International Journal of Mechanical, Industrial and Aerospace Sciences
ISSN: 2517-9950
Vol:4, No:5, 2010

Numerical Simulation of Flow Field in a Elliptic Bottom Stirred Tank with Bottom Baffles

Liu Xuedong , Liu Zhiyan

Abstract**—**When the crisscross baffles and logarithmic spiral baffles are placed on the bottom of the stirred tank with elliptic bottom, using CFD software FLUENT simulates the velocity field of the stirred tank with elliptic bottom and bottom baffles. Compare the velocity field of stirred tank with bottom crisscross baffle to the velocity field of stirred tank without bottom baffle and analysis the flow pattern on the same axis-section and different cross-sections. The sizes of the axial and radial velocity are compared respectively when the stirred tank with bottom crisscross baffles, bottom logarithmic spiral baffles and without bottom baffle. At the same time, the numerical calculations of mixing power are compared when the stirred tank with bottom crisscross baffles and bottom logarithmic spiral baffles. Research shows that bottom crisscross baffles and logarithmic spiral baffles have a great impact on flow pattern within the reactor and improve the mixing effect better than without baffle. It also has shown that bottom logarithmic spiral baffles has lower power consumption than bottom crisscross baffles.

Keywords**—**Bottom baffle, Flow field, Numerical simulation, Stirred tank.

I. INTRODUCTION

INDUSTRIAL production, particularly in the chemical industry, mixing equipment and mixing operations have a wide range of applications, most of the mixing operations are performed by mechanical stirring. Mechanical stirred tank structure includes a reasonable selection of stirring paddle, stirred tank structure and baffle structure. Study of mixing equipment at home and abroad focused on stirring paddle and baffle structure research has achieved certain results [1]-[6]. It is known that a reasonable selection of reactor, mixing paddle, the type of baffle and baffles in the reactor space allocation can better improve the mixing effect of the stirred tank.

At present, the numerical simulation of the flow field in stirred tank is mainly on the reactor with wall vertical baffle [7]-[12] while the study on the bottom baffle structure is mostly on the stirred tank with flat bottom, such as Guo Duxin [9] and others do experimental research. There is almost no one who studies the numerical simulation of the bottom baffle. The studies on the stirred tank with elliptic bottom and dish bottom are rarely involved in. Baffle structure of research is relatively less and further study is needed. When the crisscross baffles and logarithmic spiral baffles are placed on the bottom of the stirred tank with elliptic bottom, using the software fluent simulates the velocity field of the stirred tank with ellipse bottom and bottom baffle. Compare the velocity field of stirred tank with bottom crisscross baffle to the velocity field of stirred tank without bottom baffle and analysis the flow pattern on the same axis-section and different cross-sections. The size of the axial and radial velocity is compared respectively when the stirred tank with bottom crisscross baffles, bottom logarithmic spiral baffles and without bottom baffle. At the same time, the numerical calculations of mixing power are compared when the stirred tank with bottom crisscross baffles and bottom logarithmic spiral baffles. Research shows that bottom crisscross baffles and logarithmic spiral baffles have a great impact on flow pattern within the reactor and can improve the mixing effect better than without baffle. It also has shown that bottom logarithmic spiral baffles have lower power consumption than bottom crisscross baffles.

Liu Xuedong is with College of Mechanical and Energy Engineering, Jiangsu Polytechnic University. Changzhou, 213016, China (corresponding author: phone: 0086-519-83299226; fax: 0086-519-83290205; e-mail: lxd99@126.com).

Liu Zhiyan is a master student with College of Mechanical and Energy Engineering, Jiangsu Polytechnic University. Changzhou, 213016, China (e-mail: lzyde2006@yahoo.com.cn).

II. NUMERICAL SIMULATION

A. Model Structure

In the same operating conditions, comparing the numerical simulation of the stirred tank with bottom baffles and without bottom baffle were carried out. The structural diagram of the stirred tank with bottom baffles is shown in Fig. 1. The crisscross baffles and logarithmic spiral baffles are placed on the bottom of the stirred tank with elliptic bottom respectively. They are shown in Fig.2 (a) and Fig. 2 (b), respectively.

