Visual Evaluation of Effective Cleaning Radius in Model Jet-Agitated Tank

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ABSTRACT

Suspension of monosodium titanate (MST) and sludge in high level waste (HLW) tanks at Savannah River Site (SRS) is needed prior to processing of the salt solution (containing actinides, Sr-90, and Cs-137) from the supernate and the dissolved saltcake. One type III tank model, including cooling coils, was fabricated and used to carry out cost effective evaluation of jet-mixing of MST and simulant sludge in surrogate salt solution. The model tank has a diameter of 0.3 m (1 ft). Experimental work was carried out utilizing five different sludge/MST mixtures in surrogate salt solution. The examined solutions included 5% wt sludge, 5% wt 4:1 sludge/MST, 5% wt 2:1 sludge/MST, 5% wt 1:1 sludge/MST, and 5% wt MST.

The progress of the effective cleaning radius (ECR) formation was monitored during the mixing and suspension processes with and without the presence of cooling coils and at several pumping flow rates and nozzle orientations. Digital photographs of the bottom of the tank were analyzed and the ECR was measured at different pumping flow rate and nozzle orientation. It was found that it took 20 to 30 minutes in order to reach a fully developed ECR at the bottom of the tank. A qualitative analysis of the images taken for the fully developed ECR (at nozzle angles of 0^o, 45^o, and 90^o from the centerline of the tank) indicated that two counter-rotating eddies took place in the tank, resulting in full suspension of the sludge and MST except for two islands (spots) of settling sludge and MST particles. These islands of settling sludge and MST vary in size and location depending on the pump flow rate and the angle of the nozzle from the tank centerline. The presence of cooling coils in the tank hindered the suspension process and resulted in an undeveloped ECR even at high flow rates.

INTRODUCTION

Waste tanks at the DOE's Savannah River Site (SRS) contain 37 million gallons of high level waste (HLW) at a total activity of 426 million Curies (Ci). Two tanks from a total of 51 tanks have been closed. Closure of the remaining tanks and final disposition of the HLW is a high priority task at SRS. The HLW in the waste tanks are separated into layers: supernate (at the top of the tank) containing soluble fission products, and salt cake and sludge (at the bottom) containing insoluble actinides. The majority of the activity is attributed to Cs-137, Sr-90, and actinides. The Department of Energy (DOE) is evaluating alternative methods and technologies for HLW removal and processing, which, if successful, has the potential of saving $5.45 billion (Suggs et al. [1]).

One of several scenarios to perform in-tank processing of the waste, Monosodium titanate (MST) may be added to the waste inside the tank, which requires at least 24 hours to adsorb Sr-90 and actinides. Thereafter, the waste would be filtered to remove the sludge, which contains actinides, and the Sr-90-loaded MST particles from the main waste stream. The sludge and MST will be held in a storage tank until a certain volume is obtained, and then it will be mixed so that the solids are suspended in the solution and transported for verification. One option is to use a type III HLW tank as the storage tank. Prior studies (Taylor and Mattus [2]) indicated that prolonged storage at high radiation levels or temperatures may increase the yield stress of the MST/sludge mixture to a level that may result in an inability to resuspend it. Bench-scale and pilot-scale resuspension experiments revealed that scaling up from small-batch tests overestimated the ability to resuspend the MST/sludge slurry

Churnetski [3] developed an empirical correlation to predict the effective cleaning radius (ECR) at the Savannah River Laboratory's 30-meter-diameter mock-up waste tank utilizing surrogate waste and sludge model. Churnetski showed experimentally that the ECR is directly proportional to the product of the nozzle diameter and the initial jet velocity for a Bingham plastic slurry and ECR can be calculated by the following equation:

$$ECR = C_1 D_o V_o \left(\frac{\rho}{2 g_c \tau_0}\right)^{\frac{1}{2}} e^{-C_2[\tan(\frac{1}{2\theta})]} \qquad \text{(Eq. 1)}$$

where:

ECR effective cleaning radius,

C_1 and C_2 : dimensionless constants,

D_o : diameter of the jet nozzle,

V_o : initial nozzle jet velocity,

ρ : density of the solution,

τ_0 : yield stress,

θ : jet angle and

g_c : universal gravitational constant.

The jet angle, θ, was estimated by utilizing Donald and Singer [4] equation as follow:

$$\tan\left(\frac{\theta}{2}\right) = 0.238\,\nu^{0.133} \qquad \text{(Eq. 2)}$$

where υ is the kinematic viscosity with units of stokes. Churnetski gave the values of constants C_1 and C_2 as 40 and 6.2 respectively. However, when comparing current ECR measurements to their corresponding calculated values, it was found that values of 3 for C_1 and 6.2 for C_2 were observed to better fit the data.

