PNNL-11725
UC-721

Pacific Northwest National Laboratory

Operated by Battelle for the U.S. Department of Energy

# Industrial Mixing Techniques for Hanford Double-Shell Tanks

E. A. Daymo



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# Summary

Jet mixer pumps are currently the baseline technology for sludge mobilization and mixing in one-million gallon double-shell tanks at the Hanford and Savannah River Sites. Improvements to the baseline jet mixer pump technology are sought because jet mixer pumps have moving parts that may fail or require maintenance. Moreover, jet mixers are relatively expensive, they heat the waste, and, in some cases, may not mobilize enough of the sludge.

This report documents a thorough literature search for commercially available applicable mixing technologies that could be used for double-shell tank sludge mobilization and mixing. Textbooks, research articles, conference proceedings, mixing experts, and the Thomas Register were consulted to identify applicable technologies. While there are many commercial methods that could be used to mobilize sludge or mix the contents of a one-million gallon tank, few will work given the geometrical constraints (e.g., the mixer must fit through a 1.07-m-diameter riser) or the tank waste properties (e.g., the sludge has such a high yield stress that it generally does not flow under its own weight).

Pulsed fluid jets and submersible Flygt mixers have already been identified at Hanford and Savannah River Sites for double-shell tank mixing applications. While these mixing technologies may not be applicable for double-shell tanks that have a thick sludge layer at the bottom (since too many of these mixers would need to be installed to mobilize most of the sludge), they may have applications in tanks that do not have a settled solids layer. Retrieval projects at Hanford and other U.S. Department of Energy sites are currently evaluating the effectiveness of these mixing techniques for tank waste applications.

The literature search did not reveal any previously unknown technologies that should be considered for sludge mobilization and mixing in one-million gallon double-shell tanks.

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# Nomenclature

| | |
|---|---|
| ACTR | Acquire Commercial Technology for Retrieval |
| AIChE | American Institute of Chemical Engineers |
| ALARA | as low as reasonably achievable |
| BNFL | British Nuclear Fuels PLC |
| CBD | Commerce Business Daily |
| CSEE | Confined Sluicing End Effector |
| BHRA | British Hydraulic Research Association |
| DOE | United States Department of Energy |
| DST | double-shell tank |
| GAAT | Gunite and Associated Tanks |
| INEEL | Idaho National Engineering and Environmental Laboratory |
| LATA | Los Alamos Technical Associates |
| LDUA | Light Duty Utility Arm |
| MLDUA | Modified Light Duty Utility Arm |
| NAMF | North American Mixing Forum (an AIChE Division) |
| NCAW | neutralized current acid waste |
| NTIS | National Technical Information System |
| ORNL | Oak Ridge National Laboratory |
| ORR | Oak Ridge Reservation |
| PNNL | Pacific Northwest National Laboratory |
| RHO | Rockwell Hanford Operations |
| SST | single-shell tank |
| TWRS | Tank Waste Retrieval System |
| WWW | World Wide WEB |

# 1.0 Introduction

Over 100 million gallons of radioactive waste are currently stored in over 270 large underground storage tanks at U.S. Department of Energy (DOE) nuclear reservations. Of these tanks, 177 are located at the Hanford Site in southeastern Washington State, and 51 are located at the Savannah River Site in South Carolina. All of the Savannah River Site tanks and 28 of the tanks at the Hanford Site are classified as double-shell tanks (DSTs).

DSTs have a one-million-gallon capacity and a double carbon-steel lining so that leaks can be detected before contamination is released to the soil. At the Hanford Site, DSTs have a diameter of 22.86 m (75 ft) and maximum waste depth of 10.67 m (35 ft). The head space above the tank is around 3.66 m (12 ft), and all of the tanks are buried about 3.05 m (10 ft) underground. The Savannah River DSTs have similar dimensions. Access to the tanks is limited to risers that range between 10 cm (4 in.) and 1.07 m (42 in.) in diameter. The radioactive waste in the DSTs is primarily classified as liquids (saturated salt solutions) and sludge (primarily insoluble metal oxides and hydroxides mixed with an interstitial aqueous solution). Some DSTs also have saltcake layer (a mixture of insoluble salts and salt-containing liquids), which is typically located on top of the sludge and liquid layers. The sludge, supernatant, and saltcake all contain radioactive materials.

The objective of DST retrieval is to remove the sludge material from the tanks by mobilizing the sludge, forming a slurry with the supernatant solution, and pumping the slurry out of the tank. The waste in all of the DSTs must be retrieved to eventually close the tanks. However, many of the DSTs will be used as temporary storage vessels for waste retrieved from other underground storage tanks. DSTs may also be used as processing vessels for in-tank radionuclide separation or solids-liquid separation.

The current baseline approach for sludge mobilization is a "mixer pump," which is a submersible pump that produces liquid jets parallel to the tank floor that mobilize the sludge and mix the resultant slurry. Mixer pumps have been used before at both the Hanford and Savannah River nuclear reservations. Powell et. al. (1997) provides a summary of the research on jet mixing of settled sludges at Hanford and other DOE sites.

Mixer pumps are not necessarily the ideal method for mobilizing sludge in DSTs because they

- are expensive to purchase and install
- add heat to the tank waste
- have a limited operating lifetime
- may require frequent maintenance
- are difficult to dispose
- may not be able to mobilize all of the solids inside a DST, depending on the waste characteristics.

Previous engineering studies at the Hanford Site considered sluicing or recirculation with a transfer pump. In general, sluicing was found to drastically increase the waste volume because of excess dilution. Tank mobilization by recirculation of the waste through the transfer pump was thought to have limited effectiveness. Given the constraints on mixing waste within a DST (radiation, volume, and limited access to the contents through risers), mixer pumps were judged to be the best alternative for mobilizing sludge.

In 1994, however, a commercial mixing technology was identified in which large air bubbles introduced through plates near the tank floor induced slurry mixing. The mixing technology, marketed by Pulsair Systems, Inc. (Bellevue, Washington), was evaluated at Pacific Northwest National Laboratory (PNNL)[a] to determine its potential for application in DOE waste tanks (Powell and Hymas 1996). While the Pulsair mixing technology has several advantages over mixer pumps (e.g., no moving parts), it would be infeasible to install the large number of plates required at the bottom of a DST to completely mobilize the sludge. Pulsed air mixing is currently being considered for use at Idaho National Engineering and Environmental Laboratory (INEEL) and Oak Ridge National Laboratory (ORNL) (Powell 1997).

Because the Pulsair system was identified serendipitiously, the question remained whether other as yet unidentified commercial mixing systems could be applicable for DST retrieval.

The objective of this report is to document a thorough literature search for applicable commercial alternatives to mixer pumps. A commercial mixing technology is defined here as a currently available system that can be purchased by an existing company. An applicable mixing technology is one that can mobilize the sludge layer typically found in DSTs, mix the resulting slurry in the one-million-gallon vessel, operate in a radioactive environment, and be installed (preferably) through a 1.07-m (42-in.) center (or near-center) riser. Moreover, the "ideal" mixing technology would be highly reliable and inexpensive compared to jet mixer pumps.

This literature search did not seek improvements in mixer pump design (e.g., nozzle design or placement within the tank). The literature search did not seek mobilization or mixing solutions for tank heels that will likely be present after the baseline mixer pumps have completed retrieving sludge from the tanks. This task sought true alternatives to jet mixer pumps for DST retrieval.

In Section 2.0, the constraints on DST retrieval technologies are discussed. These constraints include the physical geometry of the tank, limited access to the tank contents, and the physical characteristics of the tank waste sludge. Mixing technologies are classified in Section 3.0. The advantages and disadvantages of each type of mixing technology are discussed with respect to DST sludge mobilization and mixing. The mixing technology literature search is presented in Section 4.0, and recommendations are made in Section 5.0. Finally, conclusions from this task are presented in Section 6.0.

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(a) Pacific Northwest National Laboratory is operated by Battelle for the U.S. Department of Energy under contract DE-AC06-76RLO 1830.

# 2.0 Constraints on DST Retrieval Technologies

Solutions for mixing liquids and slurries in one-million gallon or larger tanks are readily available in the chemical industry (discussed in Section 3.0). Unfortunately, many of these technologies cannot be applied directly to Hanford and Savannah River DSTs because of tank access restrictions, tank waste rheology, radiation hazards, or tank mixing objectives. This section briefly highlights the major sludge mobilization and tank mixing constraints posed by the DST configuration and the waste characteristics.

## 2.1 Double-Shell Tank Configuration

Hanford Site DSTs are 22.86 m (75 ft) in diameter and have an operational height of about 10.67 m (35 ft). Above the tank wall is a dome, which varies in height between 3.05 m (10 ft) and 3.66 m (12 ft). DSTs have a capacity of approximately 3.785 $m^3$ (one million gallons). To reduce exposure to workers, all of the tanks at Savannah River and Hanford are buried. At Hanford, the tanks are under 2.43 m (8 ft) to 3.66 m (12 ft) of soil. A schematic of a typical DST is shown in Figure 2.1.

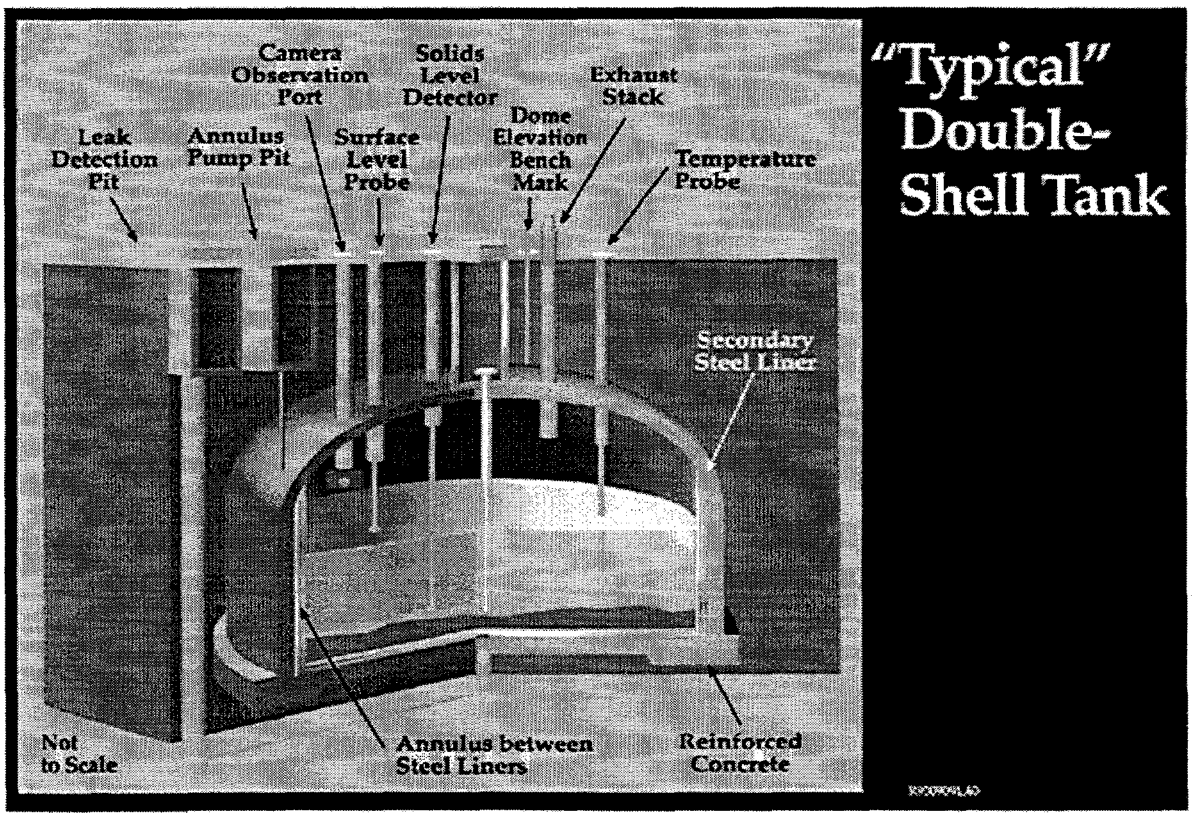


**Figure 2.1.** Cutaway of a typical DST (showing risers and in-tank hardware)

Most tanks have a 1.07-m (42-in.) diameter center riser, although additional or larger risers could be installed at a significant expense. The number, configuration, and status of the risers are different for each tank.

