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Baffle Design of Shell And Tube Heat Exchanger

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Abstract: A heat exchanger is a device that is used to transfer thermal energy between two or more fluids, at different temperatures and in thermal contact. Heat exchangers are used in wide range for different type of industrial and domestic applications. For two fluids of different starting temperatures with flow through the heat exchanger. One flows through the tubes (the tube side) and the other flows outside the tubes but inside the shell (the shell side). Baffles are placed on the shell side space which is providing the cross flow direction of shell side fluid and so the more intensive heat exchanger between fluids could be realized. Besides, baffles are carried of tube bundle, which helps then to decrease the deflection and vibration in apparatuses. In present work, experimentation of single pass, cross flow shell and tube heat exchanger containing segmental baffles at different orientations has been conducted to calculate some parameters such as heat transfer rate and pressure drop. The design of shell and tube heat exchanger are included mechanical design and thermal design. The mechanical design is included the design of main shell under internal and external pressure drop, tube design, baffle design, etc. The thermal design is involved evaluation of required effective surface area, number of tubes and finding out log mean temperature difference. The thermal model was developed using the effectiveness NTU method.

Keywords: Tube Design, Baffle, Pressure Drop, Log Mean Temperature Difference, NTU Method, Change Diameter, Experimental, Thermal Efficiency.

I. INTRODUCTION

Heat exchangers are devices used to transfer heat between two or more fluid streams at different temperatures. Heat exchangers find widespread use in power generation, chemical processing, electronics cooling, air-conditioning, refrigeration, and automotive applications. In this paper which will examine the basic theory of heat exchangers and consider many applications. In addition, this will examine various aspects of heat exchanger design and analysis. A typical heat exchanger usually for high pressure applications is the shell and tube heat exchanger. Shell and tube type heat exchanger, indirect contact type heat exchanger. It consists of a series of tubes, through which one of the fluids runs. The shell is the container for the shell fluid. Although in some cases it is possible to employ conventional units, it is often better and sometimes essential to evolve a completely new design. Therefore, this paper is intended to design a conventional shell and tube heat exchanger which is widely used in process industries. However, the calculation principle underlying the problem to design a heat exchanger are everywhere the same, and it is the purpose of this paper to present design calculations rather than to deal with the details of individual problems and special cases. In this paper, the digital computer is being used extensively to solve problems that were used to be done by hand mostly. A computer program has been written for shell and tube heat exchanger design. Normally, the heat exchanger design calculations seem to be complex and repeated calculations are required with assumed and fixed data. It is hoped that this paper will aid in classifying the many details questions that arise during design calculation and this will support practicing engineers to apply their formal backgrounds in fluid flow and heat transfer to the practical problems posed by the design, section, testing or installation of the shell and tube heat exchanger. [1]

II. TYPES OF SHELL AND TUBE HEAT EXCHANGERS

The most common type of heat exchanger in industrial applications is shell and tube heat exchangers. They are built of round tubes mounted in cylindrical shells with their axes parallel to that of the shell. They are classified by the methods used for reducing thermal stress between tubes and shell. There are four common types to eliminate thermal stresses in shell and tube heat exchanger according to heat designs. There are four types of heat exchanger that are fixed tube sheet exchanger, internal floating exchanger, U tube bundle exchanger and outside packed heat exchanger.

A. Fixed Tube Sheet Heat Exchanger

It is the simplest to fabricate and the cheapest as shown in figure 1. Internal leakage could be due only to leaky tube joints. Disadvantages are high thermal stresses between tubes and the shell which loosen the tube joints and the impossibility of mechanically cleaning the outside of the tubes. Advantages of fixed tube sheet provides maximum heat transfer area for a given shell and tube diameter. Provides for single and multiple tube passes to assure proper velocity. Less costly than removable bundles designs. The shell fluid may be cleaned because of the shell is difficult to clean and hot fluid may go into the tube; relatively cold fluid may go into the shell side. Highly corrosive fluid should flow inside the tube because it is easy to clean in the tube and to avoid the expense of special metal for both shell and tube. High pressure, temperature fluids are placed in the tube also because making high pressure shell with thicken walked is expensive. [4] To increase the overall coefficient, viscous fluid should flow into the shell side.

