Pilot-Scale Testing of Monosodium Titanate (MST) Mixing for the SRS Small Column Ion Exchange (SCIX) Process - 11224

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ABSTRACT

The Small Column Ion Exchange (SCIX) process is being developed to remove cesium, strontium, and select actinides from Savannah River Site (SRS) Liquid Waste using an existing waste tank (i.e., Tank 41H) to house the process. Savannah River National Laboratory (SRNL) is conducting pilot-scale mixing tests to determine the pump requirements for suspending monosodium titanate (MST), crystalline silicotitanate (CST), and simulated sludge. The purpose of this pilot scale testing is to determine the requirements for the pumps to suspend the MST particles so that they can contact the strontium and actinides in the liquid and be removed from the tank.

The pilot-scale tank is a 1/10.85 linear scaled model of SRS Tank 41H. The tank diameter, tank liquid level, pump nozzle diameter, pump elevation, and cooling coil diameter are all 1/10.85 of their dimensions in Tank 41H. The pump locations correspond to the proposed locations in Tank 41H by the SCIX program (Risers B5 and B2 for two pump configurations and Risers B5, B3, and B1 for three pump configurations).

The conclusions from this work follow.

- Neither two standard slurry pumps nor two quad volute slurry pumps will provide sufficient power to initially suspend MST in an SRS waste tank.
- Two Submersible Mixer Pumps (SMPs) will provide sufficient power to initially suspend MST in an SRS waste tank. However, the testing shows the required pump discharge velocity is close to the maximum discharge velocity of the pump (within 12%).
- Three SMPs will provide sufficient power to initially suspend MST in an SRS waste tank. The testing shows the required pump discharge velocity is 66% of the maximum discharge velocity of the pump.
- Three SMPs are needed to resuspend MST that has settled in a waste tank at nominal 45 °C for four weeks. The testing shows the required pump discharge velocity is 77% of the maximum discharge velocity of the pump. Two SMPs are not sufficient to resuspend MST that settled under these conditions.

INTRODUCTION

Savannah River Remediation (SRR) is developing the SCIX process to remove cesium, strontium, and select actinides from SRS Liquid Waste using an existing waste tank (i.e., Tank 41H) to house the process. The process adds MST as a slurry to the waste tank (i.e., Tank 41H) to chemically sorb the strontium and select actinides, removes the MST and entrained sludge with an in-riser rotary microfilter (RMF), and removes cesium from the RMF filtrate with an ion-exchange column containing CST. The RMF returns the concentrated solids (i.e., MST and entrained sludge) to the waste tank. After being loaded with cesium, the CST is ground to reduce its size and transferred to a waste tank (e.g., Tank 40H, 41H or 51H) as a slurry. The MST, sludge, and CST (if transferred to Tank 41H) in the waste tank will be periodically transferred to a sludge tank, and ultimately be transported to the Defense Waste Processing Facility (DWPF). Figure 1 describes the process.

