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Numerical Analysis on Flow Field of Inlet Chamber for Heat Exchanger Based on CFD

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Abstract. Taking the uniformity of the flow field and pressure field on the tube plate as a measure, this paper designs four kinds of circular distribution plates which is installed at the chamber to improve fluid field distribution. The simulation on CFD results show that the circular distribution plate can improve the flow field distribution and pressure field distribution obviously on the tube plate. Under the condition of a certain opening rate, when the diameter ratio of the circular plate to the tube plate is about 0.5, the distribution of the flow field and the pressure are more uniform. The research results have a certain guiding significance for the selection and design of the circular distribution plate in the inlet chamber.

1. Instruction

Shell-and-tube (heat) exchanger is widely used in process industry, it can change the temperature of process medium and get waste heat recovery[1]. As usually it is assumed that the fluid on the tube plate distribute uniformly. In fact because of jet flow and not fully developed, there is a great difference of fluid capacity between different heat exchange tube. The flow field distribution in the inlet chamber and on the tube plate of the shell and tube heat exchanger has an important effect on the heat transfer efficiency and leakage of the tube-to-tube plate connection. Wu Jinxing[2] studied the influence of conical tube on the flow field distribution in the inlet chamber. Li Xubo[3] put forward that the distributor can improve the uniformity in the inlet chamber. Nie Jianhu[4] analyzed the influence of baffle in the chamber of heat exchanger on the uniformity of flow field. But by now there is not a proper construction to improve the distribution of flow field and pressure field effectively in the chamber.

This paper designs four distribution plates of different size and studies the flow field and pressure field distribution on the tube plate under different distribution plates, in order to find a more suitable shunt plate to improving the uniformity of fluid field in the chamber.

2. Numerical simulation Method

2.1 Physical model

The laboratory heat exchanger is used as the prototype, a three-dimensional geometric model of heat exchanger inlet chamber is shown in figure 1. A circular distribution plate is settled in the chamber. Its geometric parameters are shown in Table 1.



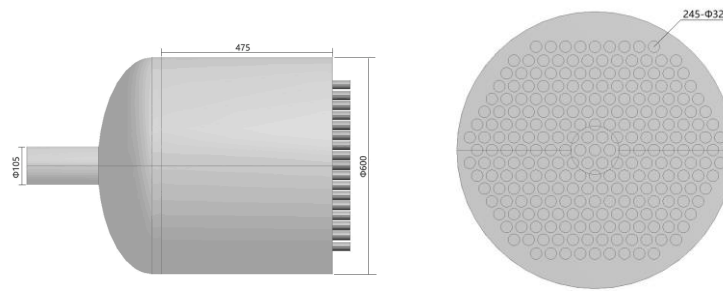


Figure 1. 3D model of inlet chamber.

Table 1. Geometric parameters of chamber.

geometric parameter	Value(mm)	geometric parameter	Value(mm)	geometric parameter	Value(mm)
Diameter	600	Head total height	150	Pipe hole diameter	32
Inlet diameter	105	Chamber height	475	Pipe hole number	245

2.2 Governing equations

Mass conservation equation and momentum conservation equation are respectively:

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x_i}(\rho u_i) = S_m \quad (1)$$

$$\frac{\partial}{\partial t}(\rho u_i) + \frac{\partial}{\partial x_j}(\rho u_j u_i) = -\frac{\partial p}{\partial x_i} + \frac{\partial \tau_{ij}}{\partial x_j} + \rho g_i + F_i \quad (2)$$

2.3 The initial and boundary conditions

No slip for inlet pipe wall, chamber wall and tube plate wall. The single-phase fluid model is selected in this paper, the water is uniform continuous medium whose physical property is constant. At the same time the flow is stable and the heat transfer in the heat exchanger is not considered. The inlet velocity is 4 m/s.

2.4 The numerical method

The paper establishes the computation model through geometry modeling and meshing by ICEM software whose grid is tetrahedron. The numerical scheme are following: using k-ε standard model and standard wall function. The convergence criteria is the stability of the outlet flow of water. The pressure velocity coupling algorithm format is SIMPLE format. Pressure interpolation scheme is first-order PRESTO format.

3. Results and discussions

This paper discusses the distribution of flow field and pressure field in heat exchanger tube plate after adding circular distribution plate with different diameter ratio (0.45 0.5 0.55 0.60) to heat changer tube plate.

3.1 The fluid field and pressure field without circular distribution plates

As shown in the Figure 2, The high velocity fluid is mainly concentrated in the center of the tube plate within 0.15m radius. The maximum velocity in the center is up to 2.75m/s, the velocity of most fluid is between 1m/s and 2.5m/s. In the edge of the tube-plate, due to the back-flow and vortex, there are many low speed fluids which reduce the flow velocity of the fluid entering the heat transfer tube. As shown in the Figure 3, the maximum pressure is 100Pa, the farther away from the tube plate center is, the smaller the pressure will be. The high pressure region is about at the same region of high velocity. As can be seen clearly from Figure 3, there is negative pressure zone in the edge of the tube-plate due to the back-flow and vortex, and the pressure difference on the tube plate is large.

