

# Flow Characteristics Analysis of A New Combination Agitator Based on CFD

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**Abstract:** The computational fluid dynamics (CFD) method was used to simulate the velocity distribution, turbulent kinetic energy distribution and power consumption characteristics of two new types of large-blade combined agitators and traditional single-blade six-blade disc turbines designed for EVOH polymerization kettle in a factory. The results show that the new type of large-blade combination agitator has a better bottom turbulent kinetic energy effect, which can effectively avoid the stirring dead zone caused by single-layer stirring. At the same speed, compared with six-straight blade disc turbines, the torque and unit energy consumption of the two types of large-blade combination agitators are higher, but the effective stirring ratio is also increased by 31% and 30.8%, which can enhance the stirring effect.

**Keywords:** Large-blade combined agitator, Six straight-blade disc turbine, Effective stirring ratio, Numerical simulation.

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## 1. Introduction

Mechanical stirring is a common mixing technology, widely used in petroleum, chemical, food and other industrial production. In actual production, single-layer agitator is often used, but its function is relatively simple, performance is insufficient, in complex production conditions, mixing production efficiency is low, stirring range is insufficient. To solve such problems, different types of agitators are usually combined according to their different characteristics. The combined agitators can effectively improve the mixing effect and apply different complex conditions to improve production efficiency. [1]

At present, many scholars have studied the mixing process of composite agitator through computational fluid dynamics. Zhao Jing [2] used particle image velocimetry (PIV) technology to measure the mixing process in a three-layer combined paddle agitator, and carried out CFD simulation of its flow characteristics with the standard  $k-\epsilon$  model. The verification shows that the prediction of flow field is more accurate with the standard  $k-\epsilon$  model. Zhou Yongjun [3] studied the influence of different layer spacing and bottom height on flow field characteristics in stirred kettle with a three-blade swept-Hedt combined paddle by numerical simulation method. Liang Yingna [4] simulated the flow field distribution of a double-layer hexastraight blade paddle in a stirring tank by using the numerical simulation method, and verified the accuracy of the simulation results through the tracer particle method. Zhang [5] used CFD to study the influence of impeller combination on gas power consumption and volume mass transfer coefficient in flapper type gas-liquid-solid stirred kettle. Yang [6] used computational fluid dynamics to analyze the gas-liquid mixing process of Rushton impeller with double-layer misaligned blades in a baffle stirring vessel. Luo Song [7] used CFD software to analyze the three-layer impeller composed of the folding blade

impeller, the four-straight blade disc turbine impeller and the six-fold blade open turbine impeller, and discussed the influence of different placement positions of the blades on mixing and diffusion. Ding Yang [8] used the Euler multiphase flow method to study the influence of the combination form and placement Angle ( $\theta$ ) of different blades on the suspension state and power consumption of solid particles in a double-layer combined agitator in solid-liquid two phases. CFD software can be used to simulate the flow field of agitator in the mixing tank more accurately.

In recent years, Japan and many developed countries have developed many new agitators for the actual needs, among which the maximum blade agitator designed can be better applied in the reaction of various viscosity, because it can run smoothly in all wide viscosity domain, does not need to take into account the change of viscosity during the process, is widely used in polymerization reaction. [9]

In this paper, based on the research of domestic and foreign scholars, the stirrers with straight edge and flanged edge and four oblique blades are produced and used in a factory. The standard  $k-\epsilon$  model is used to simulate the velocity distribution and turbulent kinetic energy distribution of the stirrers in the stirring tank. The stirring performance and power consumption characteristics were studied and compared with the traditional single-rotor six-straight blade disc turbine, in order to provide a basis for the use of a new large-blade combination agitator and a theoretical basis for the design of a combination agitator that can improve mixing efficiency.

