ISSN 2706-655X Vol.5, Issue 5: 8-15, DOI: 10.25236/IJFET.2023.050502

Simulation analysis of tube-shell heat exchanger

Wang Xiaojuan, Hu Xiaoqing, Yan Shuo, Fu Yilin, Yang Xinshuo, Lv Xiangkun

Weifang Institute of Technology, Qingzhou, Shandong, 261101, China

Abstract: *With the continuous development of social economy, the heat exchanger in refrigeration equipment is also changing with each passing day. However, the traditional heat exchanger has some problems, such as low utilization rate of heat exchange tubes, low work efficiency, and large energy waste. In view of the above problems, we have carried out a series of optimization designs: for the fluid in the tube side, we have used the U-shaped heat exchange tube to increase the distance of the fluid from the inlet to the outlet, and made full use of all the heat exchange tubes by using the baffle double compartment, which has reduced the phenomenon that the heat exchange tubes do not go through the fluid in the traditional heat exchanger; For the air fluid in the shell side, we have added two-thirds of baffle plates in the shell side. The baffle plates are sleeved on the heat exchange tubes and are located in the middle of the inlet and outlet (not more than the inlet and outlet). Six baffle plates are used to change the path of fluid flow in the shell side, slow down the fluid speed in the shell side, make their time from the flow inlet to the flow outlet increase significantly, thus making the heat exchange time longer, The heat exchange efficiency increases. After our analysis and design, compared with the traditional heat exchanger, my new shell and tube heat exchanger has higher work efficiency, greatly improved heat transfer efficiency, and significantly reduced energy waste.*

Keywords: *tube and shell-type heat exchanger; simulation and analysis*

1. Introduction

Heat exchangers are widely used in various fields of industry and agriculture, and in oil refineries and chemical plants, heat exchangers account for about 40% of the total equipment volume and equipment investment. In the heat exchanger equipment, the shell and tube heat exchanger has the advantages of strong structure, high reliability, adaptability, and a wide range of materials. In addition to some new materials new heat exchanger equipment, shell, and tube heat exchanger is still in great demand, if you can more recently develop shell and tube heat exchanger is a great future. And energy conservation is an important social awareness in today's world, we need to strengthen energy management, to take technically feasible, economically reasonable, and environmentally and socially affordable measures to reduce consumption, reduce losses and pollutant emissions, and effectively and rationally use energy. At present, the shell-and-tube heat exchanger is widely used in industry, the most important structure is the bow-folded plate type, in addition, there are also spiral folded plate types, folded rod types, tube self-supporting types, and other structures [1]. In the development stage of shell and tube heat exchanger, there are problems such as the traditional bow-folded plate heat exchanger with large pressure drop on the shell side, the existence of multiple flows "dead zones", inadequate heat transfer, easy leakage and side flow, and fluid lateral impact on the tube bundle is prone to vibration, which shortens the life of the heat exchanger [2]. Chen Guidong et al. proposed a combined multi-shell spiral folding plate shell and tube heat exchanger, so that the velocity distribution in the outer shell process in different continuous spiral cycles is approximately the same, and in the same spiral cycle, the velocity distribution is relatively uniform, continuous spiral flow to a fixed inclination impact on the heat transfer tube bundle, weakening the heat transfer boundary layer; the inner shell process using discontinuous spiral folding plate The fluid temperature increases uniformly with the flow spiral cycle, and the temperature in the leakage region of the inner shell process is lower than that in the spiral flow region, which solves the problem of uneven fluid temperature change due to the existence of local high temperature in the flow dead zone of the bow-shaped folding plate heat exchanger and the inability to exchange heat with the mainstream [2]. Liu Jiangjian by the outer circumference of the shell process cylinder at a certain distance apart and then set a concentric cylinder, between the two cylinders to form a flow channel and connected to the tube process, so that part of the low-temperature fluid from here to pass, the original shell process and atmospheric phase conduction of heat will be transferred to the low-temperature fluid, solving the shell process cylinder internal surface area As there is no heat transfer to the wall with the fluid in the tube and shell, so this part of the heat transfer area is not utilized, to the extent that the heat transferred through this area is wasted to the atmosphere, improving the heat transfer efficiency [3].