Some tanks have in-tank hardware such as air-lift circulators that could interfere with the installation or operation of mixing equipment. Such tanks include the Aging Waste tanks in the Hanford Site AZ and AY tank farms. All tanks have thermocouple trees and/or other piping within the tank that can interfere with sludge mobilization to some degree (Figure 2.1).

Since riser configurations and in-tank hardware can vary from tank to tank, the most recent and accurate DST-specific information can be found in the Tank Characterization Report written for each specific tank (e.g., Wilkins 1997).

## 2.2 Waste Characteristics

The waste within the DSTs primarily consists of sludge and liquid. Sludges range in consistency from being similar to room temperature butter to pottery clay. The physical consistency, chemical, and radionuclide content not only vary from tank to tank, but within each tank as well. Only about half of the DSTs at Hanford contain sludge and liquid; the other half only contain liquid (Hanlon 1994). Alternatives to jet mixer pumps are primarily sought for the tanks with the sludge layer since this is the waste type that is most difficult to retrieve.

Sludge properties that are postulated to be important in predicting the performance of waterjet-based retrieval methods include shear strength, sensitivity,[a] cohesiveness,[b] density, and water-absorption rate (Powell 1996). For non-waterjet retrieval methods, the shear strength and cohesiveness of the sludge are probably important, whereas the water absorption rate is probably less important than for waterjet-based retrieval methods. While much of the information about the rheology of the tank waste is qualitative and obtained from photographs of core extrusions (Figure 2.2), some quantitative data on DST sludge is available.

A recent survey of Hanford tank waste properties showed that the shear strength of Hanford tank waste sludge can range between 200 Pa and about 5,000 Pa (Willingham 1994). Rassat et. al. (1997) reported that sludge shear strengths in Hanford DSTs AW-101 and AN-103 range between 300 Pa and 7,500 Pa. The sludge shear strength is also presumed to be dependent on temperature. Tingey (1992) showed that the shear strength of DST SY-101 sludge dropped from over 10,000 Pa to around 2,000 Pa when the temperature was increased from 30 °C (hot cell temperature) to 50 °C (tank temperature).

The sludge has a yield stress of the same order of magnitude as its shear strength. In general, the sludge does not flow under its own weight. Thus, at low shear strengths, the sludge has an apparent infinite viscosity.

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(a) Sensitivity is the decrease in the shear strength of wet sludge due to mechanical disruption. A sludge with a high sensitivity will experience a drastic decrease in shear strength when mechanically disturbed.

(b) Cohesiveness is the tendency of a material to stick to other pieces of the same material.

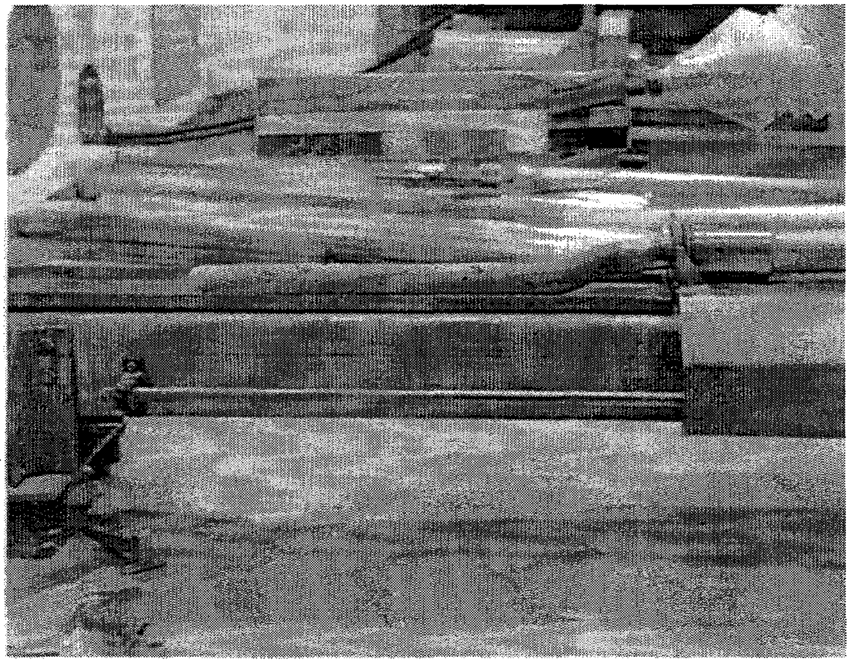

**Figure 2.2.** Core extrusion of sludge from Tank AN-103

The sensitivity of the sludge shear strength to mechanical disruption depends on the waste type, and has not been fully quantified. Hot-cell observations have shown the tank waste to be cohesive, but little is known about the water-absorption rate of DST sludge (Powell 1996).

To simulate the physical and rheological properties of tank waste sludge, 66 wt % kaolin has been suggested as a physical simulant for sludge mobilization tests (Powell 1996). This physical tank waste simulant has physical and rheological properties that are either similar to or more conservative than those of DST sludge.

## 2.3 Debris

Tank photos have shown the presence of metal tapes, gloves, and other items that could possibly interfere with tank retrieval operations. Figure 2.3 shows metal tape on top of a sludge layer in a Hanford single-shell tank (SST). Although this tank is an older SST, similar debris will likely be found in DSTs. This debris could reduce the effectiveness of some mixing methods. For example, metal tape could wrap around exposed impeller blades and render them ineffective.

## 2.4 Tank Mixing Objective

One of the initial objectives of DST retrieval is to remove the bulk of the waste inside the tank. Once the waste is removed, several of the DSTs at Savannah River and Hanford will be re-used as process or lag storage vessels. Thus, mixing techniques should be chosen that allow flexibility for future in-tank operations.

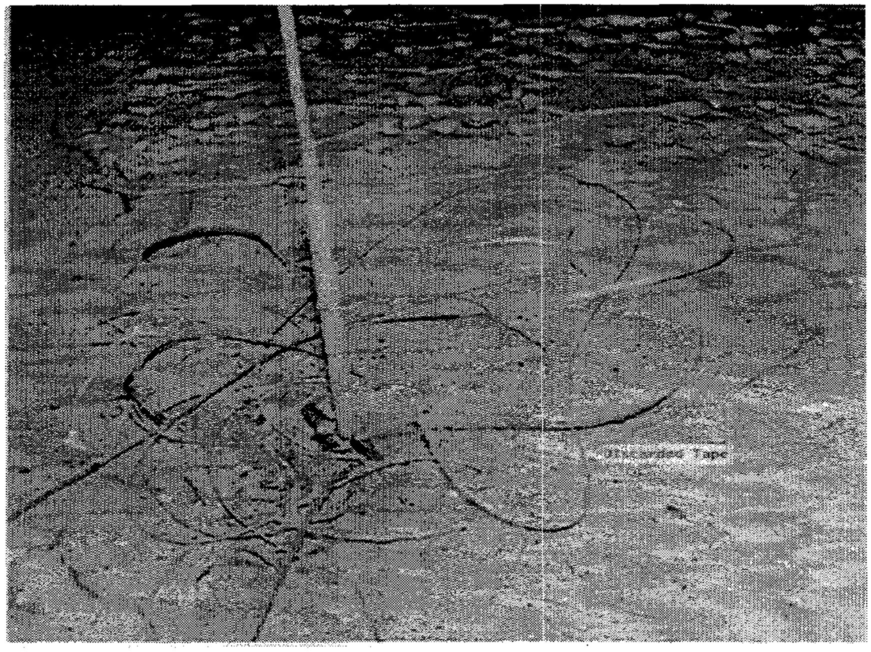

**Figure 2.3.** Photo of SST sludge with the type of debris (metal tape) that could also be found in DSTs

For example, mixing techniques that continuously mix the contents of the tank are more desirable than sludge mobilization techniques that locally "mine" sludge at the bottom of the tank (at least until the tank is ready for heel removal and closure). If a mobilization technique only "mines" sludge from a specific part of the tank, large-scale mixing or homogenization of the tank contents is probably not occurring. If the DST is to receive waste from other tanks or be used as a process vessel for sludge washing (or some other process function), large-scale mixing and/or homogenization of the tank contents would probably be required.

# 3.0 Overview of Tank Mixing Technologies

Although there are many corporations that actively market technologies for a variety of tank mixing applications, the commercially available tank mixing technologies can be readily categorized. Given the constraints in Section 2.0, there is probably no "ideal" solution for DST tank mixing. However, some technologies have more drawbacks than others. In this section, the benefits and drawbacks for each major category of mixing technology are discussed.

A similar mixing technology classification study was performed at Savannah River. The same general mixing technologies were identified and the same general conclusions about each mixing strategy were reached.[(a)]

## 3.1 Jet Mixer Pumps

Jet mixer pumps are currently the baseline sludge mobilization mixing technology at Savannah River, Hanford, and West Valley Nuclear Services. This mixing system involves the use of a submerged nozzle from which a high-velocity jet emerges. Slurry is recycled through a submerged pump and ejected through the nozzle. Momentum is transferred from the jet to the liquid or slurry, thereby causing mixing and circulation within the tank. Further information on jet mixers can be found in Harnby et. al. (1992).

### 3.1.1 Advantages

Hanford and Savannah River are jointly evaluating mixer pump designs. Savannah River has already installed jet mixers in its tanks with varying success. West Valley has installed jet mixers in 2,650-$m^3$ (700,000-gallon) tanks that are 2.33 m (70 ft) in diameter and 8.23 m (27 ft) tall. West Valley has indicated that the mixers are "very satisfactory."[(b)] Jet mixer experience at Savannah River has been generally good, but the effective cleaning radius of the mixer pumps was not always as large as expected (Powell et. al. 1997).

In general, jet mixer pumps fit through the 42-in. risers, and can be used for sludge mobilization, slurry mixing, and in-tank solids-liquid separation. The versatility of jet mixer pumps combined with their ability to work within the tank makes jet mixers an attractive option for DST sludge mobilization and mixing.

(a) d'Entremont, P. *Alternate Waste Removal Team Meeting Minutes*. Internal Memo dated December 18, 1996. Westinghouse Savannah River Company, Savannah River, South Carolina.

(b) Baumgartel, R.G. 1992. *Waste Retrieval and Pretreatment Technical Exchange Meeting*. Correspondence No. 9258417. Westinghouse Hanford Company, Richland, Washington.

