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Analysis on Optimization and Model Selection of the Heat Transmission Performance of Heat Exchanger

Yecong He[a], Tengjin Huang[b], Min Tan[c]

[a b]Hunan Province 2011 Collaborative Innovation Center of Clean Energy and Smart Grid, Changsha University of Science and Technology, Changsha 410114, China
[c]School of Civil Engineering, Hunan Urban Construction College, Xiangtan 411101, China
heyecong@163.com

In order to better optimize and develop heat exchanger technology, aimed at improved design of heat exchanger in the industrial loop reactor, this paper researches the heat transmission performance of heat exchanger based on CFD simulation and its optimization with the aim of establishing a 3D model for tube side and shell side of heat exchanger, so as to achieve optimal selection and design of heat exchanger. Circular tube heat exchanger of arch baffle plate is used for CFD simulation. Simulation results show that for shell side flow of circular tube heat exchanger of arch baffle plate, the fluid flows in a “Z” shape and there are flowing and heat transfer dead zones. It can be known from this that arrangement and structure of baffle plate have great influence on heat transmission and flow resistance characteristics.

1. Introduction

As an essential equipment during heat exchange process, heat exchanger is widely used in the power, nuclear energy, refrigeration, chemical engineering, petroleum, aviation and aerospace and others. In recent years, due to occurrence of environment, energy and resource crisis, people have a rising requirements for energy-saving and consumption reducing (Aoki, 2016). That efficient heat exchanger is used to reduce the energy consumption has become the focus of attention and research in the modern industry. During type selection and design of heat exchanger, it’s very important to know micro-information on internal fluid flowing and heat transmission (Damasceno, 2017). But, it’s very difficult to obtain detailed information on internal flow according to traditional test method and simulation calculation of process dimension. Just because of this, CFD (Computational Fluid Dynamics) becomes a new method for studying fluid flow. CFD stimulation can not only give the internal smooth distribution of the equipment, but also achieve simulated study of complicated structures. Especially, for study on new, efficiency and energy-saving heat exchanger, CFD simulation technology has obvious advantages than traditional methods.
Aimed at improved design of heat exchanger in the industrial loop reactor, this paper studies the type selection of heat exchanger with an objective of establishing 3D models of tube side and shell side of heat exchanger, obtaining internal flow field data and influence rules of different structures and operation conditions on performance of heat exchanger, and achieving optimized design and transformation of heat exchanger. The method and data obtained herein should be used as theoretical basis and model support for structure optimization and engineering enlargement of heat exchanger (Najjar et al., 2016).

2. Enhanced heat transmission technology of heat exchanger

The enhanced heat transmission technology means that with fixed heat transfer area, some measures or technologies are taken to improve heat exchanging amount of the equipment or reduce the area and volume of heat exchanger with unchanged original heat exchange amount (Nemati et al., 2017). Enhanced heat transmission is aimed at 1) reducing heat exchange area, so as to reduce the volume and weight of heat exchanger; 2) improving existing heat exchange capability of heat exchanger; 3) enabling heat exchanger to work in a low temperature difference, so as to save energy consumption or reduce operation fees; 4) reducing heat transfer resistance, so as to reduce the power consumption of heat exchanger. As for technological

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requirements, enhanced heat transmission technology of shell-and-tube heat exchanger is mainly composed of tube side enhancement and shell side enhancement.

2.1 Enhanced heat transmission technology in the heat exchange tube

Enhanced heat transfer effect inside the tube is closely related with the structure and model of the heat exchange tube (Radulov et al., 2015). So, main measure for enhanced heat transmission in the tube is to change internal surface structure of heat exchange tube (such as corrugated tube, spiral grooved tube and converging-diverging tube etc.) and add spoiler to the pipe.

(1) Corrugated tube is composed of circles of tangent arcs and edge of axial section is in wave-shape. When fluid flows through large arcs, it's necessary to reduce the speed and increase the static pressure; when fluid flows through small arcs, it's necessary to increase the speed and reduce the static pressure. Such periodic changes cause disturbance increase of the fluid, so as to enhance the heat transmission.

(2) Spiral grooved tube: it has a double-enhanced heat transmission function. One is that periodic prominence of spiral groove tube enables the fluid to produce period disturbance during flowing and enhance the turbulence degree; another is that spiral prominence in the tube also drives partial fluid to rotate and flow, which can reduce or even damage the turbulent boundary layer, so as to facilitate heat transmission.

