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EXPERIMENTAL INVESTIGATION OF THE EFFECT OF BAFFLE CUT SHAPE ON SHELL SIDE PRESSURE DROP IN SHELL AND TUBE HEAT EXCHANGER

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ABSTRACT

Shell and Tube Heat Exchanger (STHE) is widely used in industry due to its high performance and serviceability. The pressure drop and the heat transfer are considered as the major factors in the design of a STHE. In this study, an experimental investigation is carried out to predict the pressure drop in the shell side of STHE for three different types of baffle cut equivalent in the flow area. The first baffle type is a segmental baffle with baffle cut of 25%. The second and third types are concave and convex baffle cuts which have not been suggested in the literatures. Each type is tested for four baffle spacings as 175, 140, 115 and 100 mm and four mass flow rates of 1000, 2000, 3000, and 4000 kg/hr. The results show that the pressure drop increases with increasing the mass flow rate and also with decreasing the baffle spacings. Also, it is noted that the concave baffles cut cause more pressure drop. For the convex type baffles cut it is noted that the pressure drop decreases when the baffles spacing is 100 mm for all flow rate tested in contrast to other types that the pressure drop is increasing.

KEYWORDS

Heat transfer, Mass flow rate, Energy exchange, Tube bundle, Baffles spacing**.**

1. INTRODUCTION

Heat exchanger is a device used to exchange energy in form of heat. This energy exchange takes place due to temperature difference between two flowing fluid streams separated by a solid surface preventing them from mixing. Heat exchangers are widely used in power generation plants, petroleum refineries, chemical processes and in refrigeration and air conditioning systems. Shell and tube heat exchanger (STHE) is mostly used in the industries. This is because of the relatively large heat transfer area-to-volume ratio, robust geometry construction and easy maintenance compared to other types of heat exchangers [1,2].

Generally a STHE is constructed of bundle of tubes and baffles contained in a cylindrical shell. The purpose of using baffles is to obtain cross flow over the tubes in the shell side, directing the fluid in the zigzag manner across tube bundle, supporting the tube bundle and reducing tube vibration. Therefore, the overall impact of the baffles in the STHE is enhancement of the heat transfer rate, while it causes further pressure drop in the shell side of the heat exchanger.

The typical baffle type used in the STHE to the present time is the conventional segmental baffles. This type of baffles is constructed of disc with a cut area called baffle cut . However, this baffle has low heat transfer efficiency and high pressure drop. Thus, new types of baffles such as orifice baffles, rod baffles, helical baffles and flower baffles are proposed to enhance heat transfer duty, reduce tubes vibration and enhance flow characteristic [2]. The flow through the space between the baffles has a complex nature resulted from the flow streams in this region, such as flow through baffle window, leakage between the baffles and shell wall, fluid leakage between the tubes and baffles. These streams affect the heat transfer rate and pressure drop in the shell side of STHE. Accordingly, it is difficult to propose an accurate mathematical model to predict the value of pressure drop and heat transfer for this type of heat exchanger. Therefore, experimental procedures are common methods to evaluate pressure drop and heat transfer rate in the STHE for design purpose and to validate the theoretical models.

A theoretical calculation of heat transfer and pressure drop in STHE is proposed by Kern in 1950 [3]. Tinker has developed a theoretical method to predict STHE heat transfer and pressure drop included parameters accounting for various pressure losses factors and heat transfer rate [4]. The well-known Bell-Delaware method of STHE design was introduced based on a large number of experiments on shell side flow in the laboratory [5]. Due to the great role of STHE in the industry, many researches focused on enhancing the characteristics of this type of heat exchanger in order to improve its duty by maximizing the heat transfer rate and minimizing the pressure drop. The prediction of the pressure drop in the shell side of the STHE involves experimental investigation and coupling theoretical and numerical analysis with experimental data.