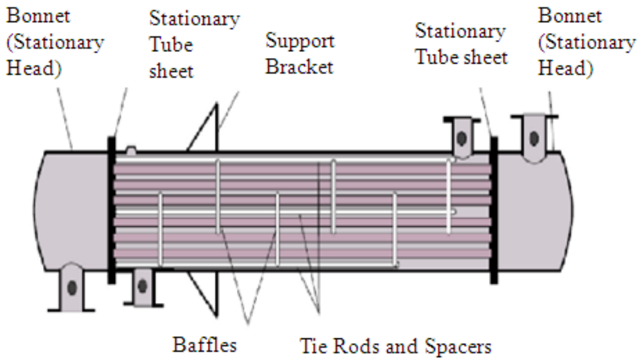

Figure 1. Fixed Tube Sheet Heat.

B. Internal Floating Heat Exchanger

Internal floating heat exchanger as shown in figure 2 eliminates the stresses between the tubes and shell. The tube bundle is removable and floating tube sheet allows for differential thermal expansion between the shell and the tube bundle. The disadvantages are the internal hidden gasket on the floating heat and which may fail and cause trouble. To provide the floating heat cover it is necessary to bolt it to the tube sheet. The bolt circle requires the use of space where it would be possible to place a large number of tubes. Tubes cannot expand independently so that huge thermal shock applications should be avoided. Packing materials produce limits on design pressure and temperature.[5]

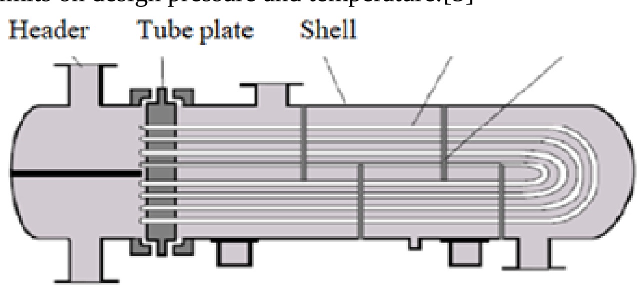

Figure 2. Floating-Head Exchanger.

C. U Tube Bundle Exchanger

U tube design allows for differential thermal expansion between the shell and the tube bundle as well as for individual tubes. Both the tube bundle and the shell side can be inspected and cleaned mechanically less costly than floating heat or packed floating head designs large difference in temperature between the shell and tubes may produce severe temperature stresses.[4] U tubes bundle is removable and require only one shell joint of the fixed end. Because of U bend some tubes are omitted at the center of the tube bundle. U tube bundle heat exchanger is show in figure 3.

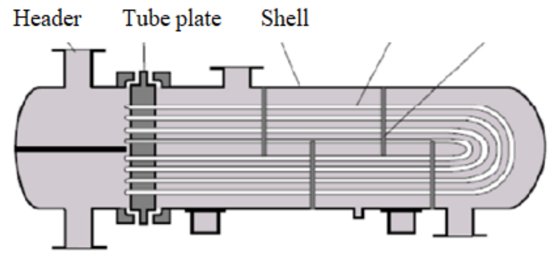

Figure3. U Tube Bundle Exchanger

III. TUBE CHARACTERISTICS

The total area of tubes becomes the desire heat transfer area in a shell and tube exchanger. Suitable length, size, tube layout and material combination can be selected to obtain optimum transfer area and transfer rate. Tubes and tube sheet are mostly made of brass or admiralty brass. Corrosive, high pressure, high temperature, viscous fluids should flow into tubes to avoid the expense of special metal for both shell and the tube. According to their tube geometry, tubes can clean mechanically or chemically. Tube size, thickness, length and pitches are entering into the calculation of heat transfer and must be chosen with care. With the help of the standard dimension, tube length and size can be adjusted. But sometimes there will be particular dimension. Narrower tubes may be used in smaller heat exchanger working with clean fluids.

A. Tube Length

Although tube lengths of 4 to 22ft are readily obtained and longer tube are available , one often selects a standard length of 8 ,12 , or 16 ft, using more than one pass where necessary .The shorter lengths are used when the exchanger is located well above grade in order to minimize the cost of platforms and equipment for removing the bundles for cleaning, where length is limited by available space or where very large shell diameters are required , the longer lengths are used when the equipment is near grade and consequently platforms are not needed.

