The Stirring Property Research on a Biaxial Agitator Propeller

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Abstract. To the special requirements of Polymer Chemical Industry, a kind of new type co-axial combined impeller was presented. Experimental investigation on mixing property of the impeller were performed, compared with the two-layer turbine and the anchor paddle, and the fluid field velocity distribution was studied with the PIV system. The result shows that mixing time of the combined impeller was reduced about 48.53% compared with two-layer turbine’s, and also uniform mixing was obtained in CMC solution. In the same Pv, the mixing efficiency of the combined impeller was six times than anchor paddle’s, four times than two-layer turbine’s; In the same speed and diameter, the quantity of fluid flow of the combined impeller was improved about 57.4% than the two-layer turbine’s. The property on axial discharging fluid of the combined impeller was better than radius’s; when the outer gate paddle was rotating, the vortices radius of the mixing solution become lager.

1. Introduction
Stirring equipment accounts for a large proportion of the process equipment in the petrochemical, chemical, pharmaceutical, pesticide, food, daily chemicals and cosmetics industries. For example, in the production of the three synthetic products of chemical industry, 90% of the reaction equipment is stirring equipment, and it accounts for 5%–25% of the whole process equipment [1]. The agitator propeller can be divided into radial flow agitator propeller and axial flow agitator propeller according to the flow pattern of fluid flow. The radial flow agitator propeller has strong shear effect at the blade end, forming turbulent diffusion, which is beneficial to stirring, however, it is also easy to divide the medium of the reactor into two circulation zones with the agitator as the boundary at the same time. In general, the interval stirring time is more than 10 times that of the in-zone stirring time, which makes the cycle stirring more difficult. The axial flow agitator propeller can make the fluid produce axial flow and strong circulation ability, but the shear capacity is weak and the local stirring effect is poor. In order to give full play to the advantages of each single agitator propeller, a hybrid flow biaxial agitator propeller is developed.

In order to obtain good stirring effect in the polymerization process, and the agitator with simple configuration, high efficiency and low consumption can be provided for industrial production, in view of the engineering characteristics of 40 kt/a polystyrene plant in Fushun Petrochemical Company being expanded to 100 kt/a, a new type of biaxial agitator propeller has been developed and compared with two types of bilayer pitched-blade agitator propeller and frame agitator propeller. [1] [2].
2. Experiment

2.1. Working Principle
The structure of the biaxial agitator propeller is shown in figure 1. It is composed of two parts: the inner propeller and the outer propeller. The inner propeller is made up of a bilayer straight blade propeller with an inclination of 45°, and the outer propeller is composed of an outer frame and a blade similar with an anchor agitator propeller. The blades are bilateral mounted on the outer frame, one piece each side, and torsion to 45°, while the direction of torsion is opposite to that of the inner propeller. The outer propeller is fixed to the upper part of the inner propeller shaft. The width of the inner and outer propellers equals to the width of the gap between the blades. The outer and lower frames of the propeller are close to the reactor wall, and a PTFE scraper is installed on the side near the reactor wall. When starting work, the inner propeller rotates counter-clockwise, and the outer propeller rotates clockwise. The two propellers are respectively connected with concentric biaxial axis, and their rotational speed can be adjusted. The structural characteristics of the biaxial propeller are composed of the flat and pitched-blade straight blade propellers, the anchor propeller and the baffle, meanwhile, the dead-angle effect caused by the baffle is also solved.

![Figure 1. Structure scheme of biaxial agitator propeller](image)

2.2. Main Raw Material
Carboxymethyl cellulose (CMC, brand is FVH 6, from China Zhangjiagang Sanhui Chemical Plant), configured into 4% aqueous solution. The consistency coefficient and rheological behavior index of CMC aqueous solution are 0.9793 N .s 2/m 2 and 0.3839 respectively which are determined by RheoStress 600 rotary rheometer made by Haake company in Germany.

2.3. Instruments and Equipment
The geometric dimensions of the bilayer pitched-blade propeller are as follows: Dj/Di is 0.56, in which Dj as the diameter of the propeller, Di as the inner diameter of the reactor; h, which is the spacing between two sloping blades is 190mm; the number of blades is 2 and the angle of blade inclination θ is 45°. For anchor propeller: Dj/Di is 0.98; H / Dj is 0.48, in which H is the height of anchor propeller; b / Dj is 0.1 and b is the width of anchor propeller.

2.4. Analysis and Testing
The stirring time is determined by iodide discoloration method. The reactants are iodine and Sodium thiosulfate [3].

