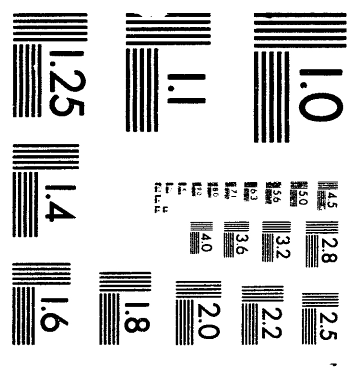
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DEVELOPING A SCARIFIER TO RETRIEVE RADIOACTIVE WASTE FROM HANFORD SINGLE-SHELL TANKS

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ABSTRACT

Radioactive waste is stored in 149 3785 m^3 (million gal) single-shell tanks on the US Department of Energy's Hanford Reservation in eastern Washington. To minimize leakage as the tanks age, the free liquid has been pumped out, leaving concentrated solidified salt cake and sludge deposits. Now methods to dislodge and remove this waste are being developed so that the waste can be retrieved and processed for permanent storage.

This paper presents research and development on ultrahigh-pressure water-jet technology to fracture and dislodge the wastes in these tanks. A water-based prototype scarifier with an integral conveyance system is being developed, and its performance demonstrated in a coupled analytical and experimental investigation. This paper describes experimental objectives and approach and results of the single jet experiments. Previous testing indicates that the method can be readily applied to salt cake waste forms; retrieval and conveyance of sludge and viscous fluid waste forms may present additional challenges.

1. INTRODUCTION

Radioactive waste is stored in 149 3785 m^3 (million gal) single-shell tanks on the Hanford Reservation in eastern Washington. The free liquid has been pumped from these tanks leaving concentrated solidified salt cake and sludge deposits. The Underground Storage Tank Integrated Demonstration supports the U.S. Department of Energy (DOE) effort to develop methods to retrieve these solidified wastes. Several types of hydraulic waste dislodging tools and retrieval methods are under evaluation: dislodging tools include high-pressure low-flow-rate scarifiers and low-pressure high-flow-rate miners; retrieval systems include pneumatic conveyance using air as the transport fluid and jet pumping using water. Initially, pneumatic conveyance will be evaluated with the scarifier and jet pumping will be evaluated with the low pressure miner. This paper describes the development of the scarifier portion of a scarifier/pneumatic conveyance waste dislodging system.

2. BACKGROUND

Scarifiers erode solid material with high pressure water jets and are currently used to remove concrete from bridge decks without injury to imbedded reinforcing bars or deck supports. Special-purpose scarifiers to decontaminate metal and concrete surfaces have been designed and manufactured by Quest Integrated, Inc. (Pezzimenti, Vlad, and Landau 1989, Tundo, Gessner, and Lawrence 1988); these scarifiers include integral systems for water and waste stream retrieval. This technology is being adapted to remove wastes contained in underground storage tanks across the DOE complex. The technology is hydraulic; however, systems have been designed to minimize water accumulation by applying suction concurrently to remove dislodged material and the water working fluid. The eroded material and water are then conveyed pneumatically away from the surface.

Proof-of-principle tests to evaluate the performance of an existing water jet scarifier prototype to erode salt cake and sludge simulant were performed by Quest (1990); the results indicated that scarifiers would successfully erode salt cake or soft sludge. However, difficulties were encountered when eroded soft sludges were conveyed pneumatically. No attempts were made to optimize the scarifier or the conveyance system during this proof-of-principle test. Based on a review of existing theories and past experiments conducted under similar conditions, a strategy (Bamberger et al 1993) has been formulated for a coupled analytical/experimental approach to develop a multi-functional scarifier coupled with a pneumatic conveyance system. Based on this analysis

- Salt cake is anticipated to be the easiest waste form to retrieve. A theoretical model of hydraulic rock fracture can be applied to estimate jet performance in fracturing the salt cake, and gas-solids transport correlations can be used to predict pneumatic transport of dry solids.

- Deformable sludge is anticipated to be the most difficult to retrieve. No theories, correlations, or data exist to predict performance in this case.