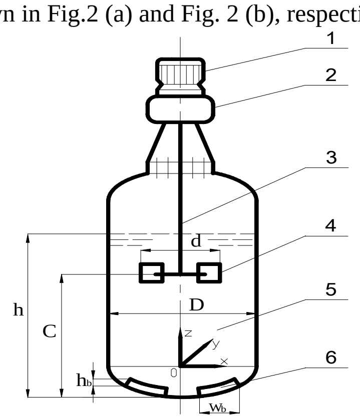
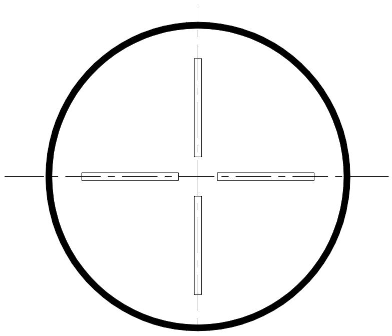


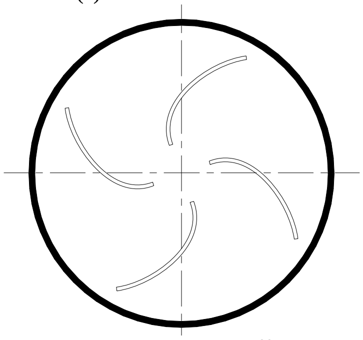
Fig. 1 Structure diagram of stirred tank with bottom baffles

1– motor, 2– speed reducer, 3– stirring shaft, 4– impeller, 5– stirred tank, 6– baffle.

International Journal of Mechanical, Industrial and Aerospace Sciences
ISSN: 2517-9950
Vol:4, No:5, 2010



(a) crisscross baffles



(b) logarithmic spiral baffles
Fig. 2 Vertical view of baffles on the bottom

A. Numerical Simulation of Stirred Tank with Bottom Baffles

a. Hydrodynamic Model

Assuming incompressible fluid, in Cartesian coordinates (x, y, z), the continuity equation is as follows,

$$\frac{\partial \rho}{\partial t}+\frac{\partial(\rho v_x)}{\partial x}+\frac{\partial(\rho v_y)}{\partial y}+\frac{\partial(\rho v_z)}{\partial z}=0 \qquad (1)$$

Where, ρ is the density, kg/m^3. v_x, v_y, v_z is respectively of the velocity component of the direction of x, y, z, m/s.

Momentum, energy and turbulent flow equations are an unified transport equation of the form that is composed of the convection, diffusion and the original items. For the variable ϕ, its transport equation is as follows.

$$\frac{\partial(\rho v_x c_\phi \phi)}{\partial x}+\frac{\partial(\rho v_y c_\phi \phi)}{\partial y}+\frac{\partial(\rho v_z c_\phi \phi)}{\partial z}= \\ \frac{\partial}{\partial x}\left[\Gamma_\phi \frac{\partial \phi}{\partial x}\right]+\frac{\partial}{\partial y}\left[\Gamma_\phi \frac{\partial \phi}{\partial y}\right]+\frac{\partial}{\partial z}\left[\Gamma_\phi \frac{\partial \phi}{\partial z}\right]+S_\phi \qquad (2)$$

b. Creating Model

By using the pretreatment software Gambit, the structural model of the stirred tank, disc turbine impeller and bottom baffles can be established. In the literature [3], we can see that paddle is 0.5 times of the cylinder inner diameter and impeller is installed in the upper part of the tank. The maximum height from the bottom of the stirred tank to impeller can be 0.75 times of the entire liquid level.

