Blending of Radioactive Salt Solutions in Million Gallon Tanks – 13002

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ABSTRACT

Research was completed at Savannah River National Laboratory (SRNL) to investigate processes related to the blending of radioactive, liquid waste, salt solutions in 4920 cubic meter, 25.9 meter diameter storage tanks. One process was the blending of large salt solution batches (up to 1135 – 3028 cubic meters), using submerged centrifugal pumps. A second process was the disturbance of a settled layer of solids, or sludge, on the tank bottom. And a third investigated process was the settling rate of sludge solids if suspended into slurries by the blending pump. To investigate these processes, experiments, CFD models (computational fluid dynamics), and theory were applied. Experiments were performed using simulated, non-radioactive, salt solutions referred to as supernates, and a layer of settled solids referred to as sludge. Blending experiments were performed in a 2.44 meter diameter pilot scale tank, and flow rate measurements and settling tests were performed at both pilot scale and full scale. A summary of the research is presented here to demonstrate the adage that, “One good experiment fixes a lot of good theory”. Experimental testing was required to benchmark CFD models, or the models would have been incorrectly used. In fact, CFD safety factors were established by this research to predict full-scale blending performance. CFD models were used to determine pump design requirements, predict blending times, and cut costs several million dollars by reducing the number of required blending pumps. This research contributed to DOE missions to permanently close the remaining 47 of 51 SRS waste storage tanks.

INTRODUCTION

The research results presented here review two projects separated by about ten years, which were combined to investigate mixing processes in 4290 cubic meter (1.3 million gallon tanks), where final conclusions and updates to previous publications are provided here. Both projects use centrifugal pumps to mix storage tank contents, and both projects used CFD models and experimental data to predict full-scale pump performance in a radioactive environment. The earlier project successfully used the ADMP (Advanced Design Mixer Pump, Fig. 1), and the recent project investigated the use of two different pumps: the SDI pump (Salt Disposition Integration Portfolio of Project, Fig. 2), and the Standard slurry pump, which is so –named due to its common use at SRS. The ADMP and Standard pumps are similar in design in that each pump is powered from a motor mounted on top of the tank. The above grade drive motor is connected to the submerged centrifugal pump by an enclosed, 10.7 meter (35 feet) long, drive shaft that passes through an opening in the tank top, called a riser. The business end of the pump entrains liquid up through the pump suction into the rotating pump impeller, which discharges two fluid jets from opposing nozzles to entrain fluids and mix the tank contents. For the SDI pump, the motor is submerged along with the pump, and a long, non-rotating, support shaft suspends the pump from the tank

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top (descriptively referred to as a pump on a stick).

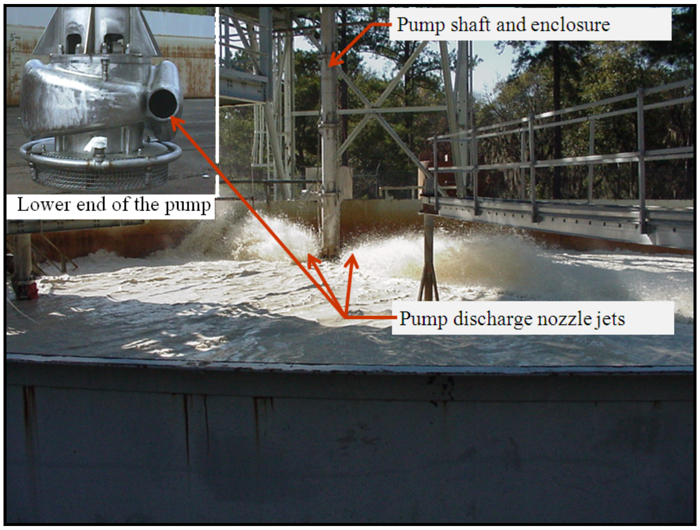
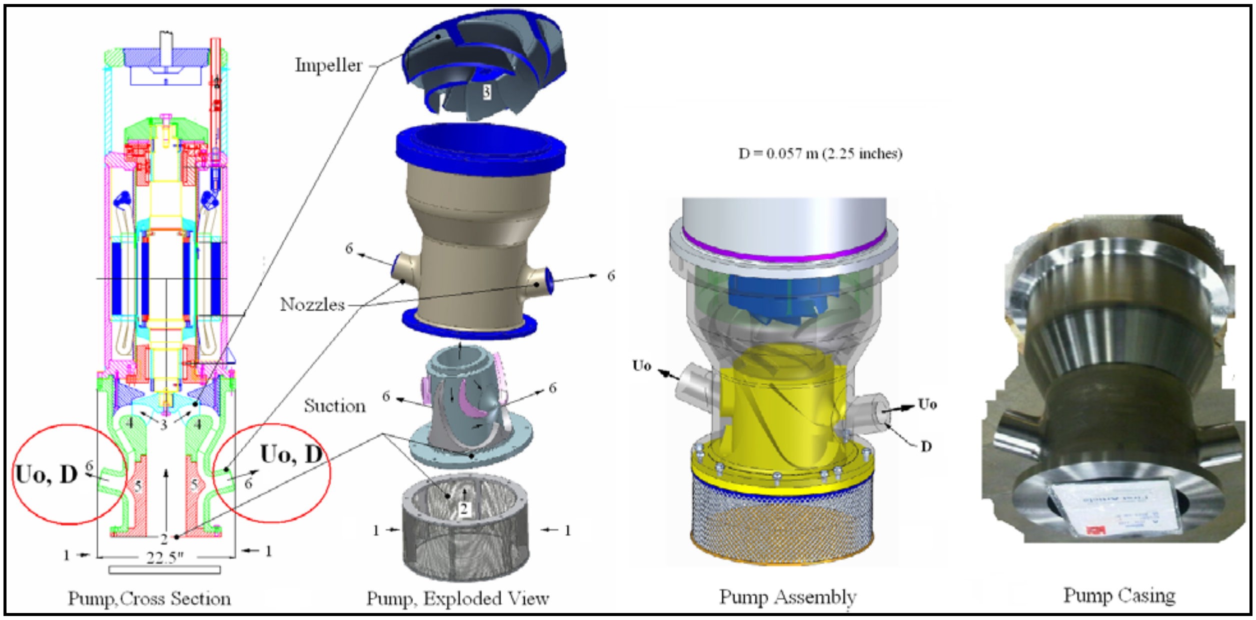


Figure 1: Partially submerged ADMP (Leishear, et al. [1-4, 7, 8])



