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RETRIEVAL TECHNOLOGY DEVELOPMENT FOR HANFORD DOUBLE-SHELL TANKS

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ABSTRACT

This paper describes the combined analytical, computational, and experimental program developed for identifying operating strategies for mobilization and retrieval of radioactive waste stored in double-shell tanks at Hanford. Sludge mobilization, slurry uniformity, and slurry retrieval investigations will produce guidelines for mixer pump and retrieval pump operation based on the physical properties of the waste and the geometric properties of the system (number of operating pumps and pump design and placement).

INTRODUCTION

Million-gallon double-shell tanks (DSTs) at Hanford are used to store transuranic, high-level, and radioactive wastes. The tanks generally contain a large volume of salt-laden solution over a smaller volume of settled sludge consisting primarily of metal hydroxides. These wastes will be retrieved and processed into immobile waste forms suitable for permanent disposal.[1] High-level waste and transuranic waste will be disposed of as vitrified glass in geologic repositories; low-level waste will be disposed of as grout in near-surface vaults. Retrieval, as indicated in Figure 1, is the initial step in the remediation of each tank.

In certain situations, the operation of downstream waste treatment processes can be simplified and made more efficient by ensuring that the slurry feed streams pumped from the tanks are nearly uniform in concentration. The current retrieval strategy utilizes mixing pumps to mobilize settled sludge to produce a uniform suspension throughout the tank and retrieval pumps to transfer slurry out of the DST, as shown in Figure 2. For certain frequently expected situations decanting is necessary, i.e. "sludge wash". However, in-tank sludge washing also requires mixing.

The mixer pumps produce high-volume, horizontally-directed jets that impact and mobilize the sludge and mix it into a slurry. The mixing pumps will also be used to maintain the solids in a nearly uniform suspension during slurry removal. Mobilization and suspension are controlled by different physical mechanisms.

OBJECTIVES

Retrieval technology applicable to the various double-shell tank wastes is being defined, developed, and demonstrated at Pacific Northwest Laboratory in conjunction with Westinghouse Hanford Company. The objectives of the investigations are to

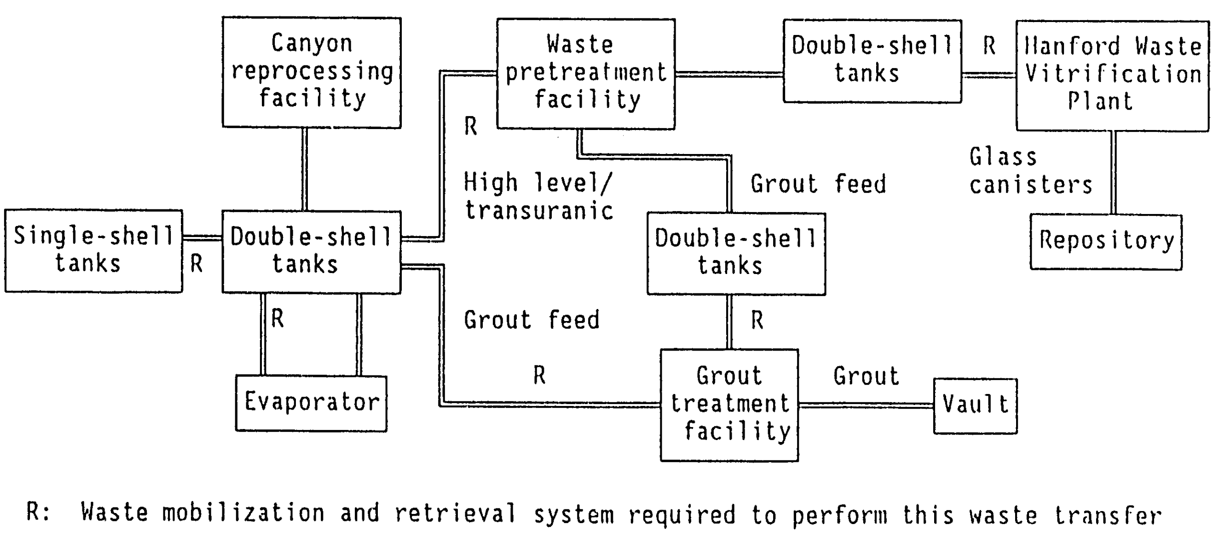

Figure 1. Double-Shell Tank Waste Treatment, Storage, and Disposal Paths

- estimate erosion/corrosion rate of the tank floor and wall caused by the operation of fluid jets [2]
- provide experimentally verified sludge mobilization models
- determine the distribution of suspended solids in the tank as a function of mixer pump configuration, operating parameters, and waste properties
- develop physics-based computational models to predict slurry uniformity and sludge mobilization[3]
- determine the static and dynamic forces upon tank components impacted by the mixer pump jets.[4,5]