- Viscous fluid is anticipated to be of intermediate retrieval difficulty. Analogies to classical two phase gas-liquid flow can be justified.

Pacific Northwest Laboratory and Quest Integrated, Inc. are collaborating in a joint effort to optimize the scarifier/conveyance system design to dislodge and retrieve tank wastes.

3. OBJECTIVE

The primary objective of this joint effort is to develop a light-weight scarifier dislodging tool with an integral pneumatic conveyance system to dislodge and convey salt cake, sludge, viscous fluids, and scarifier cutting fluid from radioactive waste stored in tanks at Hanford and other sites.

Existing scarifier and pneumatic conveyance technology will be integrated and adapted to

- operate efficiently to remove a variety of waste forms including salt cake, sludge and viscous fluids
- minimize total water accumulation in tanks by incorporating an integral removal/conveyance system
- maximize working fluid retrieval efficiency to achieve >98% fluid retrieval in a single pass
- minimize water use by using high-energy, high-pressure water jets
- decrease the volume of the scarifier unit to 0.3 m (12 in.) cube
- decrease the mass of the scarifier to between 45 and 90 kg (100 and 200 lbm) to ease its placement on robotic manipulators
- determine maximum continuous waste retrieval rates
- maximize the solid loading permitted in the conveyance system
- optimize the size of solid aggregates cut by the scarifier for transport by the conveyance system
- characterize vertical lift capability for a conveyance system; 15 m (50 ft) is required for tank deployment
- operate and survive in the high radiation tank environment
- resist plugging of the conveyance system
- reduce potential entanglement with in-tank hardware by replacing scarifier rotating jet nozzles with linear motion jet nozzles.

4. APPROACH

Modifications to the scarifier to allow it to operate in a tank environment require testing to determine the operating parameters most suited to retrieval and conveyance of the various waste forms contained in tanks. To identify the optimum parameters separate effects experiments to evaluate varying design parameters separately over a broad range are underway. Integrated effects experiments to study interactions between scarifier and conveyance components will follow. Components for testing in the integrated effects experiments will be designed on the basis of the separate effects experimental results. These prototypes will be extensively tested over a narrower range of operational parameters.

The experiments will be conducted in four phases with each phase investigating the dislodging and retrieval of increasingly complex simulants as follows: 1) homogeneous simulants with no surface contour, 2) homogeneous simulants with free surface contours and heterogeneous simulants that include veins of other waste types (for example, salt cake with inclusions of sludge or viscous fluid), 3) simulants that model in-tank debris (for example tapes and pipes), and edge effects (such as the proximity of a tank wall or large component), and 4) integrated system experiments to characterize performance during potential failure modes (such as power outages or system plugging), to determine the ability of the system to recover from upset conditions.

4.1 Scarifier Separate Effects Experiments

The objective of the scarifier separate effects scaled experiments is to provide a scarifier design that will dislodge the waste forms into discrete particulate that can be mobilized and transported pneumatically. The evaluation criteria is to produce particulate in a size distribution that allows continuous transport of salt cake, sludge, and viscous liquids at solids loadings adequate to remove approximately 0.028 m^3/min (1 ft^3/min) or more of waste. The maximum particulate size is estimated to be <0.5 cm (0.2 in.) diameter but preferably <0.25 cm (0.1 in.) diameter. Key parameters that must be determined are the optimum jet (shape, pressure, number, configuration, and translation rate) for the multiple waste forms and an initial containment shroud configuration.

Scarifier separate effects experiments are divided into three types:

- Single jet experiments: to investigate jet parameters that affect the size of particulate.
- Multiple jet experiments: to investigate the effects of jet interaction.
- Shroud development: to investigate shroud configuration necessary to mobilize the dislodged material.

The three waste forms -- salt cake, sludge, and viscous liquid -- will be used to conduct each of these investigations. Results from the single jet tests will be evaluated to determine which configurations should be investigated during multiple jet tests. Results from the multiple jet tests will be evaluated to determine whether they meet the criteria of particle size necessary for pneumatic transport. This criteria will be developed during conveyance separate effects tests.

