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Prediction of Horizontal Pipe Slurry Flow with Hindered Settling

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Extended Abstract

Efficient separation of complex flocculated waste sludges and suspensions is critically important to many waste processing activities where particle-laden turbulent flows are prevalent. For the primary separation of flocculated wastes, clarifiers and hydraulic transfer lines are some of the most widely used equipment. Despite their simple design, there are numerous performance challenges, particularly the occurrence of intense inlet recirculation zones which can cause the build-up of high concentrations of solids in outlet streams. Computational fluid dynamics (CFD) is frequently employed to simulate such equipment and the flow within them. However, current CFD models do not adequately incorporate the physics of complex and shear-dependent flocculated particle phases within large-scale separation environments. To better understand the multiphase flows involved, the key objective of this research is to predict particle concentrations in transport pipelines utilising large eddy simulation, using the OpenFOAM® software, coupled with a Lagrangian particle tracking (LPT) approach. Additionally, predictions based on LPT are compared with those of an Eulerian-Eulerian (EE) approach to modelling multiphase flows. Discrete sizes of glass particles were used for the simulation of particle-laden turbulent pipe flows with different particle concentration profiles and initial volume fractions. Validation of the predictions was carried out through the comparison with results obtained from direct numerical simulations and analytical models. This study also included a comparison of particle settling using an Eulerian-Eulerian model both with and without hindered settling accounted for.

To assess the behaviour of the particle dispersions, a modified LPT solver in OpenFoam® has been developed to directly track the dispersed solids. Solid particles are inserted at arbitrary locations within a fully developed turbulent liquid flow and assigned the local fluid velocity at those locations. A cyclic boundary condition was applied in the streamwise direction with no-slip conditions at the pipe walls. Statistical data was gathered for analysis after the particle phase had adjusted to the flow. A modified EE solver with a hindered settling model was also developed to predict these flows, with particle concentration profiles compared with those predicted using the particle tracking method and a range of validated data at industrially relevant concentrations. A modified driftFluxFoam solver was used for the Eulerian-Eulerian approach as it proved to be computationally efficient and cost-effective. The LPT solver is limited to simulating very low particle concentrations, while the Eulerian-Eulerian solver performs well across a wide range of concentrations. Results highlighted that equilibrium concentration profiles and deposited beds were formed over moderate timescales of 60–80 s, which is often longer than can be observed experimentally. Also, the incorporation of a hindered settling model significantly reduced segregation at concentrations > 3 vol%.

Ongoing work is employing population balance equation-solving techniques in OpenFOAM® to simulate flocculation build-up and shear breakdown in solid-liquid systems. Aggregate size changes over time will be coupled with the hindered settling model to simulate dynamic flocculation-controlled separation in both turbulent pipes and clarifier channel flows. We will thus be able to fully predict the influence of shear on the transportation and deposition of particles relevant to slurry flows in a number of industries, from wastewater treatment to nuclear decommissioning.