Pump, Cross Section

Pump, Exploded View

Pump Assembly

Pump Casing

Figure 2: SDI pump, views and fabricated pump casing (Leishear, et al. [13, 15])

In addition to construction differences and power requirements, the fundamental differences between pumps are the flow rates and applications. The ADMP is a high flow rate pump {39.4 m^3/minute, 10,400 gpm total, 0.152 meter (6 inch) diameter nozzles}, The Standard pump is a mid-range flow rate pump {4.54 m^3/minute (1200 gpm) total, 0.0381 meter (1-1/2 inch) diameter nozzles}, and the SDI is a low flow rate pump {1.9 – 3.0 m^3/minute (500-800 gpm) total, 0.058 meter (2.27 inch) diameter nozzles}. The purpose of the ADMP was to scour sludge from the tank bottom up into a slurry form for removal from the tank by a separate transfer pump. The ADMP successfully removed sludge from the tank bottom ten years ago for a tank that was recently filled with grout for permanent tank closure. The purpose of the SDI pump is to blend salt solutions above the sludge layer without significantly disturbing the sludge layer. The Standard pump has been used for years at SRS to slurry sludge in numerous waste tanks, both for sludge removal and for periodic mixing to prevent the accumulation of flammable hydrogen and oxygen in the sludge layer due to radiolysis and decomposition of water. For the SDI project, the Standard pump was further investigated for its ability to blend salt solutions.

RESEARCH DESCRIPTION

A final overview is presented here for mixing research conducted by SRNL, as condensed from hundreds of pages of reports and publications. Reports and publications are available to describe the ADMP research of ten years ago, and to describe design details of the ADMP and Standard pumps (Leishear, et al. [1-6], and Lee, et al. [7 and 8]). Recent research was solicited and overseen by Savannah River Remediation LLC (SRR) for the SDI project, which is required to blend 1135 – 3028 cubic meter batches (300,000- 800,000 gallons) salt solutions for feed to the Salt Waste Processing Facility at SRS. A series of four Conference papers and a Journal paper were published parallel to this research to solicit technical opinions from peer reviewers to improve research as it progressed (Leishear, et al. [9-13]). In addition to these publications, several technical reports were completed to document project success (Leishear, et al. [14 and 15] and Lee, et al. [16 and 17]). A short, semi-technical discussion about technical advancements in the field of mixing technology which resulted from this research is also in press for the ASME Mechanical Engineering Magazine (Leishear, et al [18]). Detailed recommendations, numerous references, scientific methods, equipment descriptions, calculation techniques, test results, and conclusions are available in these various publications and reports. In short, the overview presented here aims to document mixing technology advancements to assist the permanent disposition of legacy Cold War radioactive liquid waste, and to document the primary SDI blending project goal of providing technical recommendations to purchase and operate blending pumps in nuclear waste storage tanks.

CFD models provided considerable insight into blending processes, but experimental tests were essential for CFD model bench marking. SRNL procedures (Lee and Dimenna [13, 19]) equivalent to ASME standards (ASME [20]), were used to verify and validate single phase CFD models, which were commercially available from Fluent® (ANSYS [21]). CFD models provided reasonable estimates for the average blending times when tracer solutions were blended into the pilot scale tank, but the variation -- or scatter -- in blending times for comparable conditions varied by a factor of nearly three, depending on the internal obstructions in the tank. The term safety factor is used here, but the terms correction factor and design margin also appear in the literature. Also, blending performance changed significantly in the pilot-scale tank, when the blending process was changed from blending tracer additions to blending large volumes of different density and viscosity solutions. To investigate this bulk addition process, one quarter of the tank volume was added to the tank from a jet above, and perpendicular to, the liquid surface when the tank was initially ¾ full. If the added fluid was denser than (or of equal density), the downward jet of salt solution penetrated the layer of water to near the tank bottom, and adequate blending occurred due to the addition process alone, without operating the blending pump at all. When a less dense solution was added to the tank the downward water jet did not penetrate the salt layer appreciably, and the average blending time was increased by a factor of forty, or more, due to stratification of the two fluids, where the mixing process changed completely.

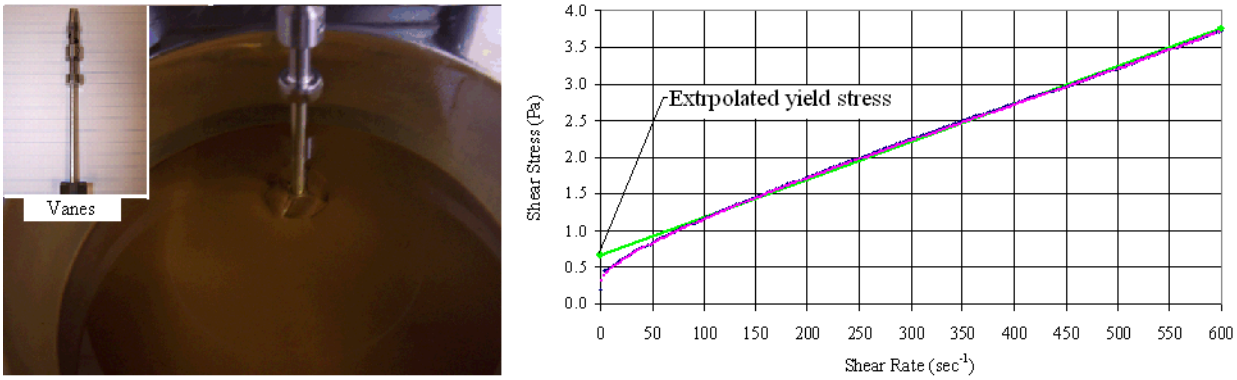
In addition to blending considerations, sludge disturbance and settling were investigated. First, pump design requirements were established to determine the minimum values needed to blend the tank contents without disturbing the sludge layer. Then, higher flow rate pumps were considered, which are expected to slurry the sludge into solution. For this case, the settling rates of the sludge particles are of concern. Classic theoretical predictions of settling times provided high settling time estimates than experimental data. Further analysis was recommended at both pilot-scale and full-scale.

All in all, non-radioactive pilot scale and full scale testing provided process insights unavailable from theory or CFD modeling. This research advanced the understanding of blending processes and yielded project recommendations for blender pump design and pump operations, but further research is warranted to fully understand the fluid mechanics of the various processes.

DISCUSSION

The earlier full-scale ADMP research laid the foundation for the subsequent SDI research. The SDI research included pilot scale modeling for blending, full-scale modeling for settling, and CFD modeling at both pilot-scale and full-scale.

