Experimental Study on the Performance of Helix Changer using Grooved and Finned Tube

DISSERTATION

Submitted in partial fulfillment of the

Requirement for the Award of the Degree of

MASTER OF TECHNOLOGY

In

THERMAL ENGINEERING

By

KUNWER SANDEEP SINGH

REG. ID: 11008400

Under the Guidance of

Mr. RAM KUNWER

Mr. VARUN GOYAL

SCHOOL OF MECHANICAL ENGINEERING

LOVELY PROFESSIONAL UNIVERSITY

PUNJAB

2015

Lovely Professional University Jalandhar, Punjab

CERTIFICATE

I hereby certify that the work which is being presented in the Dissertation entitled **"Experimental Study on the Performance of Helix Changer using Grooved and Finned Tube"** in partial fulfillment of the requirement for the award of degree of **Master of Technology** and submitted in Department of Mechanical Engineering, Lovely Professional University, Punjab is an authentic record of my own work carried out during period of Dissertation under the supervision of **Mr. Sudhanshu Dogra**, **Assistant Professor**, Department of Mechanical Engineering, Lovely Professional University, Punjab.

The matter presented in this dissertation has not been submitted by me anywhere for the award of any other degree or to any other institute.

Date: **(Kunwer Sandeep Singh)**

This is to certify that the above statement made by the candidate is correct to best of my knowledge.

Date: **(Varun Goyal)**

The M-Tech Dissertation exam of Kunwer Sandeep Singh, has been held on date __________

Signature of Examiner

ACKNOWLEDGEMENT

This Dissertation was a welcome and challenging experience for me as it took a great deal of hard work and dedication for its successful completion. It's my pleasure to take this opportunity to thank all those who help me directly or indirectly in preparation of this report.

I Kunwer Sandeep Singh student of Lovely Professional University, in my acknowledgement, I would like to thank all the people who have helped me in making this project a success. My first and foremost acknowledgement goes to my mentor Mr. Varun Goyal for the assistance and guidance that he provided throughout the session. I am ever grateful to him for that. I want to say special thanks to Mr. Ram Kunwer for helping me a lot in the completion of dissertation.

I am also thankful to my university which assigned me this project which immensely improved our technical knowledge. I am thankful to university for providing me various resources like lab, tools for the timely completion of this project.

There times in such projects when clock beats you again and again and you run out of energy and you want to finish it once and forever. Last but not the least I would like to thank family and friends for their boost and support in every sphere. Their vital push infused a sense of insurgency in me.

I thank you one and all.

Date:

Kunwer Sandeep Singh

Regd. No.: 11008400

Lovely Professional University

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURE

ABSTRACT

Heat exchanger is important heat & mass exchange apparatus in oil refining, chemical engineering, environmental protection, electric power generation, etc. Among different types of heat exchangers, shell-&-tube heat exchangers (STHXs) have been commonly used in industries. About 35–40% of heat exchangers are of the STHXs, & this is primarily due to the robust construction geometry as well as easy maintenance & possible upgrades of STHXs. Segmental baffles are most commonly used in conventional STHXs to support tubes & change fluid flow direction but conventional heat exchangers with segmental baffles in shell-side have some shortcomings resulting in the relatively low conversion of pressure drop into a useful heat transfer. The Helix changer - a heat exchanger with shell side helical flow eliminates principle shortcomings caused by shell side zigzag flow induced by conventional baffle arrangements. The new design reduces dead zones within the shell space. These results in relatively high (Heat transfer co-efficient/Pressure drop) & low shell side fouling. Thus, the helix changer exhibits much more effective way of converting pressure drop into a useful heat transfer than conventional heat transfer.

In this current experiment investigation attempts were made to find out thermal performance of helix-changer using finned and grooved tubes. During the investigation three experiments has been done, with simple straight copper tube, grooved copper tube and with finned copper tube at same operating condition. It is found that grooved and finned copper tube helix-changer have better thermal performance compared to simple copper tube heat exchanger at a particular angle 25°. By flow analysis of tube, it is found that flow pattern inside grooved tube have better fluid particle mixing which leads to the enhancement in heat transfer. Fins provides effective heat transfer area. The finned and grooved surface are passive technique.

