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A Study on the Impact of Deflection Angle and Revolving Speed of Stirring Blades on Reactor Flow Field

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Abstract. Stirring blades are the most important part of the reactor. Blades transmit the mechanical energy to the liquid through self-rotation, thus generating high degree turbulences in neighboring areas, and forcing all the liquid to flow inside the tank on a certain route for recycling. This study analyzed the speed deviation and turbulence intensity inside the reactor in case of two or four propeller blades at 45 degree forward, 45 degree backward, or at no deflection angle to explore the impact of different revolving speeds on the flow field inside the reactor. Results suggested that when the blade at positive deflection angle should be applied to generate larger turbulence intensity in the lower flow field to more easily mix relatively weighty particles or quality dispersion.

Introduction

Alloy reactor equipments are important equipment in the manufacturing process of alloy materials. In particular, in the CIGS thin solar cell manufacturing process, reactor is the major manufacturing process equipment in the making of CIGS alloy powder. The reactor stirring blades can be divided into two types: one is the axial flow blade; blender with such blades can make the liquid inside the tank to flow in the direction parallel to blade axis. The other is the radial flow blade, which can make the liquid inside the tank to flow in the direction of the blade radius and tangential direction. The blender structure may differ depending on different slurry systems and stirring purposes. The common stirring blades include the rotary propeller, turbine and propeller blades.

Regarding the physical model of mixture stirring, previous studies have focused on the mixing areas of the stirring blades. In fact, in the areas bordering the stirring blades is where main fluid mixing occurs. Stewart [1] and Remy [2] described and defined the main stirring and mixing process, and suggested that it is difficult to observe and unable to fully understand the main mixing process near the stirring blades. Hence, when discussing fluid disturbance near the stirring blades, most fluid mixing models of the past [3] assumed that the interaction between liquids caused in-homogeneity of fluid mixing, thus leading to formation of fine particle suspension or sediment or the concentration of fine particles and liquid, as well as other mixing phenomena. The mixing in-homogeneity wastes energy and time. Marina [4] considered fluid dynamics, and discussed the

relationship between different geometric shapes of stirring blade and the fluid dynamic viscosity, revolving speed and Reynolds number. Regarding the low-speed stirring studies, Chandratilleke [5] observed the fluid states of particles in the blade stirring based on low speed stirring particle mixing analysis in order to analyze causes of instability and in-homogeneity of high speed stirring, and further predicted the most appropriate stirring time, namely, the optimum design of reactor.

In the mixing and stirring process, mixing index is the basis for the judgment of homogeneity. Hence, many scholars attempted to quantitatively discuss the mixing index. Olsson et al. [6] introduced an important mixing index equation, which used the statistics and image chromaticity. Literature [5] assumed DEM, slurry and suspended particles as two different particles, and placed them inside the reactor. After the stirring and mixing, the specific particles' behavior was observed and tracked to deduce the empirical equation by statistics.

Research Method

This study established a computer simulation analysis model of the alloy reactor stirring system using the computational fluid dynamic principles, and conducted simulation analysis of the fluid fields inside the reactor. It also discussed the impact of different combinations of parameters including blade deflection angle, blade number and revolving speed of the reactor stirring system on the distribution of velocity fields inside the reactor. The parameters are shown in Table 1.