All CFD modeling was performed using single phase fluids, and the two-phase interface between the sludge layer and the salt solution was modeled as a boundary layer in the CFD models. To do so, physical properties of the sludge were required, as well as experimental measurements of the velocity required to disturb the sludge layer. Sludge properties differed between the ADMP research and the SDI research.



Rheology testing, Flat vaned impeller

Typical yield stress data, Concentric cylinders

Figure 3: Typical yield stress determination for a Bingham fluid (SDI simulant shown)
(Leishear, et al. [13, 15])

In particular, densities and yield stresses varied. Sludge tends to be gelatinous and is known to act as a Bingham plastic fluid, which requires a motive force to overcome the yield stress of the fluid, similar to catsup in a bottle. To determine the yield stresses in Pascals (10 dynes/cm^2 = 1Pa), a rheometer measured the torque during rotation using both a flat vaned impeller and concentric cylinders, and converted the torque to shear stress measurements. Equipment used for much of the rheology typical for this work is shown in Fig. 3. Also in Fig. 3, some test results from a concentric cylinder rheometer are shown to better visualize sludge properties, where the yield stress is extrapolated from experimental shear stress data as shown (See Leishear, et al. [15] for additional testing details). To aid visualization of sludge properties, note that Fig. 4 shows the differences between a non-Newtonian, Bingham plastic fluid and a Newtonian fluid such as water or oil.

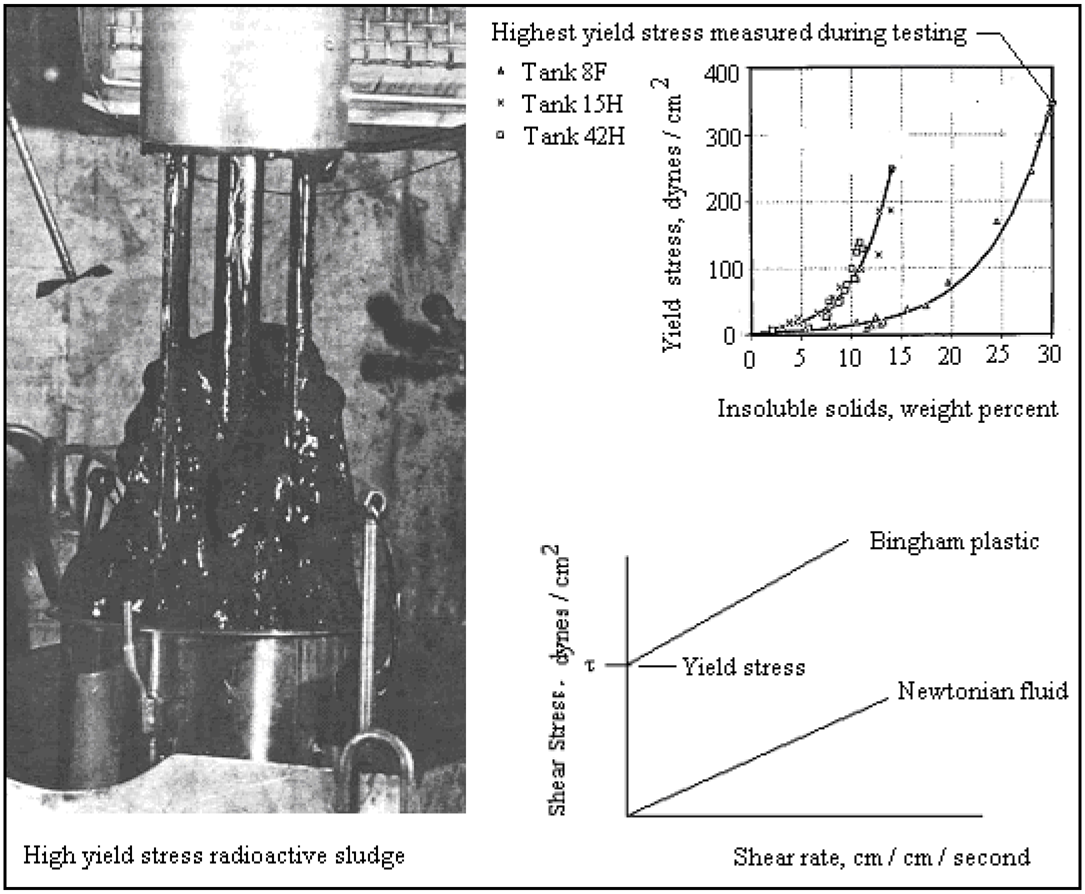
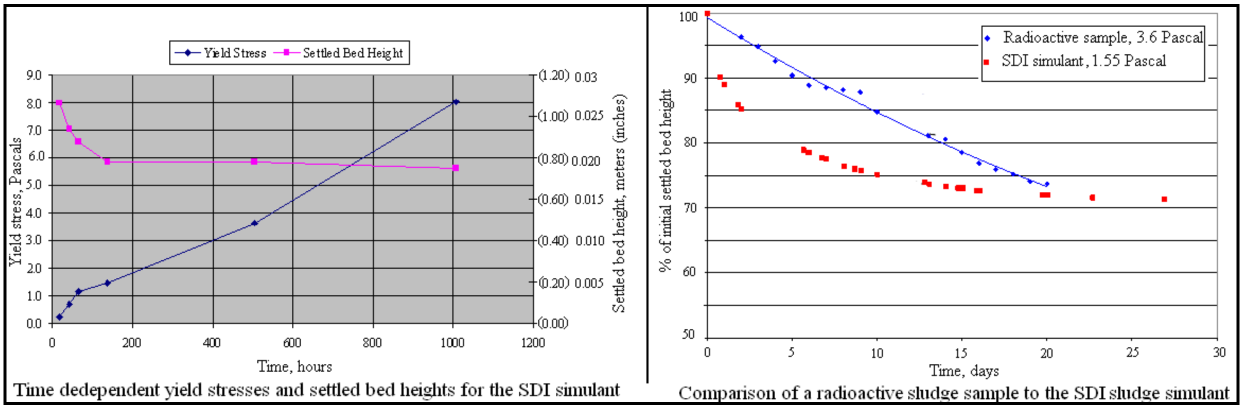


Figure 4: Yield stress data used for the ADMP research (Stone [22], Hamm and Ebra [23])

For the SDI research, a lower yield stress simulant was used for testing. The simulant was of similar chemical composition to a radioactive sludge sample taken from tank storage to be processed at SRS (referred to as SB6, sludge batch 6). Based on SRR and SRNL engineering experience, this particular simulant modeled the slowest settling sludge available to date, and as such was considered to provide bounding material properties for the SDI tests. This sludge was also observed to have increasing shear strength over time as the height of the settling bed decreased to increase concentration over time, as shown in Fig. 5. Additionally, the sludge simulant properties were compared to radioactive sludge: also shown in Fig. 5. Properties were similar but not identical. The gelatinous nature of the sludge is indicated by a drying process performed on the simulant (Fig. 6).



