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Investigation of power characteristics in a novel cup-shaped-blade mixer

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A R T I C L E I N F O

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A B S T R A C T

The impeller performance and energy utilization are closely related to the agitator design. In this article, the power characteristics of the novel cup-shaped-blade (CB) impellers were investigated by using the Newtonian fluid in a stirrer tank, considering the effects of shape parameters, angle of the blades, baffles, agitator speed and physical properties of working fluid. An accurate power correlation for the CB impellers was established. In addition, the CFD method was employed to simulate the power consumption and flow characteristics, and the calculated power value fitted well with the experimental value. The obtained results could provide the basis for the design and scale-up of the CB impellers.

1. Introduction

Mixing in stirrer tanks plays an important role in various industries processes in the field of food, agrichemicals, cosmetics and beverage industries etc [1]. The agitator is a key part in the mixing vessel which directly determines power characteristics and the mixing performance of the mixing system. It is widely recognized that the power consumption is one of fundamental design parameters [2–4]. In recent years, a lot of work has been done on the power consumption for different liquids using various agitators, adopting both experimental and simulated techniques to carry the research on power characteristics. It is desirable to design a new type agitator blade to fulfill the requirements of different situations, besides the applications of existing agitators in multi-combination modes.

The modification of agitators has been reported recently. For example, Roman et al. [5–7] studied the characteristics including power consumption, complete suspension speed and gas-liquid transfer efficiency of a modified blade Rushton turbine in different systems. They found that the modified blade turbine was more efficient than the standard turbine. Niedzielska et al. [8] investigated the power consumption of a ribbon impeller with particular design and found that the geometrical parameters had a significant impact on power consumption and efficiency of agitator. On the other hand, for the high viscosity system, with the first report by Schneider et al. [9], intensive researches on the coaxial mixer were reported by the Canadian Tanguy's group [10–15]. According to different mixed materials and working conditions, they designed and studied a series of new multiple impellers. In their research, the proximity impellers (helical ribbon, anchor) and dispersing turbines pitched blade turbine (PBT), rushton turbine (RT) were used together. The power consumption and mixing performance of coaxial mixers were mainly studied. The results showed that these multiple impellers exhibited excellent mixing performance in many specific situations. At present, there are few studies on novel agitators which have a simple structure but extensive applications. So far no report has been found on the type of cup-shaped-blade (CB) impellers.

Computational fluid dynamics (CFD) has been widely adopted to understand deeply the power consumption, flow field and the turbulent kinetic energy in the stirred tank [16–20], with the precision increased gradually. Thus, the objective of this paper is to study the power characteristics of the novel CB impellers, in combination with the CFD numerical simulation to predict the power consumption and flow patterns. Experimental and simulation methods are performed considering the different parameters, such as impeller geometry (impeller type and blade angle), agitation condition (impeller speed and power) and process condition (working fluid concentration).

2. Experimental materials and methods

2.1. Experimental setup

The experiments were carried out in a pilot-scale transparent tank made from plexiglas equipped with flat bottom, with the agitators mounted centrally. The mixer and the detailed geometrical dimensions are shown in Fig. 1. In the experiments, the liquid height H_L is equal to the tank diameter T and corresponding to a liquid volume of 0.4 m^3. The distance C of CB impellers is $T/4$ whereas that value of PBT and RT

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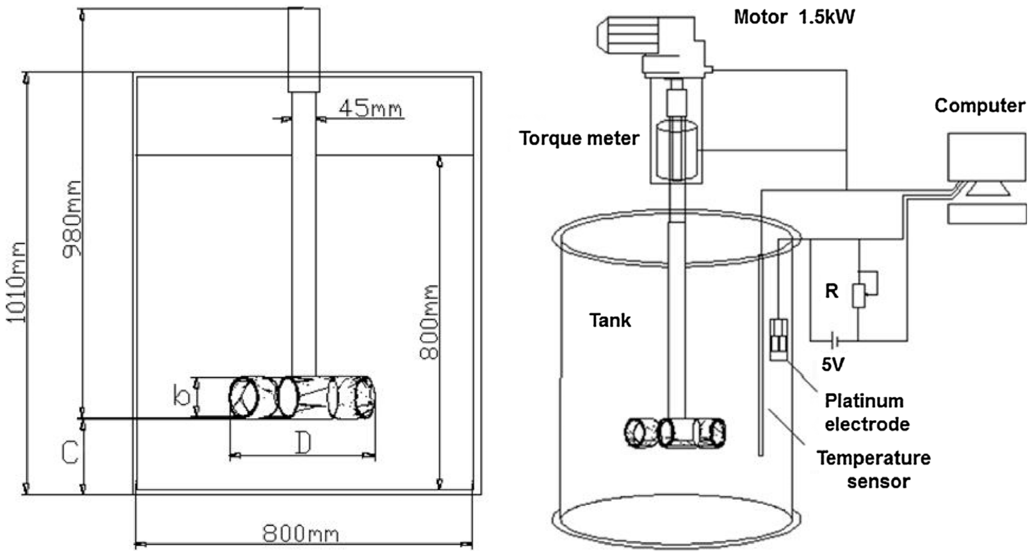

