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CFD Simulations of a Large-Scale Seed Precipitation Tank Stirred with Multiple Intermig Impellers

Guoquan Zhang, Hongliang Zhao*, Chao Lv, Yan Liu, Ting-an Zhang
Key Laboratory of Ecological Utilization of Multi-metal Intergrown Ores of Ministry of Education & School of Materials and Metallurgy, Northeastern University, Shenyang 110819, China

*Correspondence should be addressed to Hongliang Zhao, jayjayzhl@126.com

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Abstract

The three-dimensional multiphase flow in a large-scale seed precipitation tank stirred with multiple Intermig impellers was simulated by CFD method. The flow field, solid particles distribution and power consumption were numerically analyzed by adopting Eulerian Granular Model (GEM) and standard k-ε turbulence model. The tank was improved by lengthening the lowest impeller and adopting sloped baffles which largely promoted the solids suspension and fluid mixing. In the original tank, the maximum of relative solid concentration difference in the whole tank was less than 5% at the minimum rotational speed of 4.8r/min. Although the lowest lengthened impeller cost more power, the minimum rotational speed could be down to 3.8r/min. So in the improved tank, about 40% power could be saved to achieve the same mixing effect. The results have important meaning to industrial design and optimization.

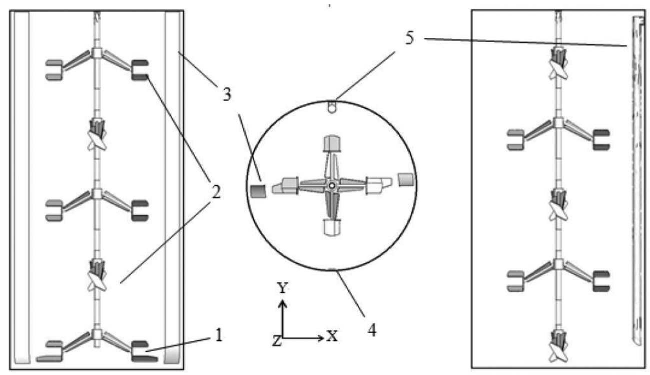
1 Introduction

Solid particles distributions in the whole tank is one of the key point for efficient design of the slurry stirred tank reactors. Many researches have focused on the condition of solids complete suspension. But in most cases of industrial processes, the impeller rotates at a speed that ensures the solid particles are completely suspended, even close to uniformly mixing. So it is notable that the solid particles are uniformly incorporated into liquid and the power consumptions are as low as possible. Many researchers have investigated the solid distributions in the tanks stirred with multiple impellers in laboratory scale.[1-3]

The large-scale mechanical agitated tank with multiple impellers has been widely used in many industrial processes of metallurgy, mining, cement, petroleum, etc., that because of good effect of materials mixing and liquidity, large capacity and low power consumption per unit volume. In this work, numerical simulations have been done on a type of large-scale seed precipitation tank agitated with multiple Intermig impellers, which is widely used in alumina production of Bayer approach. The mixing performance has been compared between the original and improved tank that has significant meaning for equipment improvement in industry.

2 Tank geometry

The cylindrical tank is with a flat bottom and installs two baffles and 5-stage impellers with 90° angle to each other. In the original tank, all the 5-stage impellers are original Intermig impellers and the baffles are vertical. In the improved tank, the lowest Intermig impeller is lengthened and two slopes are added on the bottom of the baffles. Figure 1 shows the structure of the improved tank. The model dimensions and conditions are listed in table 1.