Time dedependent yield stresses and settled bed heights for the SDI simulant

Comparison of a radioactive sludge sample to the SDI sludge simulant

Figure 5: SDI sludge and sludge simulant rheological properties (Leishear, et al. [13, 15])

Figure 6: Dried SDI sludge simulant on a 0.3 meter (12 inch) filter paper

For the ADMP research, a higher density, higher yield stress sludge was modeled, since the goal was to bound calculations to ensure that the sludge would be disturbed and completely mixed regardless of the material properties in the tank. A significant risk to this research was the fact that material properties vary from tank to tank and even within a tank. Limited data is available due to the costs and risks associated with sampling radioactive waste from the tanks. Figure 4 shows the data used for the ADMP analysis, which was obtained from various waste storage tanks at SRS (Tanks 8F, 15H, and 42H). From this data, the highest yield stress and associated density was used in Equation 1 to predict sludge mixing capabilities of the mixing pump. The maximum yield stress obtained from Fig. 4 was obtained for a sample that had settled for close to a year in the shielded cells at SRNL, where the extended settling time increased the density and yield stress of the sludge sample. Most of the samples were homogeneously mixed prior to rheology measurements. However, this particular sample had settled for a long time, and the sludge properties were obtained without remixing supernate above the sludge with the sludge itself.

Consequently, the effects of long-time setting and resultant sludge concentration were observed. Observation have also been made at SRNL that both temperature increases and length of settling time increase the yield stress.

ADVANCED DESIGN MIXER PUMP RESULTS

Having considered the material properties for this research, the experimental and CFD modeling results are next considered, starting with the ADMP research results and following with the SDI research results. The ADMP research compared experimental velocity measurements to CFD calculations. CFD models were then used to calculate velocities at the sludge layer to ensure that the velocity required to shear the sludge into solution was exceeded by the ADMP to ensure adequate mixing.

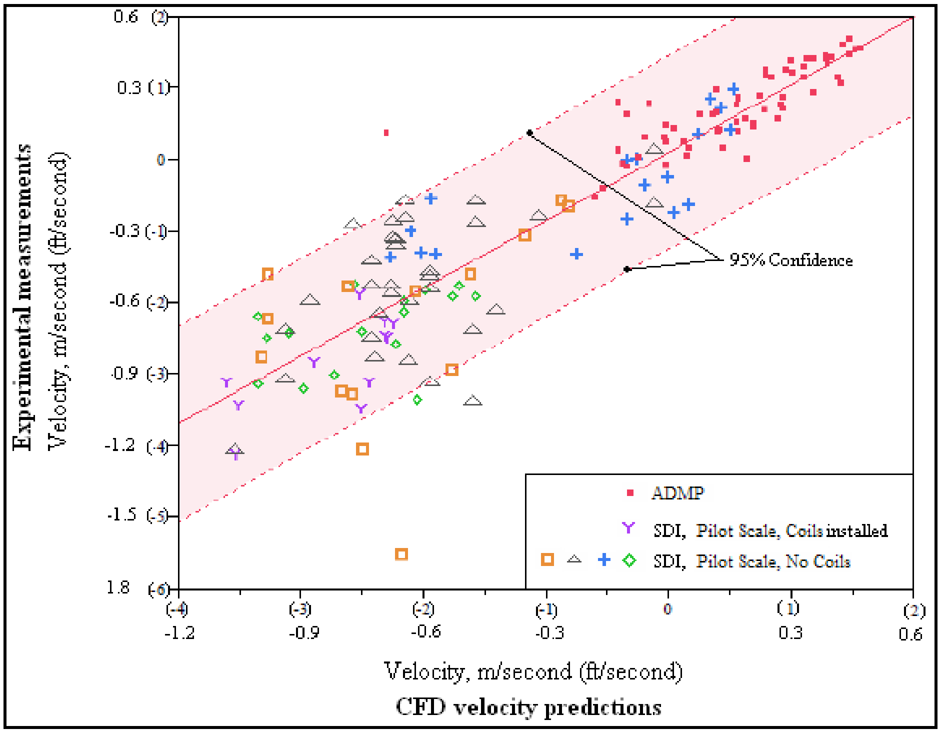


Figure 7: Comparison of CFD results to experimentally measured velocities (ADMP and SDI results) (Leishear, et al. [13, 15])

Velocity measurements and CFD predictions

Using the pump shown in Fig. 1, velocity measurements were taken throughout the full-scale tank, and compared to CFD models, which used more than a million elements and a κ-ε turbulence model. In service, the ADMP was centrally located in a tank without internal obstructions. At first, a simplified two dimensional, planar model was used to represent the horizontal plane along the pump discharge centerline. Results were completely unacceptable, since the CFD model results looked nothing like the flow patterns observed on the surface in the full-scale tank with an operating pump. Three dimensional CFD model results were then compared to velocities measured in the full-scale tank, and CFD models were shown to provide good agreement with experiment. A comparison of the ADMP and SDI results to experiment are shown in Fig. 7. From these results, a statistical analysis was performed, and the uncertainty equaled 27% with 95% confidence throughout the range of interest from pilot-scale through full-scale testing. Accordingly, a recommended safety factor of 1.27 was determined. This factor should be applied to CFD results by multiplying CFD calculated velocities times 1.27.

