CFD Modeling of Solid-Liquid Suspension Flow in a Horizontal Pipe

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Abstract

The present work focuses on the three-dimensional modeling of the solid-liquid suspension flow based on the Eulerian-Eulerian multiphase flow model. The k-ε turbulence model and particle-induced turbulence model were used to simulate the solid-liquid suspension flow. The momentum transfer between the solid and liquid phases including drag force, shear-induced lift force and virtual mass force, together with buoyancy force, were considered in the model. The simulation geometry focuses on a horizontal pipe, where an imaging probe was installed for in-line analyzing the size distribution of solid particles. The simulation results for the studied solid material (solid density 1450 kg/m3, particle size range between 200 and 650 µm) in water clearly showed that the representative particle size distribution can be captured with the critical flow rate when the in-line probe is installed at the low vertical position in the pipe.

Keywords: solid-liquid suspension, flow dynamics in horizontal pipe, CFD modeling

1. Simulation of flow dynamics

In the chemical industry, solid-liquid suspensions are usually transported in a horizontal flow. The sedimentation of difference sized particles should be taken into account in the modelling of the horizontal flow. In literature, the results of the fluid dynamics studies obtained experimentally have been presented to describe the flow pattern in the horizontal pipe (Davies, 1987, P. Doron and Barnea, 1992, Doron and Barnea, 1993). However, to our best knowledge, using CFD to model solid-liquid suspension flow in the horizontal pipe is seldom discussed in the literature. In some cases, e.g. to measure the particle size distribution in the horizontal pipe, it is important to know the accurate measurement location and the flow velocity in order to capture the representative particle size distribution. It is well known that particle size distribution in solid-liquid suspension is directly related with the flow pattern in the fluid field, and computational flow dynamics (CFD) is the useful tool to clarify the flow-based phenomena. In this work cfx5.7 was used to simulate the solid-liquid suspension flow in the horizontal pipe.

The used simulation geometry was a horizontal pipe with the length of 1.5 m and the diameter of 0.1 m, as shown in Fig. 1. The fluid was water at room temperature. The particles were dispersed in the water. The suspension density of solids was 0.1%. The density of particle was 1450 kg/m^3 and the particle shape was spherical. An Eulerian-Eulerian multiphase flow model was used to model the suspension flow. The liquid was considered as the continuous fluid and the solid was considered as the dispersed fluid. The size distribution of particles was described with seven size classes and each size class was regarded as a separate phase. Therefore, each phase possesses its own flow field. The particle-induced turbulence was modelled using the Sato Enhanced Eddy Viscosity model. The interaction between the liquid and the solid phase, i.e. drag force, shear-induced lift force and virtual mass force, was included in the interphase transfer model. The effect of buoyancy was also included in the simulation.

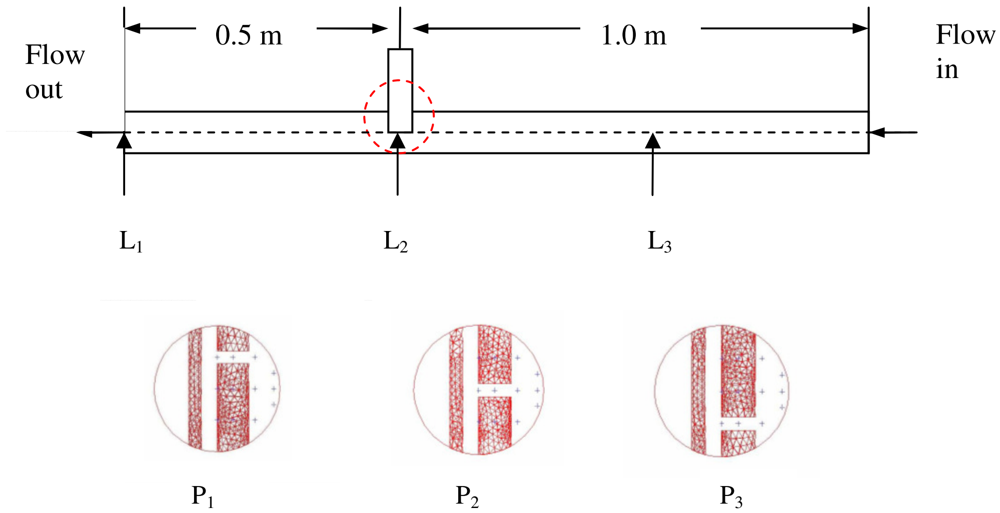

Fig. 1 The simulation geometry and the different vertical positions of in-line probe