Sparrow and Reifschneider investigated experimentally the inter baffles spacing effect on the heat transfer and pressure drop in the shell side of STHE [6]. Halle predicted an experimental measurements of the shell side pressure drop for different tube layout of segmental baffle heat exchanger [7]. A plane and finned tubes are used in the experiments and the results correlated for pressure drop versus flow rate and baffle spacing. Pekdemir presented an experimental measurement of shell side pressure drop in a cylindrical STHE for Reynolds number ranged between 270-2200 based on minimum inter tube flow area [8]. The results showed that the pressure losses is function of Reynolds number, distance between baffles and radial position. An experimental investigation of the pressure drop and local heat transfer in the shell side of STHE fitted with segmental baffles for different baffles spacing and tube arrangement presented [9]. They found that the average heat transfer and pressure drop are increasing when the baffle spacing increases. Some researcher carried out an experimental investigation to find out the effect of shell side geometry and flow quantities on the performance of STHE, they reported that the heat exchanging is strongly function of the shell side geometry [10]. Other researcher investigated experimentally the performance of STHE with new type of baffles named flower baffles [11]. The results showed that the overall performance of STHE with new model is better than the segmental baffle heat exchanger. Some researchers presented an experimental investigation of the fluid

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flow and heat transfer in STHE to examine the influence of number of the segmental baffles on STHE effectiveness [12]. The results showed that the number of baffles affect the heat transfer rate between the fluid streams and pressure drop value in the heat exchanger. An experimental investigation and numerical simulation performed in references, to study heat transfer and fluid flow characteristics of STHE [13-15].

In addition to the experimental investigations, theoretical and numerical modeling are also used by many researchers to predict the heat transfer and pressure drop for STHE. You used numerical modeling based on CFD simulation to obtain the shell-side thermal-hydraulic performances of a STHE with flower baffles [2]. Gaddis and Gnielinski presented a procedure for shell side pressure drop evaluation in the STHE with segmental baffles based on correlations for ideal flow coupled with correction factors [16]. Kapale and Chand developed a theoretical model used to estimate the shell side pressure drop for STHE [17]. Some researchers developed 3-D numerical simulations of a rod-baffle STHE using four different modeling approaches and the results validated with experimental data [18]. A thermal hydraulic performance of shell and tube heat exchangers with different geometrical tube layout was presented by Petinrin and Dare [19]. Other researcher presented 3-D numerical simulation of STHE with conventional segmental baffles and continuous helical baffle and a comparative study is performed based on the simulation results [20]. A numerical and theoretical analysis used by Bayram and Sevilgen, to investigate the effect of baffle spacing on the characteristics of a STHE [21]. Sadikin used CFD simulations to study the effect of number of baffles on flow pattern and pressure drop in the shell side of STHE [22]. Bichkar presents a numerical simulation of STHE with three different baffles type to investigate the pressure drop in this type of heat exchanger [23]. Wang presented numerical analysis and optimization study for heat transfer performance and pressure drop of shell side of STHE with staggered baffles [24].

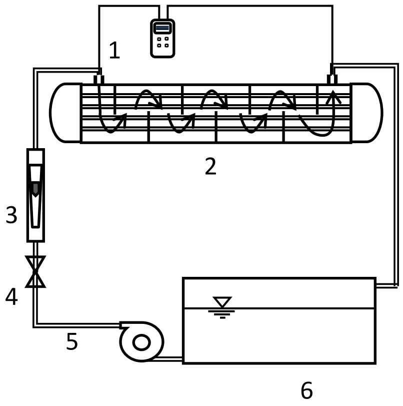
According to the literature survey it is clear that baffle shape and spacing affect the heat exchanger performance by affecting the flow direction and hence pressure drop and convection heat transfer, which are two effective parameters in the design of shell and tube heat exchanger. However, the effect of baffle cut shape on the pressure drop in the shell side of STHE is not reported, which gave motivation for the current research. The objective of the present work is to investigate experimentally the effect of segmental baffle cut shape on the pressure drop in the shell side of STHE. This includes using traditional segmental baffles and two new proposed baffle types referenced as concave and convex baffle cuts. Each of baffle type will be tested at different mass flow rates and baffle spacings. The study of the pressure drop in heat exchanger is an important engineering problem because the power consumed to force the fluid through the device is directly proportional to the pressure drop. Therefore, reducing pressure drop means reducing pumping power which in turns increase the performance of the heat exchanger. For this reason, the present work focuses on studying the effect of using new types of baffle cuts on the pressure drop in shell and tube heat exchangers.