1—lowest improved Intermig impeller, 2—upper original Intermig impellers, 3—sloped baffles, 4—material inlet, 5—feed-pipe, material outlet

Figure 1 Geometry of the seed precipitation tank equipped with five Intermig impellers

Table 1 Model dimensions and material properties

Parameter	Value
tank diameter, T	14m
fluid depth, H	29.5m
Original impeller diameter, D	0.6T
Original impeller diameter, D'	0.714T
Separation distance of each impeller, L	0.7D
Impeller rotational speed, N	1.91~5.80r/min
impeller off-bottom clearance, C	0.026T
baffle width, W_b	0.1T

3 Simulated methods

3.1 Mathematical model

The complex multiphase flows in the large-scale tank are numerically simulated by adopting Eulerian Granular Multiphase (EGM) model coupled with standard k-ε turbulence model[4-5]. The steady-state momentum and continuity equations for the fluid flow are solved without consideration of mass transfer, lift force and virtual mass force. The momentum exchange coefficient of solid-liquid two phase flow is calculated using Gidaspow model[6] whose correctness is validated by many researches on high solid content slurry system[7-8].

3.2 Boundary conditions and numerical methods

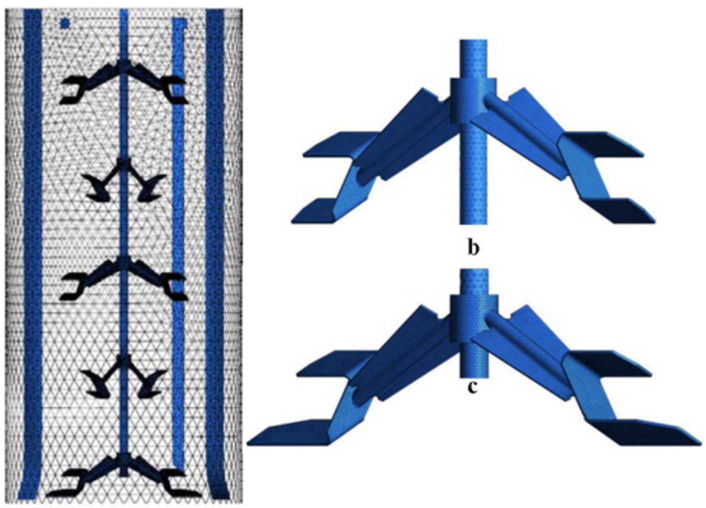
In the computational model, standard wall functions are used on all solid walls and the thickness of baffles is ignored. A steady Multiple Reference Frame (MRF) method[9] is adopted to represent the impeller rotation. The free liquid surface is treated without flux and stress. Velocity inlet with a flow rate of 0.7m/s and pressure outlet under the atmospheric conditions are used in the simulations, which keeps the same with industrial conditions. liquid and solid phases are the $NaAlO_2$ solution and the $Al(OH)_3$ particles respectively and material properties are listed in Table 2.

material	Density (kg/m^3)	Viscosity (Pa s)	Solid hold-up (g/L)	Diameter (μm)
$NaAlO_2$ solution	1330	0.007	-	-
$Al(OH)_3$ particle	2430	-	800	100

Table 2 material properties of liquid and solid phases

3.3 Mesh model

As shown in figure 2b, the Intermig impeller has two parts, the inner pitched blade and the outer double blades, and it is an interference multistage counter-flow impeller. The lower outer blade is lengthened for the improved Intermig impeller, which may promote the solids suspension on bottom region. The models are meshed by tetrahedral meshes, and it is locally refined in rotational domain and around the baffles. Based on the studies of mesh-independent verification, all the subsequent simulations were carried out with about 1200k computational cells. Figure 2a shows the mesh model of the baffled tank stirred with original and improved Intermig impellers.



(a) tank; (b) original impeller; (c) improved impeller
Figure 2 Mesh model,

Mesh independence has been studied in our previous works and the proper mesh number has been confirmed. The above work could ensure that the simulated results are unrelated to the mesh size. And the simulated results have been also verified by water model experiments[10-11].