NOMENCLATURE

A	Area (m^2)
L_B	Baffle spacing (m)
B_c	Baffle cut (m)
C_p	Specific heat at constant pressure (Kj/Kg-K)
D_o	Outside Diameter of tube (m)
D_S	Inside Diameter of shell (m)
U	Heat transfer coefficient(W/m^2-K)
N_b	Number of baffle
m	Mass flow rate (Kg/Sec)
P	Pressure (Pascal)
P_r	Prandlt number
R_e	Reynolds number
P_t	Tube Pitch (m)
C	Tube clearance (m)
K	Thermal Conductivity (W/m-K)
μ	Viscosity (kg/m-sec)
ρ	Density (Kg/m^3)
Δt_m	Logarithmic mean temperature difference
N	Number of tubes
D_E	Equivalent Diameter (m)

Subscripts

S	Shell side
T	Tube side
In	Inlet
out	Outlet
H	Hot
C	Cold

1.1 Overview

Heat exchangers have an important role in many thermal systems. A heat exchanger is a device used for effective heat transfer between two fluids. In which one is cooled and other one is heated. The application of heat exchangers can be realized by any process which involves heating, cooling, evaporation, condensation and boiling. Heat exchangers are used in a wide variety of thermal applications like power generation, manufacturing industry, air-conditioning industry, applications of waste heat recovery, petrochemical industries etc. Different types of heat exchangers are named according to their application in industry. Take example, condensers and boilers are heat exchangers, as their name they are used for condensation and boiling purpose respectively. Performance and effectiveness of heat exchangers are measured through the total amount of heat transfer using minimum heat transfer area and pressure drop in heat exchanger. Presentation of efficiency of Exchanger is done by calculating over all heat transfer coefficient. Required heat transfer area and pressure drop gives us detail for the running cost and total cost of the heat exchanger.

Heat exchanger are classified as

Direct contact heat exchanger: Both medium are in direct contact between which heat is to be transferred.

Indirect contact heat exchanger: Both medium are divided by solid wall, between which heat is to be transferred so that they can never mix.

1.2 Shell and Tube Heat Exchanger (STHE)

One of the most common heat exchanger used in thermal industry is a shell and tube heat exchanger. It is an indirect contact type heat exchanger for application where operating pressure is up to 200 bar. Contains a bundle of tubes inside the shell which may be single pass or double pass depends upon the application and industry. Shell contains a shell side fluid. Generally it comes in cylindrical shape but for different application it is used in different shapes. One fluid flow inside the tubes and other fluid flow outside of the tube in shell side. Heat is transferred from one fluid to another fluid through the outer surface of tube by means of convective heat transfer. Fluids may be liquid or gases and can flow either tube side or shell. Shell and tube heat exchanger are commonly used because of its simplicity, easy in construction and lower in cost. It has higher value of log meant temperature difference (LMTD). Tubes are mounted on tube sheet by mean of welding so that leakage doesn’t occur. In order to achieve high heat transfer, large heat transfer area should be provided. Shell and tube heat exchanger with a one phase (gas or liquid) on each side called single phase heat exchanger. Two phase heat exchanger are used to cool down the vapor into liquid are called condenser and boil the liquid into vapor, called boilers, change of phase occurs at shell side ([1]). The tube and shell side fluid is separated by the tube sheet.

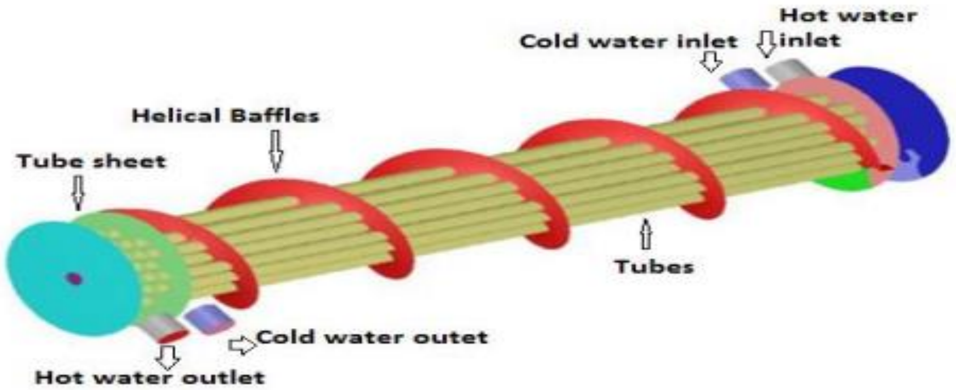


Figure 1.1 Shell and Tube Heat Exchanger

1.3 Classification of STHE

Shell and tube heat exchangers can be classified on the basis of relative direction of fluid, on the construction, on the design feature and physical state of fluids.

