A review on Baffle and Tube Orientation for Augmented Heat Transfer in Shell-and-Tube Heat Exchangers

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Abstract: This review focuses on optimizing heat transfer in shell-and-tube heat exchangers, emphasizing innovative baffle and tube orientation methods. Helical baffles are highlighted for their ability to improve heat transfer by inducing helical flow patterns. Staggered tube arrangements offer an alternative to achieve helical flow and reduce pressure drop. Adjusting tube length and shell diameter impacts heat transfer rates and pressure drop. Smaller diameter tubes are suggested to address lower convective heat transfer coefficients, but fouling concerns should be considered. The review suggests exploring tube orientation modifications to enhance flow turbulence and disrupting the thermal boundary layer. Shell-side modifications show promise for improved thermal performance, but challenges related to bypass streams and leakage need careful consideration in future research.

Keywords: Baffle & tube orientation; Shell & tube heat exchanger; Heat transfer

1. Introduction

Heat exchangers play a crucial role in transferring heat between fluids in various applications, but choosing the right one requires knowledge. The shell and tube heat exchanger is a widely used choice due to its simplicity, versatility, and cost-effectiveness. It allows heat exchange between two fluids without mixing them and is resistant to high pressure and temperature. This type of heat exchanger consists of a shell, tubes, baffles, and other components. To improve heat transfer, researchers have explored adding more tubes inside the shell and using baffles to create complex fluid flow paths. The size and spacing of baffles are key design considerations.

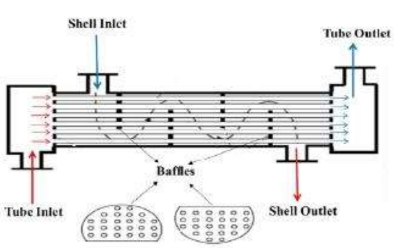


Fig. Schematic diagram of shell and tube heat exchanger

The efficiency of a shell and tube heat exchanger is influenced by factors like baffle design, tube passes, and overall dimensions. This chapter reviews the literature on these factors, presenting both experimental and numerical analyses of various heat exchanger geometries. Based on this review and identified research gaps, the study establishes the motivations and objectives of the current research work.

2. Baffle configurations

The heat transfer rate of a shell and tube heat exchanger is affected by the shape and arrangement of baffles. Segmental baffle is the generally used in shell and tube heat exchanger that directs the fluid to flow in zig-zag pattern in the shell side. However, various problems are associated with segmental baffles like, significant drop in pressure in shell-side, subsequent dead zone between two adjacent segmental baffles, vibration failure on tube bundle due high turbulence. Scientist and engineers [1-3] have proposed various methods to improve the disadvantages associated with the segmental baffle. Many researchers [4-6] have anticipated a novel design of baffle termed helical baffle.

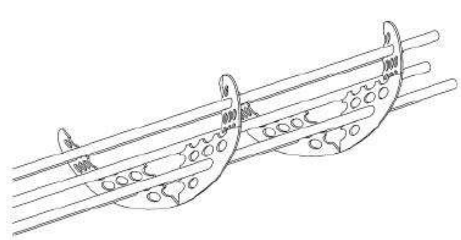


Fig. Shell and tube heat exchanger having four pieces middle over-lapped helically inclined baffle [6]

The problem associate with the non-continuous helical baffles is the short-cut movement of fluid in the shell side of the heat exchangers. To eliminate this disadvantage researchers [7-10] have put effort to improve its design. Researchers like Wang et al. [8-9], Peng et al. [8], Chen et al. [9-10] have proposed continuous helical baffles that can expand the working of shell and tube heat exchangers. Chen et al. [9] have proposed collective parallel multiple-shell-pass and Ji et al. [11] have proposed a double-shell-pass shell and continuous helical baffled tube heat exchanger. The proposed designs were found to be successful while increasing the out-put of the heat exchanger. An innovative proposal of baffle comprising of circumferential overlap trisection helix has been design by Chen et al. [12].

As discussed above, experimental [13] and analytical [14] studies on the performance of various baffle design have been reported over the past years. With the development commercial coding and computer hardware the concept of heat and shell heat exchanger having diverse baffle design is gaining popularity and importance. In this section an extensive literature review on the performance analysis of baffle configuration has been illustrated.