4 Results and Discussion

4.1 Flow Fields

Figure 3 shows the velocity vector distributions in original and improved tanks at a speed of 4.8r/min. It indicates that a circulation loop is generated between the lowest impeller and the baffle. As show in figure 3a, the circulation loop can’t provide strong upward flows for solids suspension in the original tank. The improved Intermig impeller coupled with sloped baffle (figure 3b) can enhance fluid turbulence intensity and generate strong axial circulation flows circulation loop, which promotes axial exchanges and mixing of fluids. Meanwhile, the solids can obtain more kinetic energy for suspension.

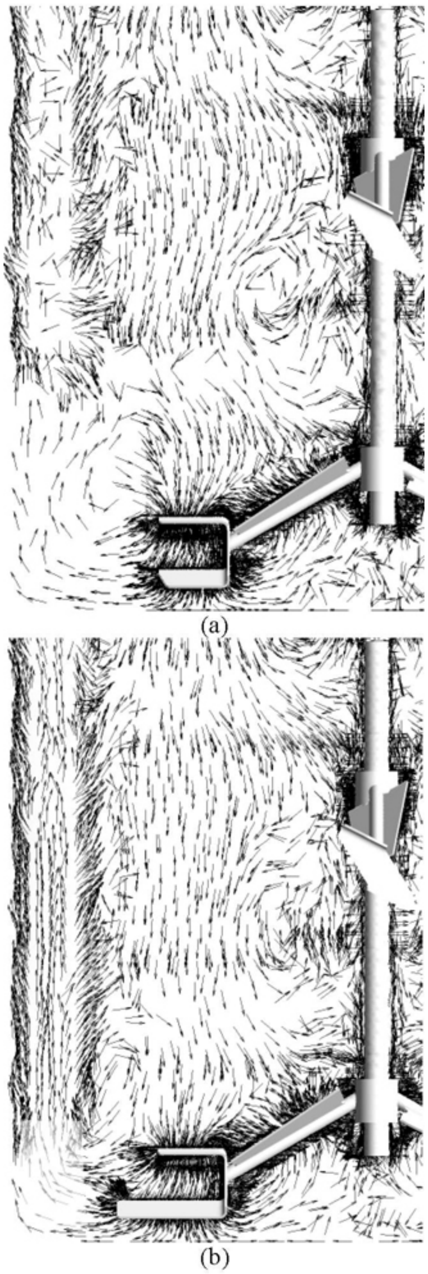


Figure 3 Velocity distributions, y=0 sections, (a) original tank; (b) improved tank

4.2 Solid hold-up distributions

Figure 4 exhibits the axial distributions of solid particles in different radial positions for the two tanks. The simulated axial profiles of solids holdup in the middle parts of the tanks distribute uniformly which indicates that the solids in these positions distributes uniformly and its holdup is nearly equal to the average value (C/C_{avg}=1). The solids holdup is evidently larger near the side wall (r/R=0.9) than it in the centre. And in the original tank, there exists large concentration difference between the liquid surface and the tank bottom. By contrast, the improved Intermig impeller coupled with the sloped baffles promotes homogeneous suspension and distribution of solid particles largely.