B. Tube Outside Diameter

The heat transfer occurs in the smallest tube diameter. Sizes used in exchanger range from 1/4 in OD to 2 in OD. The most popular sizes are 5/4 in, 3/4 in, 1in, 3/2 in OD. The larger diameters tend to be used for fluids that foul the tubes rapidly. Smallest practical size is 3/4 in, but 1in would be preferred.

C. Tube Thickness

Tube thickness is governed by many factors such as pressure, corrosion, cost and rolling the tubes into the tube sheet. Thickness should be selected not only to withstand working pressure and extreme temperature and to provide allowance for corrosion but also to facilitate expanding the tube into the tube sheets. The usual thickness used is sufficient to hold the pressure at least 200 psi.

D. Tube Pitch

The tube pitch is the shortest center to center distance between adjacent tubes, which the shortest distance between two tubes is designated as clearance. The best heat transfer is obtained with close pitches but plug easily and difficult to clean. In most shell and tube exchanger, the pitch is in the range of 1.25 to 1.5 times of the tube diameter. When the exchanger must be tight it would be best to increase the tube pitch. The clearance should not be less than one-fourth of the tube diameter, and 3.16 in, is usually considered to be a minimum clearance.

D. Tube Sheet

The tubes are fixed with tube sheet that form the barrier between the tube and shell fluids. The tubes can be fixed with the tube sheet using ferrule and a soft metal packing ring. The tubes are attached to tube sheet with two or more grooves in the tube sheet wall by tube rolling. The tube sheet thickness should be always greater than the tube outside diameter to make a good seal. The thickness of the tube sheet should be at least 7/8 in and should not be less than outside diameter of the tube. There are two common pitch types in matrix geometry of header sheet. They are (a) Square pitch type (b) Equilateral triangular pitch type. In any case, to facilitate cleaning, the clearance between tube should be at least one fourth of the outside diameter of the tubes and in no case less than 1/4 in. So, the use of wider triangular pitches in place of square pitches offer many advantages.

IV. BAFFLE ARRANGEMENT

Installing baffle in heat exchanger give better mixing of fluid and increasing the turbulence. But also increase the pressure drop in shell side. Less baffling gives poor distribution fluid in shell side. Longitudinal baffles are often used for many vapor condensers. Some users of exchangers prefer two single pass shells in series rather than one shell with a longitudinal baffle and a split floating head. To avoid vibration of the tubes, the baffle should have a thickness of 1/8in and preferably 3/16 in or 1/4in and the edges of the tube holes should be chamfered. Consequently, the baffle should be at least twice as thick as the wall of the tube. With a bored shell the clearance between baffle and shell is often 1/32 to 3/64in, but the clearance and consequently the leakage will increase because of corrosion and with unboned shell the clearance may be considerably larger because of greater tolerances. They are commonly made of copper or naval brass and four types of baffle used in heat exchangers are segmental baffle, disk and doughnut type baffle, strip type baffle and orifice type baffle. [10]

A. Segmental Baffle

It is formed by cutting a segmental from a disk. The depth of cut as a percentage of the baffle diameter is known as percent baffle cut (e.g.20% cut). The usual range of baffle cut is from 20% to almost 50% of diameter. The height of baffle should be 75% of the shell inside diameter as cute 25% cut off segmental baffle. This baffle as shown in figure 4 is most common and considered as standard. It is efficient and give good heat transfer rates for the pressure drop and power consumed and all the baffles act as support plates for the tubes. Because of the tube bundle cannot completely fill the shell, it makes by passing, the disadvantage. Clearance between baffle and shell is often 1/32 in to 1/64 in. Straight tie rods are used to hold baffle in place.

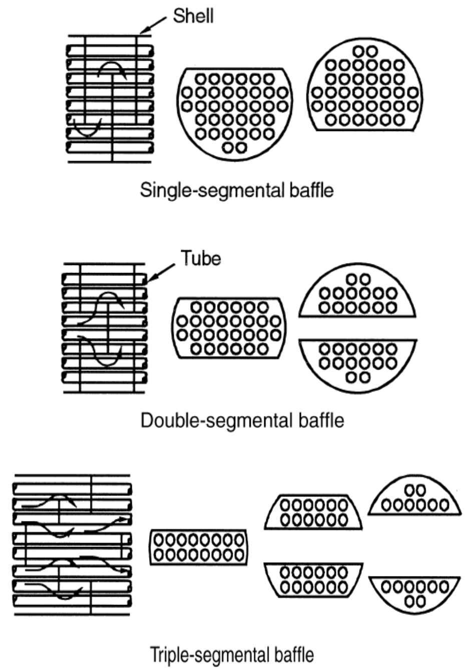

Figure 4. Segmental Baffle.