For this reason, we have studied the heat exchanger and made a simulation analysis of it, which is expected to improve the common heat exchanger in refrigeration equipment to shell and tube heat exchanger, and thus improve the cop (energy efficiency ratio) of lithium bromide chiller and further save energy. The design of shell and tube heat exchanger is based on the working condition of the equipment and non-standardized design, including physical parameters, structural parameters repeated trial calculations, calibration, etc., usually the design task is heavy and not high quality. With the help of computer-aided design, the design efficiency can be greatly improved and the quality of product design can be improved.[4] The innovative U-shaped dense tube design in the shell and tube heat exchanger can greatly improve the efficiency of the heat exchanger and reduce energy waste, thus alleviating the problem of high operating costs of large refrigeration equipment such as central air conditioners. At the same time, it also achieves the purpose of reducing the energy consumption of refrigeration and saving electricity, so that the load balance of the power grid reduces the pressure on both sides of the power supply and consumption. And it can improve the utilization rate of equipment for all kinds of users, and thus improve the economic efficiency of refrigeration and air conditioning utilization for all kinds of users. In addition, this shell and tube heat exchanger can also effectively solve the traditional heat exchanger problem of many working parts, large and heavy shapes, and low energy efficiency. The main advantages of this shell-and-tube heat exchanger over other heat exchangers are simple structure, durability, low cost, a wide range of materials, large processing capacity, easy cleaning, and can also adapt to the requirements of high temperature and pressure. In addition, the shell and tube heat exchanger has high economic efficiency and meets the needs of the majority of users. In the research process, simulation analysis plays a key driving role and is the focus of this shell and tube heat exchanger research. (Note: This shell-and-tube heat exchanger can be used for both cooling and heating).

2. Shell and tube heat exchanger structure and working principle

The shell-and-tube heat exchanger has a cylindrical shell containing a bundle of tubes, which are closely spaced and fixed to the tube plates. Two types of fluids are used for heat transfer in the shell and tube heat exchanger, one inside the tube and one outside the tube. In order to control the proper flow rate, the refrigerant enters from the lower part of the end cap and exits from the upper part, and flows back and forth in the heat exchanger tube and end cap, forming a multi-programmed flow. In the shell and tube heat exchanger work, the shell retains a certain amount of liquid refrigerant, so that its height should be about the height of the diameter of the cylinder so that most of the cooling tube is immersed in the liquid so as to carry out the exchange of heat.

3. Influencing factors of shell and tube heat exchangers

The influencing factors of shell and tube heat exchangers are divided into three points. The first is the selection of the flow path of the fluid, and the comparison of simulation results shows that the fluids of different properties go through the pipe or shell process; for example, the unclean and easy-to-scale fluids should go to the piping process, and the cooled fluid should take the shell process. The second is the selection of fluid flow rate; the simulation results show that the turbulence degree of the fluid also affects the size of the convective heat transfer coefficient; a larger flow rate is helpful to the heat transfer coefficient and makes the total heat transfer coefficient larger, but at the same time the resistance becomes larger, power consumption is more, so we need to comprehensively consider the fluid flow rate. The third is the specification and spacing of the pipe, the influencing factors of the convective heat transfer coefficient of the piping process and the shell process are different, and the specifications of the tube required for easy scaling fluid and clean fluid are also different; Tube spacing is also a very important influencing factor when the pipe spacing is small compared with the tube spacing, its heat transfer coefficient is relatively high, so the tube spacing is small, which is helpful to increase the heat transfer coefficient. The convective heat transfer coefficient of the pipe is related to the number of pipes, the number of pipes, pipe diameter, whether there is an interpolated spoiler in the pipe, and whether special pipes are used. The convective heat transfer coefficient of the shell is related to many factors, such as shell type, heat exchanger type and layout, baffle spacing and baffle slice rate [5]. In the shell process of shell and tube heat exchanger installed bow-shaped folding plate can change the shell process of shell and tube heat exchanger fluid flow direction, on the one hand, can improve the heat transfer capacity of the heat exchanger, on the other hand, the tube bundle for support and fixed.[6]

ISSN 2706-655X Vol.5, Issue 5: 8-15, DOI: 10.25236/IJFET.2023.050502

4. SolidWorks-based simulation analysis

The closure was created based on the liquid inlet and outlet of the assembly of the shell and tube heat exchanger. The model was then checked with the SolidWorks Flow Simulation plug-in to show the fluid volume, showing a good watertight closure inside the device.