Complementary investigations are planned to

- predict pressure drop for transport of non-Newtonian waste slurries in pipelines and determine pump requirements to suspend solids that may settle if pumping is halted during a transfer
- determine the effect that sludge washing will have on the ability to mobilize sludge and maintain slurry uniformity
- determine the extent of aerosol generation and radioisotope vaporization during mobilization and mixing
- design sensors to track the extent of mobilization and uniformity of resulting slurry in real time for use in scaled experiments and in waste tanks.

The sludge mobilization, slurry uniformity, and slurry retrieval investigations will produce guidelines for mixer pump and retrieval pump operation based on the physical properties of the waste, the geometric properties of the system (number of operating pumps and pump design and placement) and dynamic response based on pump flow rate and pump oscillation rate. These objectives will be accomplished through a coordinated analytical, experimental, and computational approach to understanding the physical phenomena. Results from this combined approach provide two methods to produce operating guidelines for mixer and retrieval pumps in waste tanks: via correlations developed from the experimental data and via direct numerical simulation of the proposed operating scenario using a validated and verified computer code.

BACKGROUND

The physical processes governing slurry mobilization and mixing in tanks are complex and do not lend themselves readily to exact analytical treatment. As a result, accurate predictions of prototype behavior require some degree of experimentation. Dimensional analysis is an important analytical tool that can be used to reduce the number of experiments required and also to provide a basis for the interpretation of the experimental results.

Analyses of sludge mobilization and slurry uniformity processes in tanks have shown that different dimensionless force ratios dominate the processes. These analyses have been used to design scaled experiments to determine the mixer pump performance that will be required to achieve mobilization and uniformity.

Modeling Sludge Mobilization

Mobilization of a sludge by a mixer pump jet is thought to be caused by either the impact of the jet or the shearing force of the jet at the sludge surface. The erosion of cohesive soils, similar to sludge in composition, can be modeled by using an erosion equation of the form

$$E = M(\tau_w/\tau_c - 1)$$

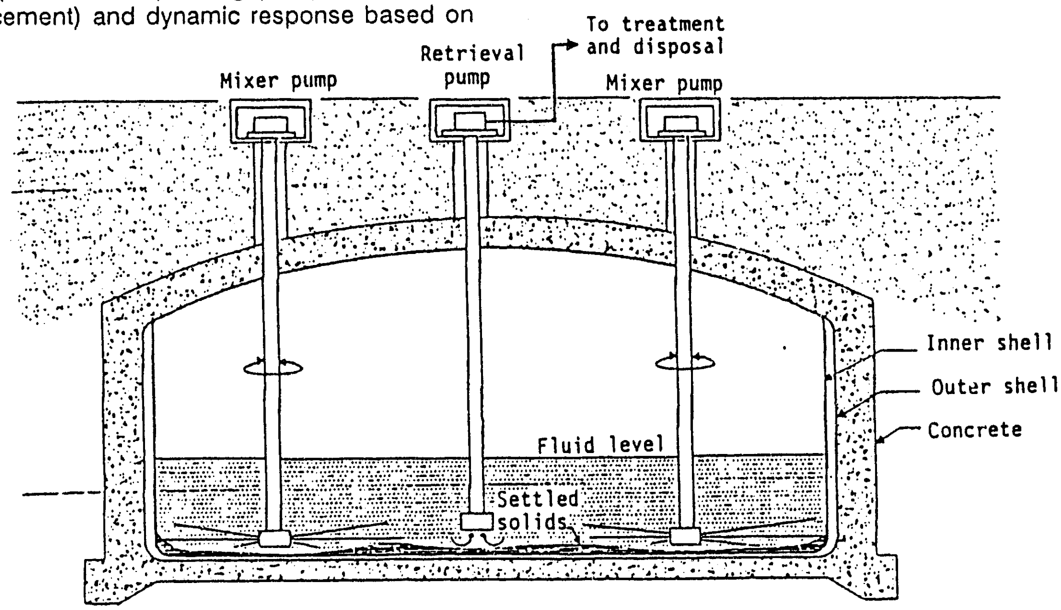

Figure 2. Double-shell tank waste retrieval equipment.

