Stabilizing Nuclear Waste

Fluid simulation solidifies its role in the radioactive waste treatment process.

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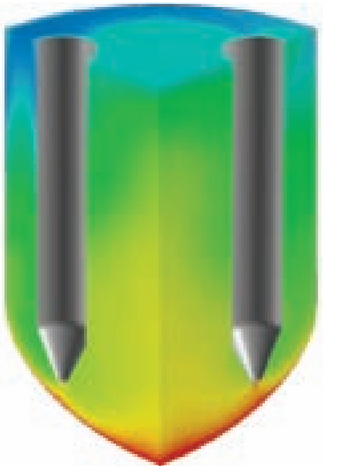


Contours of solid particle concentration: During the suction phase, the solids were found to become more concentrated along the bottom of the vessel, as shown by the red color in the early suction.

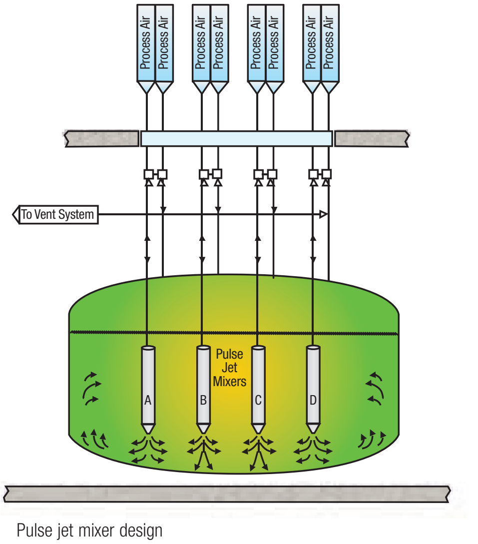
The nuclear site at Hanford, Washington, houses approximately 60 percent of America's radioactive waste. Near the Columbia River, the site stores waste in 177 underground tanks as a combination of liquid, sludge and slurry. A vast complex of treatment facilities is being constructed to convert this waste into a stable glass-like material using a technology known as vitrification, which involves mixing the waste processed in these vessels with hot glass formers such as rutile (TiO_2) or silica. The mixture is then poured into steel canisters and cooled to solidify for permanent storage. One of the major challenges in this process is keeping the solids in the waste in suspension during its time in the holding vessels before the separation and processing stages.

Avoiding contact of any mechanical components with the slurry being mixed during holding was crucial and led Bechtel National engineers working on the project to select fluidic pulse jet mixers (PJMs). The action of the PJMs is carefully controlled by compressing air inside them to drive the slurry into the vessel to create the mixing action. Only 80 percent of the slurry volume that is suctioned up into each PJM is expelled out of the mixers, which prevents air from escaping into the vessel. At that point, the compressed air is vented and a vacuum is applied to refill the mixers. PJMs thus provide mixing while keeping all mechanical components well away from radioactive materials.

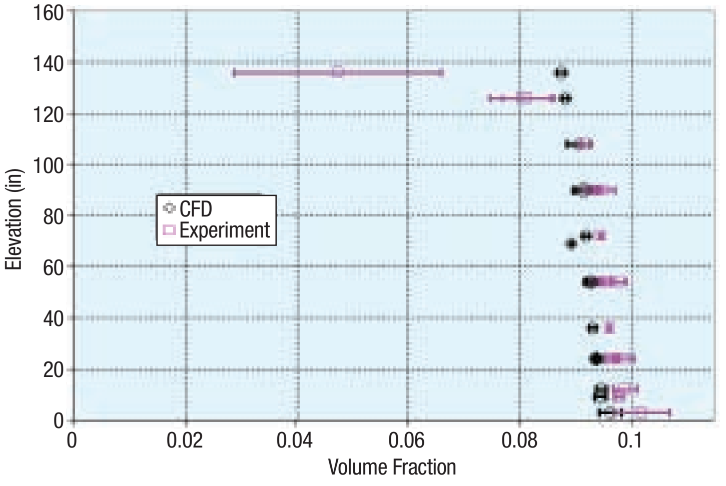
Because there had been little previous experience with PJMs in this mixing environment, it was critical that the engineering team be able to accurately predict the ability of the units to provide sufficient mixing for each of the different vessels in which the wastes will be treated. Within the waste treatment plant, each of the mixing vessels has substantially different geometries and processing requirements. In addition, there is considerable variation in the characteristics of the mixture of fluid and particles that will be processed in the different tanks due to separation and concentration of the radioactive components. The mixing performance of the PJMs is a function of the geometry of the vessel, number of PJMs per vessel, particle size, fluid characteristics, cycle time and other variables. It was important to validate the ability of the PJMs to keep the particles in suspension in each tank.