Then do the wizard, set the units (Kelvin), analysis type, default fluid, default solid, outer wall conditions, initial conditions and complete the wizard operation.

A. In the selection of physical features select the large environmental state physical heat transfer and gravity, in the selection of gravity, set the vertical x-axis direction to 0 and the negative direction to -9.81 to create the gravity effect.

B. Select the material. In the default fluid select the tube fluid air. Another fluid water. Select copper for metal and make the wall conditions adiabatic.

C. Set the thermodynamic parameters. Pressure is atmospheric pressure and temperature is 20 degrees.

D. Set the calculation domain, hide the shell part, set the tube course fluid subdomain (cooling medium), set the shell course fluid domain (default air) and set the default physical material.

E. Specify the route through which the fluid flows. Air is the default gas, and the incoming is the fluid domain selected for the shell range. Create a fluid sub-domain and select the pipe course.

F. Specify the flow rate, and the thermodynamic parameters.

Set the boundary conditions, select the fluid inlet for the pipe process, set its temperature, pressure, and fluid velocity, and set the ambient pressure for the outlet. Set the inlet velocity for the shell process and the ambient pressure (typically five atmospheres) for the outlet.

Set the simulation analysis targets, set the analysis targets for the outlet and inlet data of the tube process and the shell process: temperature difference, outlet temperature of the fluid, inlet pressure and outlet pressure. To get the inlet and outlet temperature profiles of air. Create targets for each surface by selecting the average temperature in the temperature in the surface targets. The same for water.

Create a grid, create a global grid, select a 3 level grid according to the calculation requirements, run the calculation, to verify the data we tune to different levels, 4 and 5, observe if the final result parameters will change, if the change is very small indicating grid irrelevance, then this result can be used.

Finally, load the results, insert the target figure, export Excel to view the overall data, followed by data analysis to complete the simulation analysis.

