Design and validation of a robust CFD-DEM model for the investigation of viscous solid-liquid mixing in agitated vessels

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ABSTRACT

Viscous solid-liquid mixing plays a key role in the production of a large variety of consumer goods such as pastes, paints, cosmetics, pharmaceuticals and food products. Despite this industrial relevance, the majority of the research and reported results in solid-liquid mixing has been geared towards the turbulent regime and little is known about the laminar and transitional regimes of operation. In particular, it remains unclear how the rheology of a suspension, the particle interactions and the presence of a complex rotating geometry impact the flow patterns as well as critical parameters such as the impeller torque, the just-suspension speed (Njs) and mixing indices. To shed light on these issues related to solid-liquid mixing, numerical and experimental work is essential. However, due to the opacity of most viscous suspensions, local measurements of the flow field via optical techniques are highly problematic. Consequently, almost all experimental measurements have been so far limited to global characteristics of the mixing flow. On the other hand, the CFD simulation of these systems does not suffer from these drawbacks.

A variety of models have been developed to simulate solid-liquid flows. These include the classical Eulerian-Eulerian (or two-fluid) model, and the combination of the Discrete Element Method (DEM) for the particles and CFD methods for the liquid phase (CFD-DEM). While it possesses a huge potential due to its formulation, notably as regards its natural capacity to reproduce the maximal packing fraction of solid particles, the ability of the CFD-DEM approach to accurately model viscous solid-liquid flow in complex geometries has yet to be assessed and the method has not been validated experimentally in the field of mixing.

In the present work, we extend the CFDEM framework, which combines OpenFOAM and LIGGGHTS, to study viscous solid-liquid mixing. First, the governing equations for the liquid and the solid phases are presented along with the two-way coupling strategy. The temporal numerical stability of the scheme with this two-way coupling model is studied and strategies to relax the time stability criteria for the phase coupling and stabilize the scheme by offloading the drag calculation to the DEM are discussed. Furthermore, the influence of the use of either an explicit or an implicit coupling strategy between the phases are discussed. The model is then applied to the study of solid-liquid mixing in a stirred-tank with a pitched-blade turbine. Qualitative comparison with experimental visualization of peculiar flow patterns are used to establish the validity of the CFDEM framework in this context. Then, the model is validated quantitatively by comparing the fraction of suspended solid measured as a function of the impeller rotational speed. Finally, by extending the use of a mixing index to axisymmetric solid-fluid systems, we propose a methodology to measure the degree of mixing within the tank.