The transient flow was used to simulate the solid-liquid suspension. The steady state of particle size distribution can be obtained after the certain time steps. At the initial state, it was assumed that the solid particles are homogeneously suspended at zero velocities in the pipe. Two different size distributions of particles, MI and MII, shown in Fig. 2 were obtained experimentally, which were used to describe the particle size distributions at well mixed condition. A MTS PIA 4000 LUT in-line particle size analyzer (in-line video microscope) was used in the particle size analysis. MII sample had a bimodal size distribution. For the boundary condition, the liquid phase was calculated with a no-slip boundary condition at the wall and a free-slip boundary condition was assumed for the solid phases. At the inlet of pipe, the flow velocities were set for all phases. For the outlet boundary, the relative pressure was set to be zero.

2. Simulation results and discussion

The solid-liquid suspension flow was simulated with and without probe in the pipe. Firstly, the simulation was done without using the in-line probe. The simulated particle size distributions at the different locations along the pipe are presented in Fig. 3. The different locations, i.e. L_1, L_2 and L_3, are shown in Fig. 1. The different input flow velocities, i.e. 0.4 and 0.8 m/s, were used in the simulation. From Fig. 3, it can be seen that the status of solid-liquid suspension changes along the pipe at the input flow velocity of 0.4 m/s. However, the particles can reach the better suspension condition when the input flow velocity increases to 0.8 m/s.

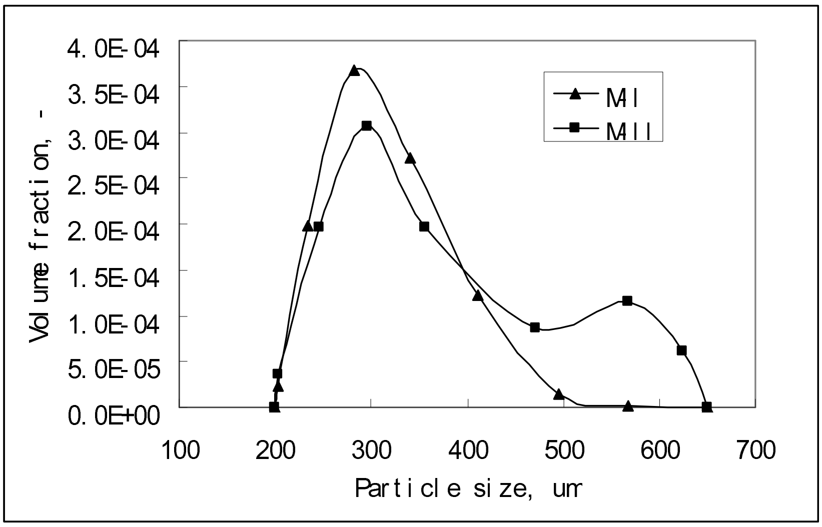

Fig. 2 Particle size distributions measured in the experiment at well mixed condition

