Stirring Up the

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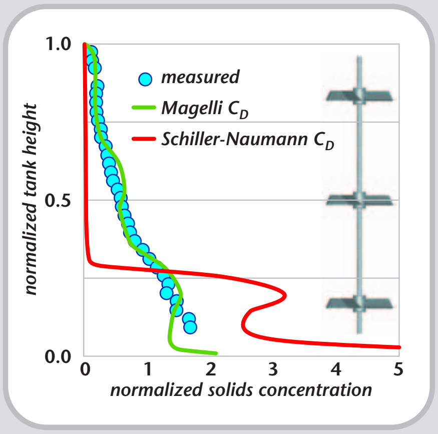
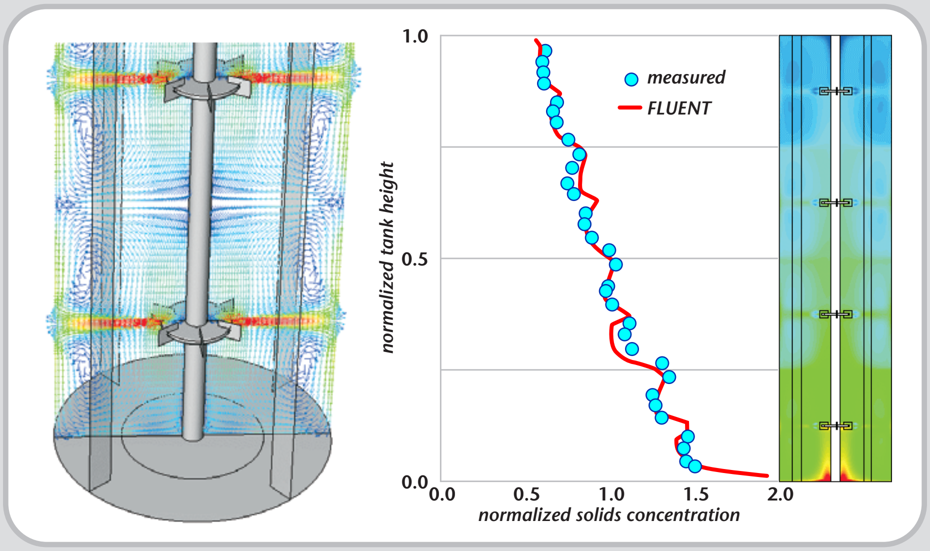


Solids concentration predicted by the Eulerian granular multiphase model in FLUENT using two drag laws, compared with experimental data



Flow field (left), solids volume fraction (right), and a comparison between the predicted solids volume fraction and experimental data (middle) for a tall baffled vessel equipped with four Rushton turbines.

Among the various industrial applications of stirred vessels, the agitation of solid-liquid systems is quite common. One important aspect of solid-liquid mixing is the distribution of solid particles inside the mixed volume, since it may affect the apparatus performance and process efficiency. Over the years, novel experimental techniques for measuring the spatial distribution of solids in solid-liquid systems have been developed by the Mixing Research Group in the Chemical Engineering Department of the University of Bologna. The experiments have been used to study a number of stirred vessels with a variety of geometrical configurations, physical scales, and solid-liquid mixtures. Recently, FLUENT has been used to predict the 3D solid distribution for a variety of mixing systems studied in the Bologna laboratory. The aim has been to determine a computational strategy that can be confidently applied to any stirred vessel and any solid-liquid system.

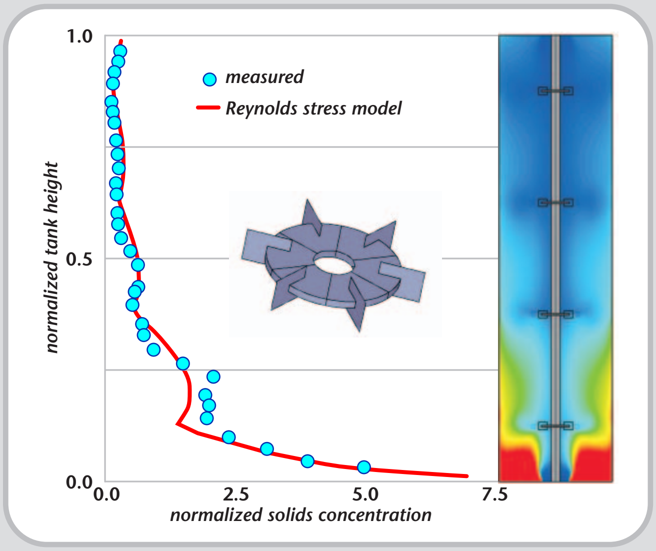
To date, most CFD simulations of solid-liquid systems in stirred tanks appearing in the literature are concerned mostly with baffled vessels and single, flat blade impellers. Since one of the goals of the present work was to demonstrate the reliability of the CFD procedure, test cases of considerable difficulty were selected; all of them consisted of multiple impeller systems in tall vessels, some made use of hydrofoil impellers, and some were carried out in swirl-dominated unbaffled vessels. Multiple impeller vessels are often adopted in industrial practice, but they are difficult to model because of the exchange flows between the circulation zones that surround each impeller. Moreover, in multiple impeller tanks, the axial profiles of solid concentration are often characterized by pronounced gradients and discontinuities. While these features are particularly helpful for pointing out any discrepancies between the simulations and experiments, they make the numerical work more challenging.