Mobilization in the shroud will be investigated to determine an initial shroud configuration and whether additional jets of air or water may be required to assist in mobilization of the dislodged material. Shroud optimization is expected to be accomplished via experimental investigations with qualitative results. It is anticipated that shroud development will continue during the integrated effects experiments.

Based on the results of these scarifier separate effects experiments, a scarifier head will be developed for use in the integrated effects experiments.

4.2 Single Jet Test Matrix

The objective of the single jet tests is to determine what regime of jet operation will work best to dislodge and mobilize the salt cake and sludge waste forms. We expect that this global optimum will be a compromise among the individual optimal designs.

The single jet tests were constructed to evaluate six parameters affecting the design of a scarifier head, using a 1/4 replicate of a $2^6 = 64$ factorial experiment. A 1/4 replicate experiment ensures that the six main effects are free of any two-way interactions. Descriptions of the test parameters follow.

Simulant. Simulants represent "typical" waste that the scarifier will encounter. Homogeneous waste forms representing salt cake and sludge, each with uniform surface contour, were evaluated. The simulant was configured to have a flat surface. A potassium magnesium fertilizer simulates the salt cake waste form, and a kaolin clay simulates the sludge waste form.

Jet Shape. Two jet shapes, shown in Figure 1, a round jet and a fan jet, were investigated. Solids are usually cut with a round jet because a high force per unit area is required for most solids. However, waste types such as sludges and viscous liquids may benefit from a fan-shaped jet, which distributes the jet force over a larger area. Both shapes were evaluated to determine which is more effective in mobilizing the simulants.

Jet Size. Jet size (orifice diameter) affects the depth of cut into the simulant, and the depth of cut is proportional to the simulant removal rate. Two diameters, 0.38 and 0.64 mm (0.015 and 0.025 in.), were evaluated. Depth of cut was measured to determine that the size of particulate dislodged is adequate for transport by the retrieval system.

Incidence Angle. A theory of hydraulic rock fracture shows that the incidence angle from the vertical can be optimized (Crow 1973). This theory applies to hard rock. A 0 degree incidence angle referenced from vertical would be expected to cut a deep slot into the simulant. Angles 60 degrees or greater would produce thinner sections of material that may fracture more readily than those cut at a 0 degree angle. Two incidence angles between 0 and 90 deg were evaluated to determine the effect of incidence angle on cutting the simulants into uniformly sized chunks.

Traverse Velocity. Hydraulic rock cutting theory predicts an intrinsic speed for rock cutting, based on the properties of the rock (Crow 1973). Salt cake simulants should reproduce this limiting case. Traverse velocities of 1.3 and 13 m/min (500 and 5000 in./min) were evaluated.

Pressure. Pressure affects the flow rate of the jet and its intensity. Two pressures, 40 and 50 kpsi, were be evaluated. The lower pressure jet is preferable because requires less water addition and a lower pressure intensifier system.

4.3 Multiple Jet Test Matrix

The single jet test results will be used to design the multiple jet scarifier configuration and test matrix. The single jet tests will determine the parameter values that produce the best dislodgement of the waste forms. Tests with multiple jets will determine whether the number of jets affects the rate of waste fracture and dislodging and particle diameter of the eroded waste.

5. EXPERIMENTAL RESULTS

The single jet test assembly consists of a computer-controlled traverse system coupled to a rotary test bed, as shown in Figure 2. Both the salt cake and sludge simulant experiments were conducted in this fixture. The simulants react differently to the round and fan jets.

In the salt cake experiments (Figure 3), the round jet cut a clean, narrow, kerf into the simulant, as shown in Figure 3; while the fan jet eroded a coarse, wide swath across the simulant. Erosion mechanisms are apparent with both jet shapes.

In the sludge experiments, the round jet "sliced through cleanly," not leaving much of a kerf below about 5 cm (2 in.) from the surface; while the fan jet seems to "push" or "dish" a wide trench through the sludge, as shown in Figure 4. In sludge, larger scale displacement in response to the localized jet pressure seems to be a more dominant mechanism than smaller scale "erosion."

The data is being evaluated to rank the effectiveness of each type of jet dislodging the waste form simulants.

