Environmental Management Science Program

Project ID Number 54656

Mixing Processes in High-Level Waste Tanks

Per F. Peterson
University of California at Berkeley
4111 Etcheverry Hall
Berkeley, California 94720
Phone: 510-643-7749
E-mail: peterson@nuc.berkeley.edu

June 1, 1998

54656

Mixing Processes in High-Level Waste Tanks

Per F. Peterson, University of California at Berkeley

Research Objective

Flammable gases can be generated in DOE high-level waste tanks, including radiolytic hydrogen, and during cesium precipitation from salt solutions, benzene. Under normal operating conditions the potential for deflagration or detonation from these gases is 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. This has complicated the task of defining the safety basis for tank operation.

Waste-tank mixing processes have considerable overlap with similar large-enclosure mixing processes that occur in enclosure fires and nuclear reactor containments. Significant differences also exist, so that modeling techniques that have been developed previously can not be directly applied to waste tanks. In particular, mixing of air introduced through tank roof penetrations by buoyancy and pressure driven exchange flows, mixed convection induced by an injected high-velocity purge jet interacting with buoyancy driven flow, and onset and breakdown of stable stratification under the influence of an injected jet have not been adequately studied but are important in assessing the potential for accumulation of high-concentration pockets of fuel and oxygen. Treating these phenomena requires a combination of experiments and the development of new, more general computational models than those that have been developed for enclosure fires.

Research Progress and Implications

U.C. Berkeley is now completing the second year of its three-year project that started in September, 1996. We made excellent progress in several important areas related to waste-tank ventilation and mixing processes.

Ceiling Air Ingress: In the first area, we completed a series of experiments using salt-water solutions to simulate buoyancy-driven flows through openings in horizontal partitions. This provides one of the major mechanisms for the entry of air through ceiling ports into inerted waste tanks following loss of ventilation, due to the density difference of the warm gas inside the tank and the cooler gas outside. We developed a laser-based diagnostic technique for measuring the transient evolution of the vertical density distribution in the experiment [1], providing data to bench mark the numerical mixing models now under development. The most interesting result of the experiments was the discovery that previous experiments by other investigators had incorrectly measured transient density evolution, requiring an empirical correction to the simplest fundamental models for the exchange flow rates [2]. With the new diagnostic method developed under this research effort, we were able to show that the transient flow rates closely follow the simple model, lending confidence to calculations that have been performed to predict the rate of air ingress into inerted waste tanks following loss of ventilation.

Mixed Convection from High-Velocity Purge Jets: Mass transfer from the liquid surface in high-level waste tanks, which controls the distribution of flammable gases, is driven by a combination of natural convection from the warm liquid to the cooler gas space, and potentially by forced convection if a high-velocity gas jet is injected, as is done for inerted tanks. We recently made new observations, based on limited data on jet-induced heat transfer available in the chemical engineering literature, that indicates that relatively simple correlations should be possible to predict the combined effects of forced and natural convection in waste tanks [3]. We are currently finishing assembly of a scaled waste-tank system to study this mixed convection problem for heat and mass transfer from a horizontal, upward facing heated surface in a cylindrical enclosure, with scaled purge jet injection.

Modeling for Transient Density Evolution: 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. The tool has been benchmarked against analytical solutions for idealized mixing conditions, showing that the numerical truncation errors are quite small, and will be benchmarked against experimental data over the next year.

1. C.J. Lee, S.Z. Kuhn, and P.F. Peterson, "Measurement of the Transient Evolution of Density in Stratified Liquid Enclosure Experiments," in preparation for submission to Experimental Heat Transfer.
2. S.Z. Kuhn, J. Christensen, C.J. Lee, and P.F. Peterson, "Enclosure Mixing Induced by Buoyancy-Driven Exchange Flows in Horizontal Partitions," in preparation for submission to Journal of Heat Transfer.
3. P.F. Peterson and R.E. Gamble, "Scaling for Forced-Convection Augmentation of Heat and Mass Transfer in Large Enclosures by Injected Jets," submitted to the ANS Summer Meeting, Nashville, TN, June 7-11, 1998.

Planned Activities

During the upcoming year we will begin accumulating experimental data 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.