### 3.1.2 Drawbacks

Side-entering jet mixers are commonly used in the petrochemical industry to mobilize sludge in million-gallon or larger petrochemical tanks (Hemrajani 1996). However, side-entering jet mixers cannot be installed in DSTs because they are buried underground, and radiation exposure and tank leakage considerations prevent the drilling of holes into the tank walls.

While top-entering jet mixers are the baseline mixing technology for sludge mobilization and tank mixing in DSTs, they are expensive to purchase and install, add heat to the waste, have a limited operating lifetime, may require frequent maintenance, are difficult to dispose, and may not mobilize all of the solids inside a DST (depending on the waste characteristics). Despite these drawbacks, jet mixer pumps are better than any other mixing technology yet identified for DST sludge mobilization and mixing.

## 3.2 Agitator-Based Systems

Mechanical agitation (with a paddle or propeller) is the most commonly used mixing technique in the chemical process industry (Oldshue 1983). Mechanical agitation includes any mixing technology whereby an impeller, paddle, propeller, turbine, or ribbon is rotated within a process vessel to cause mixing or create dispersions. Impeller-based systems are generally classified as either radial-flow or axial-flow, depending on the flow patterns generated in the process vessel. Further information on the principles of mechanical agitation can be found in Oldshue (1983), Tatterson (1991a), and Harnby (1992).

### 3.2.1 Advantages

Mechanical agitation is the most commonly used mixing technique in the chemical process industry because it is less expensive than other mixing techniques for most industrial process vessels. Moreover, mechanical agitation appears to be considered excellent for many mixing applications (e.g., gas dispersion) based on the tremendous amount of research and process knowledge that has been accumulated and can be found in the literature. Most tank mixing companies only sell mechanical agitation equipment.

Savannah River has been considering the use of a submersible mixer by ITT Flygt as an alternative to jet mixer pumps for certain DSTs. Flygt mixers would not necessarily be the best solution for sludge mobilization because a large number of Flygt mixers would need to be installed to cover the diameter of the tank. However, the small size and relative low cost of the Flygt mixers could make them an alternative to jet mixers for DSTs without a layer of settled sludge.

### 3.2.2 Disadvantages

Agitator-based systems would require excessively large impellers for mixing a large one-million-gallon tank. Impellers are typically recommended to be ½ to ⅔ of the tank diameter (Harnby 1992). Although "umbrella" configurations have been proposed for impellers so they can fit through a 42-in. riser, it is unlikely that agitator-based systems would be accepted for DST mixing. First, the DSTs are unbaffled, so agitators would create a swirling motion within the tank. This swirling action might be helpful to mobilize tank waste, but it could also destroy some of the in-tank piping. Second, metallic measuring tape or other materials in the tank could become wound around the impeller, resulting in decreased mixer performance.

## 3.3 Pulsed-Air Mixing

The Pulsair™ mixing system has been studied as a possible alternative to jet mixer pumps for DST mixing. Pulsed-air mixing induces large-scale mixing within a tank by introducing bubbles beneath circular plates located at the bottom of the tank. These bubbles move under the plate and scour the tank bottom. This scouring action mobilizes solids. As the bubbles rise, large-scale vertical circulation patterns are formed within the tank.

### 3.3.1 Advantages

The Pulsair™ system requires no moving parts be placed within the tank, so the maintenance costs for this mixer is expected to be lower than that for the baseline jet mixer pump. Moreover, tests performed at PNNL have shown that the Pulsair™ system mixes tank waste simulant slurries adequately (Powell and Hymas 1996).

### 3.3.2 Disadvantages

For the Pulsair™ system to effectively mobilize sludge within a DST, approximately 64 plates would need to be installed (Powell and Hymas 1996)—an unfeasible number of plates to install within a DST. The Puslair™ system, however, does have potential applications at the INEEL and the Oak Ridge Reservation (ORR) for smaller (approximately 50,000-gallon) horizontal tanks, in which the tank geometry and waste rheology are better suited to pulsed-air mixing.

## 3.4 Sluicing

Sluicing was previously used at the Hanford Site to retrieve waste from underground storage tanks. The sluicing systems at Hanford typically included a mechanical sluicing assembly (a discharge nozzle within the tank and nozzle position control equipment outside the tank), a sluice pump to supply pressurized liquid to the nozzle, a slurry pump to pump liquid and mobilized sludge out of the tank being cleaned, and a slurry receiver tank where the retrieved material was placed. Waters (1994) reports that fluid was discharged from the 2.54-cm (1-in.) diameter sluice nozzle at about 0.022 $m^3$/sec to 0.025 $m^3$/sec (350 to 400 gpm) at a pressure of $1.207 \times 10^6$ Pa (175 psi)

### 3.4.1 Advantages

Sluicing is probably as effective as jet mixers at mobilizing DST sludge. In addition, there is a considerable amount of sluicing experience at the Hanford Site. Sluicing was the technique previously used at the Hanford Site for the Uranium Recovery Campaign (retrieval of waste from many SSTs between 1952 to 1958) and the Special Isotope Recovery Campaign (retrieval of waste from 10 SSTs in the 1960s). Sluicing will also be used for the retrieval of tank waste sludge from Hanford Site Tank C-106 in 1998 under the Waste Retrieval Sluicing System, Project W-320.

### 3.4.2 Disadvantages

Although sluicing may be highly effective at sludge mobilization, sluicing cannot homogenize the contents of a DST as effectively as jet mixers. Large-scale mixing (or homogenization) of the DST contents is important for in-tank processing (such as in-tank sludge washing) and the transfer of slurry from the DST to downstream processing facilities. Since DSTs will need to be re-used for temporary storage or in-tank processing, sluicing is not the best mixing solution. However, sluicing may be appropriate for heel removal when the DSTs are ready for closure.

## 3.5 Pulsed-Jet Mixers

Pulsed-jet devices generally have a tube that extends close to the bottom of the tank. During operation, a vacuum is created within the tube by the use of a pump outside the tank. Fluid then rises into the tube. Next, pressure is applied and the fluid is forced out through the bottom of tube. As the process liquid hits the bottom of the tank, solids are suspended and large-scale circulation patterns are induced.

### 3.5.1 Advantages

Pulsed-jet devices have been used for sludge mobilization by British Nuclear Fuels PLC (BNFL) at the Sellafield nuclear site in England (LATA 1995) and in the former Soviet Union in their high-level waste tanks. These devices have few or no in-tank moving parts, and are effective at mobilizing waste in storage vessels. Because of the previous process history of pulsed-jet mixers at Sellafield, both Hanford and Savannah River have looked into the potential applications of pulsed jet mixers (McKeon 1992, AEA 1996, Enderlin and Mullen 1997).

### 3.5.2 Disadvantages

Pulsed jet devices have not yet replaced jet mixer pumps as the baseline retrieval method for several reasons. Depending on the design of the pulsed-jet system, a large number of tubes would need to be installed into the DST. Also, significant modifications would need to be made to the DST tank farms since the above-ground transfer of pressurized waste is currently prohibited in unshielded pipes. Subsurface pipes, control valving, and secondary confinement barrier modifications would need to be made at DST tank farms. Nevertheless, the pulsed-jet devices have several applications in smaller tanks, such as some of the horizontal tanks at the ORR.

## 3.6 Air-Lift Circulators

Airlift circulators are found in some of the Hanford and Savannah River DSTs. Air is introduced at the bottom of an open-ended pipe that is surrounded by a larger diameter shroud. Buoyant air released from the inner tube entrains liquid and rises through the outer shroud. This movement of liquid causes density-driven "convection cells" to be formed within the tank (Whyatt et. al. 1996, Serne et. al. 1996).

### 3.6.1 Advantages

Air-lift circulators are already located in several of the Savannah River and Hanford DSTs. Although inconsistent with experience, numerical models were constructed that showed air-lift circulator flow rates are high enough to resuspend solids after the air-lift circulators are shut off for short periods of time (Eyler 1983a, Eyler 1983b, and Eyler 1984).

### 3.6.2 Disadvantages

Hanford experience has shown that air-lift circulators are generally not effective at suspending sludge (Waters 1994).

## 3.7 Other Methods

Several other techniques for sludge retrieval and tank mixing are available within the DOE nuclear complex or in industry. While some of these systems have niche applications for tank waste retrieval, none of the following offer effective mixing solutions for DST sludge mobilization and mixing.

### 3.7.1 Arm-Based or Crawler-Based Retrieval Methods

Mechanical arms, such as the Light Duty Utility Arm (LDUA) have been constructed at the Hanford Site for tank waste characterization and retrieval operations. Currently, a modified LDUA (MLDUA) is being used at the ORR to facilitate retrieval of waste from the Gunite and Associated Tanks (GAAT). These arm-based systems can be outfitted with end effectors for sluicing, such as the Confined Sluicing End-Effector (CSEE). While the LDUA may be an appropriate platform for SST retrieval at Hanford and other retrieval operations at ORR and INEEL, the arm would not be an appropriate platform for DST retrieval. DSTs will likely be re-used for lag storage and/or processing once the waste currently within the tanks is removed. Thus, a mixing solution is sought that can continuously suspend solids within a DST. The LDUA retrieval systems are better at "mining" or hard heel removal than continuous mixing. A mechanical arm, such as the LDUA, might be used during DST tank closeout when some portion of the tank heel would need to be removed.

Crawler-based systems have also been proposed by industry for tank clean-out. Crawler-based systems also have several disadvantages for DST sludge mobilization and mixing. Like LDUA systems, crawlers cannot be used to continuously suspend waste within the tank. Crawlers may sink or become stuck in the tank sludge. Umbilical systems can also wrap around in-tank hardware and potentially limit the mobility of the crawler. Like the arm-based retrieval techniques, crawlers have more applications for DST heel removal than DST sludge suspension and mixing.

### 3.7.2 Wave Machines

Wave machines oscillate at the resonant frequency of a tank to generate surface waves. Such devices are typically used to generate waves in recreational pools. Literature from one manufacturer claims that these devices have also been installed recently to mix water treatment pools. While wave generators typically have no moving part in contact with the process fluid and have low power consumption, most of the energy is imparted near the surface of the vessel.[a] To mobilize sludge in DSTs, most of the energy must be imparted at the bottom of the tank, so this technique would probably not mobilize sufficient quantities of sludge. Further, the generation of waves may be of concern with respect to tank integrity.

### 3.7.3 Sonic Probe

While not a complete mixing system, sonic probes are purported to "liquefy" a region of tank waste (Stewart et. al. 1994, Lessor 1997). By reducing the viscosity of the tank waste sludge, the number of mixer pumps in each tank could be reduced and retrieval rates could potentially be improved. The sonic probe was shown to effectively liquefy a sample of sludge from Hanford Site Tank 101-SY, but it is uncertain how effective the probe will be on other DST waste sludges.

### 3.7.4 Bullets

A large quantity of small pellets, called "bullets," could be introduced to the tank. As the tank is mixed, these pellets would erode away at the sludge layers, accelerating the sludge mobilization process. However, the pellets could probably not be introduced to the tank because the waste volume would then be increased, downstream processing operations could be complicated (a filter system would need to be installed to remove the pellets), and tank integrity may be compromised (depending on how effectively the bullets erode the tank wall). This technique could be used with agitator-based or waterjet-based mixing strategies.