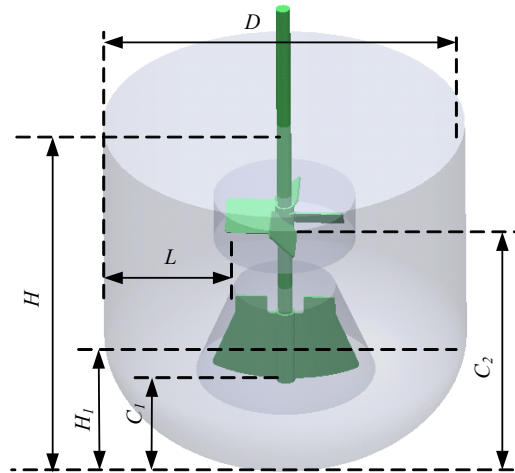
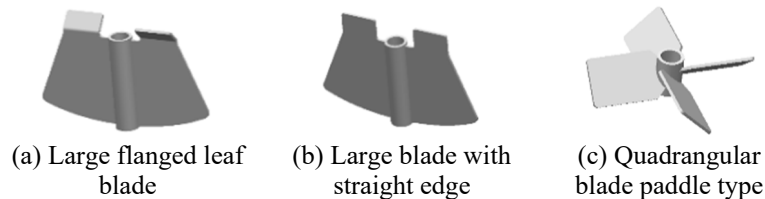
## 2. Numerical Simulation

### 2.1. Structure of agitator

The geometric model of a new large-blade combined agitator used in EVOH reactor in a factory in this paper is shown in Fig 1 and Fig 2, and the main parameters are shown in Table 1.

**Table 1.** Main structural parameters

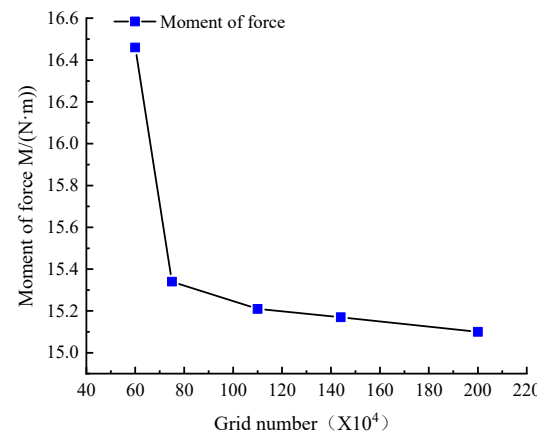
Name	Dimension(mm)
The height of the kettle body $H$	600
Autoclave diameter $D$	600
The distance between the ear of the blade and the wall of the mixing tank is $L$	215
Bottom oval head height $H_1$	200
Lower agitator mounting height $C_1$	110
Upper agitator mounting height $C_2$	400

**Figure 1.** Geometry of stirring tank**Figure 2.** Model of large-blade combined agitator

## 2.2. Meshing

In the actual stirring process, the fluid in the moving region of the stirred tank changes constantly with time, and the fluid in the moving region of the stirred tank also changes with time. Therefore, in order to solve the problem of data transmission in the flow region in the steady-state analysis, the multi-reference frame method (MRF) is adopted to import the fluid model into the DM and divide it into the dynamic region and the static region. An unstructured tetrahedral mesh was used to divide the agitator and the agitator tank model, and the mesh of the agitator blade region was encrypted. Four mesh schemes were obtained, and the number of mesh cells were 300,000 (I), 750,000 (II), 1.1 million (III), 1.44 million (IV), and 2 million (V), respectively. The stirring torque of agitator at  $300 \text{ r}\cdot\text{min}^{-1}$  was analyzed, and the results were shown in Fig 3.

The torque variation of scheme III, IV and V is less than 3%, so the precision requirements can be met when the number of grid units of large-blade combination agitator is about 1.44 million. Similarly, the six-straight blade disk turbine agitator grid is divided into 2.5 million pieces.