5. Schematic diagram of shell-and-tube heat exchanger

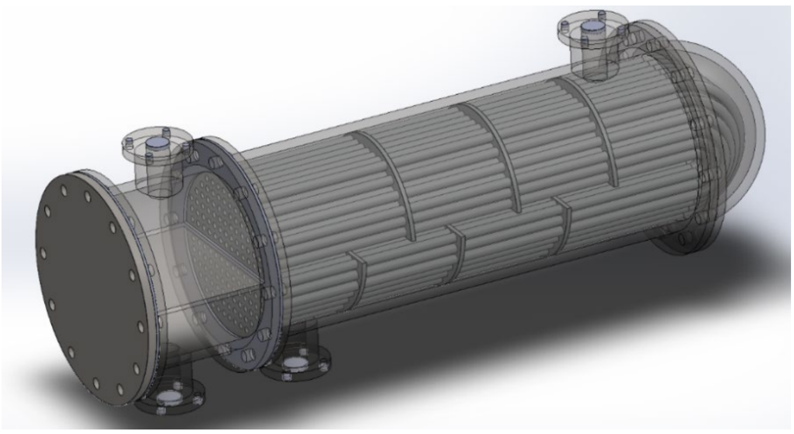

Figure 1: Three-dimensional view of shell-and-tube heat exchanger

ISSN 2706-655X Vol.5, Issue 5: 8-15, DOI: 10.25236/IJFET.2023.050502

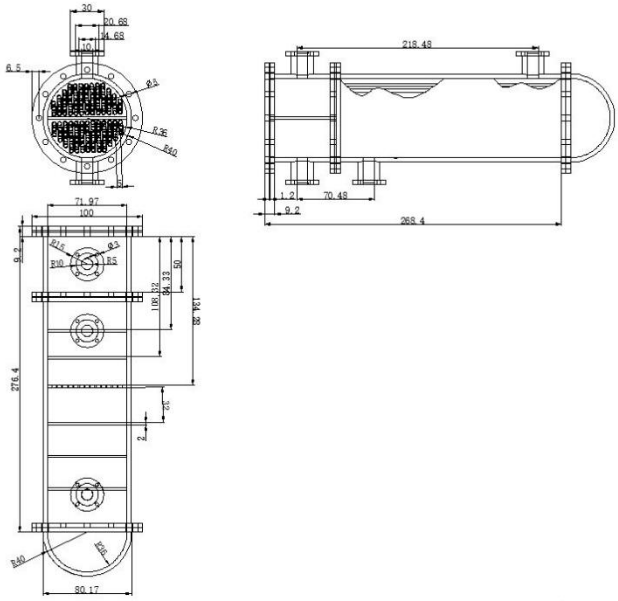

Figure 2: Three views of shell-and-tube heat exchanger

Figure 1 and Figure 2 provide a view of some of the details of this design and the dimensions of some of the details.

6. Simulation data results (with target map)

(1) Summary data comparison

Table 1: Summary data before optimization

Target name	unit	average value	rate of progress[%]	For convergence
Average temperature1	°C	20	100	Yes
Average temperature2	°C	20.257058	44.1	No
Average temperature3	°C	80	100	Yes
Average temperature4	°C	21.03548418	100	Yes
Average static pressure5	Pa	104365.6527	100	Yes
Average static pressure6	Pa	98393.81114	100	Yes
Average static pressure7	Pa	101352.2046	100	Yes
Average static pressure8	Pa	101321.4626	100	Yes
Equation target1	°C	-0.257058004	44.1	No
Equation target2	°C	58.96451582	100	Yes

Table 2: Summary data after optimization

Target name	unit	average value	rate of progress[%]	For convergence
Average temperature1	°C	20	100	Yes
Average temperature3	°C	80	100	Yes
Average temperature2	°C	21.33613665	100	Yes
Average temperature4	°C	21.21923069	100	Yes
Average static pressure5	Pa	104250.8717	100	Yes
Average static pressure6	Pa	101365.262	100	Yes
Average static pressure7	Pa	98542.83273	100	Yes
Average static pressure8	Pa	101321.6492	100	Yes
Equation target 1	°C	-1.336136651	100	Yes
Equation target 2	°C	58.78076931	100	Yes

From the comparison of Table 1 and Table 2, it can be increased to 100 percent, indicating that all aspects of heat exchange are functioning properly and that there is no uneven and uniform heat exchange.

(2) Comparison of inlet and outlet temperature difference of shellside

ISSN 2706-655X Vol.5, Issue 5: 8-15, DOI: 10.25236/IJFET.2023.050502

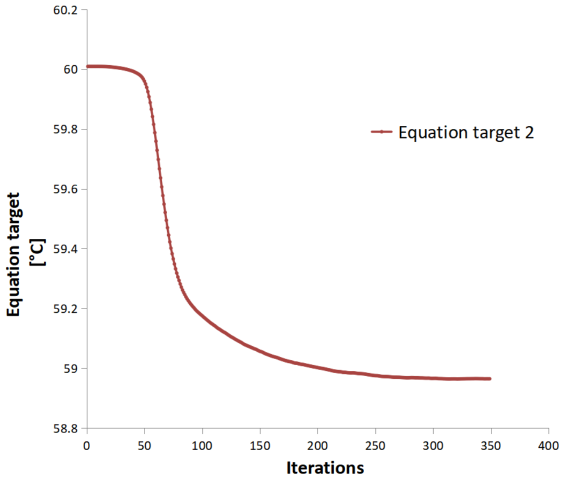

Figure 3: Temperature difference between inlet and outlet of shell side before optimi-zation

