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A novel and energy-efficient coaxial mixer for agitation of non-Newtonian fluids possessing yield stress

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HIGHLIGHTS

- A novel impeller called ASI, a combination of the A200 and the Scaba impellers, was introduced.
- Tomography and CFD were utilized to assess the mixing performance of this novel impeller.
- The ASI impeller showed superior performance in mixing of pseudoplastic fluids possessing yield stress.
- A dimensionless number based on Zlokarnik's concept was developed to evaluate the mixing efficiency.
- The ASI-anchor coaxial mixer was the most efficient mixer in terms of mixing energy.

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ABSTRACT

A novel impeller called ASI (a combination of the A200 and the Scaba impellers) has been introduced in this paper. By using electrical resistance tomography (ERT) and computational fluid dynamics (CFD), the performance of the ASI impeller in the agitation of the yield-pseudoplastic fluids was assessed and compared to the performances of the Rushton (a radial impeller), ARI (an axial–radial impeller), and A200 (an axial impeller) impellers in terms of power consumption and cavern sizes. The new ASI impeller exhibited superior performance in the mixing of the pseudoplastic fluid possessing yield stress. Agitation of such a non-Newtonian fluid in a vessel results in the formation of cavern around the impeller. An enlarged cavern can be achieved by increasing the impeller speed. However, this leads to increased power consumption as well as non-uniform mixing in the vessel, i.e. a high-shear region around the impeller and dead zones at the wall and the bottom. These issues can be resolved by using a coaxial mixer, a combination of a central impeller and an anchor. Our data revealed that the anchor-ASI impeller, the combination of the novel impeller and the anchor, was the most efficient mixer for the agitation of the yield-pseudoplastic fluids in term of mixing energy compared to the other coaxial mixers employed in this study.

1. Introduction

Mixing is an essential unit operation in many industries. The first objective of any mixing system is homogenization (Robinson and Cleary, 2012), which is followed by other process objectives such as controlling the mass and heat transfer rates (Gabelle et al., 2012), reactions (Bustamante et al., 2013), and structural changes. These mixing targets are more challenged with rheologically complex fluids such as non-Newtonian fluids, which are found frequently in such industries as food, pharmaceutical, paper coating, cosmetic, paint, and polymer. In these industries, the mixing operation is focused on having a particular final product with the specific rheological properties rather than the product homogeneity. Therefore, there is a need to develop different mixer designs to meet the specific demands. In other words, the best mixer type must be selected based on the objectives of the mixing operation. In fact, the efficiency of the mixing system is influenced by the agitator′s flow pattern dependent upon the geometry of the agitator (Chhabra and Richardson, 1999). A large demand from the industry is for the design of more efficient mixing systems, improvement in the design of existing impellers, and the combination of the existing impellers (e.g. using coaxial mixers).

An important class of the non-Newtonian fluids is the yield-pseudoplastic fluids. Mixing of these fluids results in the formation of a well-mixed zone (cavern) around the impeller with the stagnant regions in the rest of the tank (Pakzad et al., 2008a). The existence of these dead zones reduces the mass and heat transfer rates inside the mixing vessel (Amanullah et al., 1997).

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Thus, it is desirable to eliminate these dead zones by properly designing the agitation systems. In fact, the chemical industry needs the efficient mixers, which can be utilized for a wide range of applications with the least modifications. Several experimental techniques have been used to measure the cavern size and shape such as the dye method (Wichterle and Wein, 1975, 1981), hot film anemometry (Solomon et al., 1981), X-ray photography (Elson and Cheesman, 1986; Elson, 1988), laser Doppler anemometry (Hirata and Aoshima, 1994), and tomography (Pakzad et al, 2008b).

Previous studies have shown that the coaxial mixers are very effective in the mixing of fluids with complex rheology (Pakzad et al., 2013a). In fact, most studies regarding the performances of the coaxial mixers have been carried out in the last 10 years than before (Pakzad et al., 2013d). Our comprehensive literature review revealed that the main objectives of the previous research works done so far on this subject were (1) to propose a correlation to predict the overall coaxial mixer power consumption (Thibault and Tanguy, 2002; Foucault et al., 2004, 2005, 2006; Farhat et al., 2008; Bao et al., 2011; Pakzad et al., 2013a), (2) to evaluate the mixing time (Foucault et al., 2004, 2005, 2006; Farhat et al., 2007, 2008; Bao et al., 2011; Pakzad et al., 2013c, 2013d, in press), and (3) to assess the flow pattern existing in the tank equipped with the coaxial mixers (Rivera et al., 2006; Rudolph et al., 2007; Bonnet et al., 2007; Farhat et al., 2007; Pakzad et al., 2013c, 2013d).