**Figure 3.** Mesh independence verification

## 2.3. Governing equation

The governing equation of fluid follows the three laws of conservation of mass, momentum and energy. In this study, the influence of the combined agitator structure on the flow field is mainly considered, and the energy equation is closed without considering the effect of temperature. The turbulence model uses the standard  $k-\epsilon$  model. [10]

## 2.4. Simulation method

In order to ensure the accuracy of the calculation, multiple reference frame model, SIMPLE algorithm and first-order upwind difference scheme were used in this calculation, and the residual convergence of equations of all variables was  $10^{-4}$ . [11]

## 2.5. Boundary condition setting

According to the standard stirrer speed of  $10\sim 300\text{ r}\cdot\text{min}^{-1}$ , the fluid speed  $N$  in the stirring region is set at  $300\text{ r}\cdot\text{min}^{-1}$  in order to ensure adequate stirring. The contact surface between the static area and the moving area is defined as the interface interface to ensure the data transmission of speed and pressure. Agitator, stirring shaft, stirring tank wall surface, are set as static wall surface boundary; The rotation speed of the agitator relative to the region is 0; The absolute rotation speed of the stirring shaft is set at  $300\text{ r}\cdot\text{min}^{-1}$ ; The top of the stirring tank is connected with the atmosphere and is set as the free liquid level.

## 3. Results and Discussion

### 3.1. Analysis of velocity in stirring tank

The longitudinal axial section of the agitator is selected as the observation object. Fig 4 shows the streamline and velocity cloud diagram of the axial section formed by two new types of large-blade combined agitators and six-straight blade disc turbine agitators after they are fully stirred in the mixing tank at the rotating speed of  $300\text{ r}\cdot\text{min}^{-1}$ . Fig 5 shows the velocity vector diagram of the agitator formed in the mixing tank.

As can be seen from Fig 4, under the same rotational speed,

the maximum velocity of several agitators is not different, and the closer to the edge of the agitator, the greater the velocity. The mixing range of the large-blade combination agitator is larger than that of the single-blade mixer, and there is still a small low-speed area at the bottom of the large-blade combination agitator.

Fig 4 show that during agitation, water flows along the tangential direction of the agitator to the wall of the stirring tank, and is affected by reflection and gravity on the wall, so that the liquid moves tangentially along the normal direction of the blade, forming a bottom-up circulating water flow. In the flow field, a vortex ring will appear at the position above and below the blade, and eight vortex rings will be generated in the agitator of two kinds of large-blade combination, and there are four vortex rings in the agitator of six-straight blade disc turbine. This is because the beveled edge structure of the new large-blade structure causes the water in the tank to generate a central axial vortex under the action of gravitational acceleration and tangential velocity during agitation. Part of it interferes with the eddies produced by the agitator in the upper part along the wall, forming a bottom-up circulating water vortex and generating a boundary. The lower water flow is reflected from the bottom to form a small vortex. Through the design of its arc edge and bevel edge, the distance between the fluid and the wall is increased, thus generating a large vortex ring.

Compared with the six-straight blade disc turbine agitator, there are shapeless but continuous vortices at the bottom of the mixing tank for the two kinds of large-blade combination agitators. Moreover, these vortices interact with each other to make the bottom constantly mixed, thus reducing the area of  $0\sim 0.607\text{ m/s}$  at the bottom, and thus improving the mixing efficiency of the agitators.