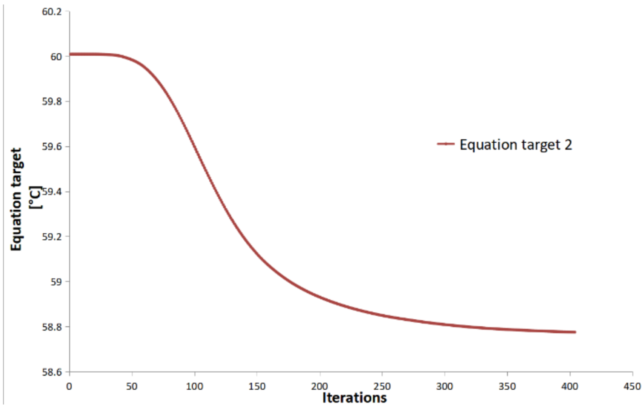

Figure 4: Temperature difference between inlet and outlet of shell pass after optimization

From the comparison of Figure 3 and Figure 4, it can be seen that before and after the optimization of the shell process inlet and outlet temperature difference, the curve is smoother, without a large drop, and the optimized heat transfer temperature difference is smaller than the temperature before optimization, indicating that the heat transfer is more stable and more adequate.

(3) Comparison of inlet and outlet temperature difference of tube side

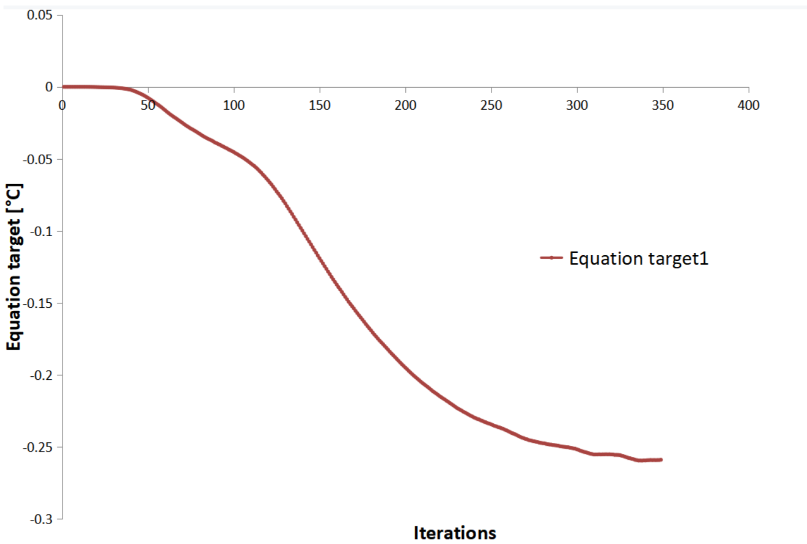

Figure 5: Temperature difference between inlet and outlet of tube pass before op-timization

ISSN 2706-655X Vol.5, Issue 5: 8-15, DOI: 10.25236/IJFET.2023.050502

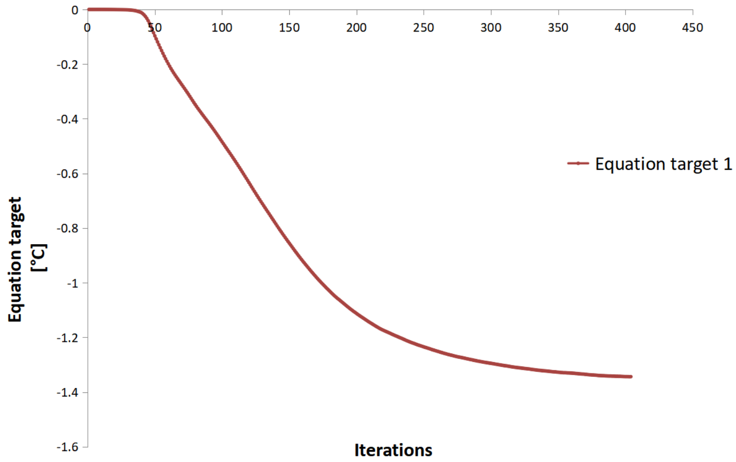

Figure 6: Temperature difference between inlet and outlet of tube pass after optimization

This can be seen from the comparison of Figure 5 and Figure 6.The temperature difference before and after the optimization of the import and export of the tube process, it can be seen that the heat transfer effect of the tube process before the heat transfer optimization is unstable curve fluctuations, while the heat transfer effect after the optimization is relatively smooth, no large fluctuations and the temperature difference between the import and export before the optimization is greater than the temperature difference after the optimization indicates that the heat absorbed by the liquid than before has improved, reflecting a more adequate heat transfer.

