SOLID VELOCITY PROFILES USING UVP AND CFD SIMULATIONS

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Abstract

Solid suspension in stirred tank reactor (STR) is commonly used in process industries for catalytic reactions, dissolution of a solid, crystallization, suspension polymerization and so on. In such slurry systems, quality of suspension is a critical parameter for reliable design, optimum performance and scale-up. Suspension quality in stirred tank reactor depends upon complex interactions of impeller generated flow and turbulence and solid particles. Recent advances in computational fluid dynamics (CFD) and experimental techniques for characterizing solid-liquid flow provide way of understanding solids suspension in stirred tanks. However, the reliable design for ensuring adequate solids suspension (suspension quality) is still not straight forward. Suspension quality depends upon drag coefficient acting on solid particle in turbulent fluid and ultimately on the local solid-liquid velocity profiles. An attempt is made here to obtain local velocities of liquid and solid phases to evaluate different drag correlations used in the CFD models.

There are relatively few studies available on measurements of local solid velocity profiles (Guiraud et al., 1997; Fishwick et al., 2003). The available experimental data is associated with significant scatter and uncertainties because of complex interactions of solid particles with free stream turbulence. Several papers have been published on modeling of solid suspension in stirred tank reactor (see for example, Gosman et al., 1992; Micale et al., 2000; Khopkar et al., 2006). However, many of these studies were limited to low volume fraction (i.e. ≤ 5% v/v) of solids. More over there is no consensus on closures of inter-phase drag force terms for solid-liquid suspension in these published studies. The main reason behind this is inadequate understanding of influence of turbulence and solid volume fraction on effective drag coefficient. Many of these studies rely on profiles of solid volume fraction to evaluate inter-phase drag closures. However, ideally local measurements of relative velocity between solid and liquid phases (slip velocity) should be used to evaluate different proposed correlations for inter phase drag coefficient. Such an attempt is made here. The knowledge of slip velocity and its variation within the reactor are also crucial for better understanding of solid-liquid mass transfer.

In this work, the local solid-liquid velocity profiles were measured using UVP (Ultrasound Velocity Profiler) technique. A cylindrical, flat-bottomed, acrylic tank of diameter 0.7 m with standard baffles of width T/10 was used to carry out the experiments as shown in Figure 1. Experiments were carried out for 6-bladed pitched blade turbine (PBTD-down-pumping) and 4-bladed Hydrofoil impeller with solid loadings such as 1, 3, 5, and 7 % v/v for particle size of 250μm and 4 different impeller speeds. Instantaneous radial velocity and axial velocity data was acquired at z/R = 0.366, 0.533 and -0.366 axial (lower/upper impeller regions and impeller discharge region) and 10 radial locations respectively. Measurements were carried out with neutrally buoyant and glass particles. The measured solid and liquid velocity profiles were used to quantify variation of solid-liquid slip velocity within the stirred reactors.

CFD model was developed using the Eulerian-Eulerian approach and the standard k-ε turbulence models. Multiple Reference Frame (MRF) approach was used to simulate impeller rotation with the steady state condition. Different inter-phase drag force closures were used and tested in this work (Brucato et al., 1998; Khopkar et al., 2006). The model was used to simulate suspension of solid particles similar to design and operating conditions of experimental set up as shown in Figure 2. Typical predicted contour plots of solid distribution at 220rpm for all mentioned solid loading shown in Figure 3. Model predictions were compared with the experimental data of local velocity profiles of solid particles. A sample of these results is shown in Figure 4. Attempt was made to evaluate sensitivity of the predicted slip velocity with respect to different inter-phase drag correlations. Comparison of these predicted results with the experimental measurements was used to evolve guidelines on selecting appropriate drag correlations.