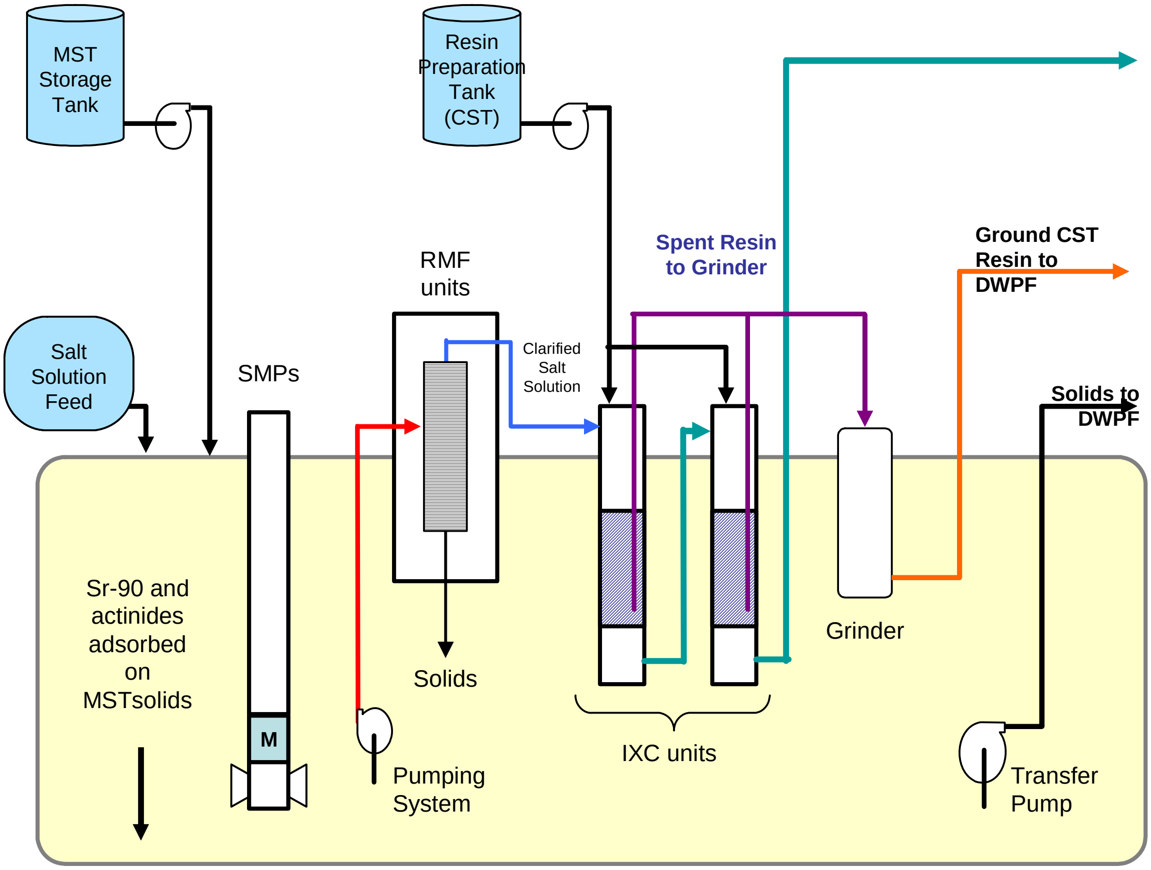

Figure 1. Small Column Ion Exchange (SCIX) process description.

To assist SRR in designing the SCIX process, SRNL is conducting pilot-scale testing to determine the number, type, and size of pumps needed to suspend the solid particles (i.e., MST, CST, and sludge) in Tank 41H [1].

The purpose of this mixing application is for the MST to adequately contact the strontium and actinide containing liquid and to remobilize the solid particles so they can be removed from the tank. There are no requirements for the MST to be homogeneous in the tank during either mixing activity.

This paper describes the tests conducted to determine the pump requirements (i.e., number, size, and speed) to initially suspend MST in Tank 41H for strontium and actinide sorption and the pump requirements to resuspend MST that has settled for four weeks at nominal 45 °C to enable its transfer from the tank.

TEST EQUIPMENT AND TESTING DESCRIPTION

Pilot Scale Test Facility Description

To meet the above objectives, personnel designed, fabricated and assembled a 1/10.85 scale facility in the Engineering Development Laboratory (EDL) of SRNL. The main tank is a nominal 2.4 m (8 foot) diameter, 1.04 m (41 inch) high transparent acrylic tank of wall thickness 0.39 cm (1 inch). A photograph of the clear tank with scaled Tank 41H cooling coils is shown as Figure 2a. The acrylic tank sits on a 0.96 m (38 inch) high open steel stand. This design facilitated direct visual observation of the pump cleaning radius from underneath since the tank bottom is transparent. At the center of the tank, a stainless steel center column is located.

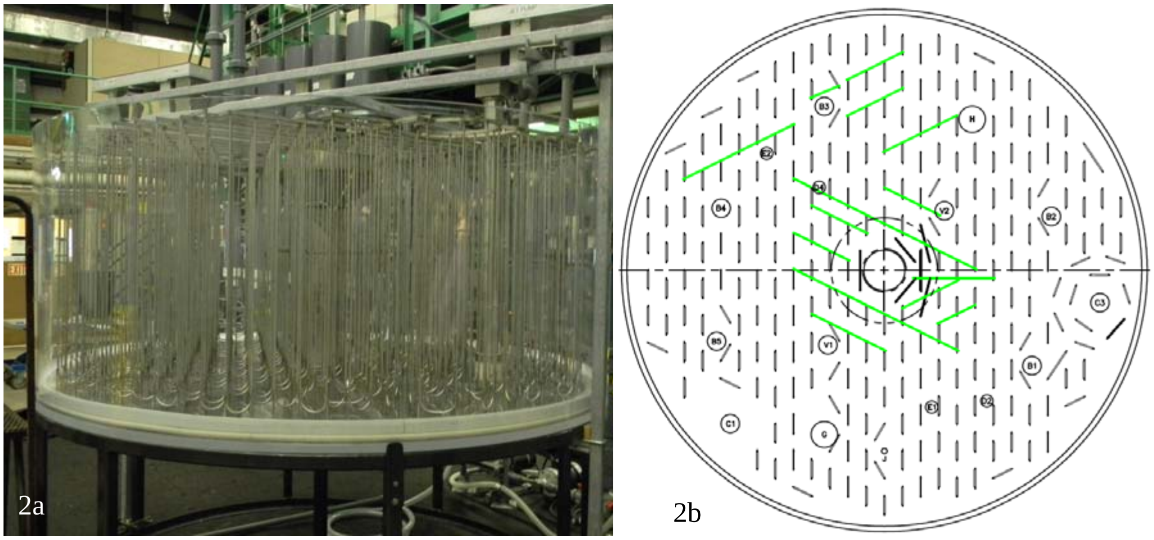

Figure 2. Pilot-scale waste tank and tank top.