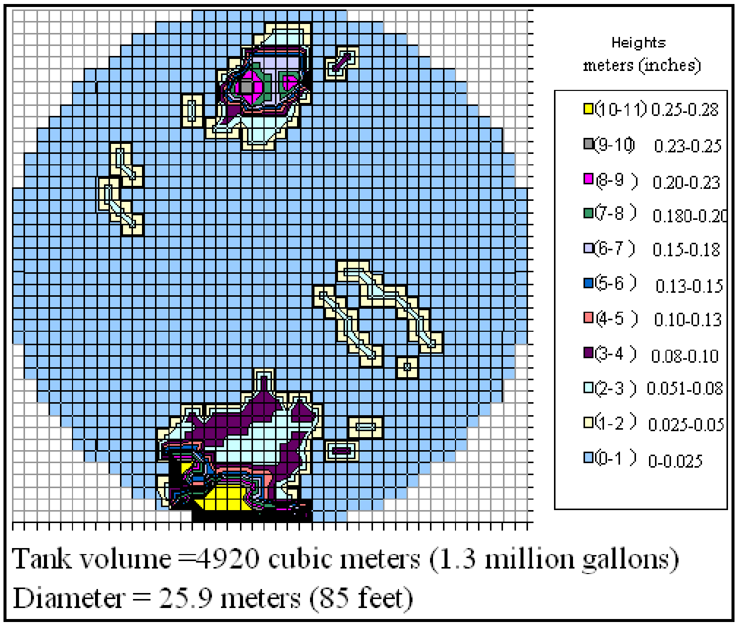


Figure 8: Residual hardened sludge on the tank floor (Tank 18F) (Augeri, et al. [1, 5])

Sludge suspension

To determine the velocity required to shear sludge into suspension, Equation 1 was used (Churnetski [24 and 25]).

$$ECR = 0.40 \cdot Uo \cdot D \cdot \sqrt{\frac{\rho}{\tau}} \cdot \left(100 \frac{cm}{m}\right) \qquad \text{Eq. 1}$$

where the *ECR* equals the effective cleaning radius (meters) or the distance to which sludge is expected to be scoured from the tank floor, *D* is the pump nozzle diameter (meters), *Uo* is the discharge nozzle velocity (meters/second), ρ is the sludge density (grams/milliliter), and τ is the sludge yield stress (dynes/centimeter^2). Material properties from Fig. 4, and measurements of the ECR obtained during sludge mixing in other waste tanks were substituted into Eq. 1. Calculating *Uo* then yielded a velocity of

0.69 meters/ second (2.27 feet/second), which was required to lift sludge into a slurry for a sludge with a 33 Pascal yield stress and a 1.25 g/ml density. This velocity was then compared to CFD models, where the velocity at the sludge surface could be calculated for a full-scale tank. When the CFD calculated velocity at the sludge surface was less than the velocity from Eq. 1, the sludge was assumed to remain in place.

At the start of the ADMP research, the engineering project manager asked a simple question, “Will the ADMP remove sludge from the tank floor throughout the entire tank?” Based on this research, the answer was that the pump would perform that function with the exception of removing hardened sludge on the tank floor, and sand-like zeolite particles that were expected to be in the tank. The ADMP performed as predicted, as shown in Fig. 8.

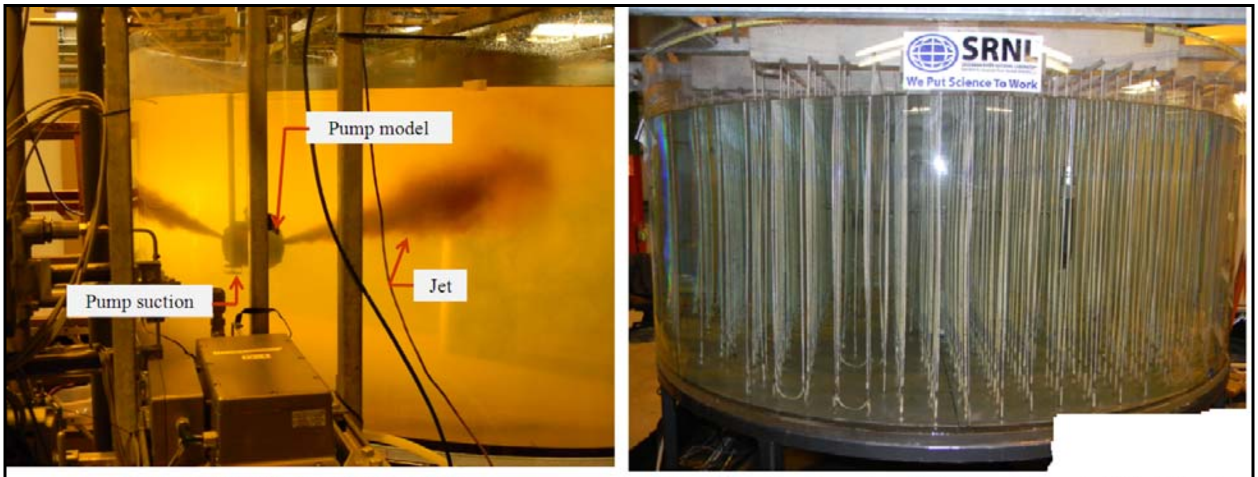
SALT DISPOSITION PROJECT RESULTS

A solid technical basis to start the SDI Project blending research was demonstrated by proven CFD model capabilities on the ADMP project to predict local velocities throughout a 1.3 million gallon tank. Even so, significant project risks, or unknowns, were identified prior to research. 1) Blending of salt solutions using dual nozzle pumps was not well understood. 2) Blending times were not understood for mixing in tanks with complex tank geometries. For example, some tanks are constructed with roof support columns in the center of the tank, and may contain several miles of vertical serpentine 2 inch Schedule 40 pipes installed for cooling. 3) The flow streams near blender pumps and transfer pumps were known to disturb, or stir up, sludge on the tank floors. How to minimize sludge disturbance required investigation. 4) If sludge was disturbed by the blender pump, the settling times needed investigation to evaluate settling time calculation techniques. 5) Large pumps were known to blend the tank contents, while significantly disturbing the sludge layer. Initially, sludge disturbance was to be minimized, and to meet this purpose the number of required blender pumps was estimated to exceed one pump per tank for a pump. Consequently, research was requested to determine if only one pump was adequate to blend the tank contents and not significantly disturb sludge. 6) Design requirements for this new pump were required. These included the pump flow rate (*Uo*), the nozzle dimensions (*D*), and the pump orientation, or position, with respect to the tank wall and floor. All of these potential project risks, and others, were realized and resolved during SRNL research with recommendations for operations and design or further research.

Laboratory researchers performed experimental blending tests and velocity measurements in an eight-foot diameter, 993-gallon nonradioactive pilot-scale tank. To do so, the lab performed a total of 126 pilot-scale tests, 260 material property tests, and created 39 CFD models over 15 months. Follow-up CFD modeling was also performed. All the pilot-scale test equipment was fabricated and initial testing started within 16 work days. More than 40 engineers, mathematicians, and technicians significantly contributed to teaming for this fast-paced research. Following initial pump recommendations, research continued to investigate the noted risks.