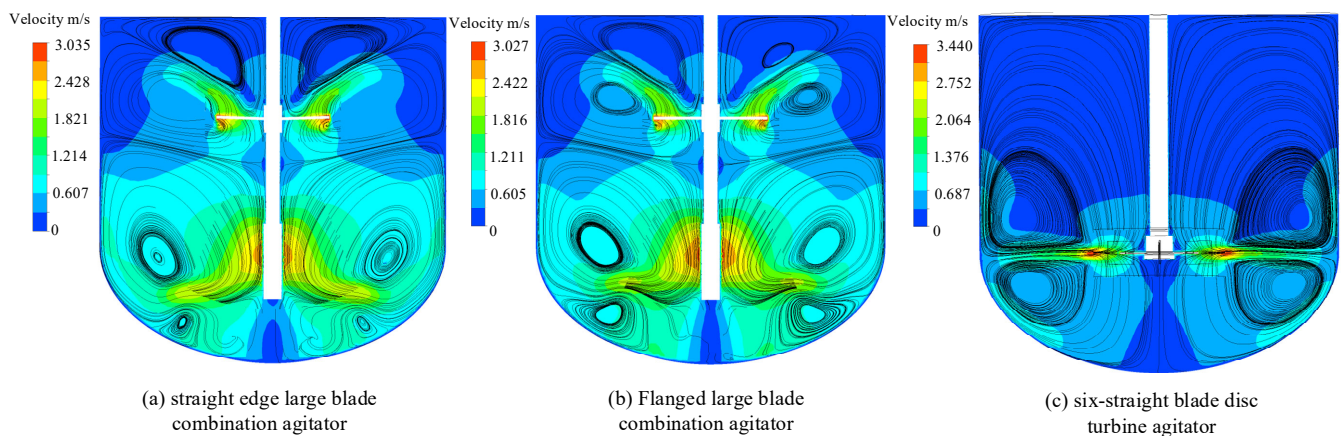
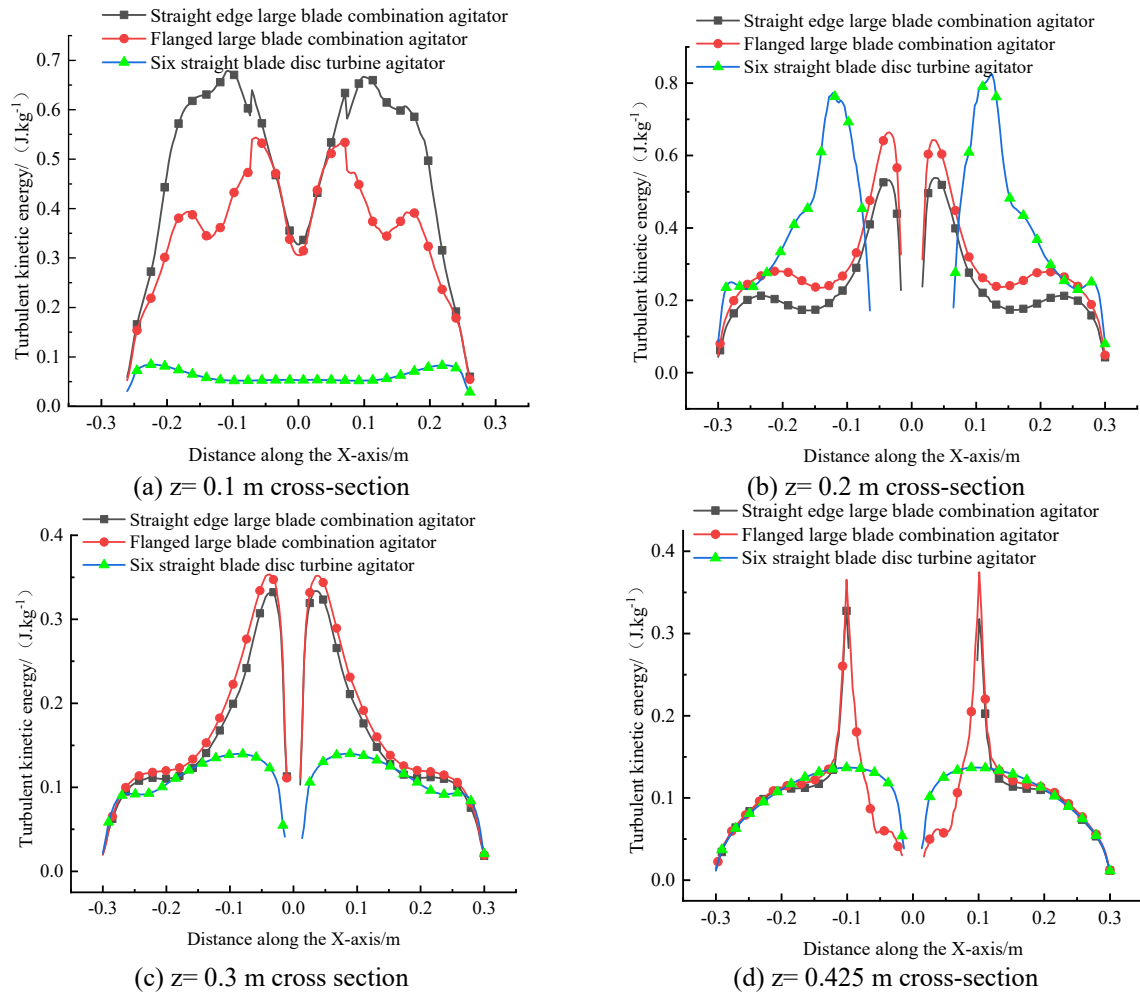