where E is the erosion rate; M is a soil dependent parameter defining soil erodibility; τ_w is the shear stress imposed on soil surface by flow of eroding fluid; and τ_c is the critical shear stress of soil. There are thought to be three regions of soil erosion.[6] When the imposed shear stress to too low to overcome the interparticle attractions of the soil ($\tau_w < \tau_c$) no erosion occurs (region I). Once the imposed shear stress overcomes the interparticle attractions ($\tau_w > \tau_c$) then erosion is characterized by removal of individual particles or flocs and the rate of removal increases linearly with τ_w (region II). When the imposed shear is high enough centimeter sized pieces or chunks are removed (region III). Region III removal occurs until the shear stress falls below some critical value and region II type erosion resumes.

Sludge mobilization may be modeled by matching Reynolds number in the scaled experiment (model) and in the waste tank (prototype). However, simulants with the physical properties required to match Reynolds number are not available; therefore, experiments are designed by matching fluid and sludge properties in the waste tank and employing mathematical relationships to extend test results to full-scale.

Modeling Slurry Uniformity

The goal of the uniformity experimental design is to produce scaled experiments in which the concentration profiles in scaled experiment (model) are similar to those in the waste tank (prototype)

$$[\underline{C}(x/D_0)/C]_{model} = [\underline{C}(x/D_0)/C]_{prototype}$$

where $\underline{C}$ is the local average concentration in the tank; C is the slurry mean weight percent solids concentration; and x/D_0 is the distance from the nozzle (x) divided by nozzle diameter (D_0).

Similarity is achieved in slurry mixing when three force ratios that describe conditions in the waste tank (prototype) and scaled experimental vessel (model) are equal: Reynolds number of the jet emanating from the mixer pump, Froude number, and gravitational settling parameter.

Fox and Gex[7] suggest that the jet Reynolds number (Re) affects mixing in tanks containing single-phase mixtures, and it is likely that this quantity also affects solids suspension. In a general flow, the Reynolds number affects the stability of the flow and its turbulence structure.

$$Re = (\rho_b U_0 D_0)/\mu$$

where ρ_b is the fluid bulk density, U_0 is the nozzle exit velocity; and μ is the fluid viscosity. It is possible that the degree of mixing achieved may become independent of jet Reynolds number in the fully turbulent range.

Fosset and Prosser[8] suggest that tank contents undergoing forced mixing will stratify at low values of a modified densimetric Froude number. This definition of Froude number cannot be directly applied to this analysis because the density difference between fluid leaving the jet and the slurry in the tank is a dependent variable with respect to slurry mixing. The Froude number (Fr) used in these analyses is based on independent variables.

$$Fr = U_0^2/(g\,H)$$

where g is the acceleration due to gravity; and H is the fluid height.

The gravitational settling parameter (Gs) describes a limiting phenomenon balancing the rate at which the jet lifts particles into the upper regions of the tank to the pull of gravity.

$$Gs = [2\,D_t^2\,H\,(\rho_s - \rho_l)\,\phi_s\,U_s\,g]/(\rho_b\,U_0^3\,D_0^2)$$

where D_t is the tank diameter; ρ_s is the solids density; ρ_l is the supernatant density; ϕ_s is the volume fraction; and U_s is the particle settling velocity.

The theory of similarity ensures that the difference in concentration between the fluid at the bottom and the fluid at the top of the vessel in both the prototype and the scaled model will obey some functional relation of the form

$$\Delta C/C = f(C, s, D_0/H, D_t/H, E/H, Fr, Re, Gs, \eta_{rh})$$

where physical properties of the waste are defined by slurry concentration (C) and ratio of solids to bulk density (s); geometric scaling is addressed in jet nozzle diameter (D_0), distance from floor to nozzle centerline (E), tank diameter (D_t), and fluid height (H); Froude number (Fr) and jet rotation number (η_{rh}) equivalence provide kinematic similarity; and matching Reynolds number (Re) and gravitational settling parameter (Gs) provide dynamic similarity.