2. EXPERIMENTAL METHODOLOGY

An experimental test rig, shown schematically in figure 1, is constructed to investigate the effect of baffle cut shape on the pressure drop of the shell side of a STHE. The test rig consists of test section, pressure and flow rate measuring devices as well as working fluid flow loop. The test section is shell and tube heat exchanger that consists of shell, tubes, tube sheets, shell heads, inlet and outlet nozzles, baffles and tie rod. All parts are detailed in Table 1. The working fluid is water and the flow loop consists of water tank connected to water pump and flow measuring device and other necessary piping connection to complete the water flow loop through the test section. A rotameter (MBLD -LZT-2520G) is used for mass flow rate measuring with accuracy of (3%). The pressure difference between inlet and outlet is measured by a digital manometer (Lutron PM9100) with accuracy of (2% of full scale) connected to inlet and outlet nozzles by 4 mm clear plastic tube ended with pressure taps.

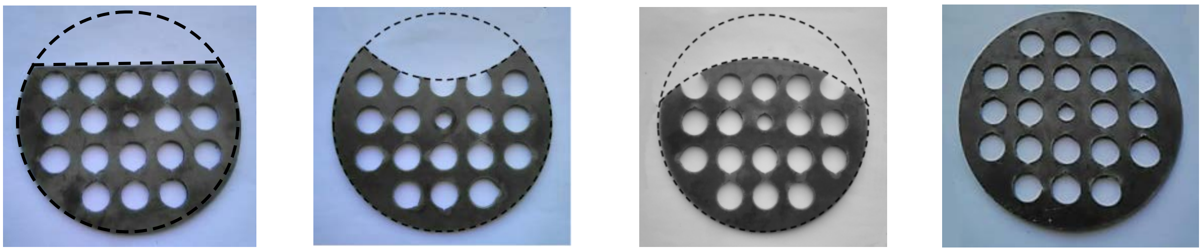
a) Shell and tube heat exchanger

b) Tube and baffles assembly



c) Experimental test rig

Figure 1: The experimental test rig, 1. Pressure measuring device, 2. Shell and tube heat exchanger, 3. Flowrate measuring device, 4. Flowrate control valve, 5. Water pump, 6. Water tank



Regular baffle cut

Concave baffle cut

Convex baffle cut

Tube sheet

Figure 2: Shows baffle types and tube sheet used in the heat exchanger

Table 1: Geometric parameters of the Shell and Tube heat exchanger

Shell side dimensions	
Shell internal diameter	152 mm
Shell wall thickness	7 mm
Shell material	PVC
No. of Shell Pass	1
No. of Baffles	7, 9, 11, 13
Baffle plate thickness	2 mm
Tube side dimensions	
Tube internal diameter	14 mm
Tube wall thickness	1 mm
No. of Tube Pass	1
No. of Tubes	20
Tube Layout	Square
Tube Length	1400 mm
Tube material	Aluminum

A Segmental baffles of 145 mm diameter made of 2-mm thickness steel plate with three different baffle cuts are used in the experiments and are shown in Figure 2. The first baffle type is a traditional segmental baffle with baffle cut of 25% of the diameter. The baffle cut of second type is concave curved edge with an arc of radius 145 mm. The center of the arc is above the baffle center by 100 mm. While the third type baffle cut is convex curved edge with an arc of 200 mm diameter and the center is located 56 mm below the baffle center. The flow area of these three types of the baffles are equal and the dimensions are specified according to this condition.