### 3.7.5 Positive Displacement Pumps

Positive displacement pumps can be used to move concrete and other viscous materials out of a process vessel. If the sludge were less viscous and had a lower yield stress (i.e., more slurry-like in nature), a single pump could be lowered into the tank to "suck" the tank contents out at a single point. Because DST sludge does not typically flow under its own weight, this option would probably not retrieve very much of the tank waste sludge. Also, this technique does not allow for continuous tank mixing.

### 3.7.6 Solution Mining

The sludge could be made easier to retrieve if the pH of the tank was altered, the temperature raised, or other chemicals introduced to the tank waste. In the mining industry, the addition of chemicals to mobilize solids is called "solution mining." While these techniques are sometimes used in industry to retrieve materials from storage vessels, they cannot be used at the Hanford Site. It is possible that the tank waste problems could be made worse by adding chemicals. For example, dangerous chemical incompatibilities could occur if chemicals are added to the tank waste. Moreover, the tank waste must stay within strict temperature and pH limits because of ventilation and corrosion concerns. In addition, altering the waste in any way can increase the waste volume and make downstream processing operations more difficult.

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(a) Demarteau, J., D. Corbugy, J.M. Gilliard. 1996. *The WOW Wave Ball: Using the Resonance Principle for Wave Generation and Liquid Stirring*. WOW Company, Naninne, Belgium.

# 4.0 Mixing Technology Literature Search

Given the constraints on DST retrieval in Section 2.0, a literature search was performed to identify innovative mixing systems that are either completely new or that offer some type of improvement over the general mixing technologies identified in Section 3.0. Since the objective of the report was to identify commercial systems, it was assumed that any applicable technologies would be identified from one or more of the following sources:

- Previous searches for alternate DST mixing technologies in the DOE complex
- Textbooks on mixing
- Research articles and chemical engineering journals
- Internet WWW pages and newsgroups
- Mixing conferences
- Mixing classes
- Expert consultation
- Thomas Register

## 4.1 Previous Searches for Alternate DST Mixing Technologies in the DOE Complex

Mixer pumps were chosen to mobilize Hanford DST waste after comparing various mixing options. Hanford technical literature contains information on other potentially applicable mixing techniques, as well as a technical basis for their deselection. In addition, during FY96, the Tank Waste Retrieval System's Acquire Commercial Technology for Retrieval (ACTR) project sought commercial alternatives to baseline tank retrieval technologies.

### 4.1.1 DST Mixing Tradeoff Studies

Waters (1994) wrote a concise historical review of DST retrieval. The report stated that sluicing systems were initially considered for tank retrieval, but "in the 1983 to 1985 time period, there was a change in philosophy from the use of sluicing systems to the use of mixer pumps for sludge mobilization and tank clean-out." The report further states that "specific documentation for this change was not found."

Waters notes that during 1985 and 1986, "literature and engineering analysis investigations of some alternative retrieval techniques were undertaken, not only for potential use in the waste tanks, but also to define the equipment and methods which would be used in laboratory and pilot scale testing, development, and demonstration programs." Such analyses were first documented in the Hanford Waste Management Plan (RHO 1984), and later by Lawler (1986a and 1986b), Scott (1986), and Stegen (1986). While the Hanford Waste Management Plan did not offer details, the major alternatives for DST sludge mobilization were sluicing, mixer pumps, and airlift circulators.

In one of Lawler's reports on DST retrieval (Lawler 1986a), the advantages and disadvantages of baseline mixing strategies were delineated by DST or waste type. In general, mixer pumps, sluicing, airlift circulators, and recirculation with retrieval pumps were considered. Table 4.1 lists the proposed retrieval methods by tank and tank type. Mechanical mixing and mechanical mining were listed as options for Double-Shell Slurry waste. Mechanical mixing (e.g., propeller blades) was dismissed as a retrieval solution because this technology is "very costly and will require a long lead time to create a reliable system." Mechanical mining was not defined, but was dismissed because "the number of disadvantages make it an unlikely alternative."

**Table 4.1.** Proposed Retrieval Methods for DST Retrieval from Lawler (1986a)

| Tank or DST Material | Baseline Technology | Alternate Technology |
|---|---|---|
| SY-102 | Mixer pumps | None |
| SY-103 | Dilute and recirculate waste (i.e., mix with transfer pump) | Sluicing or mixer pumps |
| Double-Shell Slurry | Retrieve directly, or dilute and recirculate before retrieval | Mixer pumps, sluicing, mechanical mixing, or mechanical mining |
| Neutralized Current Acid Waste | Sluice and retrieve | Mixer pumps, or add water and use airlift circulators |
| Cladding Removal Waste | Dilute waste and pump inlet and retrieve directly with transfer pump | Sluicing or mixer pumps |

In a second report on DST retrieval, Lawler (1986b) considered the advantages and disadvantages of sluicing and mixer pumps for Neutralized Current Acid Waste (NCAW) retrieval. It was estimated that the installation of a General Electric water cannon would have a life-cycle cost that is $1 Million greater (1986 dollars) than that of the mixer pump. The horizontal propeller pump was considered as an alternative to several baseline mixer pump designs, but the propeller pump was rejected because its performance was not as effective as the mixer pumps during head-to-head comparison tests (Scott 1986). The use of air-lift circulators to maintain solids suspension was recognized in this report, but it was recommended that additional mixing equipment be installed to mobilize the NCAW waste. The report concluded that in-tank mixer pumps be used to retrieve wastes from NCAW tanks. Mixer pumps offered a less expensive and more flexible retrieval solution than sluicing, as mixer pumps could be used to retrieve solids as well as facilitate solids-liquid separation and sludge washing processes.

Stegen (1986) compared and evaluated three retrieval alternatives for Tank 103-SY:

- Slow dissolution using a transfer pump to recirculate, slightly agitate, and dilute the waste
- Sluicing in conjunction with an in-tank recirculation loop to resuspend and dilute the waste
- High agitation/mixing using a mixer pump to agitate, circulate, and dilute the waste.

Use of the transfer pump to recirculate and dilute the waste was rejected because this option may leave an undesirable amount of waste in the tank. Likewise, sluicing was rejected because this would dilute the waste and could potentially result in an excessive waste volume. Jet mixer pumps were recommended for installation because this technology would remove the most waste with the least amount of dilution water. Reducing dilution water reduces the final disposal costs. The report did acknowledge that jet mixers may not reach all areas of the tank, leaving "dead spots" that may require other measures to move the waste into the area that can be reached by the jet mixer.

In summary, jet mixer pumps were selected as the baseline DST retrieval technology because use of jet mixers

- will result in higher processing rates
- can provide a more uniformly mixed feed stream
- provide the option to perform in-tank washing and processing of solids
- do not require significant upgrades or addition of waste transfer lines and auxiliary process tanks.
- require less dilution liquid.
- require less equipment and operator action in the tank farm.
- will result in lower operator exposure (ALARA).

There have been few applicable technologies identified at the Hanford Site that could be used to replace the baseline jet mixer pump. Boomer (1993) states, "there is broad unanimity in the retrieval options for DST waste retrieval; namely, mixer pumps with sluicing clean-out." As mentioned in Section 3.0, the Pulsair mixing system was tested, but it would require too many plates for DST sludge mobilization applications. Also discussed in Section 3.0, Flygt submersible mixers were considered at Savannah River for mixing liquids in DSTs, and pulsed jet devices were considered at Savannah River and Hanford for tank mixing.

### 4.1.2 Acquire Commercial Technology for Retrieval

The ACTR project sought organizations with innovative, commercially available equipment, engineered concepts, and systems for retrieving radioactive waste from Hanford SSTs and DSTs. An advertisement was placed in the December 14, 1995, Commerce Business Daily (CBD) seeking potential sources for (but not limited to) "pumping equipment, hydraulic mining equipment, tank cleaning equipment, and remote handling equipment" for DST retrieval. Vendors were "invited to submit an expression of interest in providing information about their products." A total of 17 vendors submitted requests for additional information. Vendors who responded to the advertisement in the CBD were sent additional information on DSTs and the Hanford cleanup effort (Berglin 1995).

Only one vendor, J.R. Connolly of Cornwall Consultants, recommended a mixing solution. Mr. Connolly wrote in a letter to D.C. Ramsower that "correctly designed mechanical fluid mixers, with a lower mixing impeller positioned very closely above the tank bottoms, will absolutely provide the better mixing of tank contents than any mixer pump system." While Mr. Connolly noted that impeller mixers have lower maintenance requirements than jet mixer systems, he did recognize that installing the impellers would be difficult.

## 4.2 Textbooks

Several textbooks on mixing were reviewed to find references to innovative tank mixing techniques. Each of the textbooks contained sections on mechanically agitated vessels (liquid systems mixed with impellers, propellers, or turbines), and a few contained sections on jet mixers and air-lift circulators. No previously unidentified mixing techniques applicable in Hanford DSTs were found in the examined textbooks (Harnby et. al. 1992, McCabe et. al. 1993, Oldshue 1983, Perry and Green 1984, Tatterson 1991, Tatterson 1992, Tatterson 1993a, Tatterson 1995, and Uhl 1967).

## 4.3 Research Articles and Trade Publications

Innovative mixing techniques developed at universities or national laboratories would probably appear in the technical literature. A thorough literature search was performed with Current Contents on articles published between July 1, 1989, and December 5, 1996. Except for a submission by B.A. Hamm to the *American Institute of Chemical Engineering* (AIChE) *Journal*, none of the titles found in the Current Contents search suggested that other articles would discuss techniques that could be applicable for sludge mobilization and mixing in DSTs. The article by Hamm et. al. (1989) was about sludge suspension in waste storage tanks at Savannah River using jet mixers.

Articles by Post (1995a, 1995b, and 1996) in the magazine *Chemical Processing* discussed several industrial mixing practices used in the chemical process industry, but none of the mechanical agitation methods discussed would probably be applicable to the Hanford Site. In addition, articles in recent editions of *Chemical Engineering Progress* (Tatterson et. al. 1991, Tatterson 1993b) and *Chemical Engineering* (Dickey and Hemrajani 1992, Etchells et. al. 1992) yielded no applicable solutions for the Hanford Site.

The 1996 and 1997 issues of the trade publications *Chemical Equipment* and *Processing* were reviewed to find featured equipment that could be used for sludge mobilization and DST mixing. No such equipment was found. Companies that advertised mixing equipment (primarily agitators or jet mixers) for large process vessels were contacted. However, most of these companies were already in the Thomas Register.

A literature search was also performed of documents contained in the National Technical Information Service (NTIS) database. While many reports have been issued by the Hanford and Savannah River Sites on jet mixing, there were no other reports with titles or topics that suggested alternate mixing techniques for large process vessels would be discussed.

## 4.4 Internet Search

The recent proliferation of companies on the World Wide Web (WWW) provided an additional opportunity to seek out commercial entities that could market mixing equipment for DST sludge mobilization and mixing. In addition, the Internet now has several discussion groups (Usenet News and listservers) that allow chemical engineers to exchange ideas.

### 4.4.1 WWW Search

Several mixing companies were identified through a WWW search on Excite (http:\\www.excite.com). Most of these companies were also listed in the Thomas Register (http:\\www.thomasregister.com). Table 4.2 lists the companies and associated URL found during the Internet search.