B. Disk and Doughnut Baffle

It consists of alternate disc and dough nut shaped baffles. This baffle as shown in figure 5 is occasionally used and the disc is larger than the doughnut hole usually. With disk and doughnut baffles, the disks offer no support for the central tubes unless braced to the shell. Sometimes the minimum clearance between the tubes and the edges of the holes in the segmental or disk and doughnut baffles in one percent of the tube diameter, but since the tube may have a diameter tolerance of two percent, the maximum clearance may be three percent, consequently some fluid will flow though these clearances.

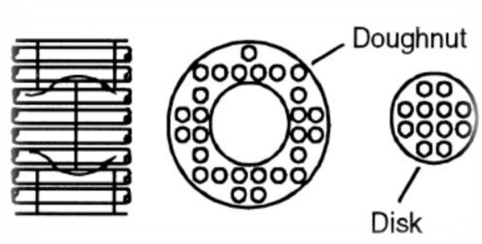

Figure 5. Disk and Doughnut Baffles.

C. Orifice Baffles

It consists of discs with oversize holes through which the tube passes. Those baffles as shown in figure 6 are rarely used because they are the least efficient and they cannot be cleaned when plugged with dirt and scale. The orifice type of baffle should fit the shell closely to prevent leakage and the baffles are placed fairly closely to give frequent changes in the velocity, this type should not be used for fluids that rapidly foul the outer surface or where corrosion or erosion is likely to cut the tubes. In a variation of the orifice type, alternate baffles have orifices for one-half the number of tubes and support the other half.

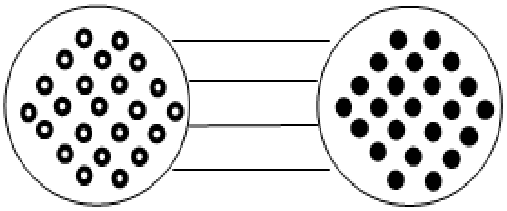

Figure 6. Orifice Baffles.

D. Baffle Spacing

The distance between adjacent baffles is called baffle-spacing. The baffle spacing of 0.2 to 1 times of the inside shell diameter is commonly used. Baffles are held in positioned by means of baffle spacers. Closer baffle spacing gives greater transfer coefficient by including higher turbulence. The pressure drop is more with closer baffle spacing. The function of the cross baffle is to direct the flow across the tube-field as well as to mechanically support the tubes against sagging and possible vibration.[9] The most common type is the segmental baffle. Baffle spacing is subject to minimum and maximum limitations for good thermo hydraulic performance and tube support. The ratio of baffle spacing to baffle cut is a crucial design parameter for efficient conversion of pressure drop to heat transfer. It is greater than 1/5 times of the shell diameter and smaller than shell diameter. Minimum spacing is 2 inches or 1/5 diameter, 2 inches is based on inability to clean the bundle and 1/5 D is based on manufacturer experiences. The closer the baffle are spaced the greater the turbulence and heat-transfer. The pressure drops increase at close spacing but in proportion to the increased transfer rate. Since the baffle may be spared closed together or far apart, the mass velocity is not entirely dependent upon the diameter of the shell.

V. BAFFLE DESIGN CONSIDERATIONS

Baffles are used to increase the fluid velocity by diverting the flow across the tube bundle to obtain higher heat transfer coefficient. The distance between adjacent baffle is called baffle spacing. The baffle spacing of 0.2 to 1 times of the inside shell diameter is commonly used. A baffle cut of 20 to 25% provide a good heat transfer with the reasonable pressure drop. Baffle spacing is defined as:

$$L_b = 0.2\ D_{s,i} \le L_b \le 1\ D_{s,i} \qquad (1)$$

where, L_b is baffle spacing and $D_{s,i}$ is the inside diameter of shell.

The inside diameter of shell ($D_{s,i}$) is defined as:

$$D_{s,i} = D_B + \text{clearance} \qquad (2)$$

where, D_B , $D_{s,i}$are tube bundle diameter, inside diameter of shell and clearance of tube.