1. Classified based on relative direction of fluid flow
   - Parallel or unidirectional flow
   - Counter flow
   - Cross flow
2. Classified based on construction
   - Fixed tube sheet
   - U tube
   - Floating head
3. Classified based on design feature
   - Concentric tube
   - Shell and tube
   - Multiple shell and tube
   - Compact heat exchanger

1.3.1 Parallel flow

In parallel flow heat exchanger both fluids enters in the same direction. Both fluids makes entry at same side and leaves at another side. In parallel flow the inlet temperature difference is greater and this becomes lesser at the end of exchanger length at exit side. Between these two ends heat transfer takes place. The amount of log mean temperature difference which is basically the driving force of heat transfer is much greater in counter flow heat exchanger. So for the same inlet and outlet conditions, heat transfer area required will be more in parallel flow heat exchanger.

1.3.2 Counter flow

In counter flow heat exchanger, both fluids enters in opposite direction. One in tube and another in shell side. A car radiator is good examples of cross flow heat exchangers. Cross flow heat exchangers are typically used for heat transfer between a gas and a liquid. In counter flow heat exchanger, maximum rate of heat transfer is achieves.

1.3.3 Cross flow

The two fluids (hot and cold) cross each other in a space, normally at right angle (90^0).

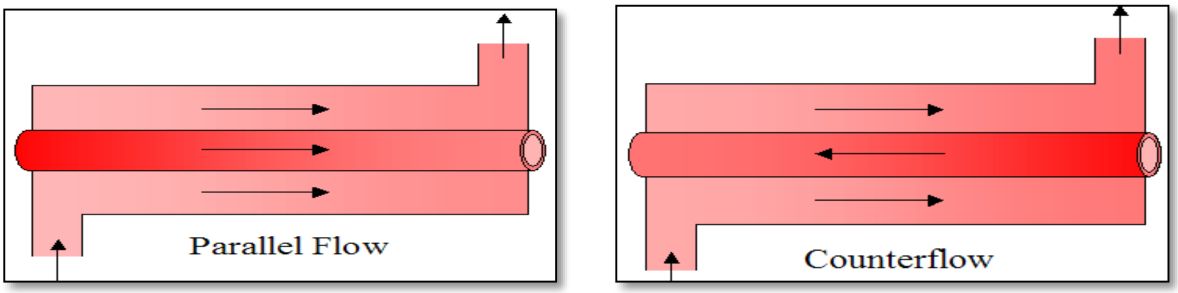


Figure 1.2 Parallel and counter flow heat exchanger.

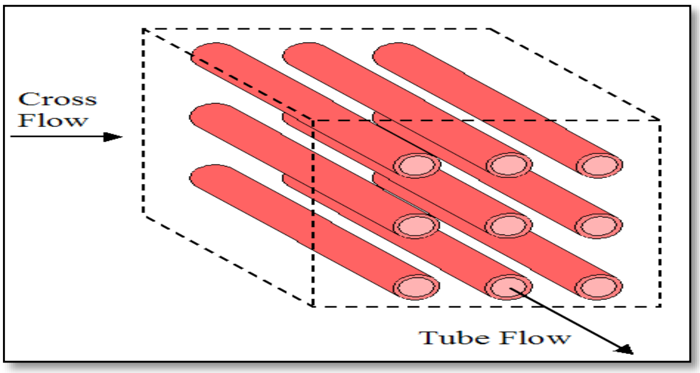


Figure 1.3 Cross flow heat exchanger

1.3.4 Fixed tube sheet

A fixed tube sheet heat exchanger has straight tubes supported by two tube sheets at both ends which are fastened to the shell. The major advantage of fixed tube sheet heat exchanger is its lesser cost and easy to construct. In all construction types, fixed tube sheet is cheapest is cost due to there is no need of expansion joints. It is having an advantages of cleaning of tubes by removing the channel cover and there is less or almost no leakage from shell side as we do not use nay flange coupling.

