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Hydrodynamics characterization of the Maxblend impeller

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Abstract

The hydrodynamic characteristics of the Maxblend^{TM} impeller have been investigated in the case of viscous Newtonian fluids. Both laboratory experiments and 3D finite element based computational fluid dynamics (CFD) simulations have been carried out. The power consumption, the mixing evolution yielding the mixing time, and the effect of baffles in the laminar and transition flow regimes have been determined. It was found that the limit Reynolds number between the laminar and transition regimes is approximately 25 and 38 for the unbaffled and baffled configurations, respectively. Based on the range of Reynolds numbers studied in this work, the best window performance of the Maxblend^{TM} mixer where fast and homogenous mixing is achieved is the end of the laminar regime and the early transition regime with baffles.

Keywords: Maxblend^{TM}; Fluid mixing; Computer simulations; Finite element method

1. Introduction

Mixing of viscous fluids is mainly carried out in the laminar and transition regimes. When standard open impellers are used, it is often associated with poor bulk motion, an inhomogeneous distribution of the various phases, and the presence of spurious rheologically induced phenomena such as caverns. In the laminar regime, mixing is obtained by sequences of stretching-folding-breaking mechanism of the secondary phase and not by highly energetic eddies, making the design of optimal mixers very challenging.

Various impellers have been proposed to respond to the needs of laminar viscous mixing. They are based either on an enlargement of open impellers (wider blades with large diameters) or close-clearance designs like anchors and helical ribbons. The Maxblend^{TM} impeller (SHI Mechanical & Equipment Inc.), registered as a trade mark in Japan and shown in Fig. 1, is a wide impeller that combined a lower paddle and a grid. For the sake of clarity, the superscript symbol TM will be omitted next. The Maxblend is claimed to be one of the most promising impellers of the new generation, due to its good mixing performance, its low power dissipation, its straight geometry that makes it easy to clean, and its capabilities of operating in a wide range of Reynolds number (*Re*) (Mishima, 1992;Kuratsu et al., 1995). The Maxblend was designed for a variety of applications in liquid–liquid, liquid–solid and gas–liquid mixing. This recent product can handle processes from suspension polymerization and crystallization operation to high viscosity gas absorption.

Detailed information regarding the Maxblend performance is limited. Sumi and Kamiwano (2001) have investigated some mixing characteristics of Maxblend with highly viscous fluids and compare it with multistage impellers. A numerical investigation on dispersive mixing of the Maxblend and a comparison with helical ribbons impellers has also been carried out (Yao et al., 2001). They concluded that in deep laminar regime, the Maxblend cannot reach an effective dispersive mixing. The Maxblend power consumption and solid suspension performance in gas–liquid–solid applications were also investigated and compared with other large-scale impellers (Dohi et al., 2004). They found out that the Maxblend creates a more uniform solid suspension in comparison to Fullzone and triple impellers. The mixing performance of Maxblend and other

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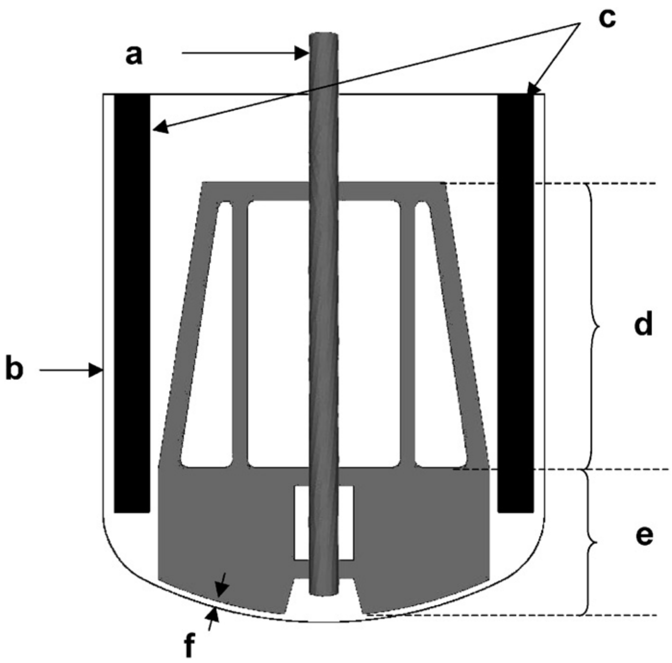