(4) Comparison of outlet temperature of tube side cold fluid and shell side hot fluid before and after optimization.

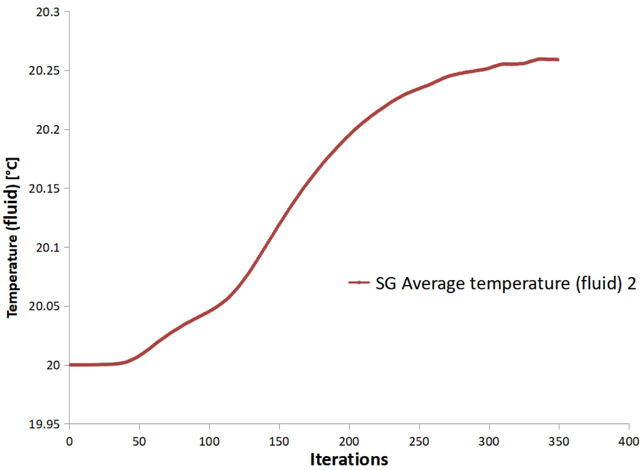

Figure 7: Tube side cold fluid temperature before optimization

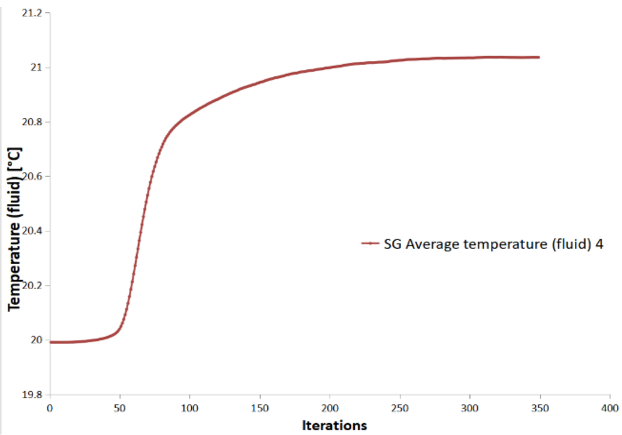

Figure 8: Shell side hot fluid outlet temperature before optimization

ISSN 2706-655X Vol.5, Issue 5: 8-15, DOI: 10.25236/IJFET.2023.050502

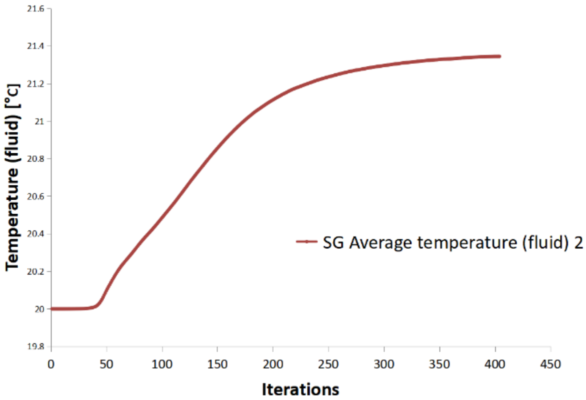

Figure 9: Outlet temperature of cold fluid at tube side after optimization

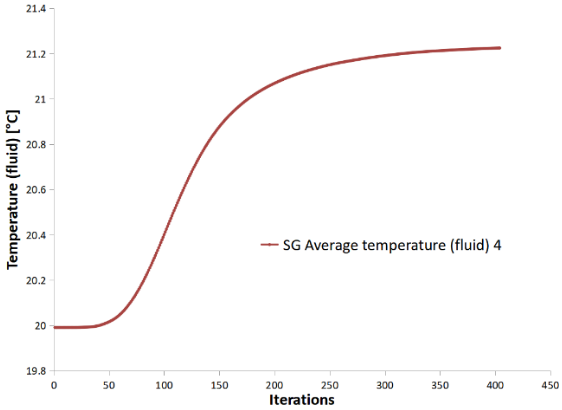

Figure 10: Outlet temperature of shell side hot fluid after optimization

This can be seen from the comparison of the two sets of curves in Figures 7,8 and 9,10.It can be seen that the temperature difference between the two outlets after optimization is smaller, reflecting a better heat transfer effect, while the temperature difference between the two outlets before the optimization is larger compared to that after optimization, in summary, the optimized heat exchanger has a better heat transfer effect and is more stable.

7. Problems needing attention in the design

In every heat exchanger, a phase change occurs, but because some fluid inlet and outlet temperatures do not differ, the load caused by the phase change can be negligible. However, when the load due to phase change is large, it needs to be calculated by entering the mass or volume percentages of liquid and gas phases, dew point, bubble point, latent heat of vaporization, and critical pressure in the parameters, and calculating the percentage of load in the distribution of load.[7]

8. Conclusion

In this paper, the simulation model of the shell and tube heat exchanger has been analyzed and studied, and the study is summarized as follows:

After comprehensive comparative analysis, unclean and easy-to-scale fluids are suitable for the tube process; corrosive fluids are suitable for the tube process; easy-to-contaminate fluids are suitable for the tube process; high-pressure fluids are suitable for the tube process; saturated steam is suitable for the shell process; fluids with low flow rate or high viscosity are suitable for the shell process; cooled fluids are suitable for the shell process; when the temperature difference between the two fluids is large, the fluid with large convective heat transfer coefficient is suitable for the shell process.