6. CONCLUSIONS

Water jets provide a continuous method to fracture and dislodge radioactive wastes stored in underground storage tanks. Research and development is ongoing to develop scarifiers for this purpose and results to date show that the technology can be successfully developed.

7. ACKNOWLEDGMENTS

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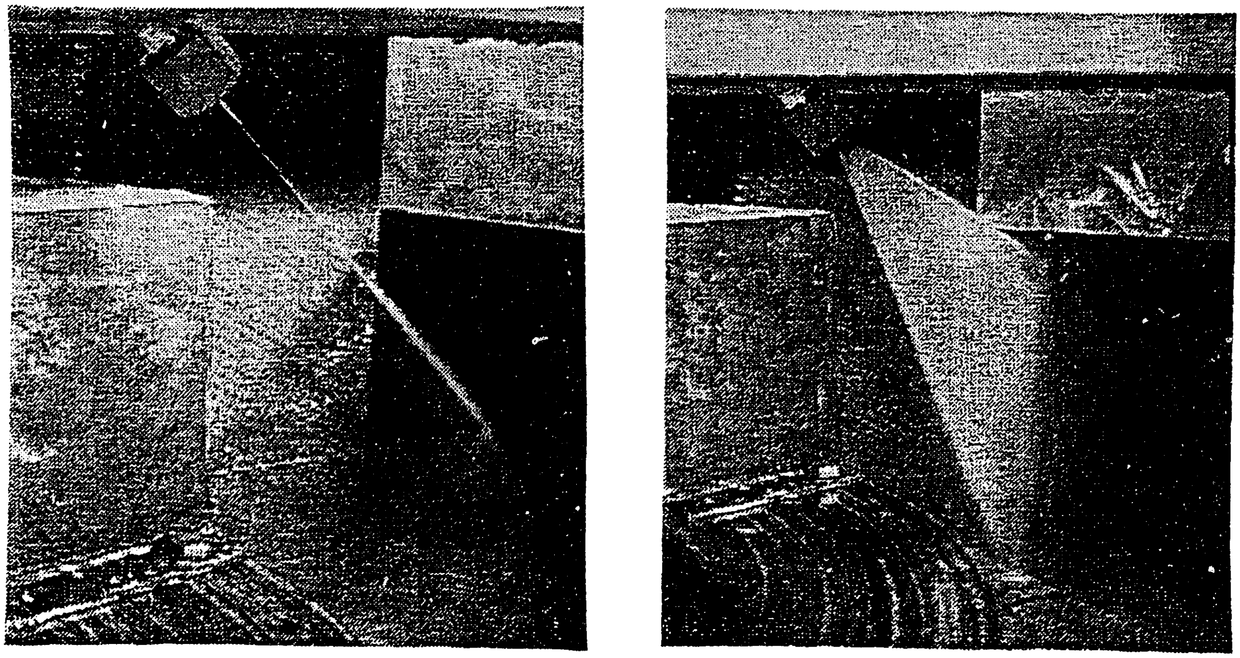

