PIV measurements of mean flow and turbulence modulation in dilute solid-liquid stirred tanks

Giuseppina Montante¹, Marie-Hélène Occulti¹, Franco Magelli¹, Alessandro Paglianti¹

1: Department of Chemical, Mining and Environmental Engineering, University of Bologna, Italy, alessandro.paglianti@mail.ing.unibo.it

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Treatment of solid-liquid mixtures in agitated vessels is a widespread unit operation in the chemical, pharmaceutical, food and allied industries. Among the different aspects of interest for equipment design and process control, many open issues concern the turbulent characteristics of the two-phase flow and the capability to predict them by appropriate theoretical considerations or computational models. Very recently, advanced experimental techniques for the collection of detailed local information on turbulent solid-liquid stirred tanks have started being adopted (Virdung and Rasmussen, 2007, 2008; Unadkat et al., 2009). Further experimental investigations may provide additional insight into the system behavior, that will improve equipment design and operation.

The experimental data collected in this work are aimed at adding information relevant to different solid-liquid systems and stirred tank geometries with respect to the previously investigated conditions. They may be also adopted as a useful benchmark for Computational Fluid Dynamics modelling validation of solid-liquid stirred tanks. The experiments were performed by a two-phase Particle Image Velocimetry technique. The measurements were performed by a pulsed Nd:YAG laser sheet ($\lambda=532$ nm light wavelength, $f=15$ Hz frequency) and two cameras of equal resolution (1280x1024 pixels). The continuous phase was seeded by polymeric particles coated with fluorescent Rhodamin B emitting light at the wavelength of $\lambda=590$ nm, while the glass particles have the same emission wavelength of the laser light, thus allowing phase separation by light filters. At least 2000 image pairs were required to obtain sample-independent velocity fluctuation measurements.

The experiments were carried out in a fully baffled flat-bottomed cylindrical vessel of diameter $T=23.2$ cm and height $H=T$. The vessel was closed on top by a lid to avoid air entrainment and was contained inside a square tank filled with water for minimizing optical errors. Agitation was provided by a standard Rushton turbine of diameter, $D$, equal to $T/3$, placed at the distance $T/3$ from the vessel base. Water and glass beads were used as the liquid and solid phases, respectively. The effect of particle size on the liquid turbulence levels was investigated by adopting two different glass mean sizes ($d_p=774\mu m$ and $d_p=115\mu m$) and the particle contents was increased stepwise from zero (single phase system) up to 0.2 vol. %. The rotational speed was fixed at 850 rpm, that is above the ‘just suspended’ condition evaluated with the well-known Zwietering correlation; fully turbulent flow regime was attained in all cases, the rotational Reynolds number being $Re=8.8\times10^5$.

The optical attenuation of the laser sheet across the vertical measurement plane, that was placed mid-way between two consecutive baffles, was acceptable up to 0.1 and 0.2 vol. % for the smaller and bigger particles, respectively; therefore, the application of this technique to solid-liquid systems is limited to very dilute conditions, although higher upper concentration limit might be obtained by adopting a more powerful laser light source. Moreover, since the percentage of validated vectors decreases moving from the vessel wall towards the centre due to progressive laser light attenuation, only the r.m.s. velocities collected in the plane portion closer to the vessel wall were found to be quantitatively accurate.

The influence of diameter and concentration of the dispersed glass phase on water mean flow was found to be negligible, while the liquid r.m.s. velocity fluctuations were found to be attenuated or augmented depending on the particle size; the Gore and Crowe criterion based on the ratio of particle diameter and turbulent length scale was confirmed. Although the upper limit of the investigated particle concentrations did not exceed the value of 0.2 vol. %, the turbulence level variations were found to be more pronounced at increasing solid content. The average change in turbulence intensity of water in two-phase and in single phase condition following the Gore and Crowe representation is shown in the figure below.

![Graph showing % change vs. dp/L for dp=0.115mm and dp=0.774mm](image)

References