2.1. Literature review based on experimental analysis of different baffle design

The result obtained by numerical analysis is necessary to validate with experimental result. The experimental observations or results obtained while studding various geometry of shell and tube heat exchanger have been considered for this literature review.

Du et al.[15] have experimentally studied the heat transfer performance of the molten salt in shell side of the heat exchanger by a specially flow layout design with U-shaped tubes. The performance of shell and tube heat exchanger with segmental baffles have been related with a heat exchanger having no baffle. The authors have reported that the working of heat exchanger with segmental baffles was better for the region with lower flow rate with 26% increment in Nusselt number.

Gao et al.[16] have studied the variation in the shell side flow resistance due to the overlapping percentage of a helical baffle through experiments. The authors have studied three different helix angles (20°, 30°, and 40°) considering two different overlapping percentage as 10% and 50%. This study reveals that shell side flow resistance and heat transfer rate are suggestively affected by change in helix angle and overlapping percentage of a helical baffle. With rise in helix angle the heat transfer rate was found to be improved. Again, considering helix angle as constant the performance of the heat exchanger was found to be better in case of small overlapping percentage. However, a helical baffle with larger overlapping percentage was found to have less irreversibility in the heat exchange process. Hence, the authors suggested to select a higher helix angle and larger overlapping percentage of a helical baffle to improve the working of the shell and tube heat exchanger.

Zhang et al.[17] have perform experimental investigation by considering different designs of baffles for shell and tube heat exchangers. The two baffle designs considered for the study of the heat exchanger performance were segmental baffle and helical baffles with different helix angles. The heat transfer coefficient was found to be more for segmental baffle while the drop in pressure in the shell-side was found to be less in case of helical baffles. The author suggested that the overall working of helically baffled heat exchanger was better than that of segmental baffled heat exchanger. Heat exchanger efficiency has been found to be best at an angle of 40° among the other consider angles (20°, 30°, 40°, and 50°).

Lei et al.[18] have carried out experimental as well as numerical investigation to study the performance of the shell and tube heat exchanger. Hydrodynamics and heat transfer characteristics of the heat exchanger has been analyzed. The authors have studied three different design of baffles such as baffle with single segment, baffle with single helical, and baffle with two layers helical. The counter flow heat exchanger considered for this study carries oil in the shell and water in tube. Wilson plots technique have been used for finding both overall heat transfer coefficient and shell side heat transfer coefficient. Authors have revealed form their investigation that for constant drop in pressure in the shell both the heat transfer coefficients were more for helically baffled design compared to segmental baffled design. When the baffle with single helical and baffle with two layers of helically inclined baffle design were compared the heat exchanger with two layers of helically inclined baffle was found to provide better overall output.

Zhang et al.[19] have performed experimental investigations to compare heat exchangers output with two designs. The two designs considered for study were helically inclined baffled having fin of single horizontal petal designed and helical baffle with three rows of low fin tubes. The heat transfer coefficient of the heat exchanger with helically inclined baffle with single horizontal petal designed fin was found to be 1.56 times the helical baffle with three rows of low fin tubes. The authors have suggested that the coefficient of heat transfer with helically inclined baffle with single horizontal petal designed fin improves the output of the heat exchanger significantly. Authors have found a good correlation between experimental results with different tube types.

Liu et al.[20] have intended a heat exchanger designed with helically inclined baffled cooler with spirally corrugated tubes. The working of this heat exchanger has been studied by performing experimental investigation and numerical analysis. The flow field and heat transfer characteristics of the heat exchanger has been analyzed. The pressure drops in both tube side and shell side was also obtained during the investigation. The authors have found a good correlation between the outcomes gained by the experimental and numerical analysis.

3. Literature review based on experimental analysis of different tube design

From the above discussion it is clear that the baffled configuration has substantial influence on the performance of shell and tube heat exchanger. Another important parameter effecting the output of shell and heat exchanger is the orientation and configuration of tubes. The zone of the heat exchanger covered by the fluid influenced by the orientation and configuration of tubes. Consequently, the heat transfer rate of the heat exchanger will alter influencing its performance. Dizaji et al.[21] have studied the effect of different arrangement of tubes on the annulus fluid stream-line. From the figure it can be understood the dependency of fluid stream-line on tube configuration. Due to the specific configuration of the tube, there was a distinct energy loss and NTU for each case and consequently created the particular stream-line in annular space.