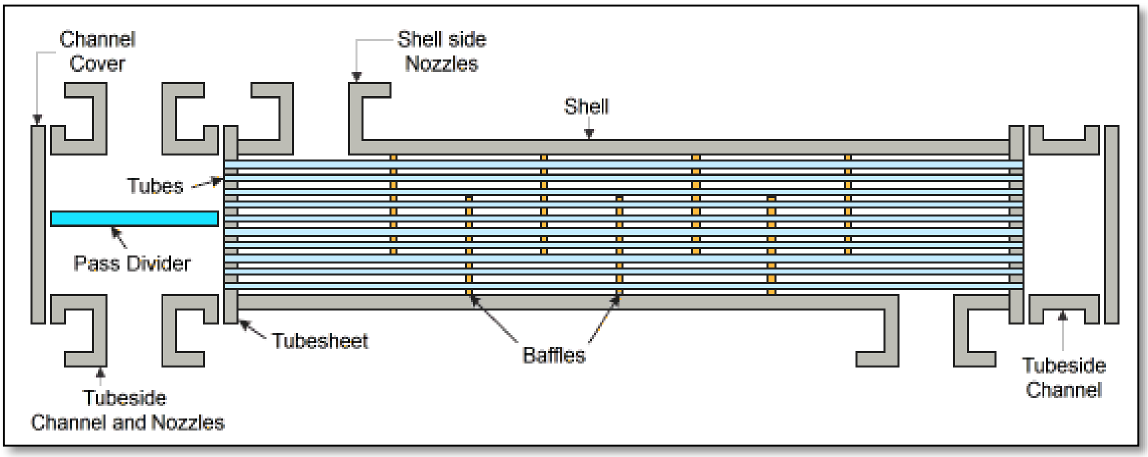


Figure 1.4 Fixed tube sheet

1.3.5 U Tube

In this kind of exchangers tubes are bend in U shape. Only one tube sheet is required at one end for the entrance of tube side flow. Here a single tube sheet is used but the cost reduction in in tube sheet in counter balanced by bending cost of tubes. So the overall cost is higher in this case. Larger diameter shell is required here because the bending of tubes. The principle advantage of a U-tube heat exchanger is that there is no stress issue because its end is free, the tube bundle can contract and expand in response to thermal stress. Outside of tubes can be cleaned but inside portion cleaning is not easy so the flexible end drill shaft are required. That's why this heat exchanger cannot be used in those application which deals with dirty fluids.

1.3.6 Floating Head

This is one of the most adaptable heat exchanger among all and also the most costly. In this only one tube sheet is used and other end is free. This design allows the thermal and mechanical expansion and cleaning of shell and tubes. This allows us to use floating head heat exchangers for application which involves the dirty fluids like petro cleaning and petro refineries.