One of the key design requirements was to provide means to keep the tank contents heated to 45 °C for prolonged periods while the tank contents are settling. We designed the heating system without compromising the ability to directly visualize solid suspension through the tank bottom by providing a false bottom inside the acrylic tank. The cooling coil assemblies are attached to two half circle 1.27 cm (0.5 inch) thick acrylic plates. The two plates were connected together before lowering the coil assembly in to the tank. The coil assembly plate is supported by 3.18 cm (1.25 inch) outer diameter hard plastic pipe placed around the inside circumference of the tank. This arrangement yields a 3.18 cm (1.25 inch) gap between the coil assembly plate and the tank bottom. This gap serves as the heating jacket to keep the tank contents at desired temperature. The 3.18 cm (1.25 inch) false bottom has supply and return lines through the tank center column to recirculate heating fluid within the false bottom. Tank supernate fluid is used as the false bottom heating fluid. This precludes any change in the tank contents from leakage between the tank and the false bottom. Personnel installed custom molded Dow Corning RTV silicon rubber in the tank bottom corner to ensure the tank bottom corner is rounded to 1/10.85 scale of the Tank 41H bottom. This addition to the tank was included to eliminate sharp corners, which could have caused atypical accumulation of solids. With the clear coil assembly plate and the tank bottom, a direct observation and quantitative measurements of cleaning radii under different pumping conditions are possible.

Figure 2b shows a top view of the pilot-scale tank with the riser locations corresponding to Tank 41H. The black and green line segments show the cooling coils. Researchers designed and built two rotating mixer pumps. The mixer pumps were placed in Risers B5 and B2. Because of the initial results obtained, SRR and SRNL increased the number of pumps to three. These pumps were placed in Risers B5, B3, and B1. Details of the mixer pump are provided in the following section. The maximum cleaning radius needed to completely suspend the MST with three pumps is 1.2 m (47.1 inches) [12.9 m or 42.6 feet in Tank 41H] in the pilot-scale tank. The liquid volume is 3 m^3 (800 gallons), which is geometrically-scaled to the expected volume in Tank 41H [3785 $m^3/(10.85)^3 = 2.96$ $m^3 \sim 3$ m^3 or 1,000,000 gallons/$(10.85)^3$) = 780 gallons ~ 800 gallons]. The pumps have discharge nozzles that simulate standard slurry pumps, quad volute slurry pumps, and SMPs. The nozzle diameters are linearly scaled to the actual pumps. Figure 3a shows the dimensions of the pilot-scale SMP.

Figure 3b shows details of the mixer pump assembly. Tank 41H pumps have their drive motors located on top of the tank. Liquid enters through a bottom opening, and it is discharged through two nozzles placed 180° apart. SRNL designed the pumps to preserve these characteristics in the pilot scale facility. The system uses an external pump to achieve the desired flow rate. The pilot scale mixer pump was designed to accommodate different pump heads at the bottom. Three sets of pump heads (SMP, quad volute, and standard pump) were designed and fabricated by a rapid prototyping method. Details of an SMP head are shown above in Figure 3a. Using an external pump has two advantages – a) an accurate measurement of flow and b) simplicity of the pump head design.

Pump heads were fabricated from acrylic, polycarbonate, and ABS/polycarbonate. During fabrication, we attempted to replicate the internal flow passages of the standard, quad volute and submersible mixer pumps deployed in the SRS Tank Farm. Because of the complexity of the flow paths, the pilot-scale pump heads were not amenable to standard machine practices. Therefore, SRNL employed the rapid prototype method to fabricate the pump heads. Following the fabrication of the pilot-scale pump heads by the rapid prototype method, key pump head dimensions were machined to reduce their variance from the target dimensions. The pump heads were inspected before, during, and after use.

As shown in Figure 3b, the fluid enters through the bottom of the pump head and after going through external pumping and flow meters, it is discharged through the two nozzles 180° apart. The fluid coming out the nozzles is parallel to the tank bottom as in Tank 41H. Measuring the flow rate to each mixer pump and knowing the nozzle diameter, the jet velocity at the discharge point was calculated. The discharge velocity is the most important parameter for resuspension of solids in the tank. Additionally, the mixer pumps are designed to rotate the pump heads. For the present tests, all mixing pump heads were rotated at 3.6 rpm. The nozzle orientation for different heads was not synchronized. Instead, it was kept at a random orientation to mimic prototypic conditions.