2.2 Enhanced transmission technology in shell side of heat exchanger

Enhanced heat transmission of shell side has two ways: one is to add many fins outside the tube or change appearance of heat exchange tube, i.e. special tubes, to achieve rough surface or expand the surface, so as to enhance transmission, such as threaded tube, external finned tube and spiral twisted tube etc.; another is to change structure or form of pipe support of shell side to reduce or even eliminate the fluid flow and heat transmission “dead zone” of shell side, so as to make full use of heat transfer area of the bundle and enhance the heat transmission of shell side (Radulov et al., 2017). The latter, i.e. enhanced heat transmission of shell side is mainly introduced herein. At present, the tube beam support structure of heat exchanger includes plate support and pole support etc.

Plate support structure: the ideas condition of shell-and-tube heat exchanger is that fluid is moved axially in the shell side of heat exchanger, i.e. fluid moves in parallel to the tube side. Single baffle plate is generally used as the support structure of the traditional heat exchanger. Fluid almost flows around the baffle plate of shell side in perpendicular to the tube bundle, i.e. transverse flow. Its disadvantages include: large pressure drop along the way; flow dead zone, bypass flow and leakage flow; contamination. In order to overcome disadvantages of single bow baffle structure, there are some new plate support structures in recent twenty years. Their common characteristics are to reduce flowing resistance of shell side and reduce heat transmission dead zone (Wang and Gao, 2017).

Pole support structure: In the 1970s, in order to prevent natural gas flow vibration of shell-and-tube heat exchanger, American Philips Petroleum Company changed the support structure from baffle plate to pole support structure, and developed baffle rod heat exchanger. For such heat exchanger, support structure, baffle plate, is replaced by baffle grid, which is made by welding certain quantity of support rods on the circular baffling ring (Wesche et al., 2016). The support rods are interlaced among heat exchange tubes. It can be used to promote longitudinal flow of shell-side fluid and disturb the fluid, so as to enhance the heat transmission. In recent years, there are some baffle rod heat exchanger with new support structure, such as wave-type flat steel supporting structure and straight and flat steel bar support etc.

3. CFD simulation of shell side of arch baffle plate circular tube heat exchanger

3.1 Influence of viscosity on different heat exchange tubes

Under same wall temperature and Re=3000, four different heat exchange tubes, i.e. circular tube, built-in band heat exchange tube ($Y=2$, $\xi=0.1$), tubes and spiral twisted flat tube (S=160mm) with same cross sectional area, are taken to study influence of different viscosities on heat transmission and flow resistance characteristics. Figure 1 and 2 give the change conditions of pressure drop and heat transfer coefficient along with the viscosity. It can be seen from the figure that 1) with increasing viscosity, pressure drop and heat transfer coefficient of four heat exchange tubes are increased. But, increasing speed of pressure drop become larger along with increasing viscosity and smaller for heat transfer coefficient. 2) With same viscosity, pressure drop and heat transfer coefficient of circular tube are the least, following the flat tube. Pressure drop of built-in band heat exchange tube is the largest. But, its heat transfer coefficient is less than spiral twisted flat tube, and their difference is also increased along with increasing viscosity.

