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Flow Visualization of Forced and Natural Convection in Internal Cavities

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Research Objective

The objective of this research program is to understand the fluid physics when corroded spent nuclear fuel (SNF) elements are passivated by injecting treatment gases into a storage canister. By developing a reliable predictive technique for the energy, mass, and momentum transfer in the presence of surface reactions, transfer and storage systems can be efficiently and safely designed. The objective will be reached by using innovative flow visualization techniques and experimental measurements of the flow field to support computational models.

Research Progress and Implications

This report summarizes work completed after eight months of a three-year, collaborative project. A generic idealization of a combined drying and passivation approach has been defined, which represents a section of a vertical canister with baskets of SNF elements. This simulation includes flow phenomena that occur in canisters for high- and/or low-enrichment fuels. A steady flow of the passivation fluid is introduced at the bottom of the canister via a central tube from the top. Fluid flows through an array of holes in the perforated basket support plate then around the simulated elements and out the top. Dimensions and flow rates for the idealized situation correspond to those for typical drying canisters. Approximate calculations have identified the ranges of values of flow parameters needed to determine the flow regimes occurring in practice.

For effective passivation, a design aim would be controlled, high mass transfer rates to the fuel elements. These rates will depend on the flow pattern and turbulence levels in the vicinity of the elements. The fundamental flow features of the generic model have been identified as follows: 1) fluctuating velocity components in low Reynolds number turbulent flow in a tube; 2) turbulent transport and laminarization of a semi-enclosed, submerged impinging jet; 3) low Reynolds number flow through an array of holes; and, 4) decay of turbulence in flow around an array of elements. Available basic knowledge for these four fundamental topics is meager to non-existent.

Preliminary flow visualization experiments using dye and neutrally buoyant particles have been performed with scaled-down versions of the idealized canister. Two geometries of basket support plates, one with a 50% open area and the other with a 4% open area, have been used. With 50% open area, the flow pattern is comparable to that of a semi-infinite impinging jet with formation of a large vortex and entrainment and recirculation through the holes near the center. Upflow is primarily through the outer holes. With 4% open area, a large recirculation region occurs above the perforated plate, and a small recirculation zone forms below the perforated plate. It appears that the flow is circumferentially periodic. This observation implies that numerical predictions and detailed measurements can concentrate on a sector of the idealized geometry rather than the full cross section. Design of a half-scale experiment, using the INEEL Matched-Index-of-Refraction (MIR) flow system, has been initiated to measure velocity and turbulence fields.

Materials for an Individual Particle Tracking (IPT) 1/2-scale model to be built at OSU have been received. The design is virtually finished and construction will proceed in the early part of the summer.

This model will be used as a proof-of-concept experiment, to provide a near realistic flow configuration to be examined with the IPT system. The computers, frame grabbers, cameras, and synchronization box have been checked, and we are moving on with the software development. The major thrust of the effort has been the development/porting of the imaging software from a DOS environment to Windows 95. This task is paramount to the integration/development of a new system. A list of key required features have been identified and about half of them have been successfully resolved. Once this task is complete, the bulk of the existing software for particle tracking can be easily ported. We expect a fully functional system under Windows 95 by late Summer/early Fall 1998.

The fully developed low Reynolds number pipe flow in the entrance tube has been modeled and numerical results have been obtained. Currently, the results are being reviewed and compared to existing experimental and/or numerical data to assess the numerical model. A comprehensive literature review has been completed in order to determine the proper form of the model for the low Reynolds number submerged jet impingement. Efforts are underway to select either previous experimental or numerical results to validate the numerical output. The validation will examine the ability of the turbulence models used within the code to predict correctly the impinging jet flow. Current efforts center on the review of the literature to find an appropriate benchmark. The flow through the perforated plate poses the greatest uncertainty for the modeling efforts. The uncertainty deals with the impact the array of holes will have on the turbulence levels on the inlet and outlet of the perforated plate. One must determine how important the upstream turbulence level is in determining the downstream turbulence levels. Without knowing this, it will be difficult to predict the mass transfer to the surface of the fuel elements, since turbulence levels impact mass transfer to the element surfaces.

Planned Activities

We will continue to develop methods to visualize flow in the presence of surface reactions. Some of the current techniques that we are investigating include chemical tracers, reacting dyes, fluorescent particles, and electrochemical surfaces. The initial experiment in the INEEL MIR flow system will concentrate on the fundamental problems of turbulent transport and laminarization in semi-confined flow of a low Reynolds number impinging jet using a new two-component Laser Doppler Velocimeter. These measurements should occur during the second year. By early Fall, the proof-of-concept experimental setup will be ready, and it is expected that the traversing Particle Tracking Velocimeter, aimed at developing the IPT, will be available during the third year. This capability will permit following individual particles (simulating motion of an oxidant) as well as determination of the three-dimensional flow field.

The perforated plate flow phenomena will be examined through the use of Direct Numerical Simulation (DNS) then the flow over the fuel elements will be analyzed. The approach to modeling the flow over the fuel elements will depend heavily on the DNS results. At present, a three-dimensional representative section of the model is being developed to examine the qualitative characteristics of the flow field. Once completed, these simulations will be compared to the experimental results.