**Table 4.1.** Companies identified in a WWW search

| Company | URL |
|---|---|
| Chemineer Home Page (mechanical mixing vendor) | http://sys1.tpusa.com/catalog/tpusa/00000072 |
| Eastern-Cleveland Mixers (mechanical agitator vendor) | http://www.emimixers.com/index.htm |
| Farwest Associates, Inc. Representing Aquastore, Inc., a jet mixer vendor) | http://www.electricstores.com/farwest/sludge.htm |
| Fluent, Inc. (Computational Fluid Dynamics software vendor) | http://www.fluent.com:80/fluent-codes/ CompanyBr/Sampler.html |
| Flygt, Inc. (Submersible pump & mixer vendor) | http://www.flygt.se/index.html |
| Holman Engineering, Inc. (Mixing consultant) | http://www.wi.net/holman/main.html |
| Lightnin (Mechanical Mixer vendor) | http://www2.lightnin-mixers.com/lightnin/ default.html |
| Mass Transfer Systems, Inc., A Waterlink Company (Jet mixer vendor) | http://www.wateronline.com/companies/mts/mixi ng.html |
| Mixing Systems, Inc. (Jet mixer vendor) | http://207.0.228.154/mixing/ |
| NETTCO Corporation (Side entering mixer vendor) | http://www.nettco.com/side.htm |
| Pulsair Systems, Inc. | http://www.pulsair.com |
| VISIMIX (Mixing modelling software vendor) | http://www.macom.co.il/Software/JSI/ VisiMix/index.html |

E-mail messages were sent to each of the companies (except Pulsair Systems, Inc.) with a short description of the DST sludge mobilization and mixing application. None of these companies responded with an applicable solution for DST sludge mobilization and mixing.

### 4.4.2 USENET Inquiry

On 12/31/96, the following message was posted to the sci.engr.chem newsgroup.

> "I am seeking commercial solutions for mixing radioactive sludge and liquid in a 1 Mgal tank (75-ft diameter) at the Hanford Site. Jet mixer pumps are currently being considered. Mechanical agitation is probably impractical because of restricted access to the tanks through a 42-in. riser. If there are any alternatives that we should be aware of, please e-mail me at ea_daymo@pnl.gov, or call me at (509) 373-6225. Thank you."

The message remained active on the newsgroup for approximately 2 to 3 weeks. No replies to the message were received.

### 4.4.3 CHEME-L (ListServer) Inquiry

On 12/31/96, the same message posted to the sci.engr.chem newsgroup was posted to the CHEME-L ListServer (CHEME-L@ulkyvm.louisville.edu). Two replies were received. Brian Barrett of THWTBN (THWTBN@aol.com) wrote to suggest "solution mining" techniques, such as adding chemicals that would solubilize the sludge or raising the temperature of the waste. Guy Metcalfe of CSIRO (Guy.Metcalfe@dbce.csiro.au) wrote to suggest his mixing technique which is used to mix large-scale vessels in the Australian mining industry. Unfortunately, CSIRO required a broad non-disclosure agreement be signed before any information on the mixing process could be released. Until CSIRO protects its intellectual property on its mixing technology, it probably cannot be shared with DOE contractors.

## 4.5 Conferences

Innovative mixing strategies would likely be presented at international conferences on chemical engineering and fluid mixing.

### 4.5.1 AIChE National Symposia

Abstracts and session titles from the AIChE 1994, 1995 and 1996 annual meetings were searched on the WWW (http://www.aiche.org:80/meeting) in order to find references to novel mixing techniques that may be applicable for Hanford DSTs. Most of the presentations focused on computational fluid dynamic models of mixing and experimental results from in-line (static) mixers, agitated tanks, or chemical reactors. One paper discussed the use of jet mixers in large tanks in the petrochemical industry (Hemrajani 1996), and another discussed the use of Pulse Air mixers in process vessels (Chang-Mateu 1994).

### 4.5.2 European Conference on Mixing

Proceedings from the European Conference on Mixing between 1974 and 1988 were reviewed for any innovative mixing technologies that could be applied at the Hanford Site (BHRA 1974, BHRA 1978, BHRA 1979, BHRA 1982, BHRA 1985, BHRA 1988, BHRA 1994). Nearly all of the papers discussed mechanical agitation, scale-up, computational fluid dynamics of mixing systems, liquid-

liquid dispersions, gas dispersions, and static mixers, and solids suspension with mechanical agitators. No applicable papers were identified.

### 4.5.3 Fluid Mixing Symposia

Proceedings from the Fluid Mixing Symposia between 1984 and 1996 were obtained (Institute of Chemical Engineers 1984, Institute of Chemical Engineers 1988, Institute of Chemical Engineers 1990, Institute of Chemical Engineers 1996). As with other symposia, nearly all of the papers discussed mechanical agitation, scale-up, computational fluid dynamics of mixing systems, liquid-liquid dispersions, gas dispersions, and static mixers, and solids suspension with mechanical agitators. No papers that discussed innovative mixing solutions for DSTs were identified.

### 4.5.4 North American Mixing Forum

A paper on the search for innovative mixing solutions for DSTs was presented at the 16th North American Mixing Forum in Williamsburg, Virginia in June 1997 (Daymo 1997). Approximately 150 people were in attendance at the talk. Although several discussions about waste retrieval from DSTs ensued, no industrial or academic attendees were able to provide useful leads to commercial tank mixing companies that would be able to provide DST sludge mobilization and mixing solutions.

## 4.6 Classes

A few classes on tank mixing are offered through the American Institute of Chemical Engineering, the Center for Professional Development, and the University of Wisconsin. A brief description of the classes is listed below.

### 4.6.1 American Institute of Chemical Engineering (AIChE) Classes

The course offered by AIChE covers an overview of impeller flow and fluid shear rate, impeller power characteristics, scale up principles, heat transfer, gas liquid processes, liquid-liquid processes, energy conservation, mechanical design, pilot plant procedures, and selected industrial applications (tailored to needs of participants). None of the topics suggest that an innovative mixing technology applicable for Hanford DSTs would be discussed.

### 4.6.2 Center for Professional Development

The Center for Professional Development (908-613-4500) has offered a course entitled Modern Industrial Liquid Mixing Technology, directed by Dr. Alvin W. Nienow (Professor of Biochemical Engineering, University of Birmingham, U.K.). The course syllabus includes the following topics: rheology and turbulence, mixing equipment (types of impellers, jet mixers, and high intensity mixers), low viscosity mixing, high viscosity mixing, mixing and homogeneous reactions, heat transfer, solid-liquid systems, gas-liquid systems, liquid-liquid systems, gas dispersion, in-line mixing, and a discussion of crystallization and fermentation applications. The course does not appear to discuss mixing techniques (other than jet mixers) that would be useful in DSTs.

### 4.6.3 University of Wisconsin Continuing Education

A course entitled "Increasing Plant Performance through Better Mixing: An Advanced Course in Fluid Mixing" was given by the University of Wisconsin Department of Engineering/ Professional Development (800-462-0876) in August 1996. The class was taught by G.B. Tatterson of the North Carolina A&T University. The topics covered by the class included: economics of mixing, mixing tank geometries, turbulent mixing (power analysis, jet mixing, gas sparging), laminar mixing (impeller mixing), gas dispersion in agitated tanks, solids suspension, liquid-liquid systems, heat transfer, and chemical reactor design. None of the topics in the course outline seemed to indicate covering innovative mixing applications that would be applicable for DST sludge mobilization.

G.B. Tatterson has also recently taught two other classes on mixing through the University of Wisconsin Department of Engineering/Professional Development: "Pilot Plant Studies" and "Process Scaling for Batch and Semi-Batch Processing, and Mixing of Pastes and Solid Powders." Neither of these classes had course contents which covered large scale mixing applications.

### 4.6.4 Holman Engineering, Inc. (In-House Seminars)

A course entitled "Consistent Mixing: the Key to Uniform Quality" is advertised over the WWW at http://www.wi.net/holman/main.html. The two day seminar includes topics on mixing mechanisms, sampling techniques, liquid solid processing, liquid-gas processing, liquid-liquid processing, heat transfer, sizing a mixer, mechanical design, mixing specifications, and batch processing techniques. None of the items listed in the course outline indicates that innovative mixing techniques that would be applicable to Hanford DSTs would be covered.

## 4.7 Expert Consultation

During the textbook and literature review, experts in the field of mixing were identified and contacted. In particular, Gary B. Tatterson of North Carolina A&T University was contacted because of his prominence in the mixing field as well as his experience as an employee at the Savannah River Site. In addition, Peter R. Holman visited the Hanford Site to discuss possible tank mixing applications.

### 4.7.1 Gary B. Tatterson

Gary B. Tatterson is a recognized leader in the area of mixing in the process industries. He has more than 20 years of experience in mixing and multiphase processing. He has worked on mixing problems for numerous companies, including Mead Paper Co., Wilson Great Batch, Akzo Coatings America, B.J. Services, Raytheon, DuPont, Savannah River Site (DOE), Rohm & Haas, Texaco, and Colgate. Dr. Tatterson has written extensively on the subject of mixing: he has published two textbooks on the subject and has been the editor of five AIChE monographs on mixing. He is also the instructor for several University of Wisconsin Department of Engineering/Professional Development classes on mixing.

Gary B. Tatterson was contacted in hopes that he would be able to identify an applicable alternative to jet mixers for Hanford DSTs. Dr. Tatterson is aware of the Hanford Site problems (he was formerly involved with the Savannah River Site's mixer pump applications), but does not know of a mixing technology other than jet mixer pumps that would be applicable at the Hanford Site, given the limited access to the tank and the size of the DST. Dr. Tatterson was aware of Pulsair Systems, Inc., and agrees that this system would be best installed in horizontal tanks at ORNL and INEEL. If the Hanford Site is interested, Dr. Tatterson offered to make a consulting trip to Richland in order to discuss ways in which the mixer pump nozzle geometry can be modified so as to improve the cleaning time and effective cleaning radius.

### 4.7.2 Peter R. Holman

Mr. Holman has over 20 years of experience in chemical process and environmental engineering. He is the author of *Liquid Mixing from the Laboratory to the Pilot Plant* and has conducted engineering seminars for the University of Wisconsin, Madison on mixing. Mr. Holman does not know of any commercial mixing systems not listed in Section 2.0 that can effectively mix the contents of DSTs if conventionally installed. During a visit to the Hanford Site, Mr. Holman recommended that an agitator-based system be installed in the DSTs to mobilize the sludge and mix the tank contents. As discussed in Section 2.0, agitator based systems are not well suited for DSTs.

## 4.8 Thomas Register

Over 100 companies were contacted to solicit interest in providing equipment or technical assistance for sludge mobilization and mixing in one-million gallon Hanford DSTs. Table 4.1 lists the companies that were contacted and the reason why each company did not respond with a tank mixing proposal that would be applicable for DST sludge mobilization and mixing.