The number of baffle is defined as:

$$N_b = \frac{L_s}{L_b + t_b} - 1 \qquad (3)$$

where, L_b, t_b, L_s and N_b are baffle spacing, baffle thickness, length of shell and number of baffles.

A. Log Mean Temperature Difference (LMTD)

In a steadily operated heat exchanger the bulk temperature of both fluids are fixed at a given position, but usually the temperature of one or both of the fluids changes as the fluid flows through the apparatus. If the cross section is constant, the velocities are fixed and each individual coefficient and consequently the overall coefficient U depend on physical properties of the fluids, which in turn depend on temperature. When a heat exchanger operates continuously the temperature differences between the hot and cold fluids usually varies throughout the length of the exchanger. [2] The log means temperature difference ΔT is a function of the inlet and outlet temperatures of both streams and their flow patterns. [4] The log means temperature differences (LMTD or ΔT_{lm}) is defined as

$$LMTD=\Delta T_{lm}= (\Delta T_1-\Delta T_2)/ \ln(\Delta T_1/\Delta T_2) \qquad (4)$$

Here ΔT_1 and ΔT_2 are temperature differences between two fluids at each end of a counter flow or parallel flow exchanger. For a counter flow exchanger,

$$\Delta T_1= T_{h,i} - T_{c,o}\ ,\ \Delta T_2=T_{h,o} - T_{c,i}$$

For a parallel flow exchanger,

$$\Delta T_1= T_{h,i} - T_{c,i}\ ,\ \Delta T_2= T_{h,o} - T_{c,o}$$

LMTD is used when designing simple heat exchanger.

B. The Effectiveness NTU Method

In the Effectiveness MTU method, the heat transfer rate from the hot fluid to the cold fluid in the exchanger is expressed as

$$Q = \varepsilon C_{min}\left(T_{h,i} - T_{c,i}\right) = \varepsilon C_{min}\,\Delta T_{max} \qquad (5)$$

Where ε is the heat exchanger effectiveness, $C_{min}$is the minimum of C_h and C_c, $\Delta T_{max}=(T_{h,i}-T_{c,i})$ is the fluid inlet temperature difference. [6] The heat exchanger effectiveness ε is nondimensional, and it can be shown that in general it is dependent on the number of transfer units NTU, the heat capacity rate ratio C^*, and the flow arrangement for a direct-transfer type heat exchanger:

$$\varepsilon = 2\left[1+C^* + \left(1+C^{*2}\right)^{1/2}\frac{1+\exp\left[-NTU\left(1+C^{*2}\right)^{1/2}\right]}{1-\exp\left[-NTU\left(1+C^{*2}\right)^{1/2}\right]}\right]^{-1} \qquad (6)$$

$$C^* = \frac{C_{min}}{C_{max}} \qquad (7)$$

The number of transfer units NTU is defined as a ratio of the overall thermal conductance to the smaller heat capacity rate:

$$NTU = \frac{UA}{C_{min}} \qquad (8)$$

C. Thermal Efficiency

In thermodynamics, the thermal efficiency (η_{th}) is dimensionless performance measure of a device that uses thermal energy, such as an internal combustion engine, a steam turbine or a steam engine, a boiler, a furnace or a refrigerator for example. The thermal efficiency is related temperature difference with hot fluid and cold fluid, mass flow rate and heat capacity. [3] The thermal efficiency is defined as;

$$Q=(mC_p)_c\,(T_{c,o}-T_{c,i})=(mC_p)_h(T_{h,o}-T_{h,i}) \quad (9)$$

$$\eta_{th}=\frac{(T_{h,i}-T_{h,o})}{(T_{h,i}-T_{c,i})},\ \text{for}\quad m_c C_{p,c}\geq m_h C_{p,h} \quad (10)$$

D. Heat Exchanger Efficiency

The heat exchanger efficiency is defined as the ratio of the heat transferred in the actual heat exchanger to the heat that would be transferred in the ideal heat exchanger.[8] The concept of heat exchanger efficiency provides a new way for the design and analysis of heat exchangers and heat exchanger networks. Efficiency is a comparison between the actual (real) and ideal (best) performances and is typically defined to be less than or at best equal to 1. The efficiency of a number of commonly used heat exchangers is given by the general expression.

$$\eta=\frac{\tanh(Fa)}{(Fa)} \quad (11)$$

Where, Fa, the fin analogy number, is the non-dimensional group that characterizes the performance of different heat exchangers. [7] This type of heat exchanger is used single shell pattern. It is related with NTU method and heat capacity ratio. The expressions for Fa for some of the commonly used heat exchangers are given in below table1.