The stirring power (Pv) is determined by directly measuring the torque of the stirring shaft. The AKC-l1 torque sensor produced by Beijing Aerospace Industry 701 Corporation is used to measure the torque and the voltage signal comes from the recorder.
The discharge quantity \( q_d \) is measured by the tracer particle method [3]. The stirring medium was water; the tracer particles are the pellets of the diameter of 5 millimetres and their density are similar to which of the agitating system. For the biaxial agitator propeller, the discharge quantity is the times that the pellets were discharged from various blades in a certain time. In formula \( q_d = \frac{mV}{t} \), \( m \) is the discharge times, \( V \) is the volume of the actor and \( t \) is the stirring time.

Stirring flow field. The velocity distribution of the flow field of the biaxial agitator propeller is measured by the Flow Map digital particle imaging velocimetry (PIV) system produced by Dantec Company in Denmark. Then the collected images are processed by Flow manager software [4] [5].

3. Results and Discussions

3.1. Stirring Time

Fig 2 shows that in CMC aqueous solution, the stirring time of the biaxial agitator propeller is about 48.53\% shorter than that of the bilayer pitched-blade propeller. In addition, Local shear mixing effect of bilayer pitched-blade propeller is better, while dead zone still exists in the bottom of the stirring tank due to the poor axial circulation capacity since the small size of the propeller and the larger viscosity of the liquid result in the stirring strength suddenly decreases at a certain distance from the blade, forming a stagnation ring. At low speed, the stirring time of the biaxial agitator propeller is slightly longer than that of the standard anchor propeller. This is mainly due to the lower rotational speed of the outer frame propeller of the biaxial agitator propeller, which makes the convection stir of the whole tank fluid slower. With the increase of the speed of the outer propeller, the convection stir of the fluid is improved rapidly, and the stir of local shear turbulence is also strengthened. Therefore, the stirring performance of the biaxial agitator propeller is better than that of the anchor propeller when the speed is higher. It is also found that there is no dead zone in the reactor and the mixture is homogeneous when the biaxial agitator propeller is used to mix the materials, while there is a dead zone in the paraxial part when the anchored propeller is used.

![Figure 2. Relationship between Re* and N0m in different type of agitator propeller](image-url)
3.2. Stirring Efficiency
The energy consumption is an important index to evaluate the agitator propeller, and its parameter is stirring efficiency [6]. Its expression is:

\[ C_4 = \frac{W_v \theta_m}{\mu_a} \]

In the formula: \( C_4 \) is stirring efficiency; \( W_v \) is stirring energy per unit volume; \( \theta_m \) is macroscopic stirring time; \( \mu_a \) is the apparent viscosity of material. The lower \( C_4 \) value is, the higher stirring efficiency is.

It can be seen from Fig 3 that the stirring efficiency of the biaxial agitator propeller is higher than that of the other two types of propeller in condition of the same \( P_v \), and the average values of the measured data are about 6 times of that of the anchor propeller and 4 times of that of the single inner propeller. This indicates that the biaxial agitator propeller can not only improve the macroscopic stir of viscous materials, but also have the effect of saving energy and reducing consumption.

3.3. Stirring Flow Field
For mixed liquids, the study of stirring flow field is the core of stirring technology stirring [7]. As is revealed in Fig 4, the axial velocity variation of the flow field is larger than that of the radial velocity. The maximum velocity of the axial velocity variation is about 12 times than the minimum speed while the variation of radial velocity is gentler when the speed of the propeller is 120 r/min and the speed of the outer propeller is 0. The results show that the axial discharge capacity and stirring ability of the biaxial agitator propeller are stronger, however, the axial stirring unevenness is larger, and the radial discharge ability and stirring ability are relatively weak. The maximum axial velocity of the flow field is about 9 times that of the minimum when the rotating speed of the propeller is 100 r/min and the speed of the propeller is 10 r/min. The variation amplitude of the axial velocity decreases and the heterogeneity of the axial stirring is improved. In addition, under the second condition, the vortex radius produced by the biaxial agitator propeller is larger than that of the former (the velocity at the trough is the smallest, which is the center of the vortex, and the maximum velocity is the outermost edge of the vortex). This indicates that the rotation of the outer propeller is beneficial to the increase of the radius of the stirring vortex and the increase of the mixed fluid involved, which makes the fluid in the reactor fully stirred.
4. Conclusion

Within this study, we acquired the final analysis:

(1) In CMC aqueous solution, the stirring time of the biaxial agitator propeller is about 48.53% shorter than that of bilayer pitched-blade propeller, and the material stirring is homogeneous.

(2) Under the same Pv condition, the stirring efficiency of the biaxial agitator propeller is 6 times higher than that of the anchor propeller and 4 times than that of the bilayer pitched-blade propeller.

(3) The axial discharge capacity and stirring ability of the biaxial agitator propeller are stronger than that of the radial direction, and the radius of the stirring vortex in the flow field increases when the external propeller rotates.

Acknowledgments

This work was financially supported by “NHKY-2017-12” fund.

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