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Experimental study on micromixing characteristics of novel large-double-blade impeller

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HIGHLIGHTS

- The LDB impeller is a novel type of impeller developed from the FZ and MB impeller.
- We studied the characteristics by iodide-iodate parallel competing reaction system.
- Influence of feeding time, viscosity, etcetera on micromixing effects were researched.
- Comparisons with widely used FZ and DHR impeller in process industries were made.

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ABSTRACT

Large-double-blade (LDB) impeller is a new type of agitator based on Fullzone (FZ) impeller and Maxblend (MB) impeller. To investigate its micromixing characteristics in rapid-reaction situations, we conducted experiments in a 380 mm diameter stirred tank. The effect of feeding time, feeding location, agitating speed and viscosity on micromixing characteristics of the novel large-double-blade impeller was investigated, adopting the iodide–iodate parallel competing reaction system. The micromixing characteristics of the novel large-double-blade impeller were also compared with that of double helicon ribbon (DHR) impeller and FZ impeller, which were widely used in process industries. The results indicate that segregation index decreases with increasing feeding time, and won't stabilize until the feeding time is greater than its critical value, when macromixing effects can be neglected. In addition, it is favorable for micromixing effects to feed in the impeller regions with high local energy dissipating rate. Segregation index is negatively correlated with stirring speed, whereas the rate of decline tends to be smaller at higher stirring speed, which means that the strengthening effect of improving rotation speed on micromixing efficiency decreases. Moreover, whether the systematic viscosity is high or not, the novel LDB impeller has the advantage of better micromixing effects over FZ and DHR impellers with the same power consumption per unit volume (P_v).

1. Introduction

Agitation is widely used in many aspects of process industries such as chemical engineering, pharmaceutical, food, metallurgy, papermaking and sewage treatment. Impeller, as the core part of stirring equipment, directly determines the mixing effects and power consumption, therefore significantly affects the performance and economical efficiency of the whole mixing system. Consequently, the optimization design and selection of efficient impellers have especially prominent and practical meanings (Zlokamik, 2001).

Conventional impellers are characterized by their simple structures, easy operation and relatively mature design approaches. Nevertheless, because of their single function, such impellers are only applicable to particular technological processes. For systems with variable working conditions, they can't meet the requirements at different stages well, whether they are low-viscosity impellers (which are applicable to low-viscosity systems) or high-viscosity impellers (which are applicable to high-viscosity systems). For this problem, there are two valid methods being proposed (Chen et al., 2014). The first one is the application of double-shaft mixers. The second one is using single-large-bladed impellers, whose projected area of blade accounts for large proportion of longitudinal area of the whole tank. The typical ones are Fullzone (FZ) impeller, Maxblend (MB) impeller and Sanmeler (SM) impeller. By comparison, the large-blade impellers are more competitive for their simple structures, easy dynamic seal and lower cost of operation and maintenance.

Previous researches on large-bladed impellers concentrated more on their macromixing performance, while micromixing

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performance was rarely studied. Lianfang Feng, etcetera experimentally studied the performances of MB, FZ, and SM impellers (Gu et al., 2000), and found that at the same Reynolds numbers, MB impeller and SM impeller had the highest and lowest power consumption, respectively. Meanwhile, in a medium-high-viscosity system, mixing efficiency of FZ mixer was the highest and SM mixer performed best at heat transfer. Dohi's experimental study focused on power characteristics and solid-liquid suspension performance of MB impeller and FZ impeller in gas-liquid-solid three-phase stirring systems. The minimum impeller speeds of MB and FZ impellers for off-bottom solid suspension and homogeneous solid suspension were measured in aerated and unaerated systems, and were compared with that of a triple-impeller system composed of two four-pitched blade downflow disk turbines (DTs) at middle and upper positions and one Pfaudler type impeller at lower position (Dohi et al., 2004). The results showed that MB and FZ impellers were proved to have better solid-liquid suspension performance, particularly MB impeller. Yao, etcetera numerically investigated the macromixing performances of MB impeller and DHR impeller, and found that MB impeller had better dispersion and mixing performances, especially in the grids region (Yao et al., 2001).

However, in practical production, large-blade impellers are mainly used in rapid-reaction situations in process industries. And earlier studies indicated that the final product quality of rapid reactions was closely associated with micromixing effects. Villermaux, etcetera concluded that micromixing performances influenced polymer's molecular mass distribution (Villermaux and Blavier, 1984). According to Pohorecki's research, micromixing could control precipitating particle size distribution during the reaction process (Pohorecki and Baldyga, 1988).