UNIFORMITY RESEARCH

A phased experimental and computational analysis is underway to investigate mixing phenomena of slurries in waste tanks. A flow chart outlining the strategy of the slurry uniformity investigation is presented in Figure 3.

The computational and experimental parts of the strategy are complementary: initially computational experiments are conducted to guide experimental design. After completion of the experiments, the data is used to validate and verify the computer model. As a result of this approach two complementary methods for predicting mixing pump performance in waste tanks are produced: correlations based on experimental data and a verified and validated computer code to use to predict mixing pump performance for configurations not explicitly tested.

Computational Modeling

An advanced version of the TEMPEST (Time-dependent Energy, Momentum, Pressure Equation Solution in Three dimensions) computer program has been developed to investigate tank mixing.[9] This computer code solves a time-dependent, three-dimensional set of transport equations. The code is well

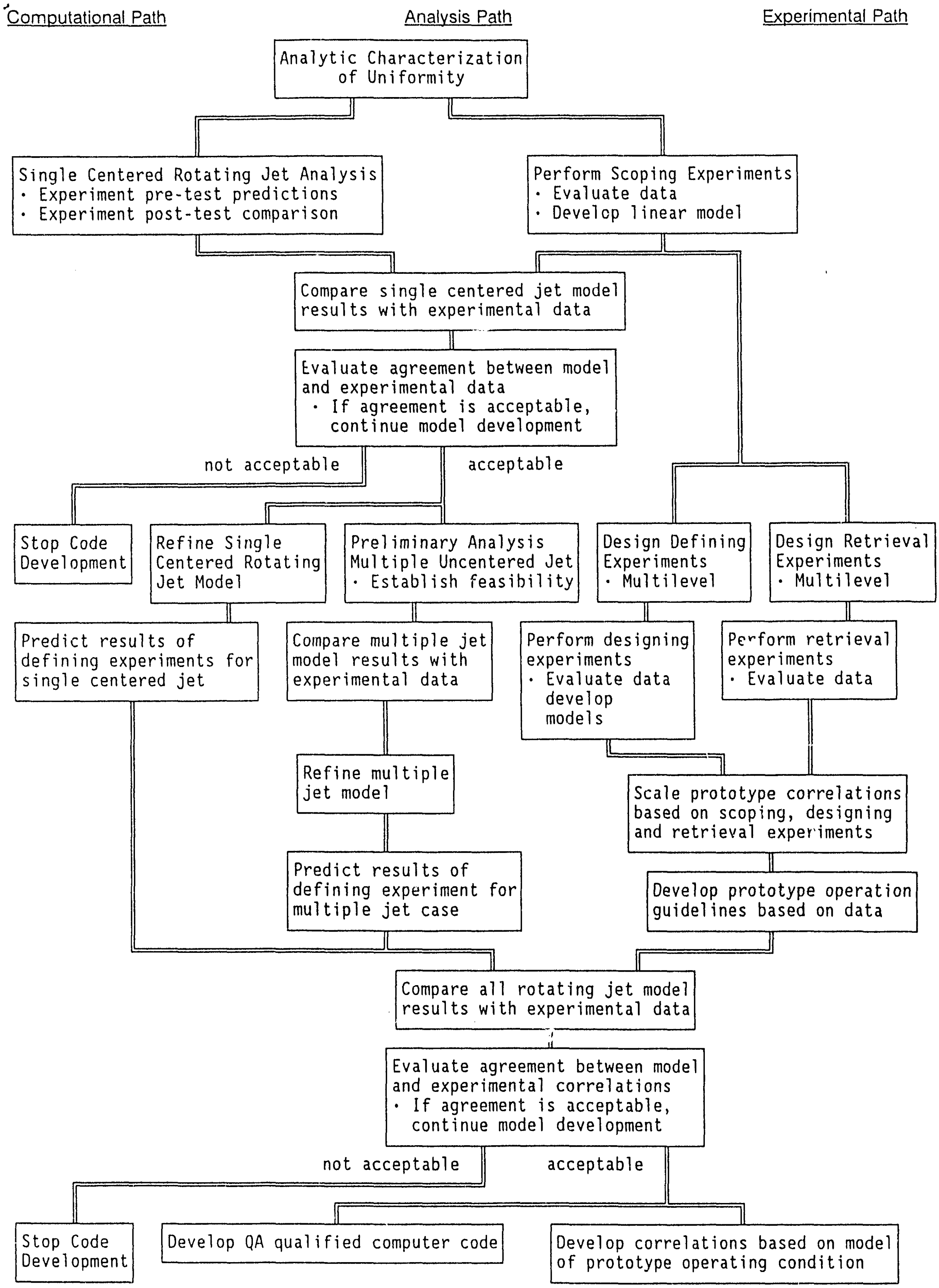

Figure 3. Tank uniformity investigation flow chart.

suited to model waste tank mixing and mobilization. A series of problems are used to confirm the calculational features and physical models in the code. Confirmation of analysis in the application geometry of the waste tank with a jet mixing pump is to be done by comparison to actual experimental data from scaled experiments of tank mixing.

Simulations have been completed describing two cases proposed for scaled tank testing based on dimensionless analysis scaling laws. One set of conditions demonstrates significant density coupling of settling particulate material with the velocity field. The other set of conditions demonstrates minimal density coupling with the velocity field. These simulations provide experiment designers with insights into the expected results and aid design of experimental measurement systems.

