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Shell-side heat transfer enhancement for shell-and-tube heat exchangers by helical baffles

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Shell-and-tube heat exchangers (STHXs) have been widely used in many industrial processes such as oil refining, environmental protection, electric power generation, refrigeration and chemical engineering, etc. because of their easy maintenance and possible upgrades. However, the shell-side heat transfer performance is usual unsatisfactory for traditional segmental baffles due to the existence of dead region. In the present paper, the recent development on shell-side heat transfer enhancement for shell-and-tube heat exchangers with helical baffles is reviewed. The main contributions on the shell-pass heat transfer performance include the continunous helical baffled STHXs, single shell-pass combined helical baffled STHXs, combined parallel multiple shell-pass STHX with continuous helical baffles and combined serial multiple shell-pass STHX with continuous helical baffles. These helical baffles changed the flow pattern, simplified the manufacturing process of continuous helical baffles. These new improved STHXs might be used to replace the conventional STHX with segmental baffles in industrial applications to save energy, reduce cost and prolong service life.

1. Introduction

Shell-and-tube heat exchangers are widely used in oil refining, chemical engineering, environmental protection, electric power generation and refrigeration, etc. The shell-and-tube heat exchangers (STHXs) have relatively simple manufacture and multi-purpose application possibilities for gaseous and liquid media in a very large temperature and pressure range, so they are still the most widely used in chemical industry, power production, food industry, environment engineering, waste heat recovery, manufacture industry, air-conditioning, refrigeration and so on (Master, 2006). In order to further enhance heat transfer between the shell side and tube side, baffles are set up in the shell pass. In addition, the baffles can provide supports for the tube bundles. However, the most commonly used STHXs with segmental baffles have many disadvantages, such as high pressure drop, low shell-side mass flow velocity, low heat transfer efficiency, short operation time and so on (Li and Kottle,1998). The idea of shell-and-tube heat exchangers with helical baffles is firstly proposed by Colston and

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many investigators have carried out experimental researches on these helical baffles (Stehlik et al., 1994). In addition, the effectiveness of heat exchangers with helical baffles is proven on test units in industry applications. Helical baffled heat exchangers, which are commercially produced by ABB Lummus (2004), are now accepted by their outstanding advantages including: (1) improving shell-side heat transfer per pressure drop; (2) lowing pressure drop; (3) reducing bypass effect; (4) reducing shell-side fouling and flow-induced vibration. These helical baffles are formed by lapped over fans or oval shaped plates, which are easy to be manufactured, and namely discontinuous helical baffles. Over these decades, different kinds of STHX have been developed and better understanding has been achieved. Many various baffle types have been designed to enhance the shell-side heat transfer performance, for example, the conventional segmental-baffles with different arrangement, the grid baffles, the overlap helical baffles, the rod baffles and so on (Wang et al., 2010). In this study, we introduce the recent contributions on the improvement of shell-side heat transfer performance of STHX with helical baffles by the group of Novel Heat Transfer Technologies and Compact Heat Exchanger (NHTT-CHEX) of Xi'an Jiaotong University.

2. Heat exchangers with continuous helical baffles

Discontinuous helical baffle are normally arranged by a central pole, of which the volume of the central pole is small, however, the leakage by discontinuous helical baffle is relatively large due to the triangle zones, which will reduce the heat transfer performance. To overcome the above defects, Wang et al (2007a) have introduced a processing technique for continuous helical baffles. The continuous helical baffles are manufactured by linking several sets of helical cycles. One helical cycle is lengthened to one screw pitch along the length (axial) direction and is rotated to 2π angle along the circumferential direction, and several helical cycles are linked end to end to form continuous helicoids, as shown in Figure 1 This method overcomes the difficulties in manufacturing whole continuous helicoids at one time and reduces the manufacture cost significantly. Another major difficulty related to the manufacturing of continuous helical baffles is drilling holes on continuous helical baffles. If the holes on the baffles are drilled in the same size as the tubes in initially plain plates, and then the pitch is varied by stretching the spiral in or out, the tube will not see a round hole rather an elliptic one. Therefore, it is impossible to pass a round tube through an elliptic hole. To solve this problem, a die, as shown in Figure 2, is used to hold the helical cycle at the required pitch, and then the required holes can be drilled on the baffles (Peng et al. (2007) who also carried out experimental researches on continuous helical baffles and the results suggested that heat transfer coefficient of with continuous helical baffles was nearly 10 % higher than that of the SHTX with segmental baffles for the same shell - side flow rate and the better locations of the fluid inlet and outlet for continuous helical baffled STHX is side-in/side-out. Wang et al. (2010) also carried out experimental studies to comprise the heat transfer quality with segmental baffles and the continuous helical baffles are superior to segmental baffles. In order to have a further understanding of the heat transfer performance of STHX with helical baffles, continuous helical baffles have been applied in a shell-and-tube evaporator of an air condition system to replace the conventional segmental baffles. The test result suggests that STHX with continuous helical baffles has much better performance than STHX with segmental baffles. Under same heat transfer area, the refrigerating output of the evaporator with continuous helical baffles is 4.9% higher than that of conventional evaporator with segmental baffles; the coefficient of performance (COP) of the evaporator with continuous helical baffles is 5.4% higher than that of conventional evaporator with segmental baffles. Wang et al. (2007b) applied the genetic algorithm to optimize and predict STHXs with continuous helical baffles. The results indicated that the predicted heat transfer rates and friction factors by genetically algorithm had a closer fit to experimental data than those by regression analysis.