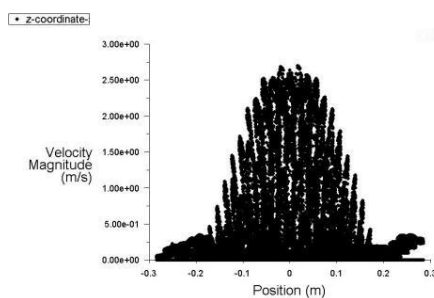


Figure 2. Scattered point diagram of flow field.

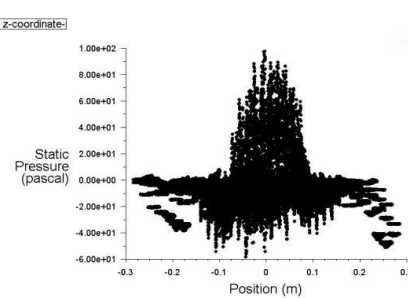


Figure 3. Scattered point diagram of pressure field.

3.2 The design of circular distribution plates

This paper designs four circular distribution plates with different diameter ratios. The distribution of the holes on the plate are shown in Figure 4. The thickness of the circular distribution plate is the same as that of the head which is 12 mm. On the base of previous research, according to the characteristics of fluid flow, the distance is set to 440 mm from the circular distribution plate to the tube plate, the initial diameter of circular distribution plate is set to 270 mm and the ratio is 0.45, the open rate is 41.7%. The sizes of the four different distribution plate are shown in Table 2. The maximum diameter of circular

Table 2. Parameters of circular distribution plates.

diameter(mm)	Diameter Ratio	Open porosity
270	0.45	41.7%
300	0.50	41.7%
330	0.55	41.7%
360	0.60	41.7%

distribution plate is set to 360 mm and the maximum ratio is 0.60.

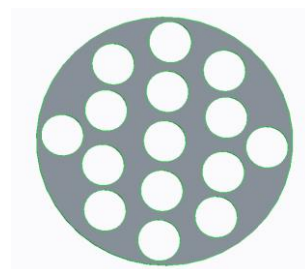


Figure 4. Circular distribution plates.

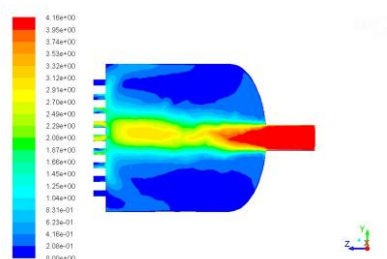


Figure 5. Velocity cloud diagram of flow field.

3.3 The fluid field and pressure field with different circular distribution plates

For better observing the effect of the circular distribution plate on flow field and pressure field, we transform cloud diagram such as the Figure 5 into scatter plots such as the Figure 6.

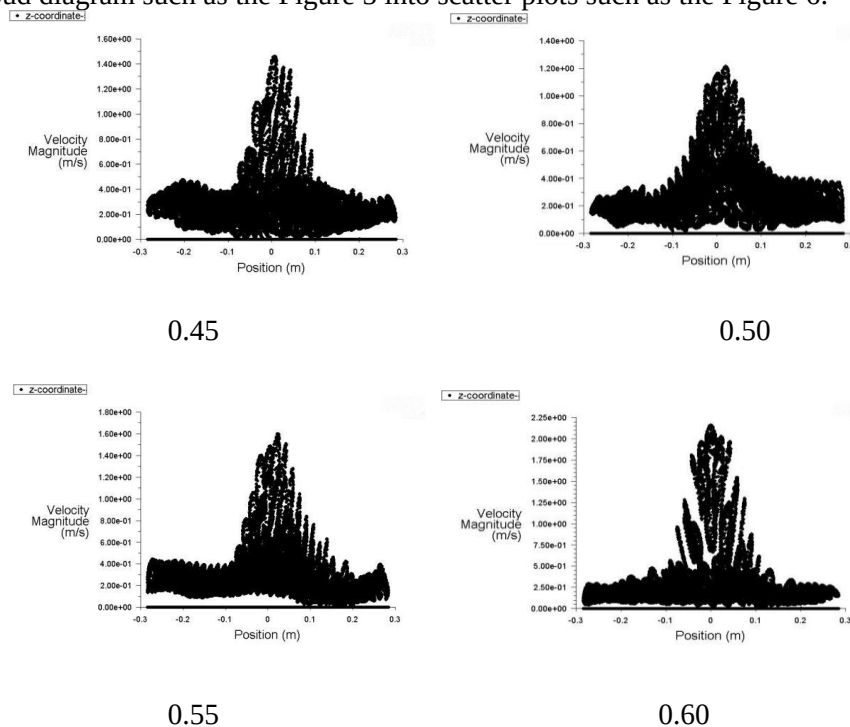


Figure 6. Scattered point diagram of flow field under different ratio.