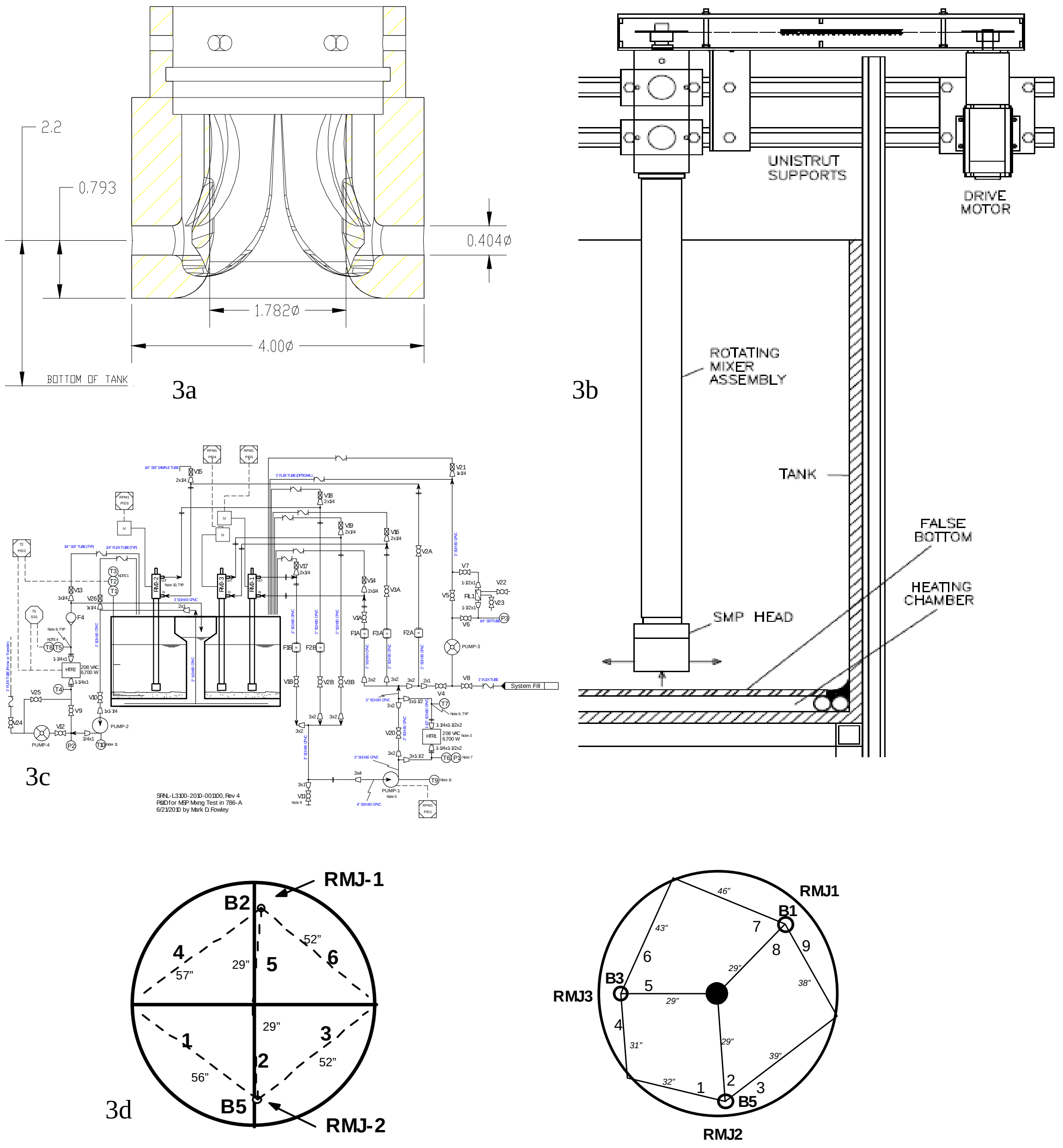

Figure 3. Pilot-scale SMP head, pump assembly, process and instrument diagram, and cleaning radius measurement locations.