Model parameters: The stirred tank inner diameter (D) is 300 mm. The height (h) of the liquid level is 400 mm. The impeller diameter (d) is 0.5D. The height (C) from the bottom of the stirred tank to impeller is 0.7h. According to the literature [13], we can see that the width of the baffle (W_b) is 0.1D, the height of the baffle (h_b) is 0.05D, the thickness of the baffle is 3 mm, the rotational speed of the stirring shaft is 180 r/min.

c. Meshing

Meshing has important impact on the results of the numerical simulation. Considering increasing the stability of convergence, tetrahedral mesh is selected. Using Multiple Reference Frame (MRF) method solves the relative motion problem between the stationary parts and rotating impeller. By this method, the entire computational domain is divided into static region and dynamic region in two parts. In the static region, the grid size is 8 mm and 297,247 grids are generated. In the dynamic regions, the grid size is 2mm and 113,223 grids are generated. Meshing is shown in Fig. 3.

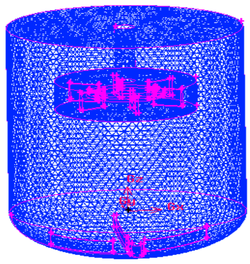


Fig. 3 Model meshing

d. Calculation Methods

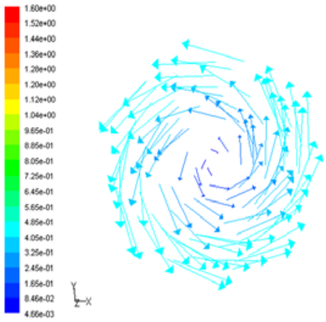
Considering the single phase flow simulation, water is selected as working medium. Using Multiple Reference Frame (MRF) method simulates the flow field. In the steady state conditions, using standard $K-\varepsilon$ turbulence model; the pressure and velocity are coupled by using SIMPLE algorithm; the pressure equation is Standard format and the rest equations are discrete by using an upwind format. The degree of energy convergence is 10^{-6} and the rest are 10^{-3}.

B. Simulation of the stirred tank without baffle

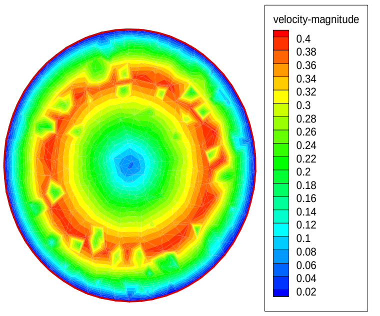
To enhance contrast, the structural model without baffle is built up. Expect baffle, all the parameters are the same as the parameters of the stirred tank with baffle. Its entire simulation methods are fully consistent as the stirred tank with bottom baffles.