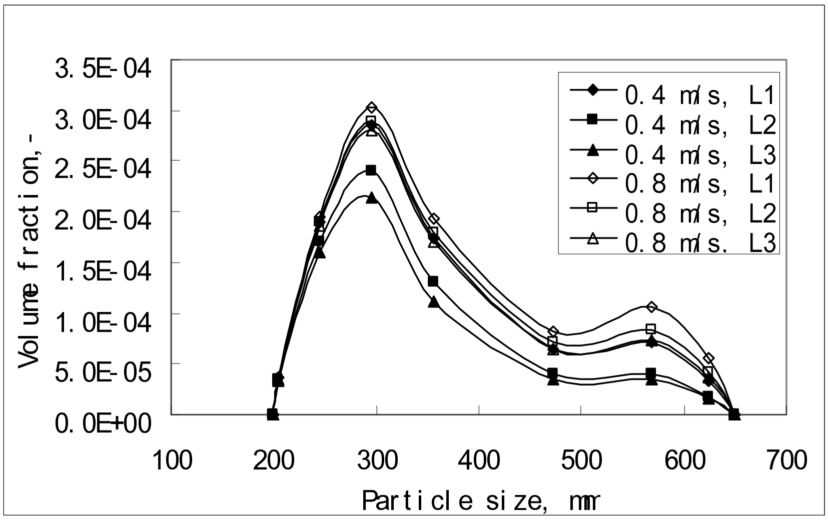

Fig. 3 Particle size distributions obtained at the different locations in the pipe at the different flow rates

When in-line probe was installed at the location of L_2 in the pipe with the vertical position of P_2 shown in Fig. 1, the solid-liquid suspension flow was simulated. Comparing with Fig. 3 at the same operating condition, the influence of in-line probe on the suspension of particles can be clearly seen from Fig. 4. With the input flow velocity of 0.4 m/s, the size distributions of particles obviously change near and after the in-line probe along the flow direction. The results imply that the representative particle size distribution can not be captured with in-line probe at the input flow velocity of 0.4 m/s. However, when the input velocity increases to 0.8 m/s, the solid particles are well suspended for in-line measurement.

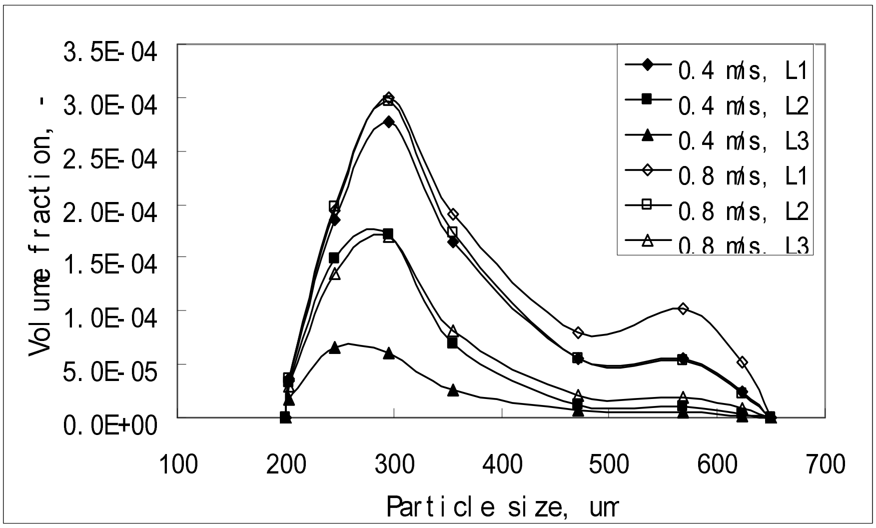

Fig. 4 Particle size distributions at the different locations in the pipe at the different flow rates

With the input velocity of 0.8 m/s, the simulations were done to investigate the optimal vertical position of in-line probe to capture the representative particle size distribution. The different vertical positions, i.e. P_1, P_2 and P_3, are shown in Fig. 1. The simulation results are presented in Fig. 5, where the particle size distribution at the well mixed condition is also shown. Comparing with the particle size distribution at the well mixed suspension, it can be seen that the low vertical position of the in-line probe is the good location to capture the representative particle size distribution.

The particle fraction having different size distribution was also simulated to study the influence of flow rate and location of in-line probe on the solid-liquid suspension. The simulation results are shown in Fig. 6. It can be seen that at the flow velocity of 0.4 m/s, it is difficult for in-line probe to capture all sizes of particle in any location. However, when the flow rate increases to 0.8 m/s, the low vertical position can capture the representative particle size distribution, which confirmed the results discussed in the above text.

