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A review of the advancements made in helical baffles used in shell and tube heat exchangers☆

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ABSTRACT

This paper provides a review about the major work done on helical baffles to improve the performance of shell and tube heat exchangers. Some of the major factors affecting the performance of shell and tube heat exchanger are discussed. A comparison between segmental baffles and helical baffles is also presented to show that helical baffles are more advantageous than segmental baffles. In most cases, discontinuous, folded, sextant helical baffles, 40° baffle inclination angle as well as low baffle spacing will give the best results when integrated in some combination, whereas continuous helical baffles eliminate dead regions. Moreover, sealing strips are more likely to improve the performance of shell and tube heat exchangers with continuous helical baffles.

1. Introduction

Heat transfer technology has its application in various fields ranging from the functioning of nuclear reactors to refrigeration systems and everything in between [1]. Some of the other areas where heat transfer must be regulated include heat engines, heat pumps, fuel cells, gas turbines, electronic packaging systems and food processing [2–5].

There are three basic modes of heat transfer; conduction, convection and radiation. Conduction is virtually involved in all operations in which heat transfer is taking place. Transfer of heat via conduction occurs through a solid surface that separates fluids having different temperatures [6]. For transferring heat by the process of conduction, heat exchangers are the most common equipment used in process industries.

Different types of heat exchangers are used worldwide that differ from each other because of their specific requirements, such as double pipe, shell and tube, plate fin, plate and shell, pillow plate, etc. are a few types of heat exchangers used on an industrial scale. Amongst these types, double pipe heat exchangers are the simplest ones, on the other hand, shell and tube heat exchangers (STHEs) are the most widely used type of heat exchangers in the chemical process industries. Worldwide, more than 35% to 40% of all the heat exchangers used industrially are STHEs.

STHEs are used in all sorts of industries because they have much lower production cost, are easily cleaned and are considered to have more flexible adaptability compared with other heat exchangers. STHEs can be divided into three categories according to the type of flow: longitudinal, transverse and helical.

This paper is focused mainly on the developments made so far with a special type of baffles called helical baffles.

2. Major factors affecting STHE performance

The major factors affecting the performance of STHE are turbulence, pressure drop, heat transfer coefficient, fouling, ratio of flow rates on the tube side to shell side, length of heat exchanger and type of baffle.

By increasing turbulence intensity level, flow resistance can be increased, which enhances the heat transfer effectively [7]. Higher pressure drop enhances the heat transfer rate but it leads to an increase in the power consumption, which is its major drawback [8,9]. So, an optimized value of pressure drop for optimum heat transfer rate as well as power consumption is used. Greater heat transfer coefficient increases the heat transfer rate. Heat transfer coefficient can be increased by increasing the shell side and tube side flow rate, coil diameter and coil pitch as well as by applying counter-flow configuration [10–13]. Fouling should be lower in heat exchanger for better performance. Fouling mainly depends on fluid composition, wall temperature and pipe material [14].

The ratio of heat transfer coefficient to pressure drop increases as the length of heat exchanger decreases [15,16]. Therefore, more turbulence, lower pressure drop, higher heat transfer coefficient as well as less fouling are some of the factors required for better performance of a shell and tube heat exchanger [8,9,17–20].

One of the important elements, considering the design of a STHE, is the type of baffle. Baffles, being an integral part of STHE, provide support to the tube bundles and maintain desirable velocity for shell side fluid

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flow; moreover, they create turbulence and resist vibrations to enhance the fluid velocity as well as the heat transfer coefficient. Various types of baffles are used in STHEs. Some of them are segmental, flower, ring, trefoil hole, disc and doughnut type and helical [21]. However, traditional STHEs with segmental baffles show low heat transfer efficiency and large pressure drop [22,23].

3. Comparison between helical baffles and segmental baffles

Helical baffles, as compared to segmental baffles, give a better performance [24–26]. Sirous et al. has emphasized the merits of helical baffles over conventional segmental baffles. Their major work was on the performance comparison and fouling investigation on the shell side of STHE. Moreover, they showed that pressure drop was less in helical STHE as compared to segmental ones while heat transfer rate is higher for segmental baffle STHE but overall performance of helical baffle STHE (HB-STHE) is better than segmented baffle-STHE (SG-STHE) [27,28]. If segmental and helical baffles are compared for use in STHEs, helical baffles serve as a more promising technology because of having less shell-side pressure drop, better heat transfer performance, less fouling and less fluid-induced vibration [29–32]. The following graph shows the comparison of segmental baffles to helical baffles (Fig. 1). It is clear from the graph that the heat transfer coefficient per unit pressure drop for heat exchanger with helical baffles is better than segmental baffles. The values for the graph are taken from the article [28].