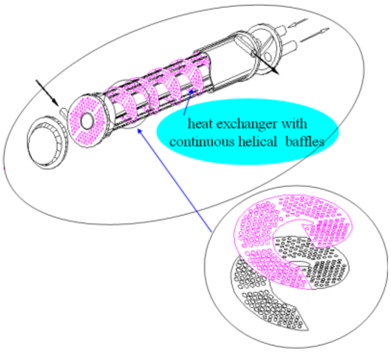


Figure:1 Continuous helical baffles

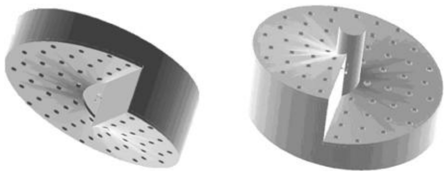


Figure: 2 Dies for drilling tube holes

3. Combined single shell-pass heat exchangers with helical baffles

In order to make full use of the advantages of continues baffles, save more space and increase the heat exchangers compactness, Wang et al.(2007d) have invented a kind of combined single shell-pass heat exchangers with helical baffles, as shown in Figure 3 This invention utilizes combined helical baffles, which means continuous helical baffles are used in most part of the inner space of the shell, and discontinuous helical baffles are used in the central region where it is difficult to process and install continuous helical baffles, thus avoiding space waste on the shell side and the tube side caused by installing central tubes. Even the pitch is large, a heat exchanger with the aforementioned advantages can still be manufactured, because the baffles are designed as discontinuous inner helical baffles and continuous outer helical baffles such that it remains easy to manufacture and install the inner baffles. Wang et al. (2009b) studied the STHXs with combined helical baffle by CFD method. The numerical results suggested that under the same mass flow rate in the shell side, the overall pressure drop of the combined helical baffled STHX is about 50% lower than that of heat exchanger with segmental baffles and its heat transfer coefficient under unit pressure drop was 81.7% higher than that of the heat exchangers with segmental baffles, as shown in Figure 4. The combined helical baffles greatly simplify the manufacturing of continuous helical baffles, however, it still cannot overcome the disadvantages of discontinuous helical baffled STHXs, that is, under the same mass flow rate, the helical baffled STHX has lower heat transfer coefficients than the segmental baffled STHX, although it also has lower pressure drop. To further enhance heat transfer performance of STHXs, the multiple shell-pass STHXs with continuous helical baffles have been introduced.

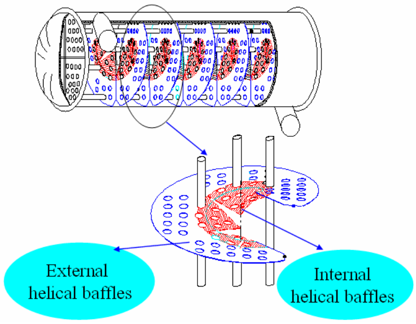
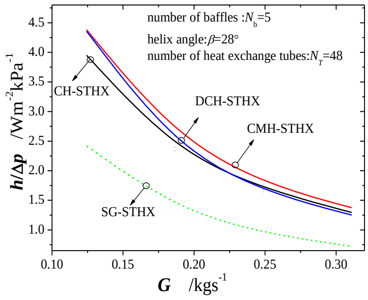