III. ANALYSIS OF SIMULATION RESULTS

A. Analysis of Flow Patterns

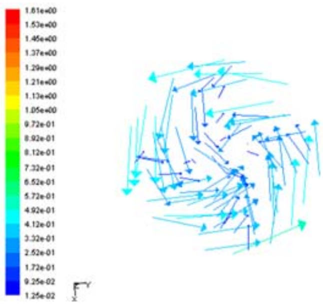


(a) velocity vector

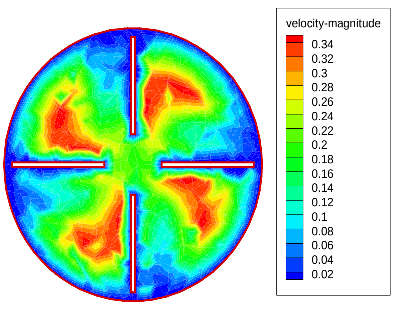


(b) velocity contour

Fig. 4 Velocity field on the cross sectional above 15 mm bottom without baffles



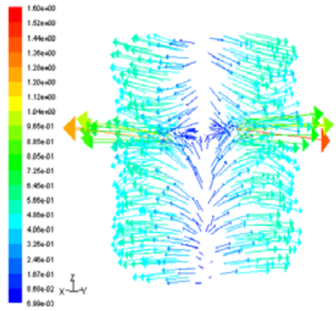
(a) velocity vector



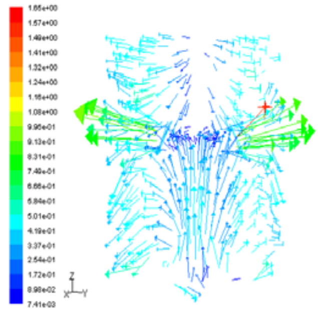
(b) velocity contour

Fig. 5 Velocity field on cross sectional above 15 mm bottom with baffles

From Fig. 4, when there is no baffle on the bottom of the stirred tank, the fluid on the cross section near the bottom of the reactor generates swirling phenomenon. The fluid velocity near the internal wall in the stirred tank is Maximum while the fluid velocity in the center of the bottom is Minimum. When the crisscross baffles are placed on the bottom, the fluid at the center of the bottom of the reactor generates the radial flow from outside to inside as shown in Fig. 5 (a) and Fig. 5 (b). At the same time, Burgess Vortex [14] is generated in the bottom of the stirred tank. The speed near the baffle in the radial between the baffle and the reactor is Maximum. The speed at the bottom center of the stirred tank is larger than the stirred tank without baffle.



(a)

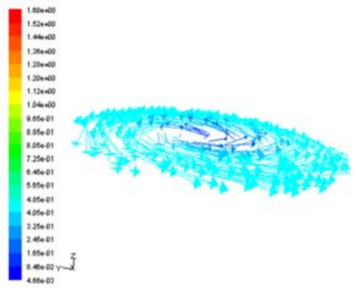


(b)

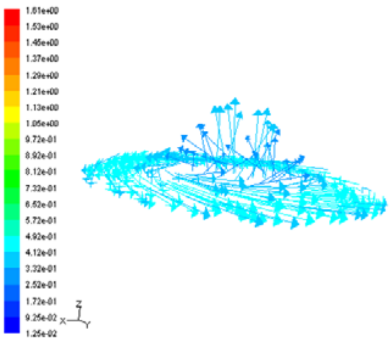
Fig. 6 Velocity vector on axial cross section,
(a) without baffle; (b) with crisscross baffles

From Fig. 6(a), when there is no baffle on the bottom of the stirred tank, the fluid in the entire stirred tank generates a rotary movement around the shaft to form a cylindrical rotary zone. When the fluid is at high velocity, the vortex will form. This flow pattern is called tangential flow. At the same time, the flux from the blade to the blade suction area is smaller and the mixing effect is poorer.

In the stirred tank, there are three basic flow patterns: radial flow, axial flow and tangential flow. Axial flow and radial flow play a major role in the mixing while the tangential flow should be inhibited. In this study, the crisscross baffles and logarithmic spiral baffles on the bottom of the stirred tank with elliptic bottom can weaken the tangential flow and enhance the axial flow and radial flow. After the crisscross baffles are placed on the bottom of the stirred tank, the fluid flow pattern is shown in Fig. 6(b). The flow pattern of the fluid at the center of the stirred tank is spiral-shaped. At the same time, a circle forms. When the radial flow generated by the impeller encounters the wall of the stirred tank, the majority of fluid will move downward along the wall of the stirred tank. After the fluid gets to the bottom of the stirred tank, the fluid will move to the center of the stirred tank along the radial direction from outside to inside. After then, with the lead of the Burgers vortex [8], the fluid reaching the center will move by a spiral upward along axial direction and get to the blade suction area. As a result, a circle forms in the stirred tank. With the lead of this circle, the fluid in the tank can easily get in touching with each other and fully be mixed. There is no dead zone in the whole stirred tank.



(a)



(b)

Fig. 7 Velocity vector on cross sectional above 75 mm bottom, (a) without baffle; (b) with crisscross baffles

In the above circle, the flow pattern is significantly different on the cross section between the impeller and the bottom of the stirred tank. From Fig. 7(a), there is no baffle in the bottom of the stirred tank, the fluid on the cross section which is 75 mm away from the bottom of the stirred tank is rotary-shaped. But From Fig. 6(b), when the crisscross baffles are placed on the bottom of the stirred tank, the fluid at the center of the cross section which is 75 mm away from the bottom of the stirred tank is spiral-shaped. These are the same as the above described that the fluid at the center of the stirred tank generates spiral upward movement.