Table 1 Reactor fluid field simulation-related parameter planning

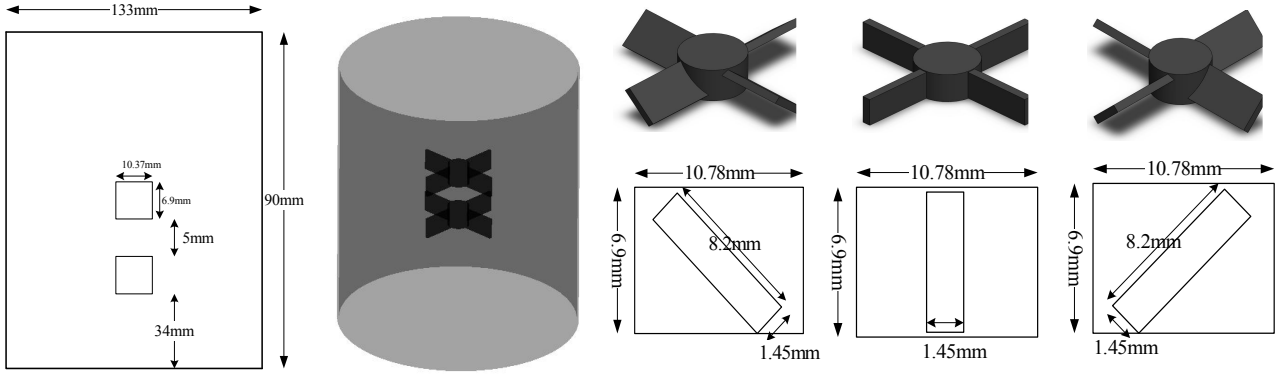
Revolving Speed	300 (rad/sec)		Revolving Speed	150 (rad/sec)	
Case	Number of Blades	Blade Deflection Angle	Case	Number of Blades	Blade Deflection Angle
1	2	-45	7	2	-45
2	4	-45	8	4	-45
3	2	0	9	2	0
4	4	0	10	4	0
5	2	45	11	2	45
6	4	45	12	4	45

This study used the FLUENT software for simulation analysis. The general form of the governing equations is as follows:

$$\frac{\partial(\rho\phi)}{\partial t} + div(\rho\vec{V}\phi) = div(\Gamma_\phi grad\,\phi) + S_\phi \tag{1}$$

Here ϕ represents each of the three air velocity components u,v and w. $\vec{V}$ is air velocity vector, ρ is air density, Γ_ϕ is the effective diffusion coefficient, and S_ϕ is the source term of the general form in the governing equations.

The reactor used the ethylenediamine as solvent and rotated counterclockwise. The turbulence model was the standard $k-\varepsilon$ turbulence model, which is a semi-empirical turbulence model to infer the transmission equation of turbulence kinetic energy (k) and dissipation rate (ε) according to basic physical control equations. The reactor structure and size and the blade shape and size of the reactor stirring system are shown in Figure 1.



(a) Reactor (b) blade deflection angle -45, 0 and 45

Figure 1 Reactor size and Reactor stirring system blade shape and size

To observe the changes in fluid fields inside the reactor, this study selected one point respectively from the upper, middle, and lower part of the blade as the observation point. The field observation points inside the reactor are shown in Figure 2. In addition to using observation points to measure the point speed, the average sectional speed was discussed.

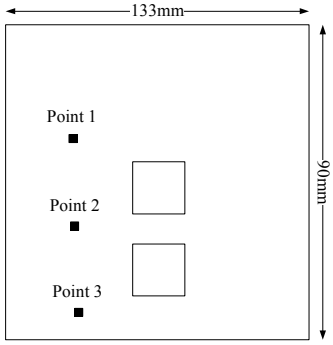


Figure 2 Observation points inside the reactor

This study used the velocity deviation to analyze the mixing homogeneity of velocity field inside the reactor. A section of the reactor was used to discuss the speed deviation, which was defined as shown in Eq. (2). When the speed deviation was large, the gap between the maximum and minimum speeds would be larger. A greater sectional speed deviation leads to larger in-homogeneity of concentration or particle distribution.

$$\text{Speed deviation}=\frac{\left|\text{Maximum Velocity - Minimum Velocity}\right|}{\text{Average Velocity}} \tag{2}$$

In addition to point speed or average speed, this study also discussed the rotating or turbulence speed regarding the mixing homogeneity using turbulence intensity to represent the turbulence strength or rotating strength inside the reactor, as defined in Eq.(3) [6]. When the turbulence intensity was larger, the rotation and turbulence strengths would be larger, thus is beneficial to the mixing or dispersion of particles. On the contrary, when the turbulence intensity was smaller, the particle mixing and mass transfer resistance would be greater and the in-homogeneity would increase.

$$TI = \frac{\sqrt{\left(\left(\zeta_x{}^2 + \zeta_y{}^2 + \zeta_z{}^2\right)/3\right)}}{\overline{V}} \tag{3}$$

where ξ is the standard deviation of changes in speed, $\overline{V}$ is average velocity.

Results and Discussion

The analysis results regarding the impact of number of stirring system blades, blade deflection angle and revolving speed on the flow field velocity and particle concentration are discussed below.