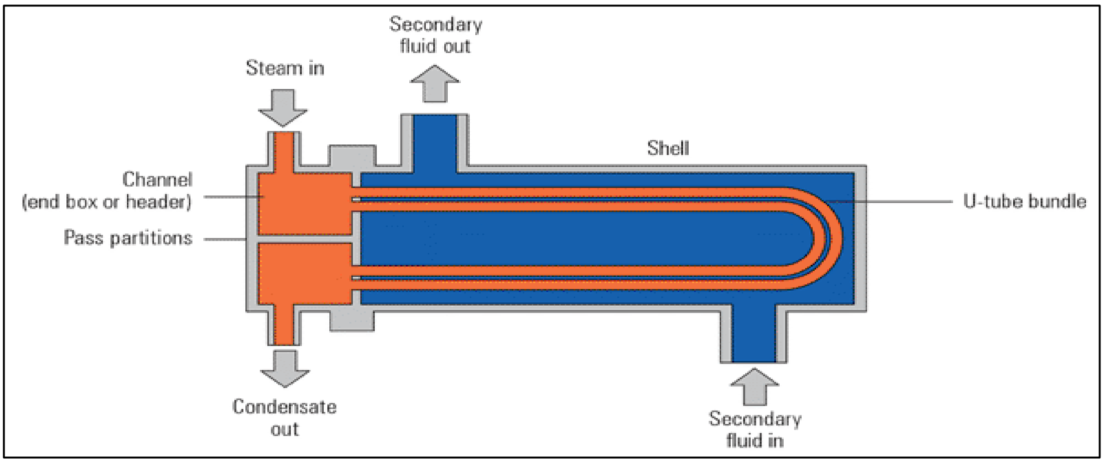


Figure 1.5 U-Tube Heat Exchanger

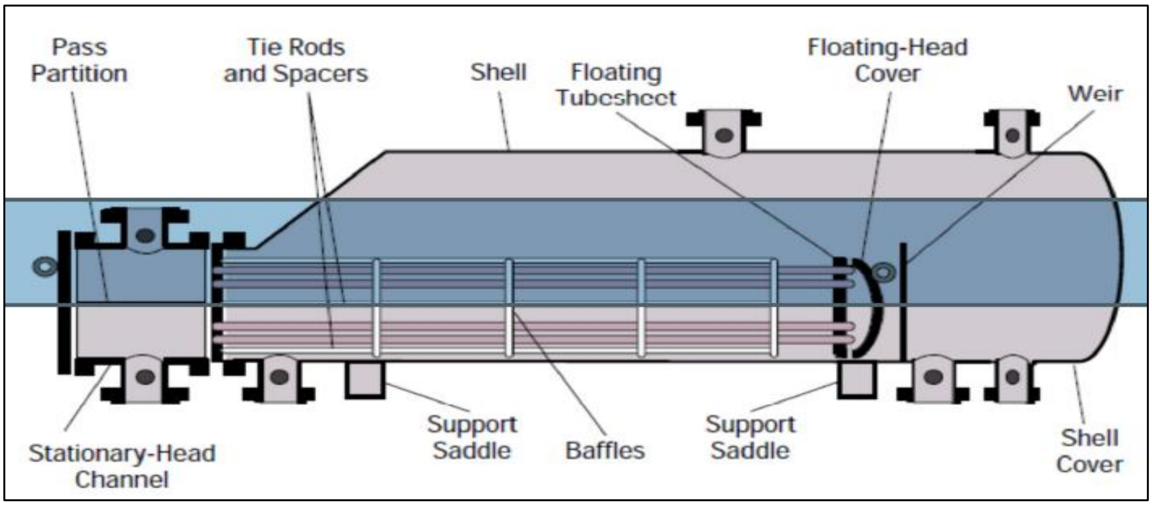


Figure 1.6 Floating Head Heat Exchanger

1.3.7 Concentric Tubes

In concentric tube heat exchanger two different diameter hollow concentric tubes are used passing two different fluids at different temperature. On behalf of application it can be used as parallel or counter flow. The effectiveness can be increased by using swirling pipe.

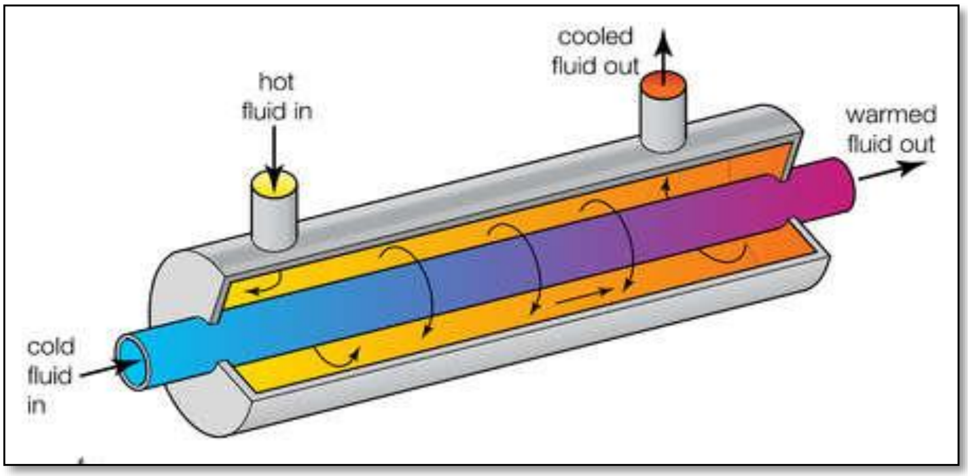


Figure 1.7 Concentric Tube Heat Exchanger

1.3.8 Compact Heat Exchanger

These are the superior kind of heat exchangers having specialty of very large surface area per unit of volume. These heat exchangers are used where convective heat transfer coefficient of one fluid is much smaller than other one.