This work investigates the influence of cooling coils on the suspension of MST/sludge mixture utilizing simulant sludge and actual MST in surrogate salt solution. A scaled-down model of a type III HLW tank, including model cooling coils was fabricated to perform the suspension experiments. Photographs of developing ECR along with measurements of well developed ECR are provided.

EXPERIMENTAL SETUP

Geometric similarity of a model tank was based on a type IIIA tank at SRS. Type IIIA tanks have a diameter of 85 ft, height of 33 ft, and a center column (6.8-ft diameter) to support the roof. Vertical cooling coils are present inside the tank, which are attached to the bottom of the tank for structural support. The cooling coils and center column have an unknown effect on sludge/MST resuspension efforts. The scaled-down model tank has a center column and cooling coils installed with dimensions that preserve geometric similarity to a certain degree. The cooling coil simulation was fabricated and installed so that it can be easily removed.

Geometric similarity would require a nozzle diameter of 0.02 inches, which is not feasible for these experiments since capillary forces will predominate. Instead, geometric similarity was attempted using the product of nozzle diameter and initial jet velocity.

Based on a low pump volumetric flow of 650 ml/min (3.80 x 10^{-4} ft^3/s) and a nozzle diameter of 1/8 inch (0.01042 ft), the product of Dv_{jet} was calculated to be 0.023 ft^2/s. Using similar calculations, the product of Dv_{jet} for the full size tank (using 900 gpm) is 9.43 ft^2/s, which scales down (using factor of 88.7) to 0.106 ft^2/s for the 1 ft tank. Increasing the nozzle diameter or the volumetric flow rate by a factor of 5 is not practical for the 1 ft tank. Therefore, a geometrically distorted model tank was used since full geometric similarity between the 1 ft tank and the full-scale tank was not feasible.

Figure 1 (a) illustrates an isometric diagram of the model tank setup. The slurry was circulated in the tank by a variable speed pump. The pump was used to withdraw the slurry from the tank. The slurry was then ejected back into the tank through a 0.003 m (1/8 inch) diameter bidirectional nozzle. The nozzle had no compartments to condition the fluid prior to ejection. Figure 1 (b) shows a photograph of the nozzle. The nozzle was placed 0.013 m (½ inch) above the bottom of the tank. The height of the slurry in the tank was kept constant at 0.025 m (1 inch) throughout the experiments. The pump flow rate varied from 0.5 L/min (0.13 gal/min) to 2.2 L/min (0.67 gal/min).

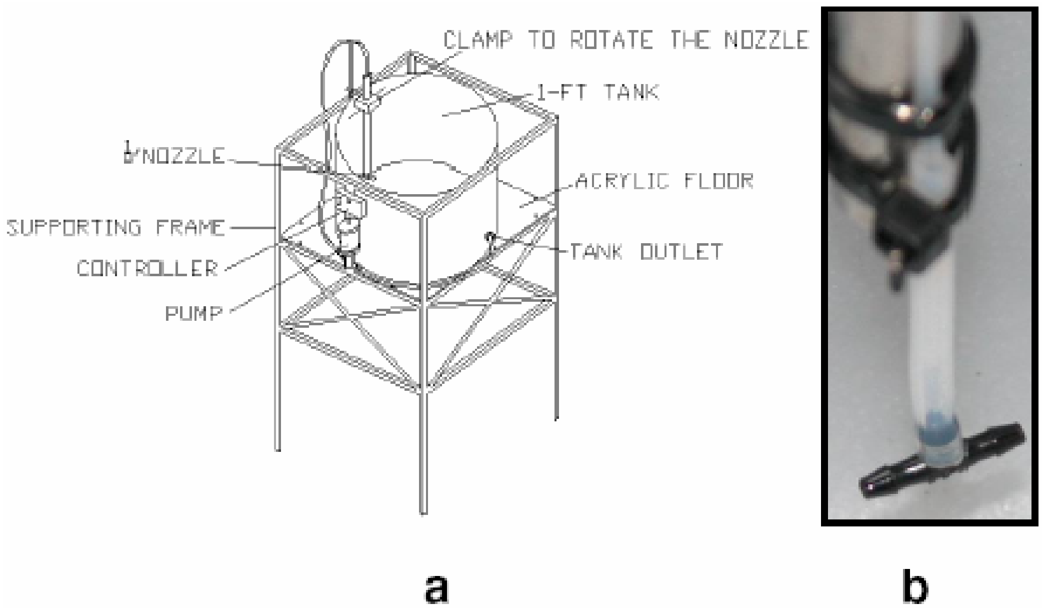


Fig. 1. (a) 1-ft diameter tank setup, (b) photograph of the 0.013 m (½ inch) diameter nozzle

The model cooling coils (Fig. 2) used in the experiments consists of 20 rows of wire. Each row is placed ½ inch apart from the next row. Each wire in the row is ¾ inch apart from the adjacent wire in the same row. The wire is 0.062 inches thick.