Figure 3c shows the process and instrumentation diagram (P&ID). It schematically shows the mixing tank, three mixer pumps, the external pump for the mixers, and instrumentation to measure flow rates and process temperatures. Additionally, the tank heating system is shown. The heating fluid in the false bottom is circulated independently by a separate pump through a 6700 watt heater. The fluid temperature at the heater outlet is measured to control the heater which turns on or off as needed. The temperature was ambient (23 ± 3) °C for the initial suspension tests and 43 ± 3 °C for the resuspension tests. The main circulation pump is controlled by a variable frequency drive (VFD). This controller varies the main pump motor speed to achieve different flow rates through the mixer pumps. Additional flow balancing in mixer pumps is achieved by throttling a valve in the flow path of each pump.

Two additional vane type pumps are provided for chemical transfers in and out of the tank. These vane pumps are also used to prime the centrifugal pump and vent the air out of the flow loop.

Experimental Steps

The researchers performed the MST initial suspension tests in the following manner. They filled the feed tank with ~ 3 m^3 (800 gallons) of simulated supernate solution that was filtered with a 0.2 μm filter. Table 1 shows the composition of the supernate. To this solution, ~ 0.038 m^3 (10 gallons) of 15 wt % MST slurry was added. This amount was selected to be equivalent to ~ 5 MST strikes and to provide a layer of settled MST approximately 1.27 cm (0.5 inch) thick. They allowed the MST to settle overnight at ambient temperature. Following the settling, they operated the mixer pumps at increasing flow rates and measured the cleaning radius along three radial lines for each pump as a function of U_0D (pump nozzle discharge velocity times the pump nozzle diameter). Figure 3d shows the locations at which we measured the cleaning radius. The pump U_0D was increased until all solid particles were suspended or the maximum U_0D of the pump was reached. These tests were performed with standard pump heads, quad volute pump heads, and SMP pump heads.

Table 1. Simulated Supernate Solution Recipe

Ionic Species	Concentration (Molar)
Na^+	6.44
NO_3^-	2.26
NO_2^-	0.74
OH^-	2.57
AlO_2^-	0.35
CO_3^{-2}	0.11
SO_4^{-2}	0.15
SiO_3^{-2}	0.004

The researchers performed the MST resuspension tests in the same manner as the initial suspension tests, except they allowed the MST to settle for four weeks at 43 ± 3 °C, and monitored the tank temperature continuously during the settling.

RESULTS

Scaling of Test Results

The pilot-scale results must be applied to the full-scale waste tanks. The detailed evaluation of scaling the pilot-scale test data to a full-scale tank is described in another SRNL document and will be summarized here [2].

The pilot-scale tank is nominally 1/10.85 linear scale of the full-scale tank (Tank 41H). The tank diameter, liquid level, pump nozzle diameter, cooling coil diameter, and cooling coil length are linearly scaled to Tank 41H. The supernate solution used in these tests was prepared to match the composition of the supernate solution in Tank 37H [1]. The MST used in these tests was made available by SRR and is from the batch currently being used in the Actinide Removal Process (ARP). The goal of scaling is to develop a relationship between the nozzle discharge velocity in the full-scale tank and the pilot-scale tank that leads to equivalent solids suspension in both tanks.

Equation [1] describes the scaling of the test results

$$U_{0\text{-full-scale}} = U_{0\text{-pilot-scale}} \left(T_{\text{full-scale}}/T_{\text{pilot-scale}}\right)^{1/9} \qquad [1]$$

where U_0 is the nozzle discharge velocity and T is the tank diameter. Since the ratio of tank diameters is 10.85, equation [1] becomes

$$U_{0\text{-full-scale}} = 1.3\, U_{0\text{-pilot-scale}} \qquad [2]$$

The nozzle discharge velocity in the full-scale tank is 30% larger than the nozzle discharge velocity in the pilot-scale tank for equivalent solid particle suspension. This scaling is based on matching the shear stress at the solid-liquid interface in both tanks. An alternative scaling approach described in reference 2 uses an exponent of 0 in equation [1] rather than an exponent of 1/9 [2]. Using an exponent of 0 gives equal pump nozzle discharge velocity at both scales.

The cooling coils will cause less drag and less reduction in jet velocity in the full-scale tank compared with the pilot-scale tank [2]. Therefore, the recommended pump nozzle velocity in the full-scale tank contains some conservatism.

The pump rotation rate in the pilot-scale tests was 3.6 rpm, and the basis for this rotation rate is described in reference [2].

MST Suspension Tests with Two Pumps

Figure 4a shows sample cleaning radii measured with two SMPs. At 0.10 m^2/s (1.1 ft^2/s), the solid particles are suspended along radial line 2 all the way to the center column. At 0.13 m^2/s (1.4 ft^2/s), the solid particles are suspended along radial line 1 all the way to the tank wall. At 0.15 m^2/s (1.6 ft^2/s), the solid particles are suspended along radial line 3 all the way to the tank wall.

