Numerical Simulation of Shell and Tube Heat Exchanger Based on Fluent

Xinyu Luo¹, Bo Chen¹, MinMin¹, MeiJin², Hongjiao Liu*¹

¹College of Intelligent Manufacturing, Jianghan University, Wuhan, Hubei, 430056
²College of Chemical and Environmental Engineering, Jianghan University, Wuhan
¹Corresponding author’s E-mail: mxw1996@jhun.edu.cn

Abstract: In this paper, the classical shell-and-tube heat exchanger is taken as the research object, and the numerical simulation of the heat exchanger is carried out by using Fluent software. The nephogram of temperature field, velocity field and pressure field on the shell side of the fixed tube-and-plate heat exchanger with different baffle spacing is obtained. The variation law of fluid flow and heat transfer coefficient on the shell side of the heat exchanger with different baffle spacing is analyzed. The ratio of convective heat transfer coefficient \( \alpha \) to the third power of pressure drop \( \Delta p \) is used as the comprehensive performance evaluation index of the heat exchanger, which has a certain reference for evaluating the comprehensive performance of heat exchanger under different baffle spacing.

Introduction

Shell and tube heat exchanger, as the most widely used heat exchange equipment in process industry, is mainly composed of four parts: shell, tube sheet, heat exchange tube and baffle plate. Its main advantages are simple and compact structure and low manufacturing cost[1]. In this paper, the shell side of the heat exchanger is numerically simulated by Fluent software, and the variation law of fluid flow and heat transfer in the shell side of the heat exchanger under different baffle spacing is analyzed, and the influence of baffle spacing on the comprehensive heat transfer performance of the shell-and-tube heat exchanger is studied, which is of great significance for promoting the optimization of the heat exchanger's own performance and its efficient application in related industries.

By now, B.K.Soltan and others explored the influence of baffle spacing on heat transfer effect, and provided an idea about determining the optimal baffle spacing[2]. Pranita Bichkar. carried out numerical simulation on single-arch and double-arch baffle heat exchangers, analyzed the variation laws of pressure drop and heat transfer performance, and determined the baffle structure with better heat transfer performance[3]. LiuLei et.al.[4] discussed the effects of baffle spacing on heat transfer and turbulence intensity on flow pressure drop.

The comprehensive performance evaluation of heat exchangers mainly considers the comprehensive effects of heat transfer coefficient and pressure drop, that is, the smaller the pressure drop, the higher the heat transfer coefficient, the better. At present, the heat transfer coefficient under unit pressure loss is adopted, namely \( \alpha / \Delta p \) as an evaluation index, \( j-f \) factor is also used as an evaluation index[6]. Compared with the above two evaluation indicators, Gao Xiaodong[6] after proposed the ratio of the convective heat transfer coefficient \( \alpha \) and pressure drop \( \Delta p \) of the third power is more accurate as the comprehensive performance evaluation index of the heat exchanger, which is shown in formula (1). This paper adopts this method as the evaluation standard.
\[ \eta = \frac{\alpha}{\Delta p^{1/3}} \]  

In which: \( \alpha \) - convective heat transfer coefficient  
\( \Delta p \) - pressure drop

2. Establishment of physical model of shell-and-tube heat exchanger

The main structural parameters of the shell-and-tube heat exchanger are shown in Table 1. After simplifying the structure of the heat exchanger, the three-dimensional model of the heat exchanger as shown in Fig. 1 and the grid model as shown in Fig. 2.

![Fig. 1 Geometric model of heat exchanger](image1)

![Fig. 2 Grid model of heat exchanger](image2)

Table 1 Main structural parameters of heat exchanger

| Structure          | Dimension          | Structure          | Physical dimension |
|--------------------|--------------------|--------------------|--------------------|
| Shell diameter     | Ø219×6mm           | Arrangement        | Regular triangle   |
| Inner diameter of shell | 207mm            | Tube spacing       | 25mm               |
| Inlet and outlet Diameter | 50mm             | Baffle thickness   | 3mm                |
| Heat exchange tube | Ø19×2mm            | Baffle spacing     | 60/100/150mm       |
| Tube number        | 33                 | Rod diameter       | Ø10                |
| Tube length        | 1000mm             | Number of tie Rods | 4                  |

3. Numerical simulation method

The simplified assumptions of the heat exchanger model are as follows: 1) other components such as tie rods are omitted, and it is assumed that there is no gap between baffles and heat exchange tubes and cylinders; 2) In order to ensure the steady flow of fluid, the straight pipe sections of shell side inlet and outlet nozzles should be appropriately increased; 3) The process of fluid flow and heat transfer on the shell side is always stable and uniform; 4) Ignore the change of fluid physical properties such as density; 5) The fluid is Newtonian incompressible fluid.