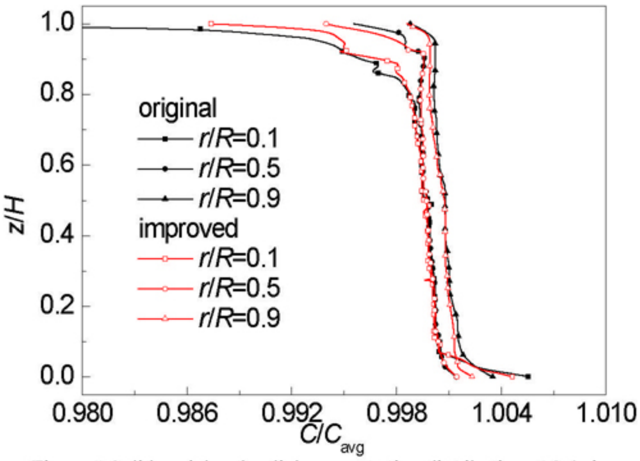


Figure 4 Solids axial and radial concentration distribution, 4.8r/min

In addition, the maximum of solids concentration difference (ΔC_{max}) with different impeller rotational speed (N) shown in figure 5 implies that the ΔC_{max} decreases faster with the increasing of N and it is much smaller at a certain N in the improved tank. In the industry, the ΔC_{max} is usually controlled below 5%, listed in formula (1), which may obtain good mixing performance and $Al(OH)_3$ output. In the original tank, the lowest N to satisfy above indicator is 4.8r/min, which could reduce to 3.8r/min in the improved one.

$$\Delta C_{max}\% = \left(C_{max} - C_{min}\right) / C_{avg} \times 100\% < 5\% \qquad (1)$$

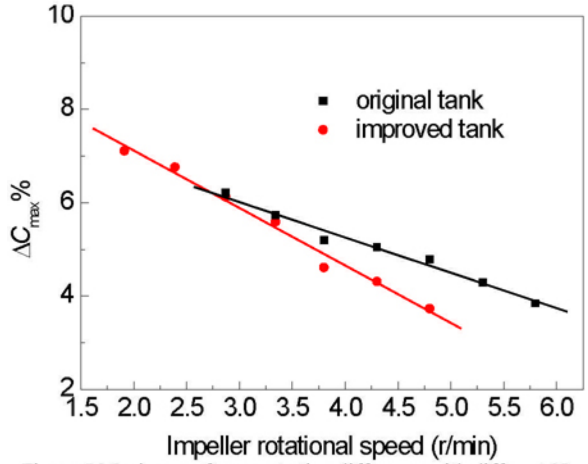


Figure 5 Maximum of concentration difference with different N

The solids distributions on the tank bottom with different N are shown in figure 6. Owing to relatively less interaction between the lowest original impeller and the commonly vertical baffles, the solids on the tank bottom could not get enough kinetic energy for suspension. So much more deposition of solids, especially at low speed, forms near the side wall and around the centre on the bottom where there has poor flowability. On the whole, the improved impeller and specially sloped baffles not only promotes the axial mixing but also improves the solids deposition on the bottom.