3. RESULTS AND DISCUSSION

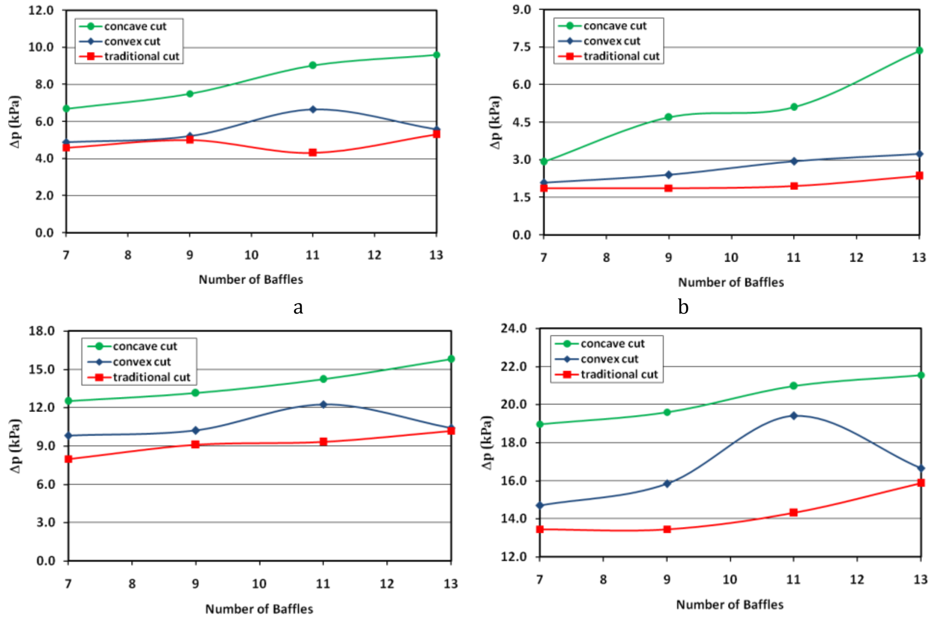
In the current study, the effect of the baffles cut shape and the space between baffles on the pressure drop of the shell side of a shell and tube heat exchanger are experimentally investigated. In this investigation twelve geometrical configuration are tested [29]. Three baffle cut shapes (concave cut, convex cut and traditional cut) and four cases of baffles spacing (175, 140, 115 and 100 mm) corresponding to number of baffles of (7, 9, 11 and 13 baffles) are tested. The tests are carried out for four mass flow rates of (1000, 2000, 3000, 4000 kg/hr) for each case. The results of the experimental data are analyzed and discussed in the following sections.

3.2 Effect of baffle cut shape on pressure drop at different flow rate

The results of the pressure drop (□p) versus number of baffles depicted in figure 3 (a through d) for three baffles type at mass flow rates, 1000, 2000, 3000 and 4000 kg/hr. As shown in the figure, at mass flow rate of 1000 kg/hr the increase of the number of baffles yields an increase in the pressure drop for all three baffles cutting shapes. This is because that increase the number of baffles decreases the spacing between the baffles and hence the flow stream undergoes sharp change in direction as it passes the baffle. This causes more dead flow zone at the corner between the baffles and the shell wall.

The pressure drop caused by concave baffle cut is much higher than other two types, whereas the traditional baffles cut results in lowest pressure drop. The largest pressure drop is observed for concave baffles cut at 13 baffles, which is about three times of that of traditional baffles. At mass flow rates of 2000 and 3000 kg/hr, the pressure drop variation with number of baffles shows approximately a same trend except that the pressure drop values for mass flow rate of 3000 kg/hr is about two times that for mass flow rate of 2000 kg/hr.

The pressure drop at mass flow rate of 4000 kg/hr is similar to pressure drop behavior at flow rates of 2000 and 3000 kg/hr but the difference is in the values of pressure drop which is more than the pressure drop for these two flow rates. The pressure drop for convex baffle cut is close to the pressure drop of traditional baffle cut but the pressure drop is increases sharply when number of baffles is 11 for flow rates 2000 to 4000 kg/hr. It is notable that for the convex cut baffle type in this figure at mass flow rates of 2000 to 4000 kg/hr, the pressure drop shows more step decrease when number of baffles is corresponding to 13. This is because of that the fluid flows on the two sides of the convex baffle cut and this causes reduction of the dead zones and smaller vortex zone and hence lower pressure drop.