Fig. 1. Schematic diagram of the experimental setup.

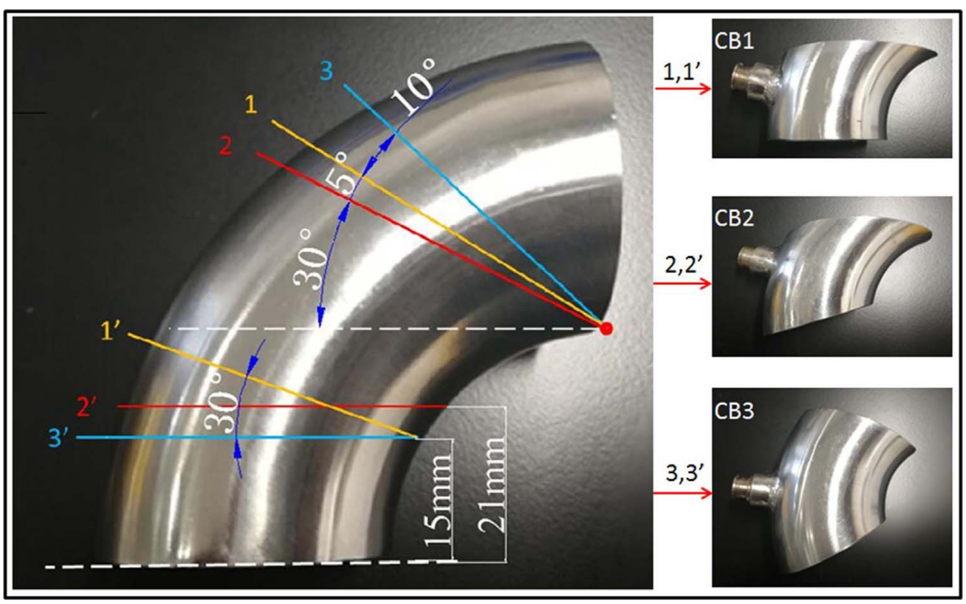

Fig. 2. Schematic diagram of the cup-shaped blades.

is *T/3*. The four removable baffles are *T/10* long, 5 mm thick, 83 cm high and can be installed into the tank every 90°.

Fig. 2 showed the schematic diagram of cup-shaped blades production and blades that were cut by the 90° stainless steel elbow with an inner diameter of 56 mm. Three types of the cup-shaped-blades (CB1, CB2, CB3) provided by FLUKO (China) were studied. The CB impellers consist of three cup-shaped blades and the angles of blades can be adjusted flexibly. Another two widely used impellers PBT and RT were also investigated as comparisons. The impellers and detailed geometrical dimensions are shown in Fig. 3 and Table 1.

2.2. Materials

Malt syrup (70–100 wt%) was employed as the Newtonian fluid, of which the viscosity could be adjusted by adding the pure water [21,22]. The rheological properties of malt syrup were determined by rotational viscometer (Brookfield DV-C). The density of the Newtonian fluids is between 1000 and 1450 kg/m^3, and the viscosity ranges from 0.001 to 4.56 Pa·s. The measurements as well as experiments were performed at 29 ± 1 °C. Table 2 lists the specific experiment conditions.

2.3. Methods

The power number is a reliable design specification in the mixing operation and has been widely used to predict the process results, following the first report of power consumption on 1934. Recently, Chapple et al. [4] studied the power consumption of PBT, RT through accurate torque measurement techniques and performed the generic power number curves. Liu et al. [22] studied the power consumption of a double inner impeller and the power curves under different conditions. Tanguy et al. [10] studied the power consumption of the blade-helical ribbon impellers at different speeds and performed a generalized power curve.

To determine the power consumption, the motor has been coupled to the torque sensor and the power could be calculated from the torque. The net power consumption can be obtained by the following formula