Figure 4. Axial section streamline and velocity cloud of agitator ( $N=300\text{ r}\cdot\text{min}^{-1}$ )

### 3.2. Turbulent kinetic energy distribution

In stirring simulation, turbulent kinetic energy can reflect stirring degree. This time, the cross sections of  $z=0.1\text{ m}$ ,  $0.2\text{ m}$ ,

$0.3\text{ m}$  and  $0.425\text{ m}$  were taken to observe the distribution changes of turbulent kinetic energy in radial positions, and its values are shown in Fig 5.



**Figure 5.** Radial variation of velocity in stirring tank

According to the combined analysis of Fig 4 and Fig 5 a combination agitator with a large blade and a straight edge at the bottom has the maximum turbulence kinetic energy and the best mixing effect compared with other positions, and a six-straight blade disc turbine agitator is prone to a dead stirring zone at the bottom. The agitator with straight edge and large blade with the same bottom distance has a wider stirring range at the bottom, greater turbulence energy and better mixing efficiency at the bottom than the agitator with folded edge and large blade.

It can be seen from Figure 5 (b), (c) and (d) that the turbulent kinetic energy of the three agitators changes similarly, with a trend of small in the middle and large around, and the turbulent kinetic energy at the edge of the agitator reaches the maximum. The turbulence of the six-straight blade disc turbine agitator at the agitator position is severe and the energy consumption is large. Due to the large contact area of the large-blade combination agitator, the turbulent kinetic energy is distributed more evenly in the stirring tank, and the energy transfer is wide, so the stirring effect is better.

By comparing the velocity distribution of the three

agitators with the turbulent kinetic energy distribution at different positions, the large-blade combination agitator can effectively improve the turbulent kinetic energy at the bottom of the stirring tank, and its bottom turbulence is strong. In the full flow field, the stirring range is large. Compared with the six-straight blade disc turbine agitator, the bottom turbulent agitation of the large-blade combination agitator is stronger, the stirring range is wider, the velocity distribution is more uniform, and the mixing effect is better.

### 3.3. Mixing volume distribution

For better quantitative analysis of motion velocity, the region less than 1.5m /s is defined as the low-speed region, and the region greater than 1.5m /s is defined as the high-speed region. The fluid volume with flow rate < 0.15m /s is regarded as the dead stirring zone, and the fluid volume with flow rate  $\geq 0.15m /s$  is regarded as the effective stirring volume of the agitator,  $\eta$  is the effective stirring ratio. [12] Effective agitation of large-blade combination agitator and six-straight blade disc turbine agitator is shown in Table 2. The speed regions of different agitators are shown in Table 3.

**Table 2.** Effective stirring ratio

agitator	Straight edge large blade combination	Flanged large leaf combination	Six straight blade disc turbine
$\eta/\%$	93.430	93.126	64.414

It can be calculated from Table 2 that when the rotational speed is 300 r·min<sup>-1</sup>, the effective mixing volume of the two

kinds of large-blade combination agitators in the whole mixing tank has little difference, which is 45% and 44.5%

higher than that of the six-straight blade disc turbine. Compared with the single-layer agitator, the effective mixing

volume of the combined agitator is larger, and its mixing effect is more obvious.