Initial computational "experiments" have been conducted to predict uniformity for a centrally-located, rotationally-oscillating, horizontally-directed jet mixing pump using a half-tank model. In this calculation, the objective was to predict the region where concentration remains within ±10% of the mean value. After several pump rotations, the concentration distribution shown in Figure 4 was obtained. The dark area at the floor indicates both the position of the jet and a region where material has been swept away. Constant mass fraction surfaces are presented for the average mass fraction (central surface), the average mass fraction plus ten percent (lower surface), and the average mass fraction minus ten percent (upper surface).

Physical experiments are planned to provide data that can be used to validate these computational predictions.

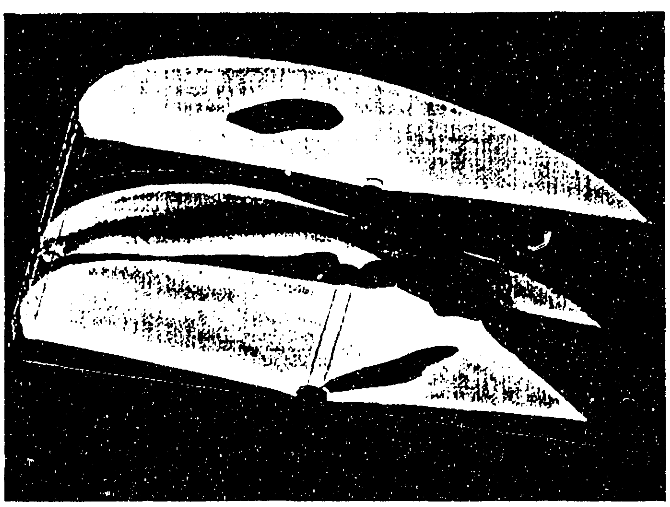

Figure 4. Visualization rendered surfaces at the average mass fraction and at plus/minus ten percent mass fraction.

Experimental Methods

To develop correlations and computational models to predict uniformity in waste tanks, experiments at two scales are underway. Facilities at Pacific Northwest Laboratory include 1/12- and 1/4-scale models of the internal dimensions of 22.9-m-diameter, 3785 m^3 (75-ft-diameter, million gallon) waste tanks. The large tank diameters are required to adequately match dimensionless ratios because the lowest available simulant viscosity range is limited to near 1 cP, that of water based fluids. The experimental results will be used to predict the degree of uniformity which will be achieved in the tank 241-AZ-101 and determine whether contents of that tank will be uniform to within ±10% of the mean concentration.

The scoping study will experimentally evaluate uniformity at the eight corners of the Reynolds number, Froude number, gravitational settling parameter space shown in Figure 5 in a 1/12-scale experiment. The test conditions will be achieved by varying the simulant viscosity, the mean particle size, and the jet nozzle exit velocity.