Blending research

This study focused on the blending processes needed to mix salt solutions to ensure homogeneity within waste tanks, where homogeneity is required to control radioactivity, chemical composition, and solids levels during subsequent processing. Requirements for this task were to determine the minimum number of submerged, centrifugal pumps required to blend the salt mixtures in a full-scale tank; to recommend reasonable blending times to achieve nearly homogeneous salt mixtures, and to blend the tank contents without disturbing the sludge layer. Essentially, the process required that a Newtonian fluid needed to be blended above a non-Newtonian fluid: much like trying to mix water above a thin syrup. The goal was to blend miscible liquids as fast as possible while limiting sludge disturbance. Prior to this research, two pumps were to be purchased for blending salt mixtures in each of the tanks, but this research showed that a single pump is adequate to blend the tank contents for tanks with or without coils, which resulted in an estimated 3.5 million dollar cost savings for pump procurement and installation requirements in a radioactive environment.



Pilot scale pump operation, no coils installed

Pilot scale tank, cooling coil models installed, 2.44 meter (8 feet) diameter

Figure 9: Experimental SDI pilot scale test equipment (Leishear, et al. [13, 15, 18])

Most of the testing was performed by adding tracer chemicals to the tank at a common point and measuring the pH at various locations throughout the tank to determine when blending was complete. The essential pilot scale equipment is shown in Fig. 9, where all of the components below the liquid level in the tank were modeled at 1/10.85 scale in a 2.44 m (8 feet) diameter tank. Controlled tracer quantities of acids (NHO_3) and bases (NaOH) were added to the pilot-scale tank at a common point to ensure similar and reproducible test results. The tank was filled with either water or a salt solution of higher density and higher viscosity for testing with tracer additions. By measuring pH changes at various locations in the tank, the time required to achieve uniform blending was obtained, using a commercially accepted 95% blending criterion (Paul, et al. [26]), which defines the time required to achieve concentrations throughout the tank that are within ± 5 % of the total change in bulk concentration.

As expected from the literature (Grenville and Tilton [27 and 28], and Dimenna, et al. [29]), test results showed that the pertinent design parameter for blending was the *UoD* value for the pumps, where *Uo* is the discharge velocity of the pump nozzle, and *D* is the pump nozzle diameter. In fact, a *UoD* value was provided to the pump manufacturer, and was used to design the SDI blender pump. For a tank without coils having a central roof support column installed, an empirical correlation from Grenville and Tilton was adapted to provide an approximation of the blending times for some cases, where

$$t = (C \cdot T^2) / (Uo \cdot D) = (3.72 \cdot T^2) / (Uo \cdot D) \qquad \text{Eq. 2}$$

where the blending time, *t*, was expressed in terms of the tank diameter, *T*, and an experimentally derived constant *C*. However, this correlation was inadequate for low flow conditions in a tank without coils, and was grossly incorrect for a tank with cooling coils installed. In other words, Equation 2 provides an inversely proportional linear approximation throughout part of the range of a non-linear process, where the correlation breaks down as flow rates decrease (see Fig. 10). Evaluation of this correlation for a tank with coils installed was not evaluated due to limited data. For a tank with, or without coils, CFD models were needed to better estimate the blending times, and typical CFD model results are shown in Fig. 11.

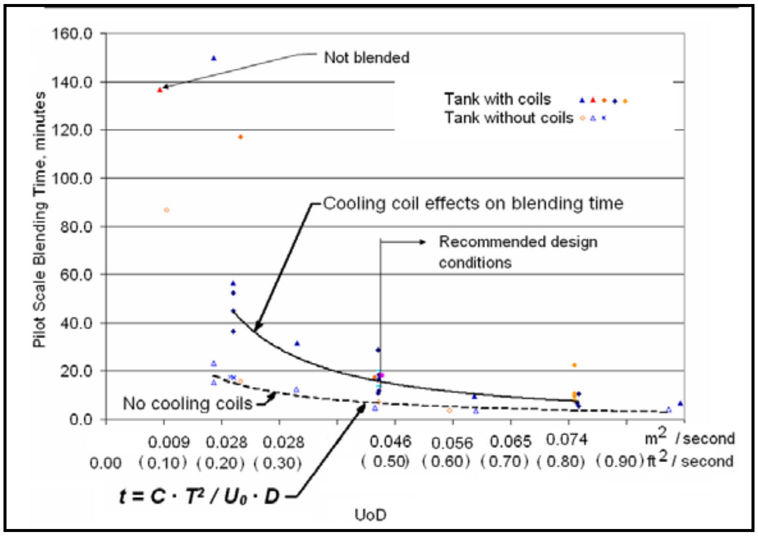
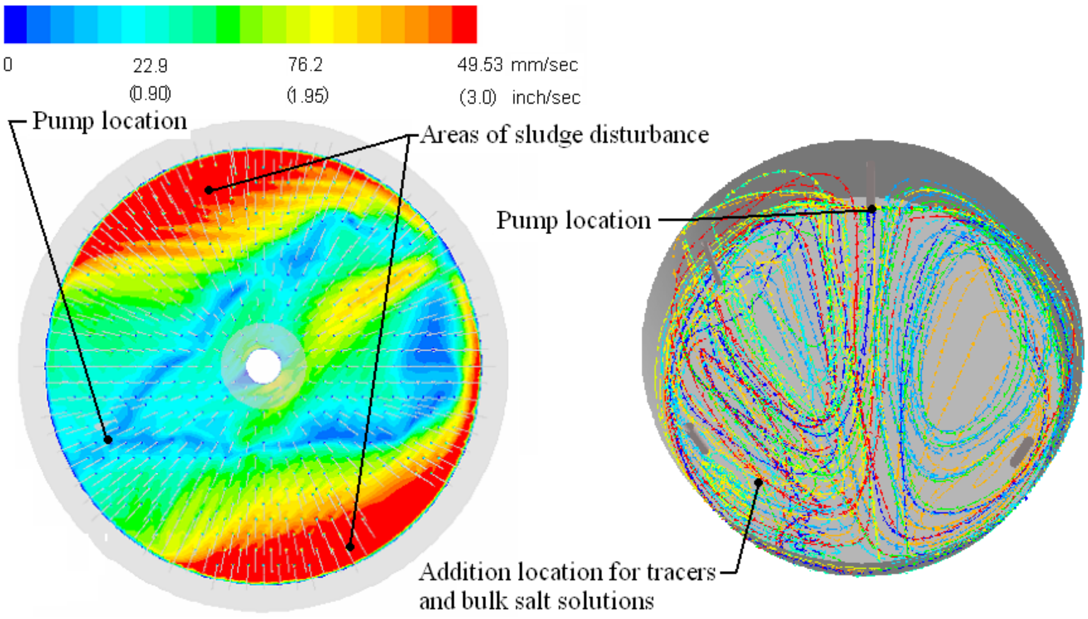