**Table 4.2.** Companies contacted for DST mixing technologies

| Company | Result of contact |
|---|---|
| A&B Process Systems Corp.<br>Stratford, WI<br>(715) 687-4332 | Manufacture mixing equipment for tanks smaller than 10,000 gallons. |
| ABS Pumps, Inc.<br>Meriden, CT<br>(203) 328-2700 | Interested in developing a solution for DST retrieval. No solution provided by 9/97. |
| Acumix, Inc.<br>Harrisburg, PA<br>(717) 549-9738 | Company does not manufacture mixing systems for one-million gallon process vessels. |
| Admix, Inc.<br>Londonderry, NH<br>(800) 466-2369 | Company constructs specialty process vessels, including agitation systems. They do not manufacture mixing systems for one-million gallon process vessels. |

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| Advanced Process Technology, Inc.<br>Middlesex, NJ<br>(908) 356-4438 | Company constructs specialty process vessels, including agitation systems. They do not manufacture mixing systems for one-million gallon process vessels. |
| AEA Technology Engineering Services, Inc.<br>Huntersville, NC<br>(704) 875-9573 | Markets pulsed jet mixing systems. Such systems have been previously identified as alternatives to jet mixers (Section 3). |
| Alsop Engineering Company<br>Kingston, NY<br>(914) 338-0466 | Company does not manufacture mixing systems for one-million gallon process vessels. |
| Alternate Energy Systems, Inc.<br>Peachtree City, GA<br>(770) 487-8596 | Custom design of engineering systems, but not mixing systems for one-million gallon tanks. |
| Apco Technologies, Inc.<br>Vancouver, WA<br>(800) 231-6231 | Company does not manufacture mixing systems for one-million gallon process vessels. |
| ATEC Environmental Systems, Div. Of ATEC Associates, Inc.<br>Cleveland, OH<br>(216) 524-4111 | Company does not manufacture mixing systems for one-million gallon process vessels. |
| Barnant Company<br>Barrington, IL<br>(708) 381-7050 | Company does not manufacture mixing systems for one-million gallon process vessels. |
| BEX, Inc.<br>Livonia, MI<br>(313) 464-8282 | Company manufactures spray nozzles (not complete mixing systems). A mixing system using BEX spray nozzles would essentially be a jet mixer. |
| Bowers Process Equipment<br>Marysville, MI<br>(800) 567-3223 | Company does not manufacture mixing systems for one-million gallon process vessels. |
| Brawn Mixer, Inc.<br>Holland, MI<br>(616) 399-5600 | Company does not manufacture mixing systems for one-million gallon process vessels. |
| Burhans-Sharpe Corporation<br>Seattle, WA<br>(800) 237-8815 | Interested in developing a solution for DST retrieval. No solution provided by 9/97. |

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| Bush Tank Fabricators, Inc.<br>Newark, NJ<br>(201) 596-1121 | Company constructs specialty process vessels, including agitation systems. They do not manufacture mixing systems for one-million gallon process vessels. |
| Champion Trading Corp.<br>Marlboro, NJ<br>(908) 780-4200 | Sells used mixing equipment. |
| Chemac, Inc.<br>Upper Saddle River, NJ<br>(201) 934-3300 | Custom design of engineering systems, but not mixing systems for one-million gallon tanks. |
| Chemineer, Inc.<br>Dayton, OH<br>(800) 643-0641 | Company manufactures mechanical agitation systems that would not be applicable for DST sludge mobilization or mixing. |
| Conhagen, Alfred, Inc., of Texas<br>La Marque, TX<br>(800) 872-5187 | Company does not manufacture mixing systems for one-million gallon process vessels. |
| Conn and Company<br>Warren, PA<br>(814) 723-7980 | Company specializes in dispersion blades, which are not applicable for DST sludge mobilization and mixing. |
| CONTECH<br>Glen Burnie, MD<br>(410) 768-6037 | Company manufactures products for bulk solids. |
| Dantco<br>Paterson, NJ<br>(201) 278-8776 | Company does not manufacture mixing systems for one-million gallon process vessels. |
| Davis, H.C., Sons Mfg. Co., Inc.<br>Bonner Springs, KS<br>(913) 422-3000 | Company does not manufacture mixing systems for one-million gallon process vessels. |
| D.C.I., Inc.<br>St. Cloud, MN<br>(800) 276-7599 | Company constructs specialty process vessels, including agitation systems. They do not manufacture mixing systems for one-million gallon process vessels. |
| Drexel Oilfield Services, Inc.<br>Conroe, TX<br>(409) 756-4800 | Company does not manufacture mixing systems for one-million gallon process vessels. |
| Drum-Mates, Inc.<br>Lumberton, NJ<br>(800) 621-3786 (out of state) | Company does not manufacture mixing systems for one-million gallon process vessels. |

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| Dynamic Air, Inc.<br>St. Paul, MN<br>(612) 484-2900 | Company manufactures products for bulk solids. |
| Eclipse Systems<br>Franklin, NJ<br>(210) 827-7878 | Company does not manufacture mixing systems for one-million gallon process vessels. |
| Ekato Corporation<br>Ramsey, NJ<br>(201) 825-4684 | Declined to participate in providing mixing equipment or consulting for DST sludge mobilization and mixing applications. |
| Elmridge, Inc.<br>Livonia, MI<br>(888) EDUCTOR | Manufactures jet mixing solutions. |
| EMI, Inc.<br>Clinton, CT<br>(800) 243-1188 | Company does not manufacture mixing systems for one-million gallon process vessels. |
| Epworth Manufacturing, Inc.<br>South Haven, MI<br>(616) 637-2128 | Company constructs specialty process vessels, including agitation systems. They do not manufacture mixing systems for one-million gallon process vessels. |
| Ertl Engineering Co.<br>Kingston, NY<br>(914) 331-4552 | Custom design of engineering systems, but not mixing systems for one-million gallon tanks. |
| Expert Industries, Inc.<br>Brooklyn, NY<br>(718) 434-6060 | Custom design of engineering systems, but not mixing systems for one-million gallon tanks. |
| Far West Associates, Inc.<br>Ft. Collins, CO<br>(970) 416-9911 | Markets a side entering jet mixer solution. |
| Farasey Steel Fabricating, Inc.<br>Cleveland, OH<br>(216) 641-1853 | Company constructs specialty process vessels, including agitation systems. They do not manufacture mixing systems for one-million gallon process vessels. |
| Faubion Central States Tank Co.<br>Shawnee Mission, KS<br>(800) 450-TANK | Company constructs specialty process vessels, including agitation systems. They do not manufacture mixing systems for one-million gallon process vessels. |

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|---|---|
| Filter Pump Industries<br>(Divison of Penguin Pumps, Inc.)<br>Sun Valley, CA<br>(818) 504-2391 | Custom design of engineering systems, but not mixing systems for one-million gallon tanks. |
| Flow Process Technologies, Inc.<br>Houston, TX<br>(281) 469-2777 | Markets an Aqua-Shear in-line mixer. In-line mixers are not-applicable for DST sludge mobilization and mixing. |
| F.R. Horman & Co.<br>Kingston, NY<br>(914) 338-3470 | Custom design of engineering systems, but not mixing systems for one-million gallon tanks. |
| Fred Burack Co.<br>Rye, NY<br>(914) 921-4146 | Company constructs specialty process vessels, including agitation systems. They do not manufacture mixing systems for one-million gallon process vessels. |
| Gardner, Paul N., Co., Inc.<br>Pompano Beach, FL<br>(800) 762-2478 | Company does not manufacture mixing systems for one-million gallon process vessels. |
| Goodway Industries, Inc.<br>Bohemia, NY<br>800-943-4501 | Company does not manufacture mixing systems for one-million gallon process vessels. |
| Greerco Corp.<br>Hudson, NH<br>(603) 883-5517 | Company does not manufacture mixing systems for one-million gallon process vessels. |
| Grovac, Inc.<br>Brookfield, WI<br>(800) 369-2475 | Company does not manufacture mixing systems for one-million gallon process vessels. |
| Hammelmann Corporation<br>Dayton, OH<br>(937) 233-4935 | Company does not manufacture mixing systems for one-million gallon process vessels. |
| Hockmeyer Equipment, Co.<br>Harrison, NJ<br>(201) 482-0225 | Company does not manufacture mixing systems for one-million gallon process vessels. |
| Indco, Inc.<br>New Albany, IN<br>(800) 942-4383 | Company does not manufacture mixing systems for one-million gallon process vessels. |
| ITT Flygt Corp.<br>Trumbull, CT<br>(800) 843-5948 | Manufactures submersible mixers which may be able to replace jet mixer pumps for DST sludge mobilization and mixing. |

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| J. Little Mercer Co.<br>Rehoboth, MA<br>(800) 230-3164 | Company constructs specialty process vessels, including agitation systems. They do not manufacture mixing systems for one-million gallon process vessels. |
| Jaygo, Inc.<br>Union, NJ<br>(908) 688-3600 | Company does not manufacture mixing systems for one-million gallon process vessels. |
| Keith Machinery Corp.<br>Lindenhurst, NY<br>(800) 348-1769 | Sells used mixing equipment. |
| KILNTECH Environmental Services<br>Lafayette, LA<br>(318) 993-0279 | Manufacturers a pump/grinding apparatus that would be appropriate for use on a in-tank crawler. Technology would probably be applicable for heel retrieval, but not DST sludge mobilization and tank mixing. |
| Kistler-Morse Corporation<br>Bothell, WA<br>(800) 426-9010, ext. 201 | Company manufactures products for bulk solids. |
| Lee Industries, Inc.<br>Philipsburg, PA<br>(814) 342-0461 | Manufacture mixing equipment for tanks smaller than 10,000 gallons. |
| Lightnin<br>Rochester, NY<br>(716) 436-5550 | Company manufactures mechanical agitation systems. Declined to provide a solution for DST sludge mobilization or mixing. |
| Littleford Day, Inc.<br>Florence, KY<br>(606) 525-7600 | Company does not manufacture mixing systems for one-million gallon process vessels. |
| Lutz Pumps, Inc.<br>Norcross, GA<br>(800) 843-3901 | Markets a solution that can be used as a mixer or as a pump for drums. Company does not manufacture mixing systems for one-million gallon process vessels. |
| Melvale Engineering, Inc.<br>Baltimore, MD<br>(410) 296-4322 | Custom design of engineering systems, but not mixing systems for one-million gallon tanks. |
| Midwest Mixing, Inc.<br>Chicago Ridge, IL<br>(800) 879-8971 | Company does not manufacture mixing systems for one-million gallon process vessels. |

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|---|---|
| Mixmor, Inc.<br>King of Prussia, PA<br>(800) 335-4981 | Company does not manufacture mixing systems for one-million gallon process vessels. |
| Mixmor, Inc.<br>Los Angeles, CA<br>(800) 335-4983 | Company does not manufacture mixing systems for one-million gallon process vessels. |
| Morchouse-Cowles, Inc.<br>Fullerton, CA<br>(714) 738-5000 | Manufacture mixing equipment for tanks smaller than 10,000 gallons. |
| MTS (a Waterlink Company)<br>Fall River, MA<br>(508) 679-6770 | Markets a bottom mounted jet mixer. |
| Myers Engineering<br>Bell, CA<br>(213) 560-4723 | Company does not manufacture mixing systems for one-million gallon process vessels. |
| New Advance Machinery Co.<br>Van Wert, OH<br>(419) 238-0042 | Sells mixer parts only. |
| Netzsch, Inc.<br>Exton, PA<br>(610) 363-8010 | Manufactures grinding and milling equipment. |
| Omni Fabricators, Inc.<br>Southampton, NJ<br>(800) 859-OMNI | Company constructs specialty process vessels, including agitation systems. They do not manufacture mixing systems for one-million gallon process vessels. |
| Paget Equipment Company<br>Marshfield, WI<br>(800) 234-3158, dept. 29 | Company constructs specialty process vessels, including agitation systems. They do not manufacture mixing systems for one-million gallon process vessels. |
| Pardee Engineering, Inc.<br>Miami, FL<br>(305) 885-8835 | Manufactures jet mixing solutions. |
| Paul Mueller Company<br>Springfield, MO<br>(800) 683-5537 | Company constructs specialty process vessels, including agitation systems. They do not manufacture mixing systems for one-million gallon process vessels. |
| Penberthy, Inc.<br>Prophetstown, IL<br>(815) 537-2311 | Manufactures jet mixing solutions. |