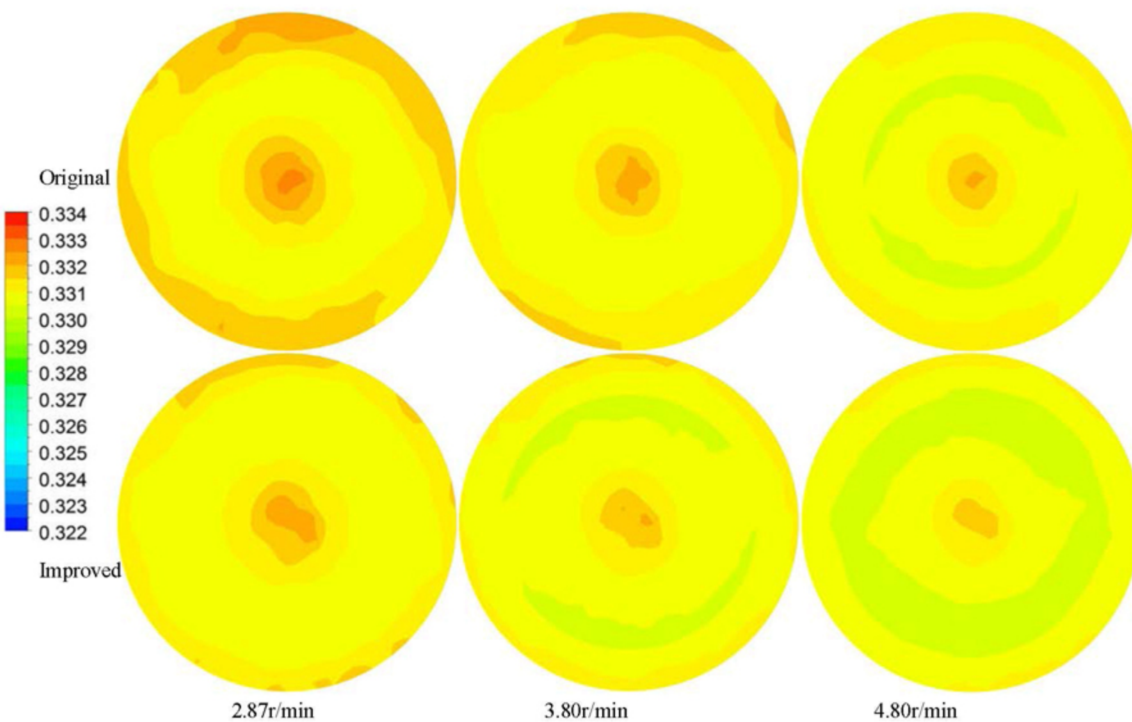


Figure 6 Solids hold-up distributions on tank bottom, z=0 section

4.3 Power consumptions

Figure 7 and 8 show the power consumptions of lowest impeller and the total power with different *N*, respectively. With the increase of *N*, the power grows rapidly, which shows cubic relation. Compared with original impeller, the improved one costs additional power of nearly 60~70%, even more with further increase of *N*, under the same stirring conditions. And the total power increment is also more than 14% in such case. However, under the indicator of $\Delta C_{max}<5\%$, the power is only 35.48kW for improved impeller at 3.8r/min, which is 58.30W for original one at 4.8r/min, and about 40% power could be saved.

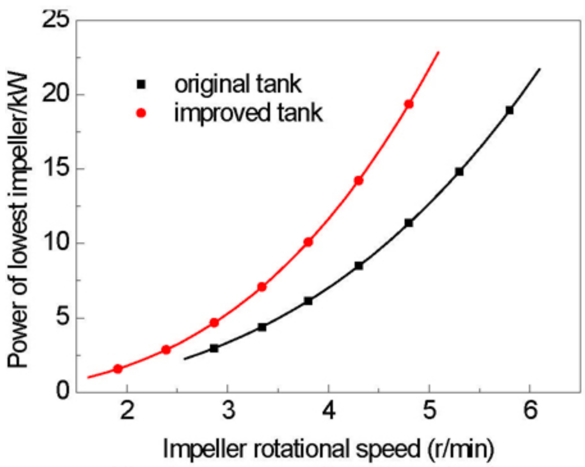


Figure7 power consumption of lowest impeller

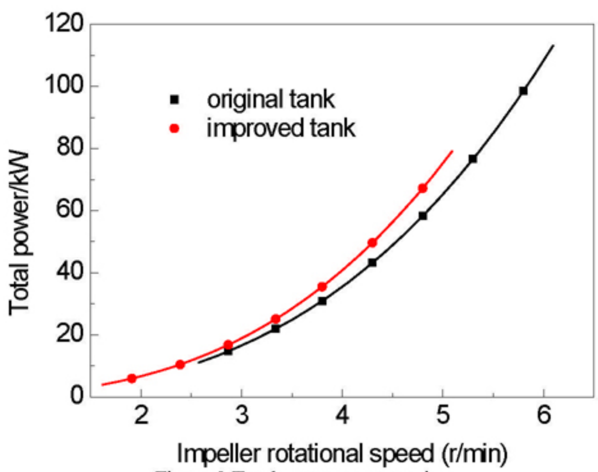


Figure 8 Total power consumption

5 Conclusions

The improved Intermig impeller coupled with sloped baffles could promote fluid mixing and solids suspension, and the maximum of concentration difference in the whole tank could be controlled less than 5% at the minimum rotation speed of 3.8r/min. Meanwhile, compare to the original tank, about 40% power could be saved under the condition of $\Delta C_{max}<5\%$.

Acknowledgment

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