Direct numerical simulations (DNS) of turbulent liquid-solid flow in cylindrical stirred tank

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Highlights

- Frist DNS of liquid-solid flow in cylindrical stirred tank
- The particle-phase effects on averaged hydrodynamic are revealed
- Discovery of turbulence suppression in near-wall region

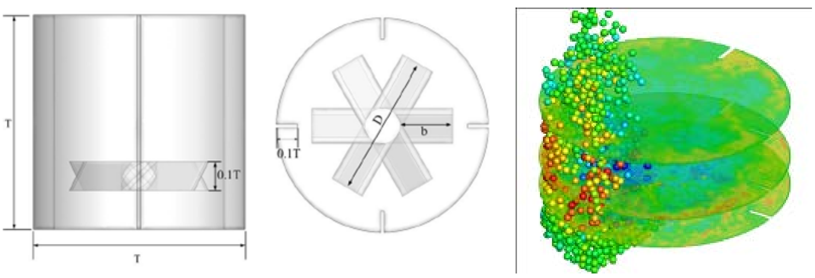
1. Introduction

Though stirred tanks are widely used in industry, the liquid-solid flow in them is far from fully understood yet, especially when the particle diameters are large compared to the Kolmogorov scale. The drag coefficient of the particles is strongly dependent on the local hydrodynamics including the turbulence characteristics, which varies significantly over the vessel [1], and the turbulence characteristics is, in return, altered by the presence of particles. Direct numerical simulation (DNS) [2] and particle-resolved experiments [3] is a powerful tool for exploring this complex two-way coupling, which appeared only recently. However, such studies for practical cylindrical stirred tanks are still absent.

In this work, DNS in the immersed boundary method (IBM) was carried out for a 4-baffled cylindrical tank with height H=32 mm and inner diameter (ID) T=32 mm and 6-pitched blade, 45˚ down-pumping impeller. Under constant impeller rotation speed N=23.88 rev/s and particle diameter d_p=1mm, we varied the solid volume fraction φ (0.10, 0.005, and 0.00 for Cases 1~3) to investigate its averaged hydrodynamic characteristics and spatial distributions.

2. Methods

The diffusive and sharp IBMs were used for the moving particles (including impeller) and static cylinder wall (including baffles), respectively. The geometry of the tank and the impeller is depicted in **Fig. 1** and the corresponding parameters are listed in **Tab. 1**.



(a) (b)

Figure 1 Schematic of the stirred tank (a) and snapshot of the three slices at three different vertical locations of fluid contour and particles distributions (represented only on one fourth of the domain) both colored with vertical velocity component

Table 1 Geometry parameters of the stirred tank (mm)

Tank height	Tank diameter	Impeller clearance	Impeller diameter	Impeller height	Blade length	Baffle width	Baffle thickness
32.00	32.00	8.00	16.00	3.20	6.08	3.20	1.00

The general flow field futures of the stirred tank are shown in **Fig. 1(b)**, and those for the radial profiles are shown in **Fig. 2**. For the single phase case (φ=0.0) in **Fig. 2(a)**, the upward fluid flow reverses into an downward flow at r/R=0.7~0.8 in region A (after baffle), which can be attributed to the dead zone in the eye of the circulating loop in this system. Examining the mean axial velocity profiles in the upper part of the tank, a clear transition to a fairly flat (or even reverse) axial velocity profile is seen at z/H=0.6~0.7, indicating that the active volume where the main circulation occurs is in the bottom 60~70% of the tank, which is similar to the reported experimental value of 70% [4]. The solid volume fraction distributions have been validated qualitatively [5] by experiments [6] also. In **Fig. 2(a)(b)(c)(d)**, we compared radical profiles of the averaged axial velocity component of Cases 1, 2, and 3 at two vertical locations, z/H=0.5625 and 0.6875. We found that in both regions A (after baffles) and B (before baffles), the maximum penetration height near wall (r/R=1) is obvious larger than in Cases 1 with φ=0.1.

3. Results and discussion

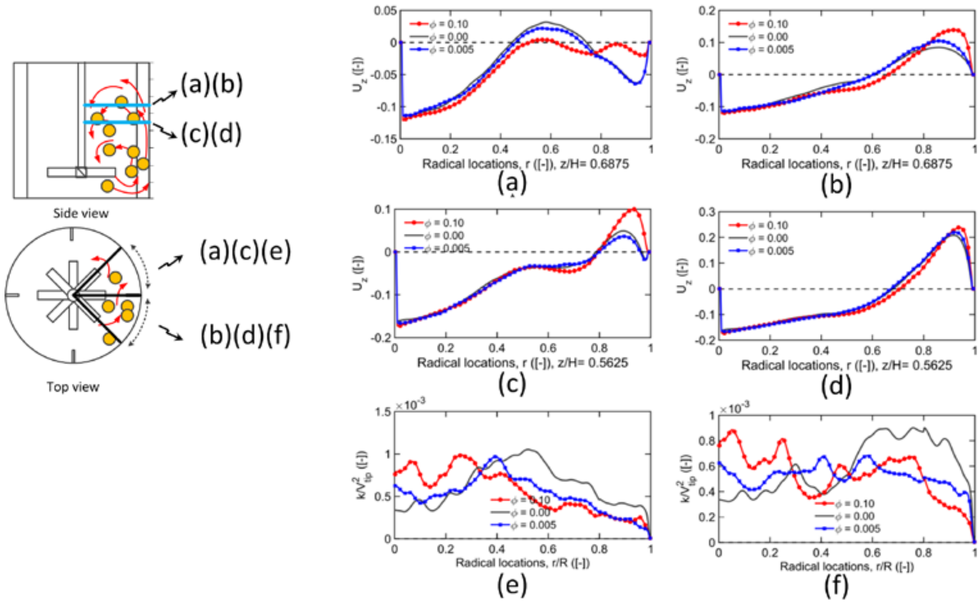


Figure 2. Radical profiles of dimensionless mean axial velocity U_z/V_{tip} at different vertical location z/H =0.5625 (a)(b), z/H=0.6875 (c)(d) and turbulent kinetic energy (TKE) k/V_{tip}^2 (e)(f) with different solid volume fractions (0.10, 0.00, 0.005) in (a)(c)(e) region-A (b)(d)(f) region-B.

The radical profiles of the turbulent energy kinetic energy (TKE) in these three cases were compared to explain this difference. In the near wall (upward flux) region, smaller TKE (**Fig. 2(e)(f)**) was found in Case 1. This causes smaller Reynolds stress as well as the entrainment between upward and downward fluxes than the single-phase Case 3, resulting in larger maximum penetration height.

4. Conclusions

In this study, DNS of liquid-solid flow in cylindrical stirred tank was carried out for the first time, turbulence suppression in near-wall region was found, leading to larger maximum penetration height of the upward jet.

References

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Keywords
liquid-solid; turbulent; stirred tank; turbulence suppression