Figure 10: Partial SDI test results from pilot-scale blending time experiments (Leishear, et al. [9, 14, 15])

Also, the blending times for selected *UoD* values were shown to vary significantly for seemingly identical tests. The scatter in blending times can be observed in Fig. 12, where experiment and CFD results for blending times are compared. Statistical analysis was performed for a 95 % confidence level to compare CFD results to experimental blending times. Accordingly, the blending time safety factor, equaled 1.74 for a tank without cooling coils, and equaled 2.64 for a tank with cooling coils. Along with the average blending times, the safety factor and blending time variability increased markedly when the cooling coil obstructions were added to the tank. These factors incorporated the velocity uncertainty as well as the uncertainty for blending times to assure conservative blending time estimates at full-scale.



Velocities at the sludge layer

Typical flow patterns in the tank

Figure 11: Typical CFD model results (Lee, et al. [13, 15, 16, 17])

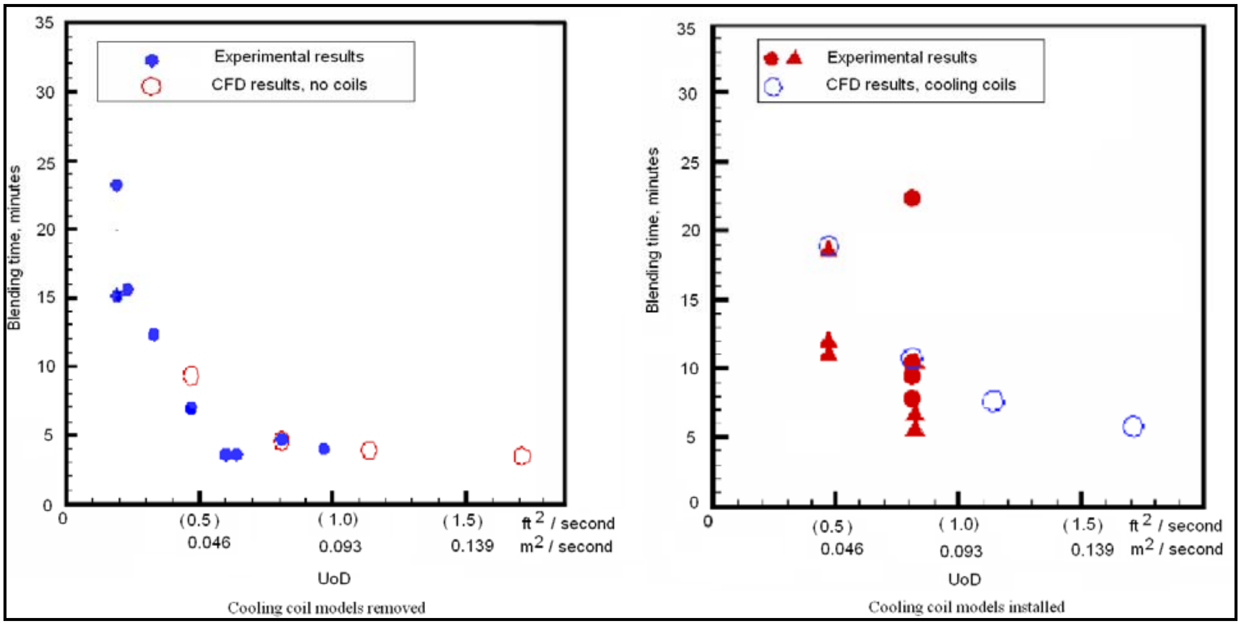


Figure 12: Comparison of SDI, CFD models to experimental results (Leishear, et al. [13, 15, 16, 17])

Sludge disturbance

After flow rates and nozzle diameters were selected to meet blending criteria for salt solutions, testing was performed using a simulated, pourable sludge. That is, initial blending tests were performed without sludge in the pilot scale tank, and then the pumps were operated with a sludge layer on the bottom of the tank. During the initial sludge tests, blending pumps scoured sludge to the tank bottom in the locations indicated in Fig. 11. Project success was then questionable, since sludge was preferred to remain on the tank bottom. Additional tests were performed with different nozzle orientations with respect to the tank floor. Sludge was found to remain nearly undisturbed if the nozzles were parallel to the tank wall and angled upward at the mid-height of the tank. The acceptance criterion was minimal sludge disturbance indicated by wisps of sludge into solution, which are shown in Fig. 13. The velocity at the sludge layer to meet minimum sludge disturbance for a sludge simulant with a 0.8 Pascal yield stress and a 1.316 g/ml density was determined to be 0.082 meters/second (0.27 ft/second), which is an order of magnitude lower than the velocity required to completely suspend sludge for the ADMP project (0.69 meters/ second).

Figure 13: Minimal sludge disturbance during SDI pilot-scale blending (Leishear, et al. [10, 13, 15])

Bulk additions to the pilot scale tank

Additional research performed for the SDI project using the pilot-scale tank illustrated the impact that solution densities can have on blending times. While intuitive that transferring large volumes of one fluid into another volume of a different fluid would produce some blending, the extent of that blending had not been quantified. Bulk addition tests were performed where one liquid volume spiked with acid was added to a separate liquid volume spiked with base (or vice versa). As one batch was added to the other, pH was monitored to predict blending times. Tests were set up to scale the transfer flow rates to those expected for the full size blend tank. Results showed that when a more dense salt solution was added to water, the transferring action alone blended the tank quite effectively without the need to then run the blend pump. However, when a quarter tank of water was added to a 5.8 molar sodium nitrate salt solution, the solutions stratified, with the stratified layer gradually decreasing in level as the jets from the pump scoured the interface layer between the lighter and heavier fluids (Fig. 14). For the case where a quarter tank of a lighter fluid (water) was added to ¾ of a tank of a more dense fluid (salt solution) in the tank, the predicted blending time increased significantly from a few hours to a few days. Further research was recommended, since only one of each test was performed, and fluids were not representative of typical, expected salt batches.

