Stirring Up a Non-Newtonian Mix

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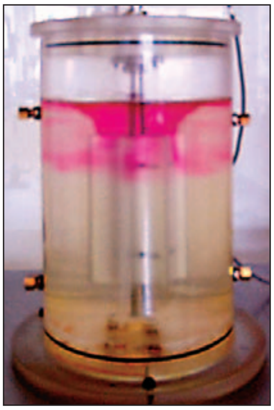
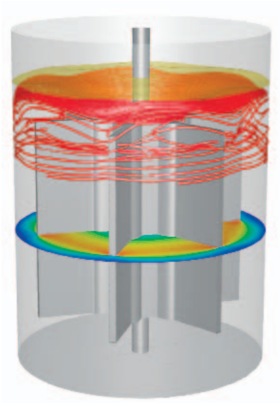




Experimental setup of the vessel with mixer (left) showing the free surface and vortex beneath it; numerical simulation also shows the free surface and vortex, as well as a plane where a relatively steady velocity field can be observed

HIGHLY VISCOUS NON-NEWTONIAN FLUIDS are common in many industrial operations, particularly in mixing processes. Such fluids often have complex rheological properties, which can increase operating costs and create other problems, like rapid torque changes during the mixing process.

The application of CFD for developing mixer geometry is widespread, but more complex CFD studies of problems that also include phenomena like non-Newtonian flow and the presence of a free surface are still rare. The object of this work was to evaluate the capability of numerical simulation to predict the localized features of non-Newtonian fluid mixing in a partially filled vessel. A tall, six-bladed radial impeller was used in a flat-bottom vessel for the mixing of carboxymethyl cellulose. Laser-Doppler anemometry (LDA) was used to measure the velocity field inside the fluid. To observe the characteristic vortex above the impeller, a tracer fluid was injected into the vessel. The final shape of the free surface was determined by a geometrical reconstruction of the images of the illuminated section [1, 2].

The experimental results were compared to numerical results obtained using FLUENT 6.2. Unsteady simulations of the mixing process were performed on a structured mesh of approximately 1,200,000 cells. A sliding mesh approach was used to capture the rotation of the impeller and a power law was used to describe the dependence of the fluid viscosity on shear rate. The flow was considered laminar in cases with very low rotation frequency; otherwise the RNG k-ε turbulence model was used. The volume of fluid (VOF) model was used to track the free surface.

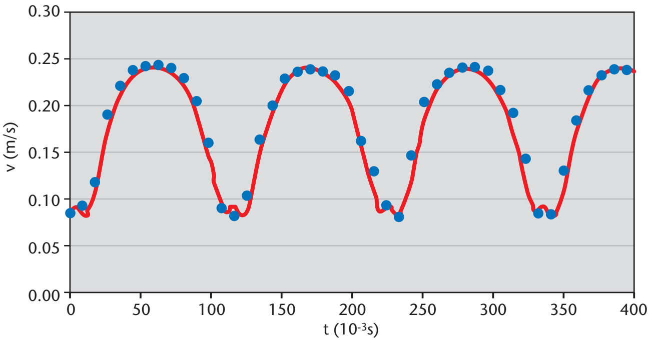
Predictions of the evolution and final shape of the vortex above the impeller were found to be in good agreement with the experiment. Discrepancies were minimal at high rotation speeds and somewhat greater at very low speeds. This is probably because pressure gradients that give rise to vortex development are small and even the smallest disturbance during the experiment can change its evolution. The periodic nature of the tangential velocity magnitude observed from the LDA measurements was very well predicted by the simulation.

The results suggest that it is possible to predict with relatively good accuracy many features of non-Newtonian fluid mixing with a free surface. The gained knowledge of numerical simulation is applicable for predicting flow characteristics and especially for optimization of real complex industrial mixing processes where experimental measurements are difficult or impossible to perform. ■

References

1 Slemenik-Perše, L.; Bajcar, T.; Žumer, M.; Širok, B.: LDA velocity measurements of high-viscosity fluids in mixing vessel with vane geometry impeller; accepted for publication in Acta Chimica Slovenica, 2006.

2 Dular, M.; Bajcar, T.; Slemenik-Perše, L.; Žumer, M.; Širok, B.: Numerical simulation and experimental study of non-Newtonian mixing flow with a free surface; accepted in the Brasilian Journal of Chemical Engineering, 2006.



Measured (blue) and simulated (red) tangential velocity 5 mm from the vessel wall at a rotation frequency of 90 rpm