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Influence of solids on macro-instabilities in a stirred tank

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ABSTRACT

Measurements were conducted in a cylindrical tank stirred with a PBT in order to study the effect of varying amounts of suspended solids, up to 11.8% by volume, on the frequency and amplitude of macro-instabilities (MI). Solid glass particles of three different sizes were used in order to investigate the influence of the particle Stokes number. Measurements were made at 18 different locations in the vessel using laser Doppler anemometry (LDA) and were evaluated with the Lomb algorithm to obtain the frequency spectrum of the liquid flow.

The results showed that the MI frequency is not influenced by the addition of solids. However, the MI amplitude was reduced by the addition of the solid phase although still detectable up to the highest concentration measured (11.8 vol.%). In the studied system there seems to be a difference dependent on the particle Stokes number.

Keywords: Macro-instabilities; Solid–liquid; LDA; Stirred tank

1. Introduction

Stirred tanks are widely used in the chemical process industry. Mean flows using standard configurations are generally accepted to be well understood (Hasal et al., 2000). Instantaneous flow, on the other hand, is extremely complex; it varies due to predictable mechanics like axis rotation and blade passage of the impeller, and unpredictable high frequency phenomena, turbulence and low frequency quasi-stationary phenomena. These low frequency phenomena are usually referred to as macro-instabilities (MI) and affect the flow pattern which in turn affects large scale mixing. MI phenomena are usually characterised by the dimensionless Strouhal number which is the frequency of the MI divided by the impeller rotation speed.

Early studies of vessels stirred with axial pumping impellers have identified MI phenomena as a consequence of double loop flow patterns (Kresta and Wood, 1993; Bruha et al., 1994). A linear relationship between impeller speed (N) and the frequency of the MI (f_{MI}) has been found. Chapple and Kresta (1994) have concluded that MI phenomena occur due to geometry, e.g. walls and baffles, and that these are linked to turbulence intensity. The investigation by Bakker and van den Akker (1994) using computational fluid dynamics (CFD) shows that interaction between two opposite vortex motions induces large scale instabilities in the flow in a tank stirred with an axial pumping pitch blade turbine (PBT). Also using a PBT, Montes et al. (1997) have found an MI that appears as the switching between one loop, or two or many loops in the large scale three-dimensional vortex structure. These were found at the top of the tank and around the baffles and appeared on a regular basis. The instabilities were more regular for lower Reynolds numbers. Kresta (1998) have reported that two separate MI phenomena exist. One corresponds to blade passage frequencies (BPF) and the other corresponds to large scale structures of the flow. Hasal et al. (2000) have used a proper orthogonal decomposition technique and image analysis to investigate the MI phenomena in a PBT stirred vessel with spatial resolution. They have determined that the length scale of an MI is comparable to the size of the vessel. The MI phenomena in the study are more pronounced in the transitional flow regime. They are hardly detectable at high Reynolds numbers. Hasal et al. (2002) have detected the MI related component of the tangential force affecting the radial baffles. From results of their experiments it follows that the MI of the flow pattern in mixing vessel generates a significant part of the force effects exerted by a flowing liquid on solid surfaces, e.g. baffles.

Studies by Roussinova et al. (2003) show that f_{MI} scales linearly with the rotational speed for $Re > 2 \times 10^4$. The same study shows that large eddy simulations (LES) are able to predict the Strouhal number ($St = 0.186$) for the same configuration. Using the LES simulations they have identified three mechanisms

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