Several CFD analyses were performed for tanks of different scales, both with and without baffles, and agitated with different impellers: pitched blade turbines (PBT), standard Rushton turbines (RT), and Lightnin A310 hydrofoil impellers. In all cases, experimental solid concentration data were available for validation of the CFD results. The Eulerian-granular multiphase model was used for the mixture, and the multiple reference frames (MRF) model was used for the rotating impellers. Different turbulence models, all extensions of single phase turbulence models to multiphase systems, were tested to find out which would lead to the most satisfactory representation of the flow field and solid distribution for each case. The simplest, the "k-ε mixture model," was found to be accurate enough for the baffled tanks. For the unbaffled vessels, a multiphase version of the Reynolds stress model (RSM) [1] was adopted, since the k-ε model could not correctly capture the strong swirling flow. Including the turbulent dispersion force in the momentum equations was found to be critical for all cases studied.

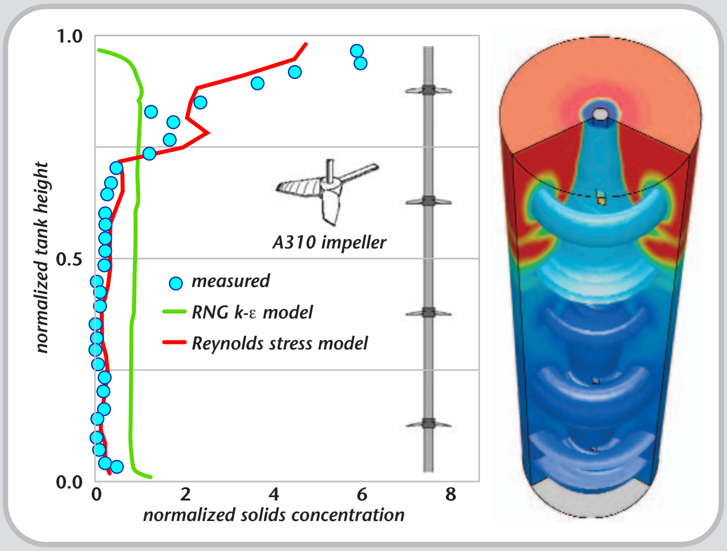
In multiphase systems, momentum transfer between the phases dictates the coupled flow field. It is based on the drag coefficient, C_D, and this parameter is critically important for successful predictions of the solid distribution. The basic drag correlation implemented in FLUENT (Schiller-Naumann) applies to particles falling in a still fluid, and this correlation [2] was tested in the simulations performed. It is well known, however, that drag coefficients measured for single particles settling in still fluids do not necessarily apply to particles settling in turbulent fluids. A modified drag law that takes into account the increase in drag due to liquid turbulence [3,4] was therefore tested as well.

A comparison of the drag coefficients was performed for a baffled vessel containing water and 675 micron glass particles, stirred with three down-pumping PBTs [5]. Axial profiles of the solid concentration were found to be in excellent agreement with the experimental data when the Magelli correlation is used, but

Phases in Tall Tanks



A comparison between experimental data and predictions using the dispersed Reynolds stress model (left) and the local volume fraction of solids (right) for an unbaffled stirred vessel equipped with four Rushton impellers



A comparison between experimental data and predictions using the RNG k-ε and dispersed Reynolds stress models (left) for an unbaffled stirred vessel equipped with four LIGHTNIN A310 impellers; the corresponding local volume fraction of solids predicted using RSM (right)

those predicted by the Schiller-Naumann correlation were not. The Schiller-Naumann correlation under-predicts the drag coefficient, causing the particles to settle more than they should. Indeed, the superiority of the Magelli correlation was found for all cases studied. For a baffled vessel stirred with four RTs, the simulation even picked up discontinuities in the distribution above each impeller.

While solids distribution simulations in baffled tanks are challenging, those in unbaffled tanks, characterized by strongly swirling flow, are even more so. One system studied makes use of four RTs, and experiments suggest that the mixing performance of this system is poor. As a result of segregated circulation patterns surrounding each impeller, most of the solids stay near the bottom of the tank. To simulate systems such as this, eddy-viscosity formulations such as the k-ε family of models tend to predict unphysical flow reversals. Meaningful flow field results can only be obtained using either RSM or the large eddy simulation (LES) model. For the unbaffled Rushton system considered, a "dispersed" Reynolds stress model, corrected for multiphase flow, was used, and a very good comparison with experimental measurements was achieved. The simulation correctly predicted an accumulation of solids below the bottom impeller, and a rapidly diminishing amount as the height increases.

A second unbaffled stirred tank validation involved the same vessel, but equipped with four LIGHTNIN A310 hydrofoil impellers, an operating condition not recommended by the impeller manufacturer, who recommends the use of baffles. Indeed, when operated with baffles, it was observed that the solids concentration profile is relatively uniform. When operated without baffles, however, a peculiar phenomenon was observed. The solids were found to slowly move upwards through the vessel and accumulate near the top [4]. Despite this unusual behavior, the dispersed RSM model was found to correctly capture the axial profiles, with the highest concentration of solid material near the top of the vessel. Additional simulations for this case were performed to test the (multiphase corrected) RNG k-ε model, and the results showed that it completely failed to capture the observed behavior. The success of the dispersed RSM model for both unbaffled systems with distinctly different operating characteristics provides a strong validation of this capability.

The results of these simulations demonstrate that FLUENT can be applied with confidence to predictions of the solid distribution in solid-liquid stirred vessels using the Eulerian granular multiphase model. Special attention must be paid to the particle drag coefficient correlation, however. Indeed, the drag coefficient, C_D, is a critical parameter for the correct prediction of solid distributions in general, and the Magelli drag correction is recommended for solid suspension in turbulent liquids. The Reynolds stress turbulence model for multiphase flow is also necessary for the case of unbaffled vessels, which are characterized by strong swirl. ■

references:

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