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| PEPCO<br>Branchburg, NJ<br>(800) 407-3726 | Develop pneumatic products for tanks up to 1,000 gallons. |
| Philadelphia Mixers, Inc.<br>Palmyra, PA<br>(800) 394-1341 | Recommend an impeller-based system. Mechanical agitation is probably not the best solution for DST sludge mobilization and mixing. |
| Picatti Brothers (represent Floway-Peabody)<br>Yakima, WA<br>(509) 248-2540 | Recommend the installation of a submersible positive displacement pump, in-tank "bladder" for grinding and injection of dilution water, and a transfer pump to send waste from the "bladder" through intra-tank slurry pipelines. This idea was not considered further since DST tank waste may not flow to the positive displacement pump. Mounting the pump on a crawler has problems as well. |
| Plenty Products, Inc.<br>Houston, TX<br>(800) 554-4225 | Company does not manufacture mixing systems for one-million gallon process vessels. |
| Pope Scientific, Inc.<br>Menomonee Falls, WI<br>(414) 251-9300 | Company constructs specialty process vessels, including agitation systems. They do not manufacture mixing systems for one-million gallon process vessels. |
| Precision Stainless, Inc.<br>Springfield, MO<br>(800) 644-0424 | Company constructs specialty process vessels, including agitation systems. They do not manufacture mixing systems for one-million gallon process vessels. |
| Premier Mill Corp.<br>Reading, PA<br>(610) 779-9500 | Company does not manufacture mixing systems for one-million gallon process vessels. |
| Proquip, Inc.<br>Macedonia, OH<br>(216) 468-1850 | Company does not manufacture mixing systems for one-million gallon process vessels. |
| Pulsair Systems, Inc.<br>Bellevue, WA<br>(206) 455-1263 | System already identified within the DOE complex. |
| Robert C. Reetz and Co., Inc.<br>Pawtucket, RI<br>(401) 722-9025 | Company constructs specialty process vessels, including agitation systems. They do not manufacture mixing systems for one-million gallon process vessels. |

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| Ross, Charles, & Son Co.<br>Hauppauge, NY<br>(800) 243-7677 | Company does not manufacture mixing systems for one-million gallon process vessels. |
| Sandmold Systems, Inc.<br>Newaygo, MI<br>(616) 652-1623 | Company constructs specialty process vessels, including agitation systems. They do not manufacture mixing systems for one-million gallon process vessels. |
| Schutte & Koerting, Inc.<br>Bensalem, PA<br>(215) 639-0900 | Manufactures jet mixing solutions. |
| Scott Turbon Mixer, Inc.<br>Adelanto, CA<br>(800) 285-8512 | Interested in developing a solution for DST retrieval. No solution provided by 9/97. |
| Shar Systems, Inc.<br>Fort Wayne, IN<br>(219) 432-5312 | Company does not manufacture mixing systems for one-million gallon process vessels. |
| Sharpsville Container Corp.<br>Sharpsville, PA<br>(800) 394-1298 | Company constructs specialty process vessels, including agitation systems. They do not manufacture mixing systems for one-million gallon process vessels. |
| Silverson Machines, Inc.<br>East Longmeadow, MA<br>(413) 525-4825 | Company manufactures in-line mixers. |
| Sonic Corp.<br>Stratford, CT<br>(203) 375-0063 | Company does not manufacture mixing systems for one-million gallon process vessels. |
| Spyral Corp.<br>Washington, D.C.<br>(202) 337-6008 | Company markets a rotating coil mixing technology that is essentially a mechanical agitator. Spyral submitted a tank mixing proposal, but a mechanical agitation solution was deemed undesirable for DST sludge mobilization and mixing. |
| Stainless Fabrication, Inc.<br>Springfield, MS<br>(800) 397-8265 | Company does not manufacture mixing systems for one-million gallon process vessels. |
| Steri Technologies, Inc.<br>Bohemia, NY<br>(800) 611-9407 | Company does not manufacture mixing systems for one-million gallon process vessels. |

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| Stricklin Co.<br>Dallas, TX<br>(214) 637-1030 | Company does not manufacture mixing systems for one-million gallon process vessels. |
| Technology General Corp.<br>Franklin, NJ<br>(201) 827-7878 | Custom design of engineering systems, but not mixing systems for one-million gallon tanks. |
| Teledyne Readco<br>York, PA<br>(800) 395-4959 | Company does not manufacture mixing systems for one-million gallon process vessels. |
| Terracon Corporation<br>Holliston, MA<br>(508) 429-9950 | Manufactures plastic tanks (can provide mixers for tanks it sells). |
| Terriss Consolidated Industries, Inc.<br>Asbury Park, NJ<br>(908) 988-0909 | Company constructs specialty process vessels, including agitation systems. They do not manufacture mixing systems for one-million gallon process vessels. |
| Tonson, Inc.<br>Litchfield, AZ<br>(800) 318-3233 | Develop pneumatic products for tanks up to 10,000 gallons. |
| Union Process, Inc.<br>Akron, OH<br>(330) 929-3333 | Manufactures grinding and milling equipment. |
| Union Standard Equipment<br>(Division of National Equipment Corp.)<br>Bronx, NY<br>(718) 585-0200 | Sells used mixing equipment. |
| United States Plastic Corp.<br>Lima, OH<br>(800) 537-9724 | Company does not manufacture mixing systems for one-million gallon process vessels. |
| United Equipment Technologies, Inc.<br>Manchester, NH<br>(603) 627-9324 | Company manufactures mechanical agitation systems that would not be applicable for DST sludge mobilization or mixing. |
| U.S. Best, Inc.<br>New Albany, IN<br>(812) 941-8867 | Company does not manufacture mixing systems for one-million gallon process vessels. |
| Utilities Supply Company<br>Medford, MA<br>(800) 314-4164 | Company constructs specialty process vessels, including agitation systems. They do not manufacture mixing systems for one-million gallon process vessels. |

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| Valchem Portable Mixers<br>Dayton, OH<br>(937) 454-3300 | Company does not manufacture mixing systems for one-million gallon process vessels. |
| Viatec Process Storage Systems, Inc.<br>Belding, MI<br>(800) 942-4702 outside MI | Company constructs specialty process vessels, including agitation systems. They do not manufacture mixing systems for one-million gallon process vessels. |
| Waukesha Cherry-Burrel<br>Delavan, WI<br>(800) 252-1045 | Company constructs specialty process vessels, including agitation systems. They do not manufacture mixing systems for one-million gallon process vessels. |
| Walker Stainless Equipment Co., Inc.<br>New Lisbon, WI<br>(800) 419-3005 | Company constructs specialty process vessels, including agitation systems. They do not manufacture mixing systems for one-million gallon process vessels. |
| Williams Equipment Co., Inc.<br>Riverdale, NJ<br>(201) 492-1551 | Sells used mixing equipment. |
| Wolfe Mechanical & Equipment Co.<br>Lugoff, SC<br>(803) 438-1093 | Company does not manufacture mixing systems for one-million gallon process vessels. |

None of the over 100 companies contacted sold a commercial alternative to jet mixers that would clearly be effective at mobilizing sludge and mixing within a DST.

# 5.0 Recommendations

No commercial alternatives to mixer pumps were identified as a result of this literature search. As such, the baseline mixing technology should still be pursued.

While already identified before this report, two alternatives to jet mixer pumps already exist in the marketplace. ITT Flygt mixers are submersible ducted turbine pumps that can serve as alternatives for some DST mixing applications (especially for cases where there is no sludge in the tank that needs to be suspended). ITT Flygt mixers have been evaluated at the Savannah River Site. Pulsed-jet devices by AEA or the former-Soviet Union could also have potential uses in DST mixing applications. AEA has already submitted a design report to the Savannah River Site, and the Hanford Site has evaluated pulsed-jet devices from the former-Soviet Union (Enderlin and Mullen 1997). Data from Flygt mixer and pulsed-jet tests should be evaluated to determine whether these mixers have the potential to replace jet mixers for certain DST mixing applications. Since most of the testing on Flygt and pulsed-jet mixers occurred this fiscal year, data was unavailable to incorporate into this study.

# 6.0 Conclusions

The principal technologies that could be used for DST sludge mobilization and DST mixing were outlined in Section 3. There is no general mixing technology category that clearly seems more promising than jet mixer pumps for DST sludge mobilization applications. However, Flygt submersible mixers and pulsed fluid jets may have some applications in DSTs where sludge mobilization is not necessary.

Commercial alternatives to jet mixer pumps were sought through a comprehensive literature search. While not every paper, textbook, expert or mixing company was consulted, the literature search was broad enough that should applicable commercial alternatives had existed, they probably would have been found in this literature search. For example, the Pulsair™ mixing system was identified four independent ways (Internet URL, Thomas Register, AIChE presentation, expert consultation). It was the serendipitous identification of the Pulsair™ system a few years ago that lead to the question of whether other potentially applicable commercial mixing technologies exist.

The following results from the literature search are reported:

- Recent Hanford engineering documents considered mixer pumps, sluicing, and in-tank recirculation (through the transfer pump) as DST mixing alternatives.

- The ACTR project found few serious respondents to a Commerce Business Daily ad seeking industrial solutions to Hanford DST tank retrieval issues. No viable alternatives to jet mixer pumps were identified.

- Savannah River conducted a similar search for alternatives to jet mixer pumps. Technologies were classified similarly to those in Section 3.

- There are two potentially viable alternatives to jet mixer pumps. ITT Flygt mixers have been tested at Savannah River as low-cost alternatives to jet mixers, and pulsed jet devices from both the former-Soviet Union and AEA hold promise. Both of these technologies should be carefully considered as possible alternatives to jet mixer pumps, particularly in tanks that do not have a settled layer of compacted sludge.

- Despite a through search through the recent literature (journal articles, textbooks, trade publications) and expert consultation, no previously unidentified commercial alternatives to jet mixer pumps were found.

# 7.0 References


AEA. 1996. *Pulse Jet Mixing for Sludge Washing*. Letter report. AEA Technology Engineering Services, Inc., Pittsburgh, Pennsylvania.

Berglin, E.J. 1995. *Double-Shell Tank Waste Retrieval Survey Package*. WHC-SD-WM-RPT-202, Rev. 0. Westinghouse Hanford Company, Richland, Washington.

BHRA Fluid Engineering. 1974. *Proceedings of First European Conference on Mixing and Centrifugal Separation*. BHRA Fluid Engineering, Cranfield, England.

BHRA Fluid Engineering. 1977. *Proceedings of the Second European Conference on Mixing*. BHRA Fluid Engineering, Cranfield, England.

BHRA Fluid Engineering. 1979. *Proceedings of the Third European Conference on Mixing*. BHRA Fluid Engineering, Cranfield, England.

BHRA Fluid Engineering. 1982. *Papers Presented at the Fourth European Conference on Mixing*. BHRA Fluid Engineering, Cranfield, England.