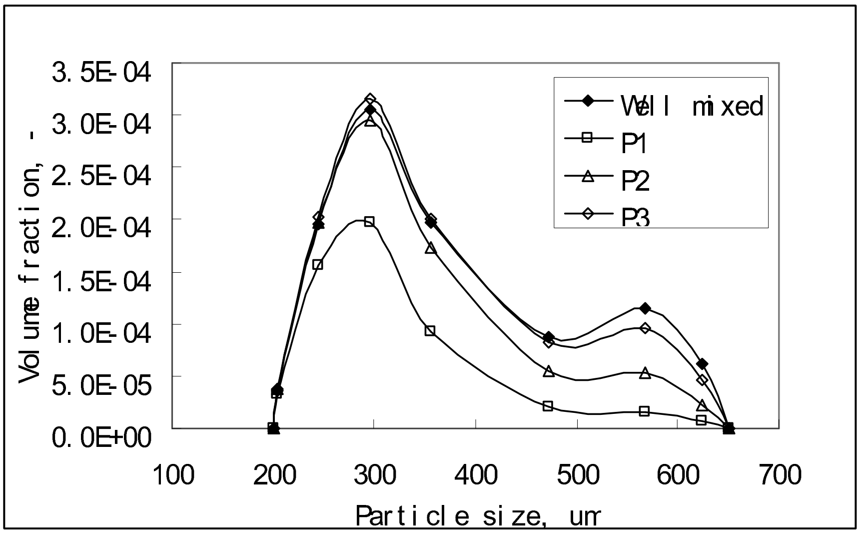

Fig. 5 Particle size distributions obtained with the different vertical position of in-line probe at the input flow velocity of 0.8 m/s.

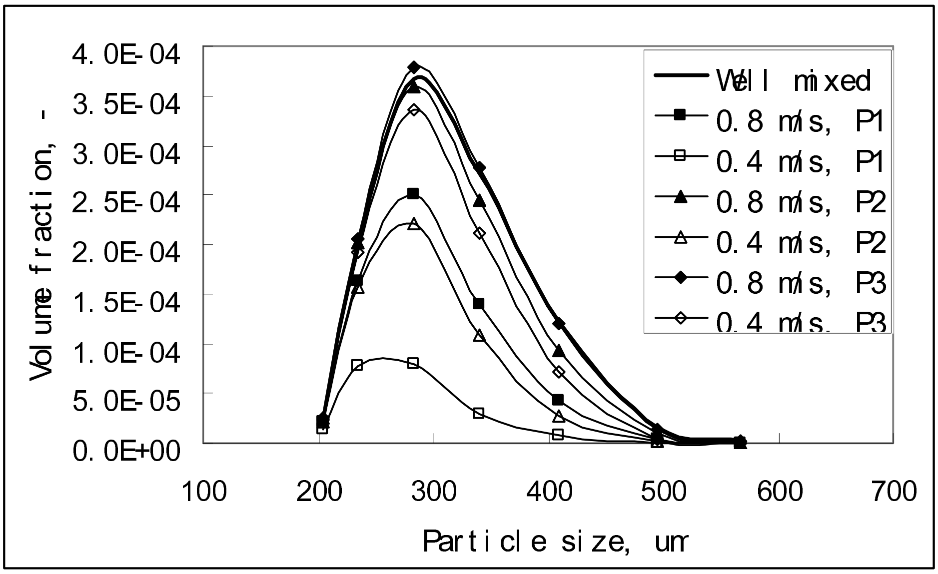

Fig. 6 Particle size distributions obtained with the different vertical position of in-line probe and the different input flow velocity

3. Conclusions

The solid-liquid suspension flow in the three-dimensional horizontal pipe was simulated with Eulerian-Eulerian multiphase flow model, with which the size distributions of solid particles were described with seven sizes classes. The simulation results showed that the suspension status of solid particles depends on the input flow rate, meanwhile, the installation of in-line probe in the pipe have the certain influence on the solid suspension. The suitable input flow velocity and low vertical position of in-line probe should be selected to capture the representative particle size distribution in the horizontal pipe for the studied solid compound.

4. Acknowledges

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5. References

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