the 305 cm vessel, however the suction losses meant that these values have to be increased to approximately 2.54 cm and 6.35 cm respectively to achieve a system that would work hydraulically. This had two impacts, it resulted in a lower linear suction velocity and also means that the nozzle diametrical spacing was greater than prototypic. The vertical suction velocity is still significantly above the bounding particle Stokes settling velocity, so this was judged not to affect the particle entrainment in the jet mixer system. The predominant mechanism for mixing is via the liquid in the jet, and the particles are not believed to impact the jet mixing behavior significantly anyway.

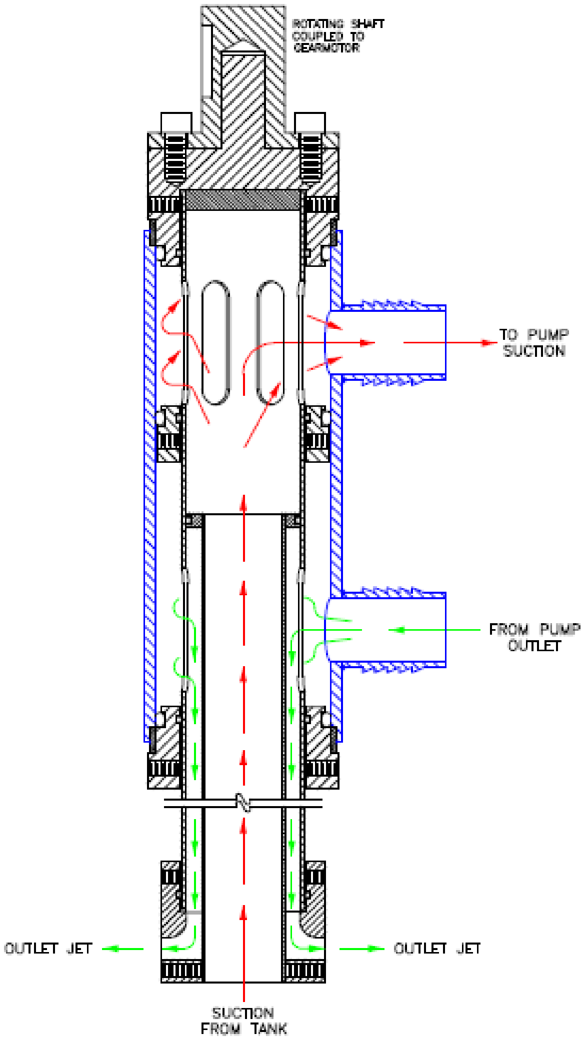

Figure 4: Scaled Mixer Pump Configuration

An analysis of line velocities was also performed, across the expected range of jet velocities to be tested, and all line velocities were sufficient to maintain particles in suspension in the vertical and horizontal (in reality, a 1:10 slope) sections of pipework.

Transfer Pump Scaling

Transfer of each 567,812 liter (150,000 gal) batch of waste out of AY-102 occurs at a flowrate of 340 – 530 lpm. The suction inlet is 5.7 cm diameter [8] and the transfer line is 7.8 cm [9]. This equates to a linear velocity of 2.21 – 3.44 m/s at the suction inlet, a linear velocity of 1.18 – 1.86 m/s in the transfer line, and a transfer time of 1143 – 1778 minutes (19 – 30 hours).

One key parameter that cannot be scaled here is the transfer velocity, since the particle size and density in the test simulants are not scaled. Scaling on flow would give too low a linear velocity, causing settling of particulates. An additional problem is that if line diameter is scaled, the diameter becomes too small to be operable. With the potential for spikes in the simulant up to (an assumed) 1000 µm, the smallest (standard) pipe diameter recommended for this system was 7 mm (six times the largest particle size) to prevent plugging issues, and testing confirmed that indeed smaller line sizes were not possible. Running a smaller bore line also gave hydraulic issues on the suction and discharge side of the transfer pump.

Thus the approach adopted for the transfer line out of the 110 cm vessel was to use a 7 mm suction inlet and match the range of linear velocities at the suction inlet to ensure similar particle entrainment to the full scale system. This equates to a flowrate of 5.3 lpm at 2.21 m/s, to 8.3 lpm at 3.44 m/s. The corresponding batch transfer times are approximately 8 mins to 14 mins.

For the 305 cm vessel, an 8 mm line was used. This yields a flowrate of 6.8 lpm at 2.21 m/s, to 10.6 lpm at 3.44 m/s. The corresponding batch transfer times are approximately 127 mins to 237 mins.

It was noted that using the same linear velocity at each scale may have the effect of drawing waste from a relatively larger effective region of the vessel, which in turn may show better apparent batch-to-batch consistency in the small vessel. This will be considered when analyzing and evaluating the test data (currently ongoing).

INSTRUMENTS

In order to meet the objectives described earlier, the test platform was heavily instrumented, and this instrumentation is the subject of a separate paper at Waste Management 2011 [10]. The instrumentation and its function is as listed below:

- Coriolis Meter – to measure slurry density in flow lines and sample lines placed at specific locations in the test vessels, both instantaneous and trend measurements.
- Metter Toledo FBRM® - to measure real time particle chord length distributions in flow lines and at specific locations in the test vessels, both instantaneous and trend measurements.
- Electro Resistance Tomography – the test vessels were equipped with radial tomography arrays and linear probes. This provided real time, 3-D visualization of the solids distribution within the vessels so areas of good and less good mixing could be identified qualitatively.
- Video and visual observations.
- Sampling – the platform had two sample loops with moveable suction wands so that samples could be withdrawn from the vessels at any location.

CONCLUSIONS

This paper has very briefly presented an overview of the design and engineering efforts required to get the Small Scale Mixing Demonstration Test Platform from paper to operating test equipment, against a very aggressive schedule. This required very close integration of several different teams from different companies. The authors would like to thanks all those involved from Energy*Solutions,* Washington River Protection Solutions, Monarch Machine & Tools Co. Inc., and DOE-ORP for enabling this project to achieve success in delivering the operating test platform to allow the necessary data to be generated to characterize the mixing and transfer operations in the DSTs feeding the Hanford WTP.

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