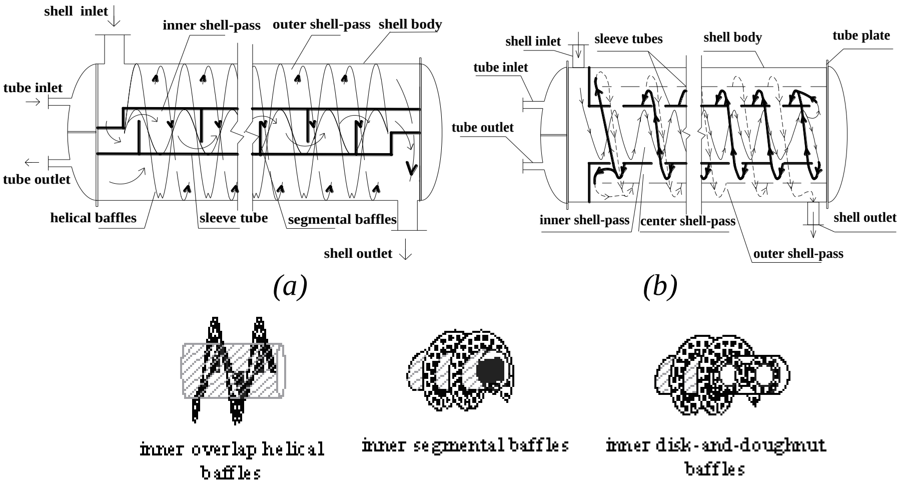
Figure:3 Combined helical baffles



Fiureg:4 Comprehensive performance of CMH-STHX

4. Combined multiple shell-pass heat exchangers with helical baffles

The combined multiple shell-pass STHX (as shown in Figure 5) have been invented and studied by Wang et al. (2007c, 2009a) to further enhance the shell-side heat transfer performance. The main improvements are as follows: there are two or more shell passes in the shell side of STHXs, where the outer shell passes are set up with continuous helical baffles and the inner pass can be equipped with other kinds of baffles (Figure 5c). Taking the two shell-pass STHX with continuous helical baffles as an example, the shell has two shell passes, the inner shell pass and the outer shell pass, which are separated by a sleeve tube. The baffles in the inner shell pass could be some traditional baffles such as segmental baffles, discontinuous helical baffles, disk-doughnut baffles, rod baffles and so on, which could be manufactured and installed easily. The outer shell pass is constructed by complete continuous helical baffles. Due to the inner sleeve tube, the inner shell-pass baffles and outer shell-pass helical baffles do not need to be fixed on the same helical surface. The inner shell pass and the outer shell pass are joined together at one end of the shell side. If the working fluid flows through the inner and outer shell pass simultaneously, the STHX is called parallel combined multiple shell-pass helical baffled STHX (Figure 5a), and if the working fluid flows through the inner and outer shell passes sequencely, the STHX is called series combined multiple shell-pass STHX with helical baffles (Figure 5b). The shell sides of the parallel combined multiple shell-pass helical baffled STHX and the series combined multiple shell-pass STHX with helical baffles have been separated into several individual shell passes. As to each individual shell pass, the cross-sectional flow area is reduced, thus the velocity of the fluid could be increased for the same mass flow rate, and therefore the heat transfer performance can be expected to have a great improvement. In addition, the combined multiple shell-pass STHX with helical baffles avoids the difficulties in manufacturing continuous helical baffles with a small size inner helix and increases its compactness. Numerical studies have been conducted on the series combined multiple shell-pass STHX with helical baffles. The pressure drop of combined double shell-pass STHX with helical baffles was lower than that of segmental baffled STHX by about 13 % for the same mass flow rate and same heat transfer rate. For the same overall pressure drop in the shell side, the overall heat transfer rate of the combined double shell-pass STHX with helical baffles is nearly 5.6 % higher than that of conventional segmental baffled STHX and the mass flow rate in the double shell-pass STHX with helical baffles is about 6.6 % higher than that in the STHX with segmental baffles. Chen et al. (2009) studied the combined serial multiple shell-pass STHXs with continuous helical baffles in the outer shell-pass and different forms of baffles (segmental baffles, discontinuous baffles and disk-and-doughnut baffles) in the inner shell pass with computational fluid dynamics method. The results indicated that for the same mass flow rate and overall heat transfer rate, the double shell-pass STHX with discontinuous helical baffles in the inner shell pass has the lowest pressure drop in the shell side.



(c)

Figure:5 Combined multiple shell-pass helical baffled STHX: (a) Combined parallel multiple shell pass helical baffled STHX; (b) Combined serial multiple shell pass STHX with helical baffles; (c) Different baffles in inner shell pass

5. Conclusions

In this study, STHXs continuous helical baffles, and combined single and combined multiple shell-pass heat exchanger with helical baffles have been introduced. The conclusions can be drawn as: (1) The heat exchanger with continuous helical baffles is superior to the heat exchangers with segmental baffles or overlapped helical baffles. (2) The combined helical baffled STHXs in single shell-pass have higher heat transfer coefficient than the segmental baffled STHXs. (3) Compared with the heat exchangers with segmental baffles, the combined multiple shell-pass heat exchangers with helical baffles can enhance the comprehensive heat transfer performance. Meanwhile, the combined single shell-pass and combined multiple shell-pass heat exchangers with helical baffles can simplify the manufacture and installation of heat exchangers.

Acknowledgements

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