References

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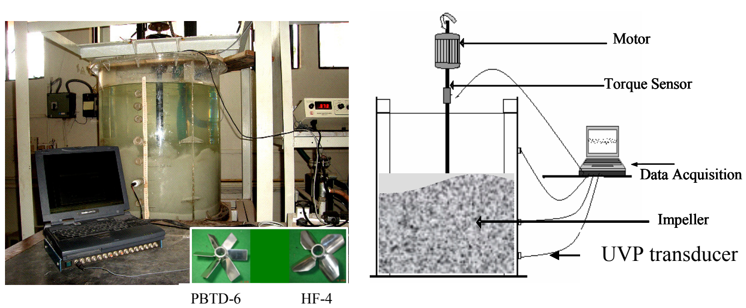

Figure 1 : Pictorial and schematic Presentation of experimental set up impellers

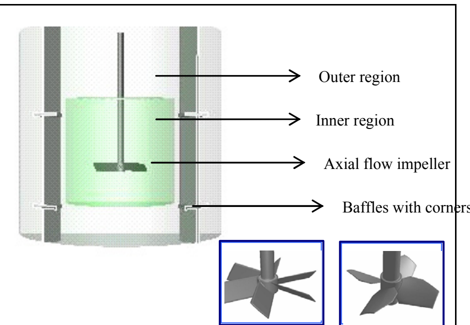

Figure 2 : Schematic presentation of computational domain and axial flow

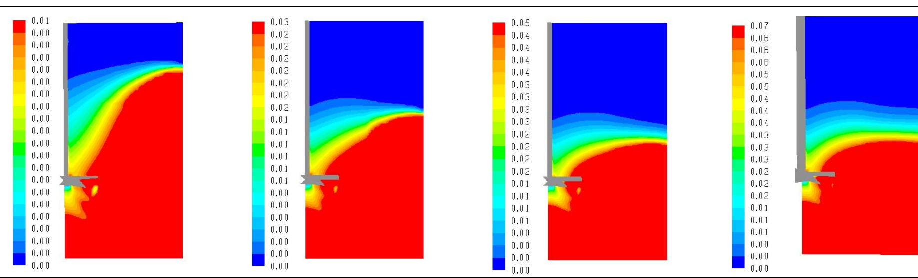

Figure 3: Contour plots of solid volume fraction for 1%, 3%, 5% and 7% v/v at 220rpm with PBTD - 6

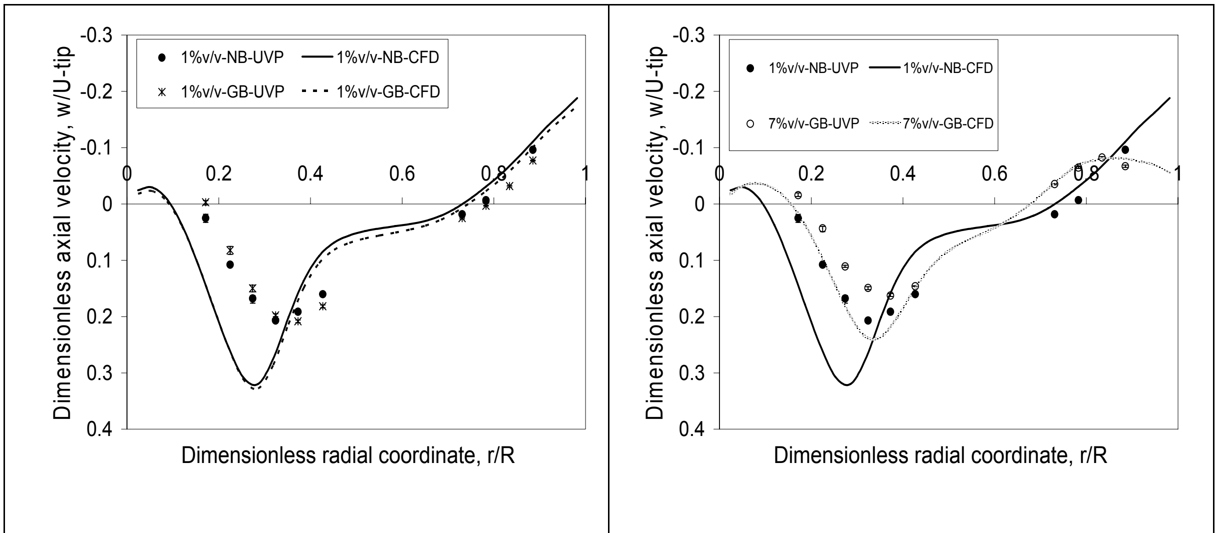

Figure 4 : Dimensionless axial velocity profiles (w/U_tip) w.r. to radial coordinate (r/R) by UVP and CFD

Key words: Solid suspension, Cloud height, UVP, Slip velocity, CFD

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