B. Analysis of Velocity

From Fig. 8, when there is no baffle on the bottom of the stirred tank, the axial velocity of the fluid in the stirred tank is very small and the fluid basically does not move upward along the axis. After the crisscross baffles and logarithmic spiral baffles are placed on the bottom of the stirred tank, the axial velocity of the fluid in the stirred tank increases significantly and the fluid produces an upward axial movement. The axial velocity of the fluid in the stirred tank with logarithmic spiral baffles is larger than the axial velocity of the fluid in the stirred tank with crisscross baffles. The upward axial movement of the fluid is more apparent and the stronger axial flow forms.

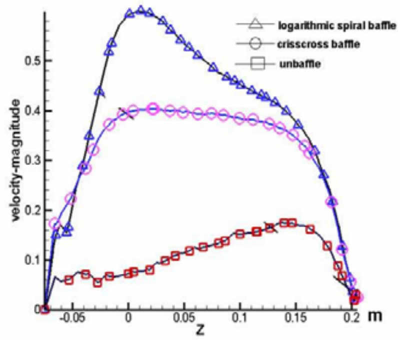


Fig. 8 Velocity profile along z-axis of axial cross section

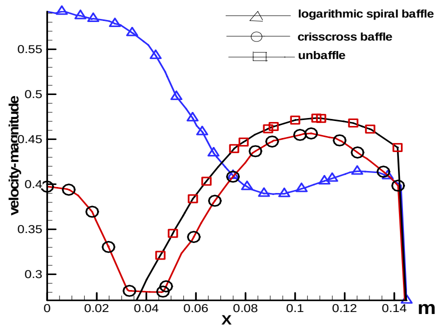


Fig. 9 Velocity profile along x-axis cross section above 75 mm bottom

From Fig. 9, when there is no baffle on the bottom of the stirred tank, the radial velocity of the fluid in the stirred tank is very small and the fluid basically doesn't move along the radial. After the crisscross baffles are placed on the bottom of the stirred tank, the radial velocity of the fluid in the stirred tank increases significantly and the fluid produces a radial movement. When the logarithmic spiral baffles are placed on the bottom of the stirred tank, the radial velocity of the fluid at the center of the stirred tank is larger than the axial velocity of the fluid in the stirred tank with the crisscross baffles. The radial movement of the fluid is more apparent and the stronger radial flow forms.

C. Comparision of Power

In this study, the comparison of the mixing power is carried out by comparing the mixing power of the stirred with the crisscross baffles to the mixing power of the stirred tank with the logarithmic spiral baffles. In the same operating conditions, when the rotational speed of the shaft is 120 r/min 、180 r/min、240 r/min and 300 r/min, respectively, the numerical simulation is carried out. Through the numerical calculation, the total moment of the impeller can be obtained and the mixing power can be obtained through the following formula [15].

$$P = M\omega \tag{3}$$

Where, P is the mixing power and M is the total torque of the impeller. ω is the angular velocity of rotational shaft.

TABLE I
SIMULATION VALUES OF THE MIXING POWER AT DIFFERENT SPEEDS

Rotational speed (r/min)	P (w)	
	Crisscross baffles	Logarithmic spiral baffles
120	1.84	1.76
180	6.71	5.64
240	15.34	14.58
300	29.44	28.02

The simulation values of the mixing power of the stirred tank with the crisscross baffles and logarithmic spiral baffles are shown in Table 1. Though comparing the simulation values, the mixing power consumed by the stirred tank with the logarithmic spiral baffles is smaller than the stirred tank with the crisscross baffles. As a result, the stirred tank with the logarithmic spiral baffles is more energy-efficient than the stirred tank with the crisscross baffles.

IV. Conclusion

From these numerical simulation studies and comparative analysis of simulation results, the following conclusions can be obtained.

When the crisscross baffles and logarithmic spiral baffles are placed on the bottom of the stirred tank with elliptic bottom, the tangential flow can be weakened and the axial flow and radial flow can be enhanced. Compared with the stirred tank without baffle, the mixing effect has been greatly improved.