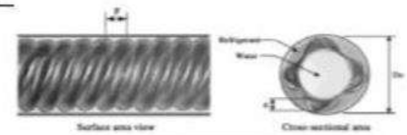
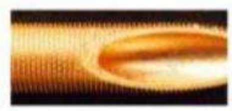
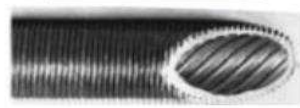
Initially researchers [22] have investigated the output of heat exchanger by installing corrugated tube only in the inner tube of a shell and tube heat exchanger. Dizaji et al. [23] have studied the effect of outer tube corrugations on the working of shell and tube heat exchanger. However, the concept of double heat exchanger with corrugated inner and outer tube was given by Dizaji et al. [21]. Researchers like Dong et al [22] have used spirally corrugated tubes in the heat exchanger for enhance its efficiency. Spirally grooved tube, coil tube, helically coiled tubes have been used by the researchers like Lu et al. [24], Dizaji et al. [25], Dizaji et al. [26] respectively, to study their effect on heat exchanger performance. Aroonrat et al. [27] have studied performance of a heat exchanger installed with vertical corrugated tube. Some of the tube configuration used by researchers are enumerated in Table.

Rossi et al.[28] have experimentally investigated the performance of a helically corrugated wall tube in a shell and tube heat exchanger. The helically corrugated tube that has been used by the authors is shown in Table. The authors have also conducted comparison investigation between the smooth tube and helically corrugated wall tubes. The authors have reported that performance of the heat exchanger has been significantly improved while using helically corrugate tubes.

Darzi et al. [29]have conducted experiments to obtain influence of nano-particles and helically corrugated tube on turbulent heat transfer and friction factor in a Al_2O_3-water nano-fluid heat exchanger. The authors have revealed that with increased in nano-fluid concentrations the heat transfer and friction factor increase both in plain and helical corrugated tube. However, in helical corrugated tubes the effect is significantly noticed when height of corrugation was more and pitch was small. Hence, the authors have reported that the heat transfer rate of a corrugated tube heat exchange can be improved by considering high concentration of nano-particles, high corrugation height and low corrugation pitch.

Hosseini (2007) [62] has experimentally investigated three different configurations of tubes in heat and shell heat exchanger. The considered designs were: smooth tube, corrugated tube and tubes with micro-fins.

Table: Various configuration of tubes used by researchers

Tube configurations	Figures
Fluted tube	
Corrugated tube	
Helically corrugated tube	
Alternating elliptical tube	
Fine tube	
Helically ribbed tube	

For each of the configuration authors have studied the heat transfer coefficient and pressure drop on the shell side. The data experimental investigation was corelate with the available theoretical data. The authors have kept the factors such as geometry of tube bundles, configuration, number of baffles and length constant. Authors only differed the external tube surfaces inside the same shell. The performance of corrugated and micro-fin tubes was found to be poor at low Reynolds number (Re<400). By increasing the Reynolds number, the authors were able enhanced the performance of the heat exchanger with micro-finned tubes.

4. Conclusion and Future Directions

Most of the work has been done on the shape of baffles. It is found that helical baffle is the most suited baffle, because it provides helical shape to the flow. Other than this, helical flow can be obtained by the using staggered arrangement, without using helical baffle. Other main reason of using helical baffle is reduction in pressure drop, as it provides easy passage to the flow. Dimension of set-up also affects the desirable parameter, such as by increasing the length of tubes, heat transfer rate and pressure drop both increases. Similar trend can be observed for increase in diameter of shell.

Heat exchanger design has seen research in modifying tube and shell sections. Reduced convective heat transfer coefficients on the tubular side due to lower fluid velocity have led to considerations like using smaller diameter tubes, although fouling issues arise. Tube orientation modification to increase turbulence remains unexplored. Altering tube geometry may disrupt the thermal boundary layer, warranting research in this direction. Shell-side modifications can enhance thermal performance but pose challenges such as bypass streams and leakage. Balancing heat transfer and safety is a key focus for future research.

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