Figure 4b shows sample cleaning radii measured with three SMPs. At 0.055 m^2/s (0.6 ft^2/s), the solid particles are suspended along radial line 8 all the way to the center column. At 0.11 m^2/s (1.2 ft^2/s), the solid particles are suspended along radial lines 3 and 7 all the way to the tank wall. At 0.15 m^2/s (1.6 ft^2/s), the solid particles are suspended along radial line 6 all the way to the tank wall. The data does show a nonlinearity in the cleaning radius along line 6 due to a small mound (~ 2.54 cm or 1 inch across).

Figure 4c shows the cleaning radius as a function of U_0D for the quad volute, standard slurry pump, and submersible mixer pump. The graph shows the cleaning radius to be a linear function of U_0D and good consistency between the three pumps. The cleaning radius plotted in Figure 4c is the minimum measured from the two pumps. Some areas of the tank exhibited a larger cleaning radius than shown in Figure 4c. A cleaning radius of 1.34 – 1.44 m (53 – 57 inches) is needed to ensure all of the MST particles are suspended with two pumps. Actual required cleaning radius depends on which side of the tank the last particles to be suspended are located. All of the MST particles could be suspended when the minimum measured cleaning radius is less than 1.44 m (57 inches).

Table 2 shows the U_0D needed to suspend all of the MST with each of the pumps, as well as the predicted U_0D needed to suspend the MST in a full-scale tank.

Table 2. Pump Parameters Needed to Initially Suspend MST

Pump	2 Standard	2 Quad Volute	2 SMP
$U_0D_{\text{pilot-scale}}$	Did not suspend	0.143 m^2/s (1.56 ft^2/s)	0.167 m^2/s (1.82 ft^2/s)
$U_0D_{\text{full-scale}}$ (n=0)	Will not suspend	1.55 m^2/s (16.9 ft^2/s)	1.81 m^2/s (19.7 ft^2/s)
$U_0D_{\text{full-scale}}$ (n=1/9)	Will not suspend	2.02 m^2/s (22.05 ft^2/s)	2.36 m^2/s (25.7 ft^2/s)
Max $U_0D_{\text{full-scale}}$	1.25 m^2/s (13.6 ft^2/s)	1.99 m^2/s (21.7 ft^2/s)	2.66 m^2/s (29.0 ft^2/s)

The standard pump was not able to initially suspend all of the MST particles in the tank and had a maximum cleaning radius of ~ 0.38 m (15 inches). One reason for the small cleaning radius of this pump is the large resistances in the pump internals and nozzle. These large resistances result from decreasing the diameter of the pump internals and the pump nozzle. The maximum U_0D achieved with this pump was 0.039 m^2/s (0.42 ft^2/s) [11.4 m/s (37.5 ft/s) nozzle discharge velocity]. Even if the pilot-scale standard pump would have been able to achieve the same nozzle discharge velocity as a full-scale standard pump (33 m/s or 109 ft/s), the maximum U_0D of the pilot-scale pump (0.11 m/s or 1.22 ft^2/s) would have been significantly less than the U_0D needed by the quad volute and SMP pumps to suspend the MST (0.143 – 0.167 m^2/s or 1.56 – 1.82 ft^2/s). Two standard slurry pumps are not sufficient to suspend the MST in Tank 41H for the SCIX process.

The quad volute pump was able to initially suspend all of the particles with a U_0D of 0.143 m^2/s (1.56 ft^2/s) [17.0 m/s (56.1 ft/s) nozzle discharge velocity]. This velocity is ~ 80% of the nozzle discharge velocity of a full-scale quad volute pump. Using the scaling described by equation [2], the required nozzle discharge velocity for two quad volute pumps to initially suspend the MST is 22.1 m/s (73 ft/s), which exceeds the maximum discharge velocity of a quad volute pump (21.8 m/s or 72 ft/s).

The SMP was able to initially suspend all of the particles with a U_0D of 0.167 m/s (1.82 ft^2/s) [16.2 m/s (53.6 ft/s) nozzle discharge velocity]. This velocity is ~ 70% of the nozzle discharge velocity of a full-scale quad volute pump. Using the scaling described by equation [2], the required nozzle discharge velocity for two SMPs to initially suspend the MST is 21.2 m/s (70 ft/s), which is 88% of the maximum discharge velocity of an SMP (23.9 m/s or 79 ft/s).