Helical baffles give spiral flow, which eliminates leakage dead zones and causes a decrease in fouling as well. Although helical baffles require high capital investment, they are economical for long-term use due to low operating and maintenance costs. The effectiveness of the heat exchangers with two layered helical baffles is higher than that of heat exchangers with single layered helical baffles [11,33].

Fig. 2 shows the creation of fouling over time for both types of baffles. The graph is plotted by values taken from the research article [27]. η is the ratio of used water in the clean heat exchanger to the used water in the unclean one. $1/\eta$ indirectly shows the fouling. It is evident from the graph that fouling is less in STHE with helical baffles.

4. Design optimization of HB-STHE

The major factors that affect the design criteria for helical baffles are:

Baffle shape
Continuous vs. discontinuous baffles
Plain vs. fold baffles
Baffle inclination angle
Baffle spacing
Sealing strips

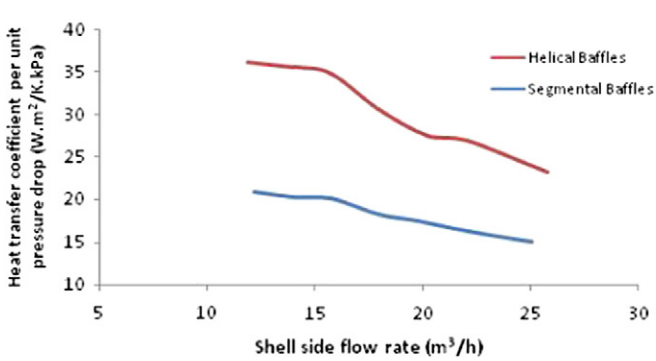

Fig. 1. Performance comparison of helical and segmental baffles.

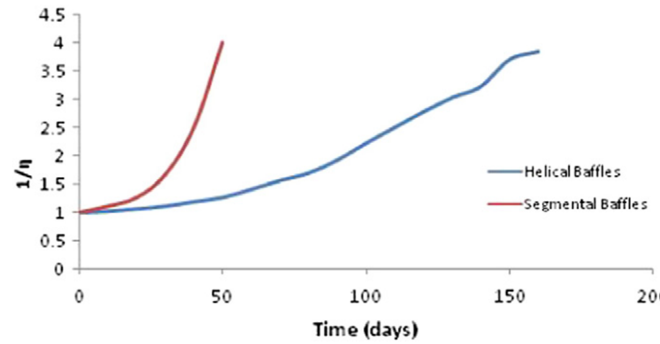

Fig. 2. Fouling comparison in helical and segmental baffles.

4.1. Baffle shape

Baffle shape is one of the prominent factors affecting the performance of STHE. Wenjing et al. described the effects of baffle shape in STHE. In their work, they investigated three physical models with baffles of different shapes, i.e. trisection, quadrant and sextant sector. Sextant HB-STHE showed a better comprehensive heat transfer performance than that of the quadrant and trisection HB-STHEs because the leakage flow in the triangle area is evidently reduced and the fluid streamline appears much closer to an ideal spiral flow, while the trisection and quadrant HBHE show more scattered and disordered streamline distributions [31,34]. Inserting sextant helical baffles instead of trisection helical baffles lowers pressure drop on the shell side (Fig. 3) [35,36].

4.2. Continuous vs. discontinuous helical baffles

Continuous helical baffles (CHB) and discontinuous helical baffles (DCHB) are generally used in STHEs. Jian et al. made a comparison between CHB and DCHB. It was found that the heat transfer coefficient per unit pressure drop of the discontinuous helical baffles is appreciably

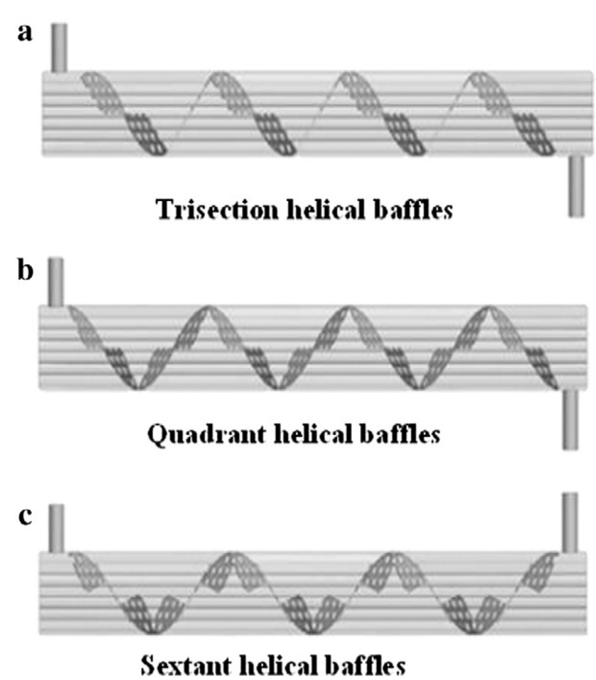

Fig. 3. Different shapes of helical baffles.