After the crisscross baffles and logarithmic spiral baffles are placed on the bottom of the stirred tank with elliptic bottom, the liquid generates a radical movement from outside to inside. The liquid which is closed to the wall of the reactor slowly spins down the wall and the strong spiral axial flow forms at the center of the stirred tank.

Between the crisscross baffles and the logarithmic spiral baffles, the mixing effect of the stirred tank with logarithmic spiral baffles is better and the power consumption is lower.

By using FLUENT software, the Multiple Reference Frame (MRF) method is feasible for the simulation of velocity field in the stirred tank with elliptic bottom and bottom baffles.

References

[1] Lu Wei-Ming , Wu Hong-Zhang , Ju Ming-Ying, “Effects of baffle design on the liquid mixing in an aerated stirred tank with standard Rushton turbine impellers,” Chemical Engineering Science, vol. 52, issue 21, pp. 3843–3851, Apr. 1997.

[2] Fitch,A.W. , Ni,X. , Stewart,J., “Characterisation of flexible baffles in an oscillatory baffled column,” Journal of Chemical Technology and Biotechnology, vol. 76, issue 10, pp. 1074–1079, May 2001.

[3] Guo, Du-Xin, Hao, Hui-Di, Wei, Yu-Mei, and Liu, Qing-Chang, “New type mixer - Central ascending screwy flow mixer,” Chemical Engineering, vol. 30, issue 4, , pp. 28–31, 2002.

[4] CHEN FENG, HUANG Xiong-Bin, “Mixing Character of Two Kinds of Installation of the Mixer with Baffle Assessed,” Chemical Research, vol. 14, issue 1, pp. 48–50, Mar. 2003.

[5] TONG Li-jun, “Study on Baffle in Mechanical Agitating Tank,” Non-ferrous Metallurgical Equipment 03, pp. 17–18, 2005.

[6] SHEN Chun-yin, “CHEN Jian-pei; ZHANG Jia-ting and DAI Gan-ce. Performance and Design of Baffles in Mechanically Agitated Gas-liquid Reactor,” Journal of Chemical Engineering of Chinese Universities, vol. 19, issue 2, pp. 163–167, Apr 2005.

[7] Andrej Bombac, Iztok Zun, “Individual impeller flooding in aerated vessel stirred by multiple Rushton impellers,” Chemical Engineering Journal 116, pp. 85–95, 2006.

[8] M.H. Vakili, M. Nasr Esfahany, “CFD analysis of turbulence in a baffled stirred tank, a three-compartment model,” Chemical Engineering Science 64, pp. 351–362, 2009.

[9] S.Bhattacharya , D.Hebert and S.M.Kresta, “air entrainment in baffled stirred Tanks,” Chemical Engineering Research and Design, vol. 85, no.5, pp. 654–664, 2007.

[10] M.Al-Sammarraee,A.Chan, “Large-eddy simulations of particle s edimentation in a longitudinal sedimentation basin of a water treatment plant. Part 2: The effects of baffles,” Chemical Engineering Journal 152, pp. 315–321, 2009.

[11] G.M. Cartland Glover, J.J.Fitzpatrick, “Modelling vortex formation in an unbaffled stirred tank reactors,” Chemical Engineering Journal 127, pp. 11–22, 2007.

[12] H. Hartmann, J.J. Derksen, H.E.A.van den Akker, “Numerical simulation of a dissolution process in a stirred tank reactor,” Chemical Engineering Science 61, pp. 3025–3032, 2006.

[13] WANG KAI, YU JUN, agitator mill, Beijing: Chemical Industry Press, 2003, pp.34–36.

[14] DONG BIN-gang, ZHANG Bin-xuan and Cui ER-jie, Unsteady flow and vortex motion, Beijing: National Defence Industrial Press, 1993, pp.118–119.

[15] WANG Le-qin, DU Hong-xia, WU Da-zhuang, “Numerical Simulation of Mixing Process In Stirred Tank with Multiple Impellers,” Journal of Engineering Thermophysics, vol. 28, issue 3, pp. 418–420, May 2007.