(1) Simulation results show that the degree of turbulence of the fluid also affects the size of the convective heat transfer coefficient, so we need to take into account the fluid flow rate.

(2) The simulation analysis shows that the size of the tubes required for a scaling-prone fluid is

ISSN 2706-655X Vol.5, Issue 5: 8-15, DOI: 10.25236/IJFET.2023.050502

different from that for a clean fluid, and the tube spacing is also an important influencing factor. For scaling-prone or unclean fluids, a large tube diameter can be chosen, and for clean fluids, a small tube diameter can be chosen; a small tube spacing is helpful for increasing the heat transfer coefficient.

(3) This shell-and-tube heat exchanger increases the efficiency of the heat pipe by increasing the utilization rate of the heat transfer tube and increasing the heat transfer area.

Acknowledgement

Fund program: Exploration and practice of multi-dimensional collaborative education model based on OBE concept - taking energy and power engineering as an example (M2021160), Optimization design of high-efficiency shell and tube heat exchanger (X202213379064), 2022 Weifang Institute of Technology "Challenge Cup" final "optimization design of high-efficiency shell and tube heat exchanger".

References

[1] Tian Y, Wang Z H. Flow Simulation-based modal analysis of shell-and-tube heat exchanger water with R1 34a heat exchange Application, 2015-05-19:46-52.
[2] Chen G D, Chen Q Y, Zeng M, Wang Q W, Numerical simulation study of combined multi-shell spiral folded plate shell and tube heat exchanger[J]. Journal of Engineering Thermopics, 2009, 30(8): 1357-1359.
[3] Liu J J, Application of a high-efficiency shell-and-tube heat exchanger[R]. Dyeing and finishing technology. 2006-08-02:44-49.
[4] Wang J, Liu Y F, Tian L, Computer-aided design and optimization of shell-and-tube heat exchangers [J]. New Industrialization. 2022, 2022, 12(11); 239-242, 246.
[5] Wang Q F, Pang X, Zhao S, The Factors affecting heat transfer efficiency of shell and tube heat exchanger and numerical simulation analysis[J]. China Petroleum Machinery, 2015, 43(10): 102-107.
[6] Hu B, Study on the Influence of Baffle Plate Structure on the performance of Shell-and-tube Heat Exchanger [D]. Wuhan: Jianghan University, 2022.
[7] Bai Z G, Design of shell-and-tube heat exchanger [J]. Shipbuilding of China, 2002, 43:256-258.