Fig. 2. Model cooling coils placed in the 1-ft diameter tank to mimic HLW type III tanks at SRS

RESULTS AND DISCUSSION

Measurements of the ECR were compared to their corresponding calculated values utilizing modified Churnetski’s correlation, (Table 1). Moreover, a statistical analysis was carried out to determine if the differences between the measured and calculated ECR were significant. A paired t-test indicated no significant differences between the measured and calculated values of

ECR using modified Churnetski's correlation. Calculated values of ECR using modified Churnetski's correlation were in good agreement with their corresponding measurements. However, validation of modified Churnetski's correlation in larger tanks was not possible due to the lack of experimental data in larger tanks. Table 1 illustrates a comparison between the measured and calculated ECR in the 1-ft tank.

Table 1. Comparison between measured and calculated ECR

Solution	**ECR (ft)**		
	Modified Churnetski	**Original Churnetski**	**Experimental Values**
5 wt% MST in surrogate salt solution	0.37	4.93	0.36
5 wt% sludge in surrogate salt solution	0.47	6.27	0.40
5 wt% (1:1) sludge/MST in surrogate salt solution	0.37	4.93	0.41
5 wt% (2:1) sludge/MST in surrogate salt solution	0.38	5.07	0.40
5 wt% (4:1) sludge/MST in surrogate salt solution	0.38	5.07	0.39

Photographs and video tapings for the development and formation of the ECR in the 1-ft tank were taken at pumping flow rates of 2200 ml/min and 500 mil/min and at three distinct nozzle orientation angles; 0^o, 45^o, and 90^o. Figure 3 shows a sequence of images for developing ECR in the 1-ft tank using 5% wt MST at a pumping flow rate of 2200 ml/min and without the presence of cooling coils. The nozzle was at an angle of 90^o from the centerline of the tank. Similar results were noticed by Daas and Srivastava [5] during examination of the other slurries. Fully developed ECR formed after 20 minutes of continuous jet mixing and suspension.