(1) Number of blade

The simulation analysis is conducted on the impact of two or four stirring blades on the stirring flow field of the reactor. The average velocity simulation results of the observation point 2 in the middle of the blade are as shown in Table 2. As seen, the number of blades can affect the average velocity of the stirring flow field. In case of four blades, the average velocity of observation point 2 is greater than that in case of two blades. The trend would be more obvious along with increasing revolving speed.

Table 2 Average speed of observation point 2 inside the reactor flow field in case of different number of blades

Revolving Speed rad/sec	Blade Deflection Angle	Number of Blades	
		2	4
300	-45	0.63	0.75
	0	0.66	1.11
	45	0.59	0.75
150	-45	0.26	0.33
	0	0.33	0.50
	45	0.27	0.33

(2) Blade deflection angle

Regarding the analysis and simulation of the impact of the blade deflection angle at -45, 0 and 45 degree on the flow field inside the reactor, Table 3 shows the turbulence intensity of observation points inside the reactor flow field in case of four fixed blades at different deflection angles. Moreover, the blade deflection angle would affect the reactor flow field distribution. When the blade deflection angle was negative, the flow field velocity at the middle and upper parts of the reactor would be greater and the turbulence intensity would be higher. On the contrary, when the blade deflection angle was positive, the lower part flow field velocity would be greater and the turbulence intensity would be higher. Although deflection angles at negative and positive 45, the values at various experimental points at positive 45 degree were slightly lower than those of the negative 45 degree. As the gravity effect offset partial energy affecting flow or rotation, the impact of blades at positive deflection angle on the upper part velocity and turbulence intensity inside the reactor was slightly smaller than the flow field lower part velocity and intensity of blades at negative deflection angle.

Table 3 Turbulence intensity at various observation points in the flow field of reactor in case of different blade deflection angles and revolving speeds

point1	point2	Point3	Blade Deflection Angle								
Turbulence Intensity (%)			-45			0			45		
Revolving Speed 300rad/sec			14.9	11.2	8.95	12.7	15.0	13.0	7.92	11.1	14.3
Revolving Speed 150rad/sec			8.61	6.32	4.64	7.60	9.10	7.23	4.41	6.00	8.55

(3) Revolving speed

As shown in Tables 2 and 3, the average velocity and turbulence intensity increased along with increasing revolving speed. However, when the revolving speed doubled, the average velocity and turbulence intensity did not double but increased by less than two times. This was because of the partial energy attenuation due to viscosity effect.

Conclusions

To sum up the impact of above parameters of the reactor stirring system on the flow field homogeneity inside the reactor, when the number of blades was four, the velocity at observation points and turbulence intensity were better than those in case of two blades. In this case, the blade at positive deflection angle should be applied to generate larger turbulence intensity in the lower flow field to more easily mix relatively weighty particles or quality dispersion. On the contrary, blades at negative deflection angles should be selected. As far as homogeneity was concerned, blades of higher revolving speed had larger velocity and stronger turbulence intensity.

Reference

[1] Stewart, R. L., Bridgwater, J., Zhou, Y. C. and Yu, A. B., “Simulated and Measured Flow of Granules in a Bladed Mixer”, Chem. Eng. Sci. 2001, 56 (19), 5457–5471.

[2] Remy, B., Khinast, J. G. and Glasser, B. J., “Discrete Element Simulation of Free Flowing Grains in a Four-Bladed Mixer”, AIChE Journal, 2009, 55 (8), 2035–2048.

[3] Kim, J. Y. and Laurence, R. L., “The mixing effect on the free radical MMA solution polymerization”, Korean Journal of Chemical Engineering, 1998, 15(3), 273

[4] Marina, C. and Alfredo S., “Appraisal of Fluid Dynamic Efficiency of Retreated-Blade and Turbofoil Impellers in Industrial-Size CSTRs”, Ind. Eng. Chem. Res. 2002, 41, 1370-1377

[5] Chandratilleke, G. R., Zhou, Y. C., Yu,A. B. and Bridgwater, J., “Effect of Blade Speed on Granular Flow and Mixing in a Cylindrical Mixer”, Ind. Eng. Chem. Res. 2010, 49, 5467–5478

[6] Wang, C. C., Chou, Y. Y., Sheu, S. R., Jang, M. J., Che, J. S. and Huang L. W., ”Flow Field Analysis of Different Types of Blade and Baffle in a Fermentor”, IEEE, 2010, 978-1-4244-5567-6/10.