Fig. 1. Schematic of the Maxblend: (a) Maxblend impeller; (b) wall tank; (c) baffles; (d) impeller grid part; (e) impeller bottom paddle part; and (f) bottom gap region of thickness $\delta = 0.01\,\text{m}$.

large impellers in boiling stirred tank reactors was investigated by Takahashi, T. et al. (2006), who found that the Maxblend has essentially the same performance as the other impellers in this application. Numerical and experimental comparisons of Maxblend with double helical ribbon (DHR) were carried out by Takahashi, K. et al. (2006). They concluded that although Maxblend and DHR have almost the same power consumption, Maxblend has longer mixing time where $Re < 10$ and shorter where $Re > 10$.

The use of computer simulations to investigate the dynamics of mixing in stirred vessels is now well established in the laminar and transition regimes. Several articles dealing with close-clearance impellers can be found in the literature (e.g. Tanguy et al., 1992; De La Villeon et al., 1998; Iranshahi et al., 2006). For a long time, the mixing in laminar regime was examined without consideration of the concentration profile. Among the working hypothesis, it was assumed that the diffusion had no effect on the laminar mixing and the mixing was governed only by bulk transfer. Consequently, the mixing system simulation consisted of only the flow equations regardless of any mass transfer phenomena involved in the mixing. In the present study, mass conservation together with momentum conservation has been considered to better understand the mixing mechanisms of the Maxblend mixer.

The objective of the present work is to characterize experimentally and numerically the Maxblend mixer in the laminar and transition regime with Newtonian fluid. Experiment consists of two parts namely the power measurement of the impeller and mixing evolution measurements yielding the mixing time. In addition, computational fluid dynamics (CFD) simulations are also performed using the commercial 3D finite element software POLY3D$^{\text{TM}}$ (Rheosoft), developed in our group, that possesses all the numerical features required in this work. The fact is that several ways exist to handle the problem. We have judged that it is useful for the reader to mention briefly the numerical recipe and parameters setup used that help to obtain accurate results within reasonable computational times. This is particularly true because the mass transfer problem studied herein is governed by almost pure advection. This problem is well known to be challenging from a numerical standpoint and a particular attention is needed to obtain accurate numerical results, from a physical point of view. In this work, the simulation procedure comprises two steps: (i) a validation step involving the comparison of the predictions versus experimental data; (ii) the investigation of mixing criteria and comparison of the results obtained for baffled and unbaffled configurations.

2. Methodology

2.1. Experimental setup and methods

The Maxblend configuration is shown in Fig. 1. It consists of a vessel of diameter D of 600 mm and a liquid height H of 720 mm. The Maxblend impeller has a diameter d of 450 mm and a height h of 600 mm and is driven by a variable speed motor. The speed is carefully controlled by a solid-state frequency changer, receiving a feedback signal from a speed encoder. In addition, the shaft is equipped with a torquemeter to measure the effective power consumption of the impeller. The tank can be equipped with four equally spaced baffles of 50 mm wide. In this work two mixing configurations are studied: unbaffled configuration and baffled configuration.

A Newtonian glucose syrup aqueous solution having a viscosity μ of 5 Pa s and a density ρ of 1279 kg/m^3 was used as the working fluid. The temperature was carefully monitored to control the significant viscous dissipation caused by the bulky shape of impeller and correct the viscosity value in the result analysis accordingly, as glucose syrup is a very thermally sensitive medium.

Mixing evolution yielding the mixing times were evaluated by means of discoloration technique based on a fast acid-alkaline indicator reaction (Lamberto et al., 1996). The tracer solution was prepared with 0.08% bromocresol purple as an indicator in water. A volume of 900 mL of this solution was mixed with a 900 mL of aqueous corn syrup, added to the tank and thoroughly mixed. Subsequently, a solution consisting of 1000 mL of aqueous corn syrup and 20 mL of 10 N NaOH was added and solution was mixed until a uniform purple color was observed. Then, the mixer was stopped and 1000 mL of aqueous corn syrup and 20 mL of 10 N HCl was added at time zero and mixed until a uniform yellow color was observed corresponding to the mixing time. For comparison purposes between the different operating conditions, this solution was always added at the same injection point at the free surface close to the shaft. Mixing times were measured only from the alkaline state to the acidic state, since the visualization of the color change from purple to yellow is much easier to distinguish than from yellow towards purple. The fluid viscosity measurement as well