The fluid flows turbulently in the shell side of the heat exchanger. In this paper, the standard K-\( \varepsilon \) model and the standard wall function are selected. Simple algorithm is used to couple velocity and pressure. Main structural parameters of heat exchanger as shown in Table 1.

The fluid of Shell side Shell is water, the Temperature 298K Inlet velocity 1.2m/s Tube Temperature 373K.

4. Analysis of shell-side fluid simulation results of heat exchanger

Fig. 3 is the velocity vector diagram of shell side of shell-and-tube heat exchanger. It can be seen that

![Fig. 3 Velocity vector diagram](image3)
after entering the shell side from the inlet, the fluid flows in the shell side in a "Z" shape. The fluid flows in the direction orthogonal to the tube bundle at the rear side of the baffle and constantly scouring the heat exchange tube, the fluid velocity in this area is large, which leads to the increase of turbulence and the higher heat transfer coefficient; however, there is a dead zone behind the flow stream, which will form a certain degree of vortex, which greatly affects the heat transfer performance of the heat exchanger. When the fluid flows through the notch of the baffle, the flow direction is parallel to the direction of the tube bundle, where the velocity is larger.

In this paper, the shell side of single bow baffle with baffle spacing of 60mm, 100mm and 150mm is numerically simulated, and the nephogram of temperature field, velocity field and pressure field of shell side of heat exchanger is obtained.

4.1. Temperature nephogram under different baffle spacing
The temperature cloud picture as shown in Fig.4, the temperature of the cold fluid gradually increases from the inlet to the outlet. The smaller the distance between baffles, the more uniform the temperature change between adjacent baffles, and the greater the temperature difference between inlet and outlet. This is mainly because the smaller the baffle spacing is, the more severe the lateral turbulence of fluid, the more sufficient the contact between fluid and heat exchange tubes, the more sufficient the contact between fluid flowing through heat exchange tubes, and the increase of total heat exchange capacity. However, in the leeward region of the baffle plate, the change of cold fluid temperature is small, because there is a dead zone in this region and the fluid velocity is small. The heat transfer in this region is mainly heat conduction, and the heat transfer effect is poor. With the decrease of baffle spacing, the flow dead zone decreases, and with the increase of heat transfer, the heat transfer of the whole heat exchanger will increase and the temperature difference will be larger.

![Fig.4 Temperature nephogram](image)

![Fig.5 Velocity nephogram](image)

4.2. Velocity nephogram under different baffle spacing
According to Fig.5 of the velocity nephogram, because of the existence of baffles, the cold fluid enters the shell side through the inlet and then flushes the wall of the heat exchange tube transversely, and its flow passage area is determined by the spacing of baffles. The smaller the baffle spacing is, the greater the velocity of fluid on the shell side is. At the same time, due to the obstruction of the baffle to the fluid flow, the shell-side fluid is forced to change the flow direction and flow transversely, and the whole fluid flows in a "Z" shape. The smaller the distance between baffles, the smaller the dead zone of flow at the leeward side of baffles, and the more severe the disturbance degree of fluid.
4.3. pressure nephogram under different baffle spacing

The pressure nephogram as shown in Fig.6, the pressure of cold fluid decreases gradually from inlet to outlet. The smaller the baffle spacing is, the greater the overall pressure drop of the heat exchanger changes. The pressure drop mainly occurs at the baffle around the fluid flow, and the pressure change is small at the notch of the baffle.

![Fig.6 pressure nephogram](image)

5. Analysis of simulation results

Simulate the outlet temperature, pressure drop and heat transfer coefficient of the heat exchanger. According to the selected new heat transfer evaluation index \( \eta \), it can be seen from table 2.