1.3.9 Multiple Shell and Tube Pass

These heat exchangers multiple shell and tube passes are used to enhance the heat transfer rate. Shell side fluid transverse more than once in exchanger by using multi pass. By proper designing the tube side fluid can travel back from one shell to another by external means in same way the shell side fluid can transverse more than once.

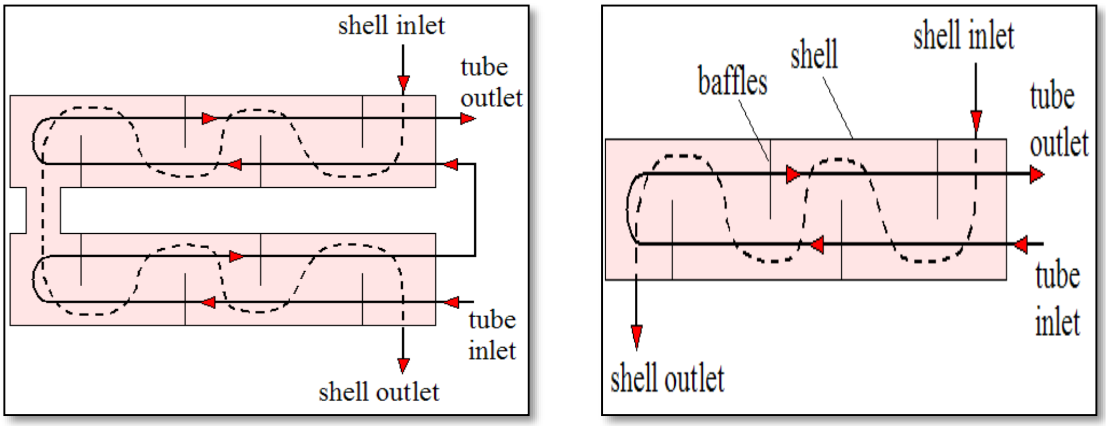


Figure 1.8 Multiple shell and tube passes

1.4 Component of STHE

There are some basic parts of the heat exchanger given below:

- Tubes
- Tube sheet
- Shell
- Impingement tubes
- Channel covers
- Baffle

1.4.1 Tube

The tube is one of the basic component of the heat exchanger provides the heat transfer between the two fluids flowing inside the tube and outside around the tubes. The heat transfer takes place at the outer surface of the tube so it is recommended that material of the tube should be highly thermal conductive. Otherwise complete heat transfer will not take place. Generally copper, aluminum tubes are used in heat exchanger. From the design point of view the main parameters of tubes are its length, tube diameter, thickness, tube pitch.

1.4.1.1 Tube diameter

It is prefers that small diameter tubes should be used for economical and effectiveness point of view, but the problem comes of cleaning and fouling. Cleaning of bundles of tubes by mechanical means is not easy. This can be overcome by using of large diameter pipe, but problem here is that it is more costly and less compact so effectiveness will be decreases.

“Table 1.1” shows the criteria of tube selection for shell and tube heat exchanger. The outer diameter is decided by this table for various fluid property in shell and tube heat exchanger. Table is given below.

Table 1.1 Tube Selection

Unit	Outside diameter
Small unit with clean fluid	6.34 mm
Small unit with normal fluid	19.04 mm
Units with heavy tars	50.07mm

1.4.1.2 Tube Wall Thickness

The tube wall thickness is an important parameter while selecting the tubes, it should be checked against the pressure inside and outside of the tube. But in every case it is must be checked against the internal and external pressure. But in some cases it is not that important factor like designing the exchanger for application up to pressure of 200 bar 19.04 mm outside diameter tube can be used for a temperature range of 350° C. [2]

1.4.1.3 Tube length

Heat exchanger with small diameter and long length with proper spacing, tube is preferred for a given surface area. Heat exchanger as long as possible depends on availability of the length of tube available in the market and sellers. Standards tube lengths are:

Standard tube length = (8, 12, 16, 20 and 24 ft.)

1.4.1.4 Tube pitch

It is mandatory that tube pitch should not be less than 1.25 than outside diameter of tubes. Basically tube pitch is a center to center distance of two tubes. But is some application where clean fluids used the pitch to diameter ratio can be 1.20.

Table 1.2 Selection of pitch angle on the basis of flow

Pitch angle	Pitch pattern	Nature of shell side fluid
Triangular	30	clean
Rotated triangular	60	clean
Square	90	fouling
Rotated square	45	fouling

1.4.1.5 Tube sheets

Tubes are held in horizontal position with the help of tube sheets which are placed at the both ends. Tube sheet are drilled and grooved circular metal plate which holds tube in proper position.