Figure 1. Round and Fan Jet Profiles

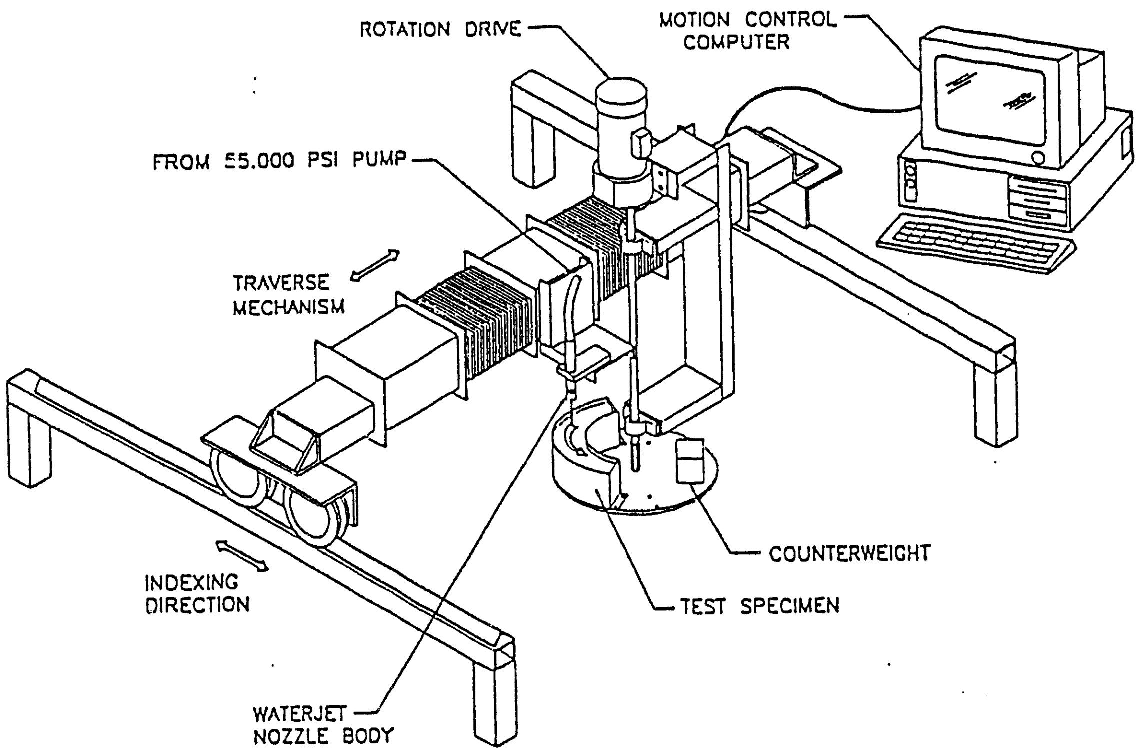

Figure 2. Scarifier Separate Effects Experiment Test Fixture

Figure 3. Examples of Round and Fan Jet Cuts through Salt Cake Simulant

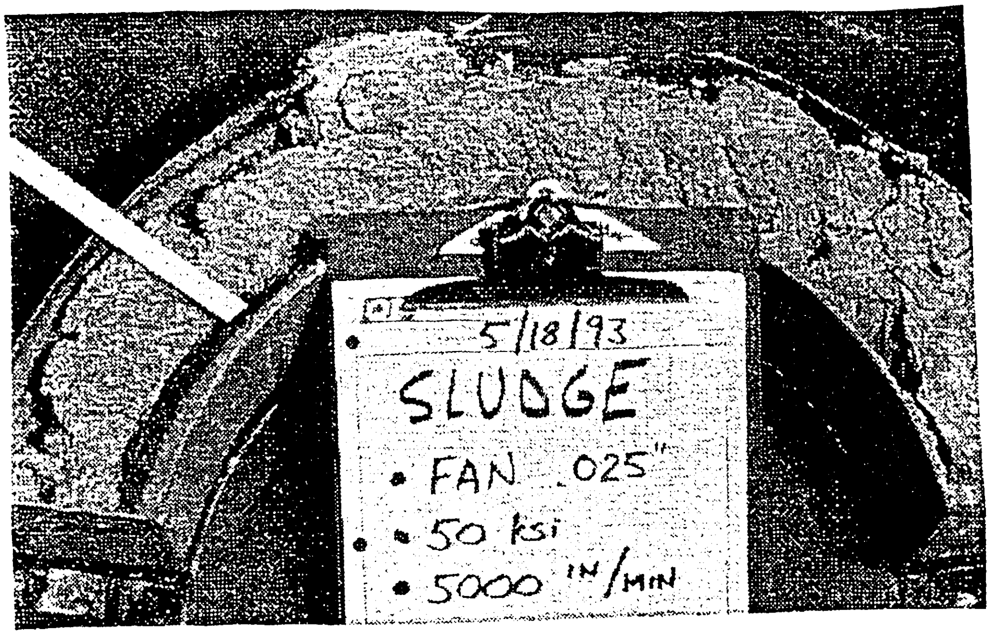

Figure 4. Example of Fan Jet Cut through Sludge Simulant

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