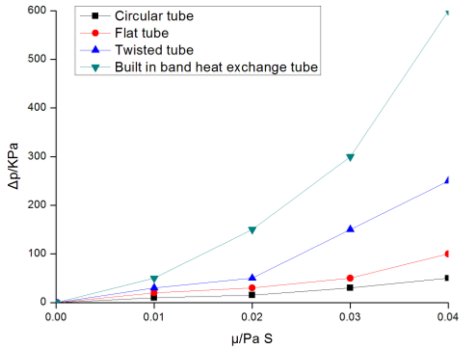

Figure 1: Relationship between pressure drop and viscosity

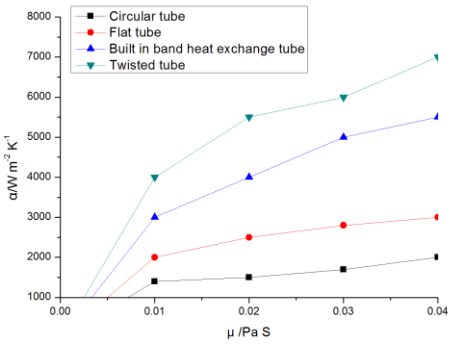

Figure 2: Relationship between heat transfer coefficient and viscosity

3.2 Influence of Re on heat transmission of heat exchanger

With unchanged structure of heat exchanger, heat exchanger with six baffle plate, distance 240mm and round flaw height 32mm (0.3755D) is used as the simulation object to change inlet speed, i.e. simulation under different Reynolds numbers Re, so as to get the change conditions of pressure drop and heat transfer coefficient with Re, as shown in Figure 3. It can be known from the drawing that with increasing Re of the fluid, heat transfer coefficient of heat exchanger is increased linearly accordingly, i.e. increasing the heat transmission amount of heat exchanger. Meanwhile, pressure loss is firstly slowly increased along with Re and then increased sharply. Therefore, it’s necessary to set a reasonable shell side flow rate of the fluid, so as to enable the heat exchanger to satisfy the heat transfer requirements, obtain good heat transfer effect, enable the pressure drop of the fluid of the shell side to be no more than the permitted maximum pressure drop, and avoid excessive power consumption.

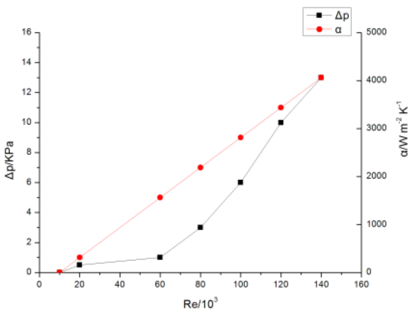

Figure 3: Pressure drop and heat transfer coefficient variation with Re in shell-side

3.3 Influence of distance of baffle plate

When the round flaw height of heat exchanger is 32mm (0.3755D) and other structure dimensions are unchanged, only baffle spacing is changed, inlet flow rate is 1m/s and Re=99520, it's necessary to simulate heat exchanger with baffle spacing 400mm, 240mm, 170mm, 130mm and 110mm, i.e. quantiy of baffle plates is 4, 6, 8, 10 and 12, and analyze the results. Figure 4 shows change of pressure drop and heat transfer coefficient of single-arc shell-and-tube heat exchanger at shell side along with baffle spacing. It can be known from the figure that with increasing baffle spacing and reducing quantity of baffle plates, pressure drop and heat transfer coefficient are decreased at the same time. But, heat transfer coefficient is decreased evenly. But, pressure drop is firstly decreased rapidly. But, with increasing baffle spacing, the pressure drop is gradually decreased slowly.

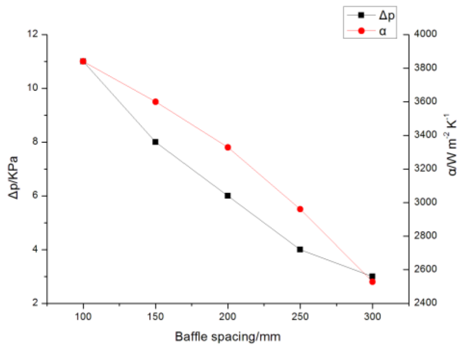

Figure 4: Pressure drop and heat transfer coefficient variation with different baffle spacing

Through simulation and calculation, it's necessary to get heat transfer coefficient and pressure drop under different baffle spacing. Among them, heat exchanger with baffle spacing 400mm (four baffle plates) is used as the reference heat exchanger to get the variation of j-f factor with baffle spacing, as shown in Figure 5. It can be seen from the figure that with increasing baffle spacing, j-f factor is firstly increased and then reduced. When baffle spacing is 170mm, i.e. eight baffle plates, the largest value of j-f factor is 1.104. At this time, the heat exchanger have the best comprehensive performance. In other words, for heat exchanger with above structure and working conditions, when there are eight baffle plates, a relatively small pressure drop can be used to achieve good heat transfer effect.