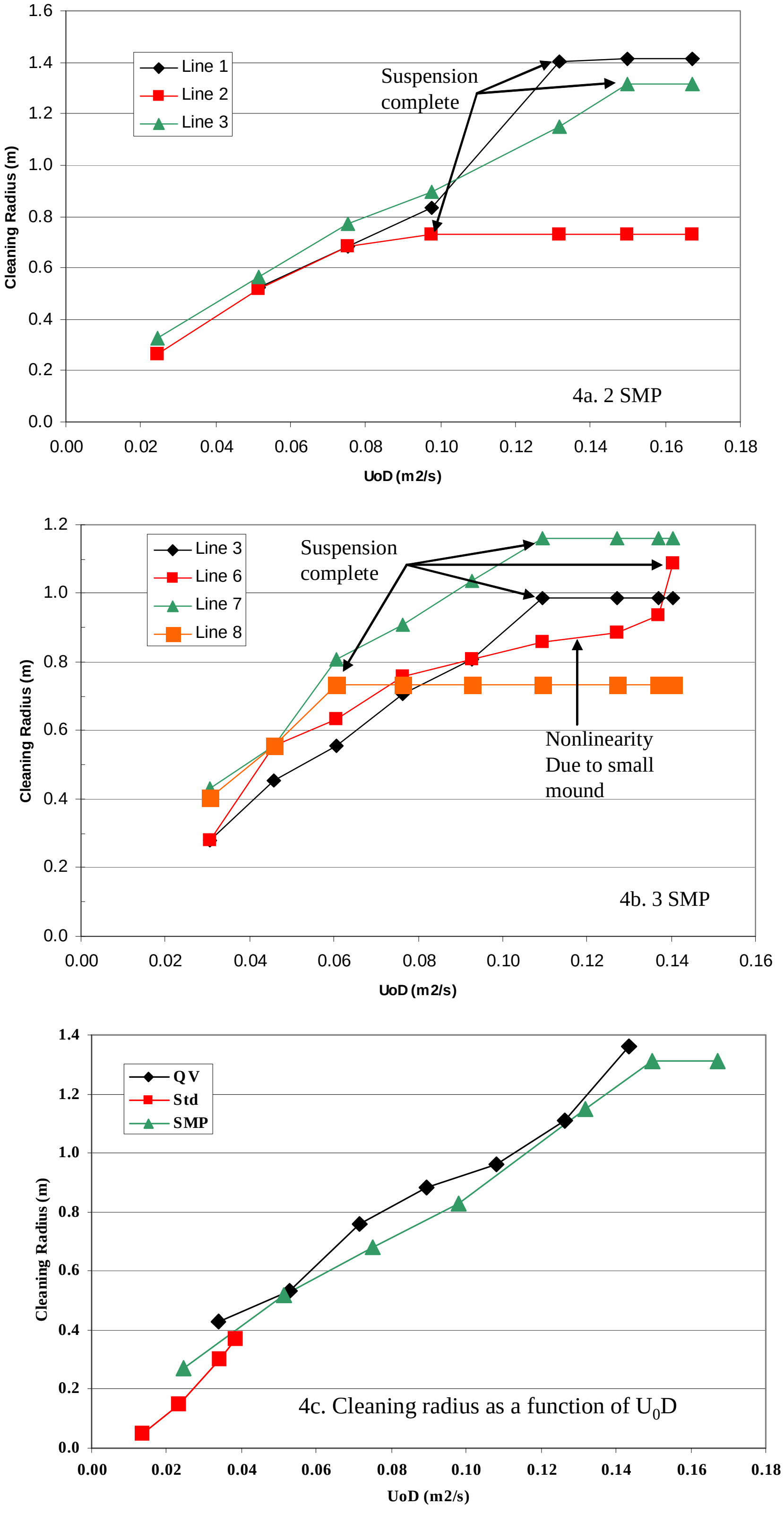

Figure 4. Sample cleaning radii.

According to Table 2, the quad volute pump was able to suspend all of the MST at a U_0D of 0.143 m^2/s (1.56 ft^2/s) versus a U_0D of 0.167 m^2/s (1.82 ft^2/s) for the SMP, a 17% difference. During these tests, the cleaning radius was measured at discrete values of U_0D rather than continuously from 0 – 0.167 m^2/s (0 – 1.82 ft^2/s). The required U_0D is between two measured values, with the larger value being shown in Table 2 and recommended for the SCIX mixer pumps. The actual required U_0D for the SMP is between 0.143 – 0.167 m^2/s (1.63 – 1.82 ft^2/s). The actual required U_0D for the quad volute pump is between 0.127 – 0.143 m^2/s (1.38 – 1.56 ft^2/s). At a U_0D of 0.127 m^2/s (1.38 ft^2/s) with the quad volute pumps, only two of the six radial lines showed complete suspension all the way to the center column or tank wall. However, at a U_0D of 0.143 m^2/s (1.63 ft^2/s) with the SMPs, complete suspension was observed along five of the six radial lines. Along the sixth radial line, MST suspension was observed to 1.39 m (55 inches) along a 1.44 m (57 inch) line. Therefore, a U_0D of 0.143 m^2/s (1.63 ft^2/s) was very close to suspending all of the MST particles.