Recently, Pakzad et al. (2013c) utilized electrical resistance tomography (ERT) and computational fluid dynamics (CFD) to explore the effect of the central impeller type on the performance of the anchor coaxial mixers used in the agitation of the yield-pseudoplastic fluids in terms of mixing time, specific power consumption, and flow pattern. They found that the combination of the anchor with the axial–radial impeller called ARI, which is a combination of the pitched-blade and the Rushton turbine, was

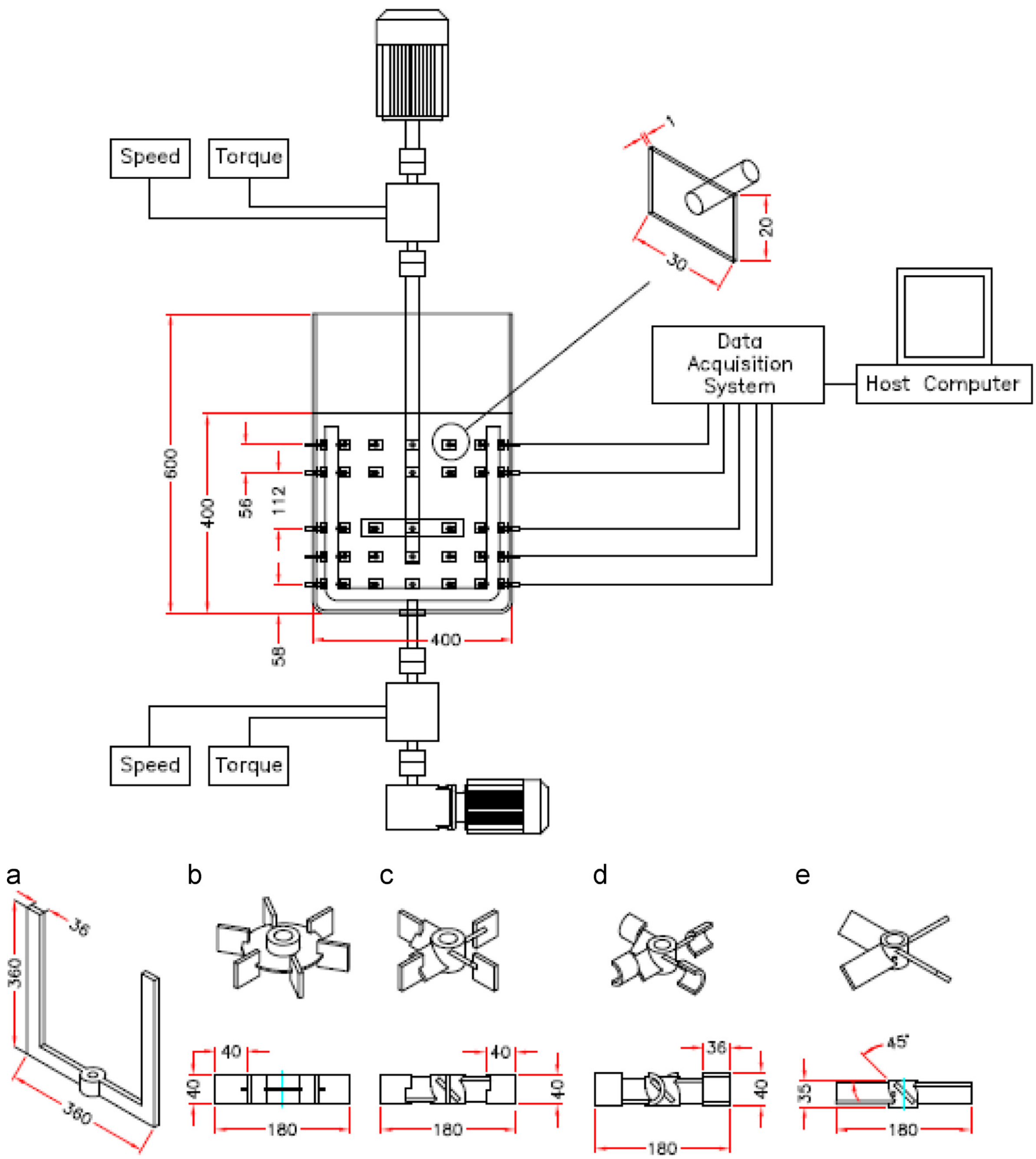

Fig. 1. Schematic diagram of the experimental set-up (dimensions in mm): (a) anchor impeller, (b) Rushton turbine, (c) ARI impeller, (d) ASI impeller, and (e) A200 impeller.