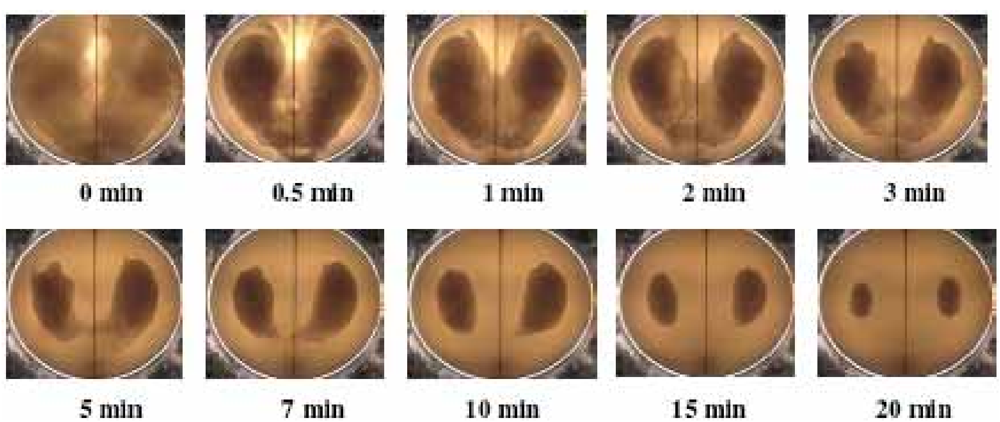
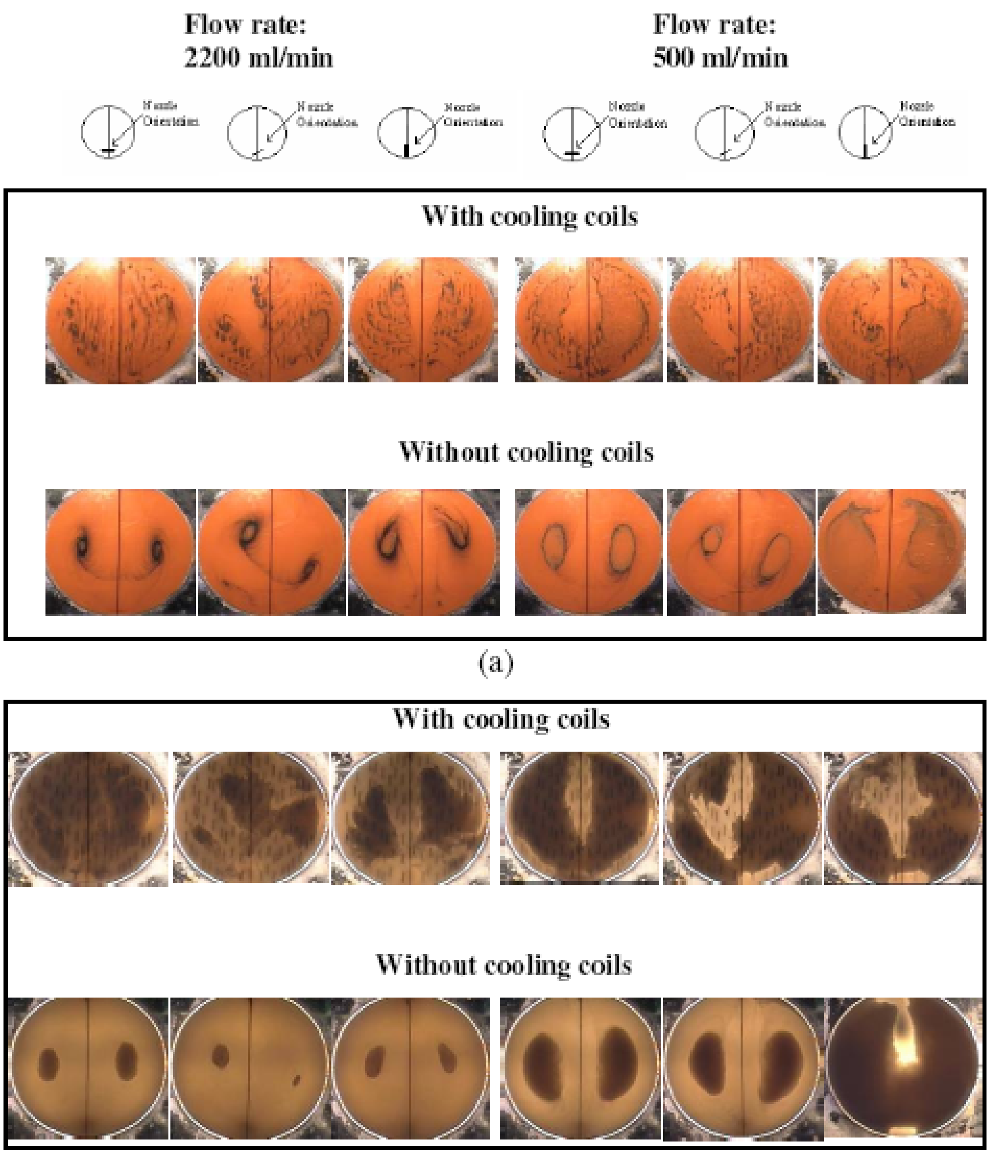


Fig. 3. Development of ECR in the 1-ft tank without the cooling coils for 5% wt MST, 2200 ml/min, nozzle angle is 90^o from the tank axis.

Illustrative results from a qualitative comparison of photographs for fully developed ECR in the 1-ft tank are presented in this paper. The photographs indicated that more sludge and MST were suspended at higher pump flow rates; initial nozzle jet velocity. Furthermore, the presence of cooling coils hindered the suspension process and resulted in undeveloped ECR even at high flow rates as shown in Figure 4. Two islands of settling sludge/MST were formed upon reaching fully developed ECR. The size and location of these islands varied with pumping flow rate and the nozzle orientation.



(b)

Fig. 4. Photographs illustrating the impact of cooling coils on the fully developed ECR in the 1-ft diameter at three nozzle orientations, (a) 5% wt simulant sludge, (b) 5% wt MST

CONCLUSIONS

Experimental work to study the effective cleaning radius in a 1-ft diameter tank was carried out. The ECR was measured using photographs and video tapings of the tank bottom. A model developed by Churnitski [3] to calculate the ECR in jet-agitated tanks was verified using experimental ECR measurements. The Churnitski [3] model overestimated the ECR significantly. The model was then modified based on experimental data and flow conditions, and the subsequent results from the modified model were satisfactory with the experimental results. A qualitative analysis of the images taken for the fully developed ECR (at nozzle angles of 0^o, 45^o, and 90^o from the centerline of the tank) indicated that two counter-rotating eddies took place in the tank, resulting in full suspension of the sludge and MST except for two islands (spots) of settling sludge and MST particles. These islands of settling sludge and MST varied in size and location depending on the pump flow rate and the angle of the nozzle from the tank centerline. The presence of cooling coil in the tank hindered the suspension process and resulted in an undeveloped ECR even at high flow rates.

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