MST Resuspension Test with Two Pumps

The SMP was able to resuspend all of the particles that had settled for four weeks at 45 °C with a U_0D of 0.22 m^2/s (2.40 ft^2/s) [21.4 m/s (70.6 ft/s) nozzle discharge velocity]. Table 3 shows the calculated U_0D needed to resuspend the MST in a full-scale tank. Using the scaling described by equation [2], the required nozzle discharge velocity for two SMPs to resuspend the settled MST is 27.9 m/s (92 ft/s), which exceeds the maximum discharge velocity of an SMP (23.9 m/s or 79 ft/s). Because of this result, subsequent tests were performed with three pumps.

Table 3. Parameters Needed to Resuspend MST after Settling for Four Weeks at 45 °C

Pump	2 SMP
$U_0D_{pilot\text{-}scale}$	0.22 m^2/s (2.40 ft^2/s)
$U_0D_{full\text{-}scale}$ (n=0)	2.39 m^2/s (26.0 ft^2/s)
$U_0D_{full\text{-}scale}$ (n=1/9)	3.09 m^2/s (33.7 ft^2/s)
Max $U_0D_{full\text{-}scale}$	2.66 m^2/s (29.0 ft^2/s)

MST Suspension Test with Three Pumps

Table 4 shows the U_0D needed to initially suspend MST with three pumps in a full-scale tank. The SMP was able to initially suspend all of the particles with a U_0D of 0.125 m^2/s (1.36 ft^2/s) [12.2 m/s (40.1 ft/s) nozzle discharge velocity]. This velocity is ~ 50% of the nozzle discharge velocity of a full-scale quad volute pump. Using the scaling described by equation [2], the required nozzle discharge velocity for three SMPs to initially suspend the MST is 15.8 m/s (52 ft/s), which is 66% of the maximum discharge velocity of an SMP (23.9 m/s or 79 ft/s). Three SMPs should be able to initially suspend the MST particles added to Tank 41H, so that they can contact the supernate and sorb the strontium and actinides present.

Table 4. Parameters Needed to Initially Suspend MST

Pump	3 SMP
$U_0D_{pilot\text{-}scale}$	0.125 m^2/s (1.36 ft^2/s)
$U_0D_{full\text{-}scale}$ (n=0)	1.36 m^2/s (14.8 ft^2/s)
$U_0D_{full\text{-}scale}$ (n=1/9)	1.76 m^2/s (19.2 ft^2/s)
Max $U_0D_{full\text{-}scale}$	2.66 m^2/s (29.0 ft^2/s)

MST Resuspension Test with Three Pumps

Table 5 shows the U_0D needed to resuspend MST with three SMPs in a full-scale tank. The table shows three SMPs will be able to resuspend MST that has settled for four weeks at nominal 45 °C, with 23 % conservatism.

Table 5. Parameters Needed to Resuspend MST that Settled for Four Weeks at 45 °C

Pump	3 SMP
$U_0D_{pilot\text{-}scale}$	0.146 m^2/s (1.59 ft^2/s)
$U_0D_{full\text{-}scale}$ (n=0)	1.58 m^2/s (17.2 ft^2/s)
$U_0D_{full\text{-}scale}$ (n=1/9)	2.06 m^2/s (22.4 ft^2/s)
Max $U_0D_{full\text{-}scale}$	2.66 m^2/s (29.0 ft^2/s)

Future tests will evaluate the ability of three pumps to resuspend MST plus CST particles that have settled for four weeks at 45 °C and MST plus CST plus simulated sludge particles that have settled for four weeks at 45 °C.

CONCLUSIONS

The conclusions from this work follow.

- Neither two standard slurry pumps nor two quad volute slurry pumps will provide sufficient power to initially suspend MST in an SRS waste tank.
- Two Submersible Mixer Pumps (SMPs) will provide sufficient power to initially suspend MST in an SRS waste tank. However, the testing shows the required pump discharge velocity is close to the maximum discharge velocity of the pump (within 12%).
- Two SMPs will not provide sufficient power to resuspend MST that has settled in a waste tank at nominal 45 °C for four weeks.
- Three SMPs will provide sufficient power to initially suspend MST in an SRS waste tank. The testing shows the required pump discharge velocity is 66% of the maximum discharge velocity of the pump.
- Three SMPs will provide sufficient power to resuspend MST that has settled in a waste tank at nominal 45 °C for four weeks. The testing shows the required pump discharge velocity is 77% of the maximum discharge velocity of the pump.

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