**Table 3.** Speed zones of different agitators (%)

agitator	Below 0.5	Below 1	Below 1.5	Below 2	Below 2.5
Straight edge combination	37.168	80.126	91.514	97.676	99.827
Hem assembly	38.668	68.201	91.827	97.504	99.535
Six straight blade disc turbine	65.829	95.995	98.378	99.411	99.723

According to the analysis of Table 3, the proportion of large-blade combination agitators in the high-speed region of a flow field is significantly higher than that of six-straight blade disc turbines at 1-1.5 m/s, with little difference, but the proportion of six-straight blade disc turbines is too large in the slow-stirring region at 0-0.5 m/s. It is found that the mixing effect is better and the distribution of fluid velocity is more uniform.

Combined with the analysis of velocity cloud diagram, it can be seen that the phase of the new large-blade combined agitator is in a smaller range of stirring dead zone. At the same speed, although the maximum speed of the six-straight blade disc turbine is much higher than that of the two kinds of combined agitators, the mixing uniformity and effective mixing are smaller than that of the two kinds of combined agitators. It can be expected that in practical application, the large-blade combined agitator will stir more evenly when it is working. Mixing works best.

Combined with the flow diagram and velocity cloud map, it is found that the mixing of straight edge and large blade is more continuous in the flow line at the bottom than that of the

big blade with folded edge. The mixing of straight edge and large blade is more intense on the bottom, with a smaller range of dead stirring zone and less slow stirring area.

### 3.4. Power consumption characteristic

Stirring power is an important basis for the selection of agitator motor. According to its stirring power, the stirring degree and fluid motion state in the stirring tank can be judged, and the energy required in the stirring process can also be calculated.

$$P_1 = \frac{2\pi nM}{60} \quad (1)$$

Where, M is torque, N·m, which can be obtained directly from CFD calculation; n is rotational speed, r·min<sup>-1</sup>; V is the volume of flow field, m<sup>3</sup>; P<sub>1</sub> is the mixing power, kW; P is the unit stirring power, kW·m<sup>-3</sup>.

The torque value can be obtained by CFD simulation. When the rotational speed is 300 r·min<sup>-1</sup>, the unit energy consumption of the agitator is shown in Table 4.

**Table 4.** Power consumption of agitators

agitator	moment M/(N·m)	Unit power P/(kW·m <sup>-3</sup> )
Straight edge combination	14.65	3.062
Hem assembly	15.17	3.171
Six straight blade disc turbine	9.77	2.041

According to the analysis of Table 4, the torque and unit energy consumption of the combination agitator with folded edge and large blade are the highest, and the effective agitation of the combination agitator with straight edge and large blade is larger under the same power. The unit energy consumption of the large-blade combination agitator is 50% and 55% higher than that of the six-straight blade disc turbine. The unit energy consumption to achieve effective agitation is only 103% and 107% of that of the six-straight blade disc turbine, with a small gap.

## 4. Conclusion

In this paper, the speed distribution and power consumption characteristics of agitators of two new large-blade combined agitators and traditional single-blade six-blade disc turbines are compared by numerical simulation method, and the following conclusions are drawn:

(1) The beveled edge structure of the new large-blade combined agitator increases the distance to the wall surface and generates a large vortex ring through tangential injection of fluid, which expands the stirring range to a certain extent and improves the mixing effect in the stirring tank.

(2) The new large-blade combined agitator has better

turbulent kinetic energy effect at the bottom, which can effectively reduce the influence of stirring dead zone caused by single-layer stirring. Its larger contact area makes the velocity distribution in the flow field more uniform and the mixing effect better.

(3) At the same rotation speed, compared with six-straight blade disc turbines, the torque and unit energy consumption of the two kinds of large-blade combined agitators are higher, but their effective stirring ratio is also increased by 31% and 30.8%. The effective stirring volume is larger, the stirring is more uniform, and the stirring effect is better.

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