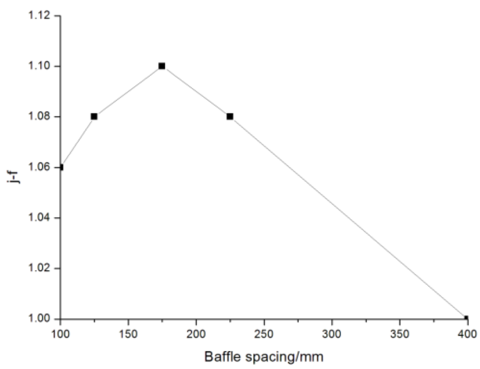

Figure 5: Relationship between. j-f and baffle spacing

3.4 Influence of round flaw height of baffle plate

When baffle spacing of heat exchanger is 170mm (eight baffle plates) and other structure dimensions are unchanged, only round flaw height of baffle plate is changed, inlet flow rate is 1m/s and Re=99520, eight different heat exchangers with round flaw height of baffle plate to be 0.2D-0.5D are simulated to get variation of pressure drop and heat transfer coefficient with h/D, as shown in Figure 6. It can be seen from the figure that with increasing round flaw height of baffle plate, pressure drop of shell side is firstly decreased quickly and later slowly. Because with increasing round flaw height of baffle plate, under the baffle plate, fluid area is increased, flow rate is decreased, turbulence degree is weakened and consumption of pressure drop is decreased. But, heat transfer coefficient of shell side is also relatively decreased evenly along with increasing round flaw height of baffle plate. Because with increasing round flaw height of baffle plate, fluid flow rate in the shell side is decreased and turbulence degree is weakened, so that the heat transfer effect is worsened and the speed is almost reduced evenly.

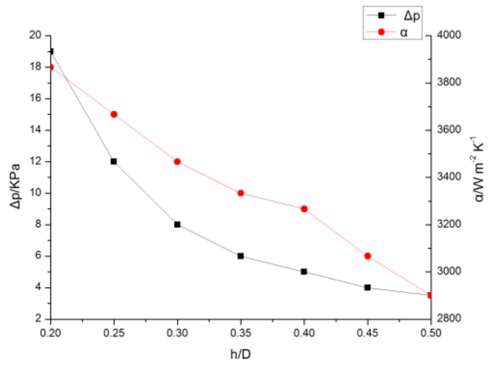

Figure 6: Pressure drop and heat transfer coefficient variation with h/D

Heat exchanger with 0.2D as round flaw height of baffle plate is used as the reference heat exchanger, so as to get the variation of j-f factor with round flaw height rate of baffle plate.

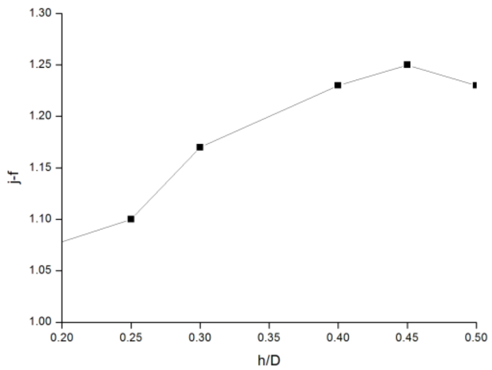

Figure 7: Relationship between. j-f and h/D

It can be seen from Figure 7 that with increasing round flaw height of baffle plate, J-f factor is firstly increased and later decreased. When round flaw height of baffle plate is 0.4D, j-f factor has the maximum value 1.265. At this time, heat exchanger has the best comprehensive performance. In other words, 0.41D is the best value of round flaw height of baffle plate with above structure and under above conditions. If round flaw height is too large, heat transfer efficiency is too low; if round flaw height is too small, pressure loss is too large.

4. Conclusions

For circular tube heat exchanger at shell side of arch baffle plate, this paper uses computational fluid dynamics (CFD) method and fluid dynamics simulation software Fluent 6.3 to simulate and research its tube side and shell side, optimizes the type selection and improves the design of industrial heat exchanger, and comes to following conclusions: for shell side flow of heat exchanger of arch baffle plate, fluid flows in a “Z” shape and there are flowing and heat transfer dead zones. Compared with circular tube heat exchanger of arch baffle plate, shell side of flat tube heat exchanger of arch baffle plate has similar flowing mode. But in the stagnant zone, the circular tube heat exchanger of arch baffle plate has a relatively larger vortex velocity and higher outlet temperature; Arrangement and structure of baffle plate have an important influence on its heat transmission and flow resistance characteristics. When inlet flow rate is 1 m/s, the quantity of baffle plates is 8; when round flaw height is 0.41D, comprehensive performance of heat exchanger is the best; for heat exchanger of self-supporting helical twisting flat tube, shell-side fluid velocity and temperature are distributed evenly without flowing and heat transmission dead areas. Fluid spirally flows along pipes and it’s the typical longitudinal flow.

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