To simulate the pulse jet mixing process, Bechtel engineers used the ANSYS FLUENT fluid flow simulation package because of the software's unique capability depth in modeling multiphase mixing. The Eulerian granular multiphase model in ANSYS FLUENT software made it possible to predict the distribution of solids from the top to the bottom of the vessel. This model solves a separate set of Navier–Stokes equations for the fluid and solid phases. It accounts for the coupling between and within the phases using exchange coefficients, the most important of which is for the fluid–solid interaction. The results made it possible to determine whether the mixing criteria were met under given operating conditions.

Each vessel in the plant has a different mixing criterion; however, most simply require that the solids remain in suspension and are mixed well enough for accurate sampling and transfer to the next step of the vitrification process. Since pulse jet mixing is



Pulse jet mixer design



Comparison of fluid flow predictions and experimental results for solid particle volume fractions averaged over tank radius and mixing cycle for a 140-inch-high tank

a turbulent process, Bechtel engineers chose ANSYS FLUENT software's k-epsilon turbulence model based on the results of a preliminary study. In this study, computational fluid dynamics (CFD) specialists compared the results of various turbulence models to experimental data to determine which model was best at predicting the velocity in scaled hydrodynamics tests.

The engineering group controlled time-varying boundary conditions by a user-defined function that prescribed

Mid-suction

the time-dependent velocities of each jet and tracked the solids concentration flowing through the nozzles and at the top of the domain. This eliminated the need to track the free surfaces inside the PJMs and at the fluid–air interfaces inside the mixing vessels, greatly simplifying the models.

The Bechtel team could perform only very limited physical testing due to the high cost of building and testing the vessels and mixers. The company commissioned the construction of a full-scale PJM vessel to perform experimental testing at Battelle Pacific Northwest National Laboratory. Fluid flow predictions of concentration and velocity were then compared to the measured data. The results showed that the ANSYS FLUENT simulations slightly underpredicted the solid-phase volume fraction, except at the higher elevations in the tank. This difference was not significant compared to the cyclic variations in the concentration. At higher elevations, there were more significant differences between the experiment and simulation, with the simulation

End-suction

predicting more uniform mixing than the experiments demonstrated.

Even though the ANSYS FLUENT results demonstrate slightly better mixing than the physical experiments, the results were close enough to give Bechtel confidence in the ability of the fluid flow model to provide pass–fail judgments in rating the performances of the PJMs. Bechtel uses ANSYS FLUENT technology to model the many different vessel designs and to determine whether or not PJMs could provide adequate mixing for each configuration. The use of fluid dynamics in this application can potentially save a significant amount of time and money that otherwise would be spent on additional physical testing prior to beginning actual waste processing. ■

See also:

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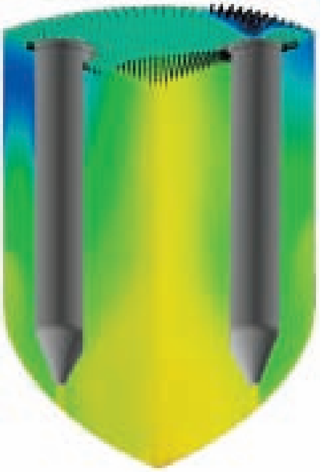

At the end of the drive phase, higher concentrations are predicted at the top boundary of the fluid domain while concentrations were reduced at the bottom as the solids were pushed away from the jet nozzle exits.