Table1. Fin analogy number various heat exchangers

Counter	Parallel	Single stream	Single shell
$Fa=NTU(1-C^{*})/2$	$Fa=NTU(1+C^{*})/2$	$Fa=NTU/2$	$NTU\sqrt{1+C^{*}}/2$

VI. RESULTS (Effects of Other Parameters Changing With Tube Diameter)

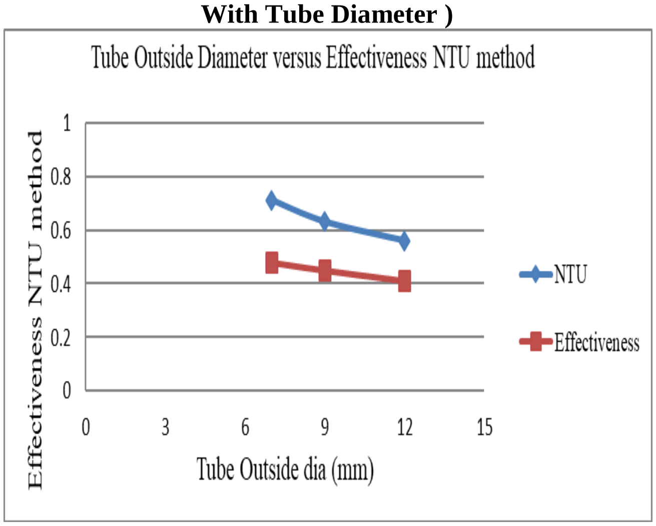

Figure 7. Tube outside diameter versus Effectiveness NTU method.

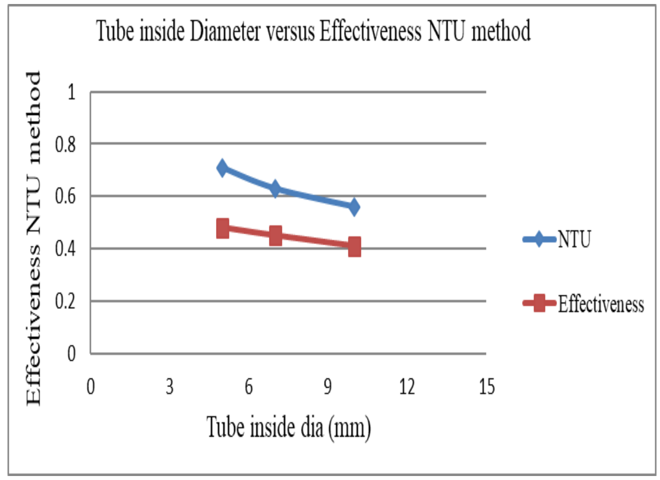

Figure 8. Tube inside diameter versus Effectiveness NTU method.

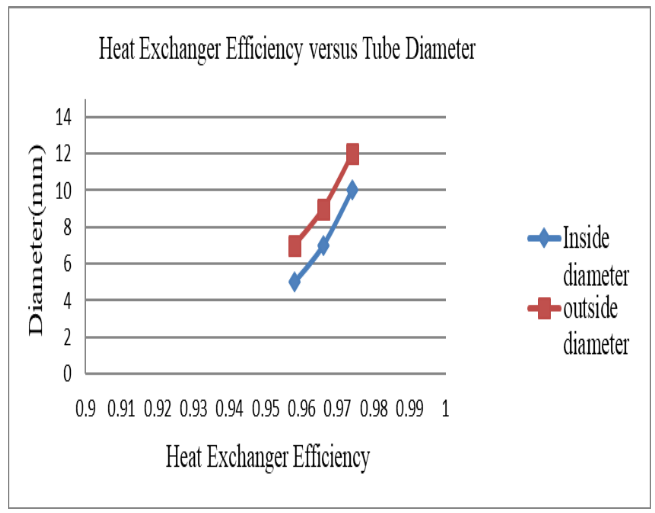

Figure9. Heat exchanger efficiency versus tube diameter.

VII. THEORETICAL/EXPERIMENTAL RESULTS OF SHELL AND TUBE HEAT EXCHANGER

Figure 10. Shell and tube heat exchanger.