Comparing with the Figure 2, it can be seen from the Figure 6, the amount of high speed fluid and low speed fluid are significantly reduced when the circular distribution plate is installed in the chamber. By and large, the velocity difference of the fluid on the tube plate is reduced and the uniformity of flow field is improved. The maximum velocity in the center of the tube plate is shown in Table 3 under different conditions. As can be seen from the Table 3, the smallest velocity is 1.2m/s for 0.5 of diameter ratio and the largest is 2.75m/s for without the circular distribution plate.

As shown in the Figure 7, there is an approximate corresponding distribution between the pressure field and the flow field. When the proportion of diameter is larger than 0.5, the larger the diameter ratio is, the greater the pressure will be in the central region, it can be seen from Table 4. Comparing with the Figure 3, the volume of high pressure fluid in the center region of tube plate decreases

Table 3. Maximum velocity in the center region.

diameter ratio	Maximum speed (ms^{-1})
0	2.75
0.45	1.50
0.50	1.20
0.55	1.60
0.60	2.00

obviously, and the maximum pressure is also below 100Pa. Most of the fluid pressure is about 20Pa. The amount of negative pressure fluid and high pressure fluid on the whole tube plate are

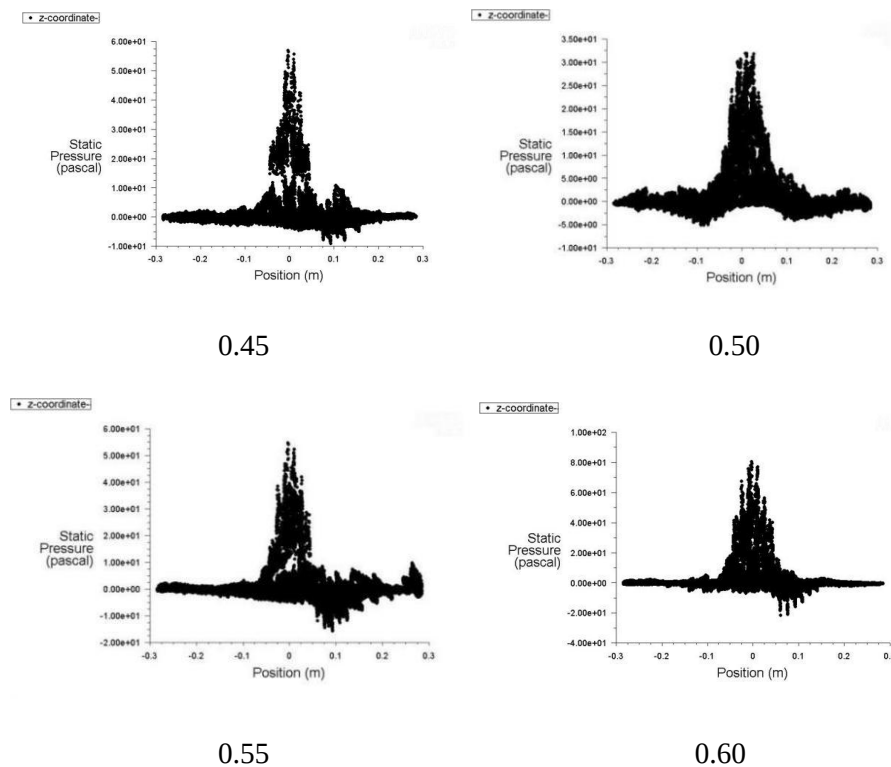


Figure 7. Scattered point diagram of pressure field under different ratio.

Table 4. Maximum pressure in the center region.

diameter ratio	Maximum pressure (Pa)
0	100
0.45	54
0.50	35
0.55	58
0.60	80

decreased, the proportion of medium and low pressure fluid are increased, and the whole pressure of tube plate tends to be uniform. The force condition of tube-plate is improved obviously by installing circular distribution plate, the peak pressure in the center of the inlet chamber is the smallest when the diameter ratio is 0.5.

4. Conclusion

This paper discusses the flow field and pressure field of the inlet chamber for Shell-and-tube (heat) exchanger. In the chamber, the flow field and pressure field are not uniform, the fluid is mainly concentrated in the jet zone of the inlet chamber. Compared with other places, the fluid velocity and pressure are also very high in tube sheet center. After installing the circular distribution plate, the uniformity of fluid velocity and pressure distribution on the tube plate are obviously improved. For four different the circular distribution plate, the uniformity of velocity and pressure are the best when the diameter ratio of circular plate to tube box is 0.5. The uniformity of flow field can effectively improve the heat transfer efficiency. If the pressure distribution is improved, the erosive effect of the fluid at the tube-plate connection is weakened effectively and the service life of heat exchanger can be prolonged.

Reference

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