BHRA Fluid Engineering. 1985. *Papers Presented at the Fifth European Conference on Mixing*. BHRA Fluid Engineering, Cranfield, England.

BHRA Fluid Engineering. 1988. *Proceedings of the 6th European Conference on Mixing. BHRA Fluid Engineering*, Cranfield, England.

BHRA Fluid Engineering. 1994. *Proceedings of the 8th European Conference on Mixing. BHRA Fluid Engineering*, Cranfield, England.

Boomer, K.D., S.K. Baker, A.L. Boldt, J.D. Galbraith, J.S. Garfield, C.E. Goldberg, B.A Higley, L.J. Johnson, M.J. Kupfer, R.M. Marusich, R.J. Parazin, A.N. Parga, G.W. Reddick, E.J. Slaathaug, L.M. Swanson, T.L. Waldo, and C.E. Worcester. 1993. *Tank Waste Technical Options Report: Appendix F, Waste Retrieval and Transfer*. WHC-EP-0616, Rev. 0. Westinghouse Hanford Company, Richland, Washington.

Chang-Mateu, M. "Large Pulsed Air Bubble Induced Mixing." Presented at the AIChE 1994 National Meeting, San Francisco, California. Rhom and Haas Company, Birstol, Pennsylvania.

Dickey, D.S. Hemrajani, R.R. 1992. "Recipes for Fluid Mixing." *Chemical Engineering*. McGraw Hill, Inc., New York, New York. v99, n3.

Daymo, E.A. 1997. *Sludge Mobilization and Mixing Techniques for Double-Shell Tanks at Hanford.* PNL-SA-28969. Presented at the 16th North American Mixing Forum, Williamsburg, Virginia. Pacific Northwest National Laboratory, Richland, Washington.

Enderlin, C.W. and O.D. Mullen. 1997. *Russian Retrieval Equipment Quarter-Scale Equipment Testing.* Letter Report. Pacific Northwest National Laboratory, Richland, Washington.

Etchells, A.W., R.R. Hemrajani, D.J. Koestler, and E.L. Paul. "The Many Faces of Mixing." *Chemical Engineering*. McGraw Hill, Inc., New York, New York. v99, n3.

Eyler, L.L. 1983a. *Sediment Settling and Resuspension in Waste Storage Tanks with Air Injection Circulators.* Letter Report FATE-83-109. Pacific Northwest Laboratory, Richland, Washington.

Eyler, L.L. 1983b. *Sediment Settling and Resuspension in Waste Storage Tanks with Air Injection Circulators Including Effect of Solids Concentration-Dependent Viscosity.* Letter Report FATE-83-120. Pacific Northwest Laboratory, Richland, Washington.

Eyler, L.L. 1984. *Three-Dimensional Numerical Simulation of Settling and Resuspension of Solids in Storage Tanks with Air Injection Recirculators.* PNL-SA-11586. Pacific Northwest Laboratory, Richland, Washington.

Hamm, B.A., W.L. West, and G.B. Tatterson. 1989. "Sludge Suspension in Waste Storage Tanks." *AIChE Journal,* v35, n8.

Hanlon, B.M. 1994. *Tank Farm Surveillance and Waste Status Report for May 1994.* WHC-EP-0182-74. Westinghouse Hanford Company, Richland, Washington.

Harnby, N., M.F. Edwards, and A.W. Nienow. 1992. *Mixing in the Process Industries, Second Edition.* Butterworth-Heinemann Ltd., Boston, Massachusetts.

Hemrajani, R. R. *Mixing Technologies for Crude Oil Processing in Refineries.* Presented at the 1996 AIChE National Meeting, Chicago, Illinois. Exxon Research & Engineering, Florham Park, New Jersey.

Institute of Chemical Engineers. 1984. *Fluid Mixing II.* Pergamon Press, New York, NY.

Institute of Chemical Engineers. 1988. *Fluid Mixing III.* Hemisphere Publishing Corporation, New York, NY.

Institute of Chemical Engineers. 1990. *Fluid Mixing IV.* Hemisphere Publishing Corporation, New York, NY.

Institute of Chemical Engineers. 1996. *Fluid Mixing V.* Institution of Chemical Engineers, London, England.

LATA. 1995. *BNFL Waste Retrieval Experience with Submerged Waterjet Technology.* Letter Report. Los Alamos Technical Associates, Inc., Richland, Washington.

Lawler, J.H. 1986a. *Double-Shell Tank Waste Retrieval Technology Program Plan.* SD-WM-TPP-009, Rev. 1. Rockwell Hanford Operations, Richland, Washington.

Lawler, J.H. 1986b. *Neutralized Current Acid Waste (NCAW) Retrieval Methods*. SD-WM-TI-231, Rev. 0. Rockwell Hanford Operations, Richland, Washington.

Lessor, D.L. 1997. *Applicability of a Single Sonic Probe to Retrieval Enhancement in Hanford Waste Tank 241-SY-102.* Letter Report. Pacific Northwest National Laboratory, Richland, Washington.

McCabe, W.L., J.C. Smith, and P. Harriott. 1993. *Unit Operations of Chemical Engineering, Fifth Edition.* McGraw Hill Publishing Co., New York, New York.

McKeon, D.T., D. Bouette, D. Snedeker. 1992. *BNFL Developed Mixing Technologies to Support the WHC Organics Tank Program, Rev. 1.* BNFL, Inc., Puyallup, Washington.

Oldshue, JY. 1983. *Fluid Mixing Technology*. McGraw Hill Publishing Co., New York, New York.

Perry, R.H., and D.W. Green. 1984. *Perry's Chemical Engineers' Handbook, 6th Edition.* McGraw Hill Publishing Co., New York, New York.

Post, T. 1995a. "Basics of Mixing Theory - the First in a Series." *Chemical Processing.* v58, n2.

Post, T. 1995b. "Defining the Mixing Process - A Key Factor in Mixing System Design." *Chemical Processing*. v58, n6.

Post, T. 1996. "Applying Mixing Principles to Real-World Problems." *Chemical Processing*. v59, n3.

Powell, M.R., C.M. Gates, C.R. Hymas, M.A. Sprecher, and N.J. Morter. 1995. *Fiscal Year 1994 1/25-Scale Sludge Mobilization Testing*. PNL-10582. Pacific Northwest Laboratory, Richland, Washington.

Powell, M.R., and C.R. Hymas. 1996. *Retrieval Process Development and Enhancements: FY96 Pulsed-Air Mixer Testing and Deployment Study.* PNNL-11200. Pacific Northwest National Laboratory, Richland, Washington.

Powell, M.R. 1996. Initial ACTR Retrieval Technology Evaluation Test Material Recommendations. PNNL-11021. Pacific Northwest National Laboratory, Richland, Washington.

Powell, M.R., Y. Onishi, and R. Shekarriz. 1997. *Research on Jet Mixing of Settled Solids in Nuclear Waste Tanks at Hanford and Other DOE Sites: A Historical Perspective.* PNNL-11686. Pacific Northwest National Laboratory, Richland, Washington.

Powell, M.R. 1997. *Retrieval Process Development and Enhancements Pulsed-Air Mixing DOE Site Assessment.* PNNL-11584. Pacific Northwest National Laboratory, Richland, Washington.

Rassat, S.D., P.A. Gauglitz, P.R. Bredt, L.A. Mahoney, S.V. Forbes, and S.M. Tingey. 1997. *Mechanisms of Gas Retention and Release: Experimental Results for Hanford Waste Tanks 241-AW-101 and 241-AN-103.* PNNL-11642. Pacific Northwest National Laboratory, Richland, Washington.

Scott, P.A. and R.T. Allemann. 1986. *Rating Panel Evaluation of Double Shell Tank Waste Mixing Pump Concepts*. 7H35-86-7. Pacific Northwest National Laboratory, Richland, Washington.

Serne, R.J., G.A. Whyatt, S.V. Mattigod, Y. Onishi, P.G. Doctor, B.N. Bjornstad, M.R. Powell, L.M. Liljegren, J.H. Westsik, Jr., N.J. Aimo, K.P. Recknagle, G.R. Golcar, T.B. Miley, G.R. Holdren, D.W. Jeppson, R.K. Biyano, and G.S. Barney. 1996. *Fluid Dynamics, Particulate Segregation, Chemical Processes and Tank Inventory Discussions that Relate to the Potential for Criticality in Hanford Tanks*. WHC-SD-WM-TI-757, Rev. 0. Westinghouse Hanford Company, Richland, Washington.

Stegen, L.C. 1986. *Alternatives for Retrieval and Cross-Site Transfer of the Waste in SY-103*. SD-WM-TI-242. Westinghouse Hanford Company, Richland, Washington.

Stewart, C.W., L.A. Schienbein., J.D. Hudson, E.J. Eschbach, and D.L. Lessor. 1994. *Assessment of Alternative Mitigation Techniques for Hanford Flammable Gas Tanks*. PNL-10105. Pacific Northwest Laboratory, Richland, Washington.

Tatterson, GB. 1991. *Fluid Mixing and Gas Dispersion in Agitated Tanks*. McGraw Hill Publishing Co., New York, New York.

Tatterson, G.B., R.S. Brodkey, and R.V. Calabrese. 1991. "*Move Mixing Technology into the 21st Century*." Chemical Engineering Progress. American Institute of Chemical Engineers, V87 N6.

Tatterson, GB. 1992. *Process Mixing: Chemical and Biochemical Applications, Part I*. Symposium Series #286. American Institute of Chemical Engineers, New York, New York.

Tatterson, G.B. 1993a. *Process Mixing: Chemical and Biochemical Applications, Part II*. Symposium Series #293. American Institute of Chemical Engineers, New York, New York.

Tatterson, G.B. 1993b. "Mixing Theories." *Chemical Engineering Progress*. American Institute of Chemical Engineers, New York, New York. V89, N11.

Tatterson, G.B. 1995. *Industrial Mixing Fundamentals with Applications*. Symposium Series #305. American Institute of Chemical Engineers, New York, New York.

Tingey, J.M. 1992. *Rheological Properties of Waste from Tank 101-SY*. Letter Report. Pacific Northwest Laboratory, Richland, Washington.

Uhl, Vincent. 1967. *Mixing: Theory and Practice, Volume II*. Academic Press, New York, New York.

Waters, E.D. 1994. *Background and Status of Hanford's DST Retrieval Technology*. WHC-SD-WM-TI-593, Rev. 0. Westinghouse Hanford Company, Richland, Washington.

Wilkins, N.E., J.G. Field, L.W. Shelton, and T.L. Welsh. 1997. *Tank Characterization Report for Double-Shell Tank 241-AN-103*. HNF-SD-WM-ER-702, Rev. 0. Lockheed Martin Hanford Company, Richland, Washington.

Willingham, C.E. 1994. *Thermophysical Properties of Hanford High-Level Tank Wastes.* PNL-9419. Pacific Northwest Laboratory, Richland, Washington.

Whyatt, G.A., R.J. Serne, S.V. Mattigod, Y. Onishi, M.R. Powell, J.H. Westsik, Jr., L.M. Liljegren, G.R. Golcar, K.P. Recknagle, P.M. Doctor, V.G. Zhirnov, and J. Dixon. 1996. *Potential for Criticality in Hanford Tanks Resulting from Retrieval of Tank Waste.* PNNL-11304. Pacific Northwest National Laboratory, Richland, Washington.

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