Concentration measurements at sampling locations throughout the tank will be used to assess the degree of uniformity achieved during each test. An ultrasonic measurement system that provides real time measurement of attenuation in the test fluid will be used to monitor concentration as a function of elevation and radial location within the test vessel. The undissolved solids concentration at these locations will be analyzed to determine whether the tank contents are uniform ($\leq \pm 10\%$ variation about mean) or nonuniform ($> \pm 10\%$ variation about mean) in concentration. Concentration inhomogeneity observed in the 1/12-scale experiments will be modeled as a linear function of the dimensionless groups. Experimental conditions planned for the 1/4-scale experiments will permit evaluation of non-linear effects.

The measured degree of inhomogeneity during the tests will be used in the numerical analysis task for comparison with computational predictions. In addition, measurements will be taken to quantify the jet velocity along the tank wall to support computational modeling.

The experiments are conducted using simulants with physical properties appropriate to match dimensionless force ratios at experimental scales. Viscosities of 2 and 3.4 cP have been chosen to match Reynolds number; particle diameters of 5 and 20 μm have been chosen to match gravitational settling parameter; Froude number will be matched by varying jet nozzle exit velocity.

Quarter-scale experiments will be designed after the results of the 1/12-scale experiments have been analyzed.

CONCLUSIONS

The experimental correlations and computational models developed using this research strategy will support waste remediation and retrieval efforts underway at Hanford. In addition, the tools can be used to predict performance of other non-Newtonian fluid flow problems and waste remediation efforts at other sites. It is anticipated that the transport correlations developed during investigations of non-Newtonian slurry transport will also support remediation of single-shell tanks.

ACKNOWLEDGMENTS

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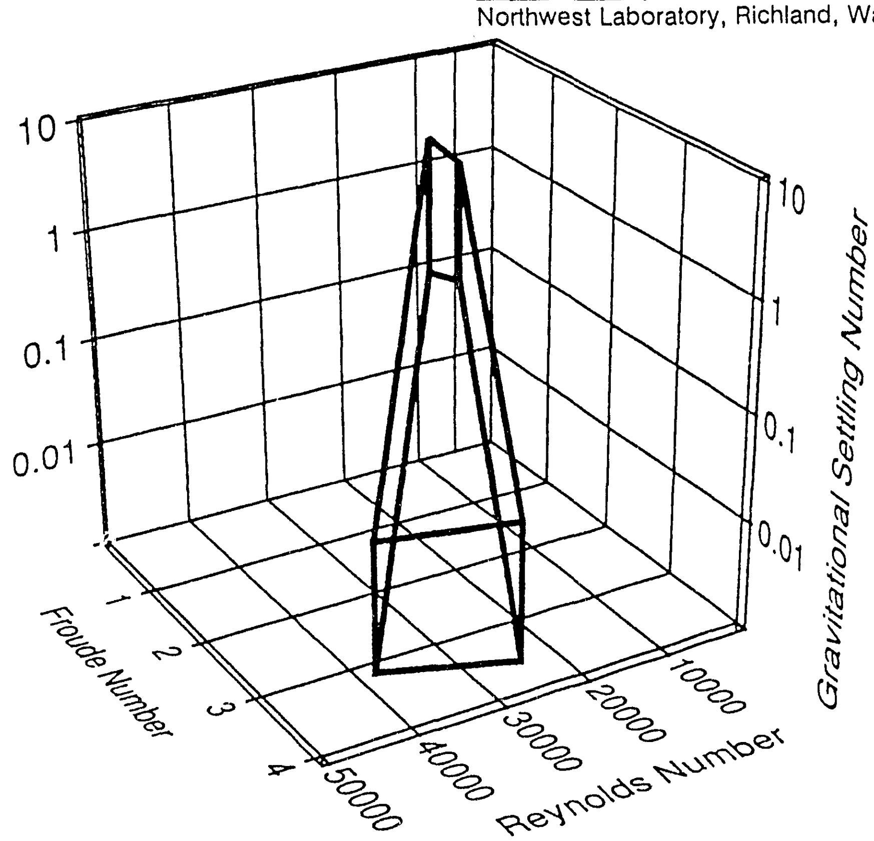

Figure 5. Conceptual illustration of the scoping study experimental region.

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