Comparing the outlet temperatures with baffle plate spacing of 60mm, 100mm and 150mm, the temperature value decreases gradually, which indicates that the heat transfer effect decreases gradually, and the plate spacing is the lowest. The smaller the plate spacing, the better the heat transfer effect. The result shows that when the distance between baffles is small, the flow area of fluid between baffles, especially the gap, decreases significantly, which leads to the increase of flow velocity. At the same time, the fluid washes the heat exchange tubes and the turbulence degree is large. At this state, because there are many baffles, there are many opportunities to scour the tube bundle, so the convective heat transfer coefficient is naturally higher and the heat transfer effect is good.

The distance between baffles will affect the pressure drop. It can be seen from table 2 that the pressure drop is 5637pa when the baffle spacing is 60mm, which is 3 times of the pressure drop when the baffle spacing is 150 mm. The smaller the baffle spacing, the greater the flow resistance, which indicates that the pump consumes a lot of energy and the running cost increases instead.

The comprehensive evaluation index of heat exchanger first increases with the increase of baffle spacing, reaches the maximum when the baffle spacing is 100mm, and then drops sharply. It shows that the heat transfer performance in the rising stage is greatly affected by pressure drop, which is greater than the influence of heat transfer coefficient and evaluation index \( \eta \). The maximum value is

| Baffle spacing | Outlet temperature \( T \) | Pressure difference \( \Delta P \) | Heat transfer coefficient \( \alpha \) | \( \eta = \frac{\alpha}{\Delta P^{1/3}} \) |
|---------------|----------------------------|-------------------------------|---------------------|------------------|
| 60mm          | 340.015 K                  | 5637.06 Pa                    | 2323.02 W/m².K      | 130.53            |
| 100mm         | 330.78 K                   | 2744.51 Pa                    | 1922.10 W/m².K      | 137.34            |
| 150mm         | 323.18 K                   | 1824.21 Pa                    | 1557.13 W/m².K      | 127.438           |
137.34 when the plate spacing is 100mm, indicating that the comprehensive performance of the heat exchanger is the best under this spacing, which is consistent with the reference spacing given by the heat exchanger standard.

6. Conclusion
Baffles in shell-and-tube heat exchangers not only support the heat exchange tube bundle, but also affect the heat transfer performance and pressure drop level of the shell-side fluid. In this paper, the numerical simulation of shell-and-tube heat exchangers with different baffle spacing is carried out, and the distribution nephogram of velocity field, temperature field and pressure field is obtained when the baffles spacing is 60mm, 100mm and 150mm respectively. By comparing the two main heat transfer performance influencing factors (pressure drop and convective heat transfer system) with different plate spacing, it is found that with the gradual increase of baffle spacing, the pressure drop and convection heat transfer coefficient of shell-and-tube heat exchanger will decrease correspondingly. Similarly, with the decrease of baffle spacing, the corresponding convection heat transfer coefficient and pressure drop will also increase, which leads to the increase of energy consumption of the heat exchanger, which has an adverse impact on the overall heat transfer performance. When the baffle spacing is 100mm, the comprehensive heat transfer performance of the heat exchanger is the best.

Acknowledgments
Acknowledge the financial of innovation and entrepreneurship training program for college students Hubei Province in 2020 (202011072080) and student academic science and technology project of Jianghan University 2020 (2020zd079)

References
[1] Li Zhaonan. Overview of heat transfer enhancement technology for shell-and-tube heat exchangers [J]. Chemical Management, 2016(09):91.
[2] B. Khalifeh Soltan, M. Saffar-Avval, E. Damangir. Minimizin g capital and operating costs of shell and tube condensers using optimum baffle spacing[J]. Applied Thermal Engineering,2004,24(17):.
[3] Aniket Shrikant Ambekar, R. Sivakumar, N. Anantharaman, M. Vivekenandan. CFD simulation study of shell and tube heat exchangers with different baffle segment configurations[J]. Applied Thermal Engineering, 2016,108.
[4] Liu Lei, Song Tianmin, Guan Jianjun. Numerical simulation and analysis of shell-side flow field of shell-and-tube heat exchangers based on FLUENT [J]. Light Industry Machinery, 2012,30(01):18-21.
[5] Wang Qingfeng, Pang Xin, Zhao Shuang. Influencing factors and numerical simulation analysis of heat transfer efficiency of shell-and-tube heat exchangers [J]. Petroleum Machinery, 2015,43(10):102-107
[6] Gao Xiaodong, Feng Xiao. Analysis on evaluation method of heat transfer enhancement in shell side of shell-and-tube heat exchanger [J]. Journal of North China Electric Power University (Natural Science Edition), 2007 (02): 95-97.