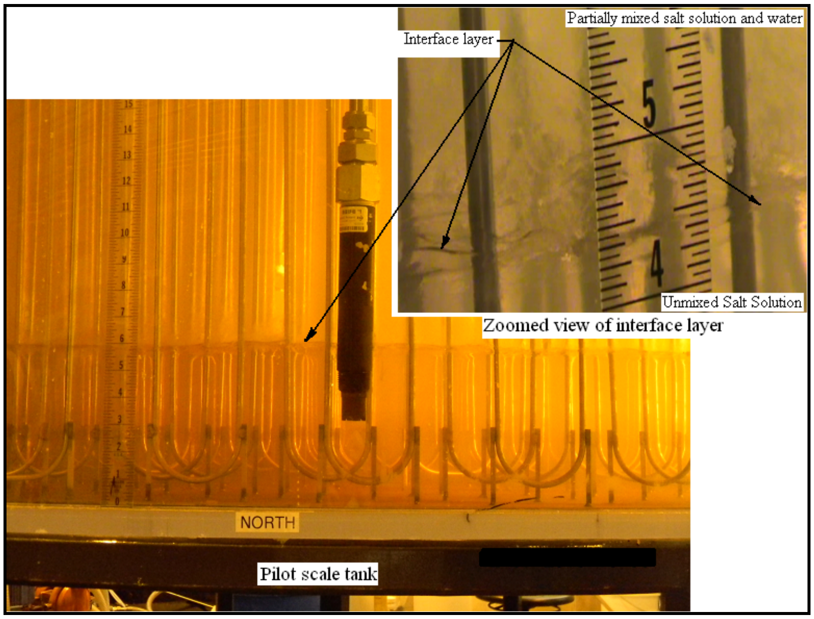


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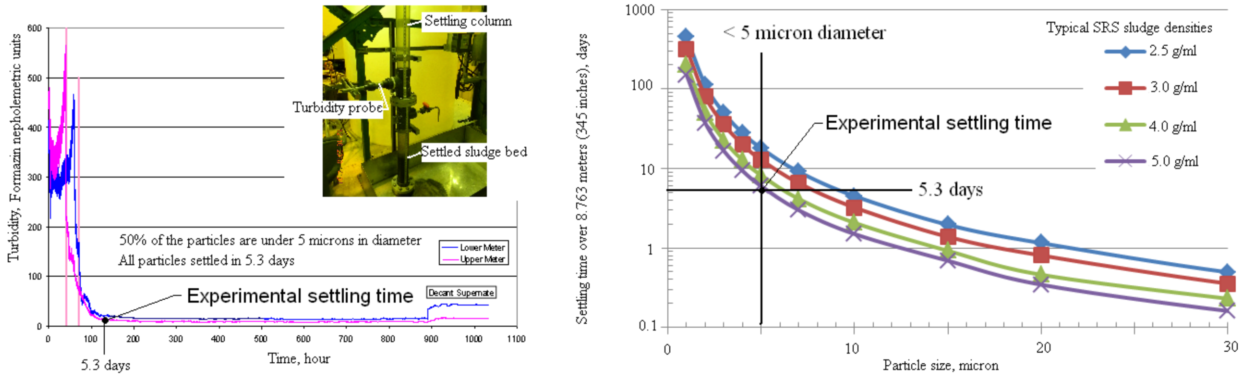
Figure 14: Stratified salt layers during bulk addition of water to a salt solution, SDI
(Leishear, et al. [13, 15, 16])

Transfer pumps

Sludge entrainment during transfer pump operations was also investigated. Minimum required clearances between the transfer pump suction inlet and the sludge layer were established to prevent sludge entrainment, using CFD models and pilot scale experiments. Additionally, sludge entrainment effects due to a bottom plate mounted below the pump suction were evaluated. These topics are not discussed here (See Leishear, et al. [15]).

STANDARD SLURRY PUMP RESULTS AND SETTLING TIMES

To reduce installation costs, an existing Standard pump was also considered, which blends the tank contents faster than the SDI pump since it has a higher *UoD*. Experimental blending tests were not required, since the SDI research already established relevant safety factors. Blending times were less than an hour for similar salt solutions. However, this higher flow rate pump will significantly disturb sludge. The amount of disturbed sludge was not predicted, but the settling time was investigated using a settling column of prototypic height. Measured settling times were considerably less than calculated settling times presumably due to large agglomerated particle sizes, as shown in Fig. 15. Particle size agglomeration was considered to be a probable cause of settling time differences, and further analysis was recommended at both pilot-scale and full-scale. Some additional full-scale data is already available (Gillam, et al. [30]).



Settling test in a 9.144 (30 feet) column

Calculated settling times

Figure 15: Comparison of experimental to calculated settling times, SDI (Leishear, et al. [13, 17])

CONCLUSIONS AND RECOMMENDATIONS

A single pump was evaluated to provide technical recommendations for mixing salt solutions in 4290 cubic meter (1.3 million gallon) tanks. To do so, research was performed in the areas of pump flow rate, pump design requirements, pump installation requirements, and obstructions installed in the tanks, using non-radioactive simulants, limited full-scale test data, numerous pilot-scale tests, and many CFD models. Much more detail is available in the referenced reports and publications to describe plant operations, experimental equipment, and scientific methods. Also in those papers, numerous project recommendations and conclusions with respect to blending processes are discussed. In fact, the experimental results presented here are the basis for an ASME magazine article (Leishear, et al. [18]) in printing to the ASME membership of 125,000. In particular, the magazine article discusses the danger of using CFD models for complex processes like mixing without experimental bench marking and safety factors, which is a bold claim at this point in time when CFD model results are readily accepted by many engineers. A summary of the more important conclusions and recommendations follows.

1. CFD models should be validated with experimental data. Otherwise, inadequate, or even unacceptable, results may be obtained. Once validated, safety factors can be readily applied to CFD models to compensate for experimental scatter in blending times or velocity measurements.
2. A single, non-rotating pump (rather than two pumps per tank as initially contracted) was determined to be adequate for blending the tank contents. A 3.5 million dollar cost savings was realized, along with the potential benefit of reduced radiation exposure to workers.
3. Pump design parameters (flow rate, nozzle diameter, *Uo·D*, and pump orientation) were established using CFD models and safety factors determined during this research.

4. Empirical equations from the literature provided approximate blending time estimates for tanks without cooling coils, but were inconclusive when installed cooling coils complicated the blending process.
5. The measured settling time for the selected SB6 sludge simulant was significantly less than conservatively calculated settling times. Further research was recommended.
6. Experimental results can vary significantly with respect to process changes. For example, the blending time for a bulk water addition to a salt solution in a pilot-scale tank was forty times greater than the average blending time for a tracer addition to the tank. On the other hand, the mixer pump was not needed at all for a bulk salt solution addition to water. Further research was recommended.

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