a

b

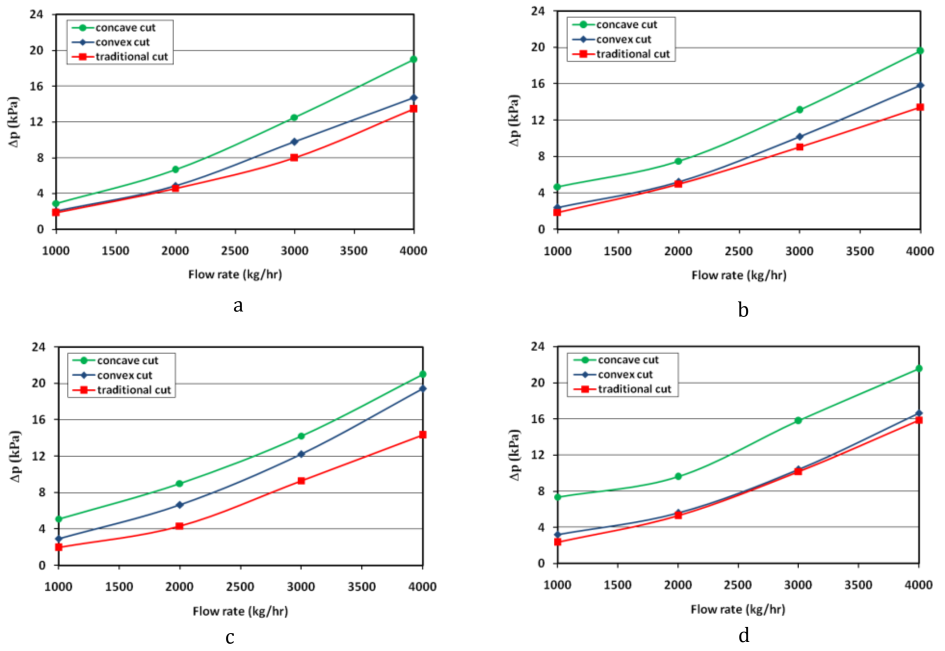
c

d

Figure 3: Variation of pressure drop with number of baffles at different mass flow rate a) 1000 kg/hr b) 2000 kg/hr c) 3000 kg/hr d) 4000 kg/hr

3.2 Effect of baffle cut shape on pressure drop at different baffles spacing

The pressure drop at different baffle spacing for three baffle cut shape is shown in figure 4(a through d). As can be seen from these sub figures, the pressure drop is increasing with the increase of the mass flow rate for all baffle spacings. It's clear that the concave baffle cut causes higher pressure drop, whereas the traditional baffle cut results in lower pressure drop at all number of baffles. A close examination of figure 4-d shows that, when the number of baffles is 13 the pressure drop for traditional cut is very close to that of convex cut for all mass flow rates, this is caused by approximately same flow behavior for these two types of baffles when the space between the baffles reduced.



a

b

c

d

Figure 4: Variation of pressure drop with flow at different number of baffles a) 7 baffles, b) 9 baffles c) 11 baffles d) 13 baffles

4. CONCLUSIONS

Pressure drop in the shell side of the STHE is investigated experimentally using three segmental baffles cut. These cuts are traditional, concave and convex baffle cut. Four baffle spacings are considered as 175, 140, 115 and 100 mm which correspond respectively to 7, 9, 11 and 13 baffles. For each case, four mass flow rate are used: 1000, 2000, 3000 and 4000 kg/hr. By examining the results obtained from this work, the following conclusions can be drawn:

- The increase in the number of baffles leads to more pressure drop for all flow rate, because the space between the baffles decreases as number of baffles increases, which leads to more obstruction in flow path.
- The higher pressure drop occurs at higher mass flow rate and this is consistent with all predicted pressure drop formulas available in the literatures which states that the increase in the velocity leads to increase in the pressure drop.
- The traditional baffle cut causes lower pressure drop, whereas concave baffle cut results in larger pressure drop.
- The case of convex baffle cut with 11 baffles results in maximum pressure drop for mass flow rates of 2000 to 4000 kg/hr. Whereas the pressure drop at 13 baffles decreases and approaches to that of traditional cut and could be lower for the number of baffles greater than 13, and this needs more investigation in future works.

In general, the results indicated that the baffles cut shape has a significant role in the formation of the flow path and hence affects the pressure drop value in the shell side of a STHE so that more attention should be given to the baffle cut shape in the future researches. The author would like to suggest more studies on the pressure drop and heat transfer for shell and tube heat exchanger taking in to consideration the effect of varying the number of tubes, tubes layout and shell and tubes diameters using different baffle cut shapes and other cut shapes. On the other hand, the study can be extended to include other fluids rather than water to study the effect of the properties of the fluids on the pressure drop and heat transfer for these types of baffle cuts.

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