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Mixing Processes in High-Level Waste Tanks

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RESEARCH OBJECTIVE

Mixing and transport in large waste-tank volumes is controlled by the multidimensional equations describing mass, momentum and energy conservation, and by boundary conditions imposed at walls, structures, and fluid inlets and outlets. For large enclosures, careful scaling arguments show that mixing is generated by free buoyant jets arising from the injection of fluid or buoyancy into the enclosure, and by temperature and/or concentration gradients generated near surfaces by heat and mass transfer at walls, cooling tubes, and liquid-vapor interfaces. For large enclosures like waste-tank air spaces, scaling shows that these free and wall jets are generally turbulent and are generally relatively thin.

When one attempts to numerically solve the multi-dimensional mass, momentum, and energy equations with CFD codes, very fine grid resolution is required to resolve these thin jet structures, yet such fine grid resolution is difficult or impossible to provide due to computational expense. However, we have shown that the ambient fluid between jets tends to organize into either a homogeneously mixed condition or a vertically stratified condition that can be described by a one-dimensional temperature and concentration distribution. Furthermore, we can predict the transition between the well-mixed and stratified conditions. This allows us to describe mixing processes in large, complex enclosures using one-dimensional differential equations, with transport in free and wall jets modeled using standard integral techniques. With this goal in mind, we are constructing a simple, computationally efficient numerical tool which can be used predicting the transient evolution of fuel and oxygen concentrations in DOE high-level waste tanks following loss of ventilation, and validate the model against a series of experiments.

RESEARCH PROGRESS AND IMPLICATIONS

This report outlines research progress made since September, 1998, in our studies of mixing processes in high-level waste tanks, and requests permission for a one-year no-cost extension to complete the remaining tasks outlined in our original grant proposal, as a part of completing the dissertation of the primary doctoral student working on this research project.

Over the last year we have made substantial progress in our research efforts, both in experiments and numerical model development. In coordinating our spending rates and task completion, we recognized the importance of having our primary doctoral student working on the project, Jakob Christensen, complete his dissertation on the topic. Our request for a one-year no-cost extension will allow to complete the writing of the dissertation, which will insure broader dissemination of the experimental and analytical results. A second doctoral student, funded by General Electric, is working concurrently studying mixing processes in large, stratified volumes, along with a postdoctoral researcher who has focused on the experimental program. Additionally, one Masters student has completed his research project supporting the study.

Our studies focus on the mixing processes that control the distribution of fuel and oxygen in the air space of DOE high-level waste tanks, and the potential to create flammable concentrations at isolated locations, achieving all of the milestones outlined in our proposal. A major motivation for the research has come from efforts at Savannah River to use a large tank process (Tank 48) for cesium precipitation from salt solutions, which release benzene. Under normal operating conditions the potential for deflagration or detonation from these gases would be precluded by purging and ventilation systems, which remove the flammable gases and maintain a well-mixed condition in the tanks. Upon failure of the ventilation system, due to seismic or other events, however, it has proven more difficult to make strong arguments for well-mixed conditions, due to the potential for density-induced stratification which can potentially sequester fuel or oxidizer at concentrations significantly higher than average. As evidence of the importance of the issue, last year a decision was made to move away from the in-tank precipitation process. While this reduces the direct relevance of the research to SRP tank operations, important applications remain for modeling of radiolytic hydrogen mixing in large tanks, modeling of enclosure fires, and modeling of reactor containment response.

Our mixing experiments have two primary components: a series of experiments conducted in plexiglas tanks studying scaled mixing processes in water and water/salt or water/sugar systems, and a larger experiment in a scaled SRP-tank-geometry cylindrical enclosure using heated air to study mixing under stratified conditions, driven by combined natural and forced convection heat transfer. Substantial progress was made in conducting the water experiments during the past year, and completion of the large tank experiment was also achieved.

The water experiments completed this year have addressed two issues of importance to waste tank operations, as well as more generic problems in enclosure fires. The first involved the study of exchange flows through perforated horizontal partitions. Such exchange flows, driven by buoyancy and fluctuating external pressure, are the primary mechanism bringing ambient air into waste tanks through the many openings in the tank cover, following loss of ventilation. Our experiments, described in the the appendix of last year's report and in reference [1], provided fundamental information for modeling exchange flow rates into the tank vapor space.

These experiments also allowed us to simulate the evolution of the vertical density and composition distribution in a stratified volume. The primary question here is how a dense, buoyant plume of air would mix upon entering a tank from the ceiling, and how much dilution would occur before the plume reached the tank liquid, where fuel concentrations would be the highest. The water system provided a useful analog for this process. In addition to employing standard techniques to measure the velocity of the jets entering the bottom volume of the experiment (hot film anemometry) and to visualize the buoyant jets (ink), we developed a new experimental method to measure the vertical density distribution directly, using the deflection of a sheet laser to measure the vertical distribution of the index of refraction, as described in greater detail in the appendix.

Construction of the air experiment is complete, and data will be collected over this summer. As described in the proposal, this experiment will allow the study of mix processes under scaled conditions more closely matching waste tank conditions.

PLANNED ACTIVITIES

During the upcoming year we will complete experimental data quisition for mixed convection heat transfer in a cylindrical enclosure with an injected purge jet. This work will be augmented by benchmarking studies with the detailed numerical model now under development. Upon completion, modeling results and insights will be transferred to support waste-tank safety basis calculations. In addition, the significantly more general treatment of the new model, compared to zone models, will provide improved analysis for building fire and reactor containment applications.

INFORMATION ACCESS

Additional information about this research project can be found at:
http://www.nuc.berkeley.edu/thyd/peterson/tank.html

References:

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