Table 2. Theoretical/Experimental of performance results

			Theoretical	Experimental
S/N	Quantity	Units	Value	
1	Baffle spacing	m	0.041	0.0414
2	Number of baffles	-	16	16
3	Heat load	W	9738.9	8347.64
4	Log mean temperature different	℃	48	40
5	Effectiveness	-	0.54	0.51
6	Number of transfer unit	-	0.63	0.81
7	Heat capacity ratio	-	0.2	0.151
8	Tube side heat transfer coefficient	W/m^2K	6566.8	5136.86
9	Shell side heat transfer coefficient	W/m^2K	1177	1164.34
10	Overall heat transf r coefficient	W/m^2K	952.38	899.28
11	Thermal efficiency	%	50	62
12	Heat exchanger efficiency	%	97	95

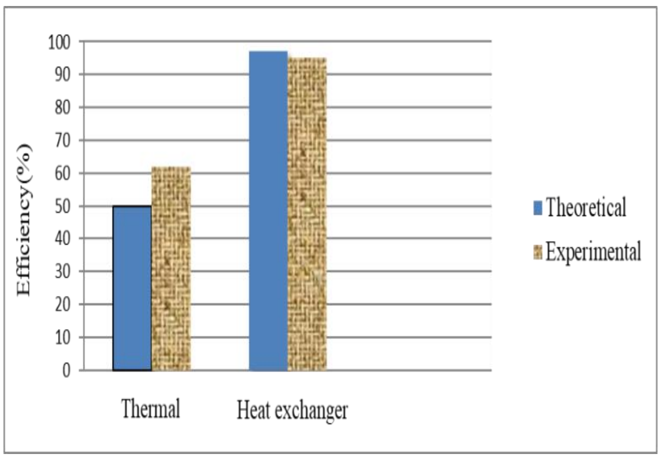

Figure11. Comparison of theoretical & experimental for efficiency.

VIII. DISCUSSIONS AND CONCLUSION

Heat exchangers are widely used in industries both for cooling and heating large scale in industrial process. Baffles are used to increase the fluid velocity by diverting the flow across the tube bundle to obtain higher heat transfer coefficient. A baffle cut of 20 to 25% provide a good heat transfer with the reasonable pressure drop. The distance between adjacent baffle is called baffle spacing. The effect of baffle spacing variations from 0.2 to 1 of shell inside diameter millimeter was considered on heat transfer and pressure drop. There are many types of heat baffle. Among them, segmental baffle is selected in this design. This type of baffle is probably the most popular. Segmental baffles with a 25 percent baffle cut are used on the shell side and baffle spacing is set at 41mm. In this design, 25 percent baffle cut is used according to the method of Wolverine. If the shell side pressure drop is higher than the allowable limits, the baffles spacing is increased slightly, the shell side pressure drop will be satisfactory. Segmental baffles normally should not be spaced closer than 0.8 of the shell inside diameter and the least baffle spacing is considered 41 mm. In the present study, experiments were conducted on various types of heat exchangers to compare their efficiencies, effectiveness and overall heat transfer coefficients. The results of theoretical and experimental of effectiveness are 0.54 and 0.51. The results of theoretical and experimental of overall heat transfer coefficient are 952.38 W/m^2K and 899.28 W/m^2K. The results of theoretical and experimental of efficiency are 0.95 and 0.97. The various heat exchangers are shell and tube heat exchanger, plate fin heat exchanger, spiral heat exchanger and plate type heat exchanger. The experimental results showed that the required area to provide a thermal duty of 8347.64 W is about $0.19m^2$ with tube side and shell side heat transfer coefficients of 5136.86 W/m^2K and 1164.34 W/m^2K . The average temperature of shell side and tube side with cold water and hot water is 25℃ to 31℃ and 90℃ to 50℃. The outside and diameter of the tubes are 9mm and 7mm with a clearance between tubes of 13mm. Baffle spacing is set 41mm and the number of baffles are at16. The shell side and tube side pressure drop of 133.68 N/m^2 and 65.76 N/m^2. These results can be very important when it comes to maximizing the efficiency of a shell and tube heat exchanger. Therefore, the results from this experiment lead to information that will help to optimize the shell and tube heat exchanger. Since heat exchangers are very common in industry, designing a maximum efficiency heat exchanger will have a vast impact in furthering the development of the industrial world.

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