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# Analysis of dilute solid–liquid suspensions in turbulent stirred tanks

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ABSTRACT

In this work, dilute suspensions of solid particles in stirred tanks are investigated by Particle Image Velocimetry measurements, which were specifically designed to determine the effects of the dispersed phase on mean velocity and turbulence levels of the continuous phase and the local solid–liquid slip velocity. In order to determine the effect of particle size and concentration, glass particles of narrow size distribution were selected; the particle content was increased stepwise up the maximum of 0.2 vol.%. Overall, moderate dampening of liquid turbulent fluctuations was found with the smaller particles, while turbulence enhancement was observed with the bigger ones. Continuous phase turbulence was found to affect the local map of the particle settling velocity, which was also discussed on the basis of a force balance analysis. The reduction of particle settling velocity due to free stream turbulence under specific conditions is confirmed.



*Keywords:* Particle; Stirred tank; Multiphase flow; Turbulence; Slip velocity; PIV

## 1. Introduction

Treatment of solid–liquid mixtures in agitated vessels is a widespread unit operation in the chemical, pharmaceutical, food and allied industries, with purposes ranging from catalytic slurry reactions to crystallization just to mention a few examples.

The two-phase turbulent flow typical of stirred tanks has a strong impact on the performance of the operation, since it affects heat and mass transfer as well as the chemical reactions (Derksen, 2003). Moreover, understanding of basic operation mechanisms such as floating solids withdrawn is associated to the knowledge of turbulent characteristics of the flow (Khazam and Kresta, 2008). As a results, turbulent solid–liquid stirred tanks have been widely investigated so far, but many open issues still remain – especially on the turbulent characteristics of the two-phase flow (Micheletti and Yianneskis, 2004). Further efforts in this field will help to improve the current modelling capability and, ultimately, to guide better equipment design and process control.

Generally, turbulence dampening or augmentation in two-phase flow was reported. It has usually been found that small particles tend to attenuate turbulence and large particles tend to augment it and that the extent of this phenomenon is related to the ratio of particle size and a characteristic turbulence scale (Crowe et al., 1998) – though firm conclusions and generally accepted models that can be applied to all flow conditions are not yet available. Experimental studies on turbulence modulation have been reported since the early 1990s (Crowe, 2000), mainly for pipe flows or jets and with gas as the continuous phase, while more limited information has been collected so far on stirred solid–liquid systems. Advanced experimental techniques for the determination of detailed local information on turbulent solid–liquid stirred tanks have started being developed recently; so far the effect of particles on the continuous phase turbulence has been investigated in few conditions (Nouri and Whitelaw, 1992; Guiraud et al., 1997; Micheletti and Yianneskis, 2004; Virdung and Rasmuson, 2007, 2008; Unadkat et al., 2009). The experimental data have confirmed the applicability of the Gore and Crowe's criterion in some cases (e.g. Virdung and Rasmuson, 2008) and they have not in others (e.g. Unadkat et al., 2009).

The simultaneous determination of the flow fields of the continuous and dispersed phases would allow a direct evaluation to be made of the particle–fluid slip velocity, which knowledge is important because of its influence on the

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