When intrinsic rate of the reaction is approximate to or faster than the stirring rate, the reaction will have already or nearly been completed before the reactants reach molecular-scale homogenization. In such situations, actually, the rapid reaction proceeds in a local inhomogeneous state, thus influencing the distribution and quality of the reaction products and the system stability. That is why micromixing affects rapid reaction processes.

Therefore, considering the application status, research status of large-blade impellers in rapid reactions and the effects of micromixing on the products of rapid reactions, it is extremely essential for micromixing performances of large-blade impellers to be studied. In this article, the micromixing performance of the novel LDB impeller in viscous systems was experimentally studied, providing guidance for optimization design of impellers and mixing operations.

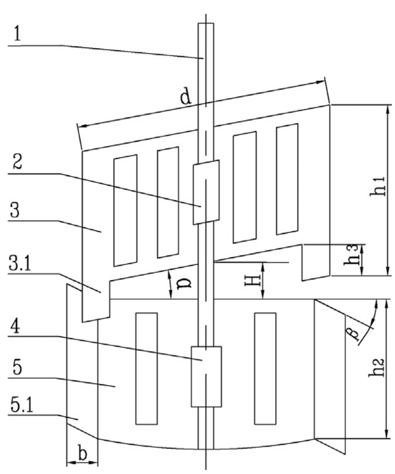

Fig. 1. Structure of novel large-double-blade impeller. 1-stirring shaft, 2-upper shaft sleeve, 3-upper blade, 3.1-extension plate, 4-lower shaft sleeve, 5-lower blade, 5.1-flanged plate.

2. Structure of LDB impeller

LDB impeller, a new type of wide-adaptability stirrer based on FZ and MB impellers, is composed of upper and lower blades fixed on stirring shaft by upper and lower shaft sleeves. As shown in Fig. 1 (Xu and Lin, 2011), the two blades are arranged with certain axial distance and angle, both of which have symmetrical grids. The upper blade is equipped with extension plate at the lower tips, while the lower blade, whose bottom shape matches the structure of channel-head, has flanged plates in the periphery.

Structure determines performance. So, unique structure of this novel LDB impeller determines its extraordinary performance advantages, as follows: (1) As a kind of large-blade impeller whose blade projection area accounts for more than 70% of longitudinal area of the whole tank, this new impeller combines the virtues of MB and FZ impeller, shows good adaptability in various systems,flow regimes and occasions (Liu et al., 2013; Liu et al., 2013). (2) The upper blade is π- shaped, whose extension plate can promote fluid flow between the upper and lower blades. (3) The flanged plates in the lower-blade periphery are favorable for strengthening radial flow. (4) α represents the angle between the upper and lower blades. H is their axial distance. C is the distance of the lower blade from the bottom of vessel. Adjusting their values could improve fluid circulation in the stirred tank, optimize flow pattern and reduce power consumption. (5) Symmetric grids on the blades play a positive role in shearing and fine grinding fluid as well as power consumption reduction. (6) Large fluctuation of liquid level is allowed. It can maintain efficient mixing characteristics. Moreover, it also has advantages of simple structure and convenient processing.

3. Experiment

3.1. Experimental setup

The experiment was conducted in a PMMA stirred tank with a diameter of 380 mm, equipped with standard elliptical head in the bottom. During the experiment, the stirred tank, with 418 mm high liquid level, had two feeding points of F1, F2 and one sampling point P positioned at the same location as F1. Their specific locations are shown in Fig. 2. The novel LDB impeller was employed. And for reference, FZ and DHR impellers which have wide applications in viscous systems were also used. Structures and main sizes of the three impellers are given in Fig. 3 and listed in Table 1, respectively. The impeller was fixed on the mixing shaft by set screws and was easy to install, dismantle and replace.

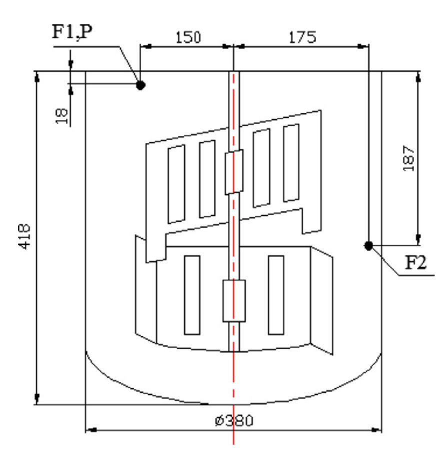

Fig. 2. Stirred vessel structure and feeding points and sampling location F1-feeding point near surface, F2-feeding point in impeller region, P-sampling point.