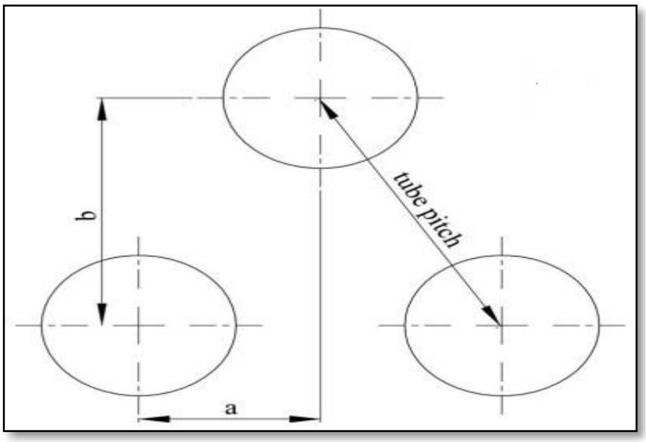


Figure 1.9 Tube Pitch

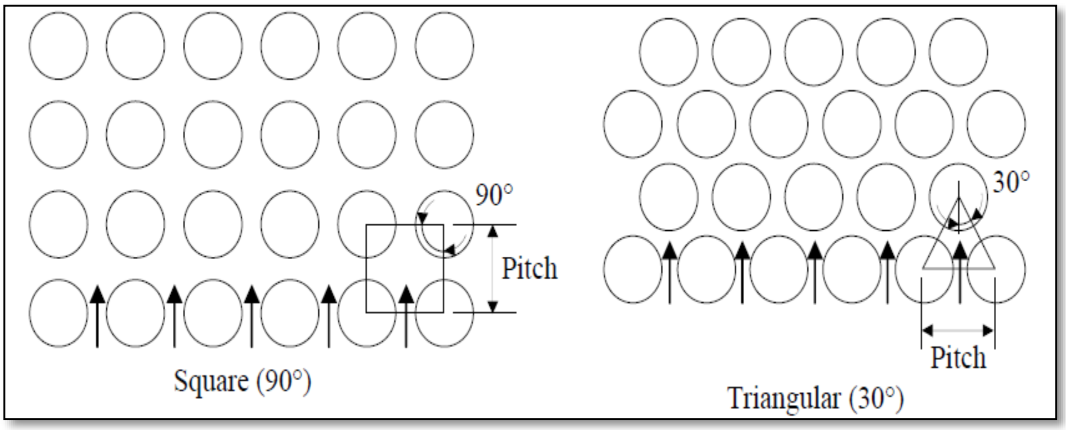


Figure 1.10 Pitch Pattern

1.4.2 Shell

The shell is circular container in which shell side fluid flows, tube bundles, baffles are fitted in a shell. Two nozzles are fitted one for inlet and another for outlet of fluid. Generally Shell is made by rolling of metal plates and then welded. Outer surface of shell must be insulated so we can control the loss of heat.

1.4.3 Impingement Plates

When the fluid from nozzle at high pressure enters the shell side, there is more chances that fluid will be strike tubes directly. At high pressure this can damage the tubes so it is necessary that the kinetic velocity of fluid must be converted before striking the tubes. So Impingements plates are used to eliminate the KE of fluid [3].

1.4.4 Pass driver

A pass divider is necessary part of bonnet when heat exchanger having u tube or two tube side pass. It divides the fluid pass portion so that fluid returns can exit in that same pass.

1.4.5 Channel Covers

The channel covers are round plates that bolt to the channel flange and can be removed for tube inspection without disturbing the tube side piping. In smaller heat exchanger bonnets with flange nozzles or threaded connections for tube side piping's are often used.

1.4.6 Baffle

Baffle is one of the most important parts in shell and tube heat exchangers. It has some important function in heat exchanger

- Support the tubes in their proper positioning, preventing vibration developed by the eddy during the assembly and operation.
- Provides proper way to shell side fluid across the tube field for proper mixing, increasing velocity and heat transfer rate.
- Increases the contact time between tubes and shell side fluid.

"Figure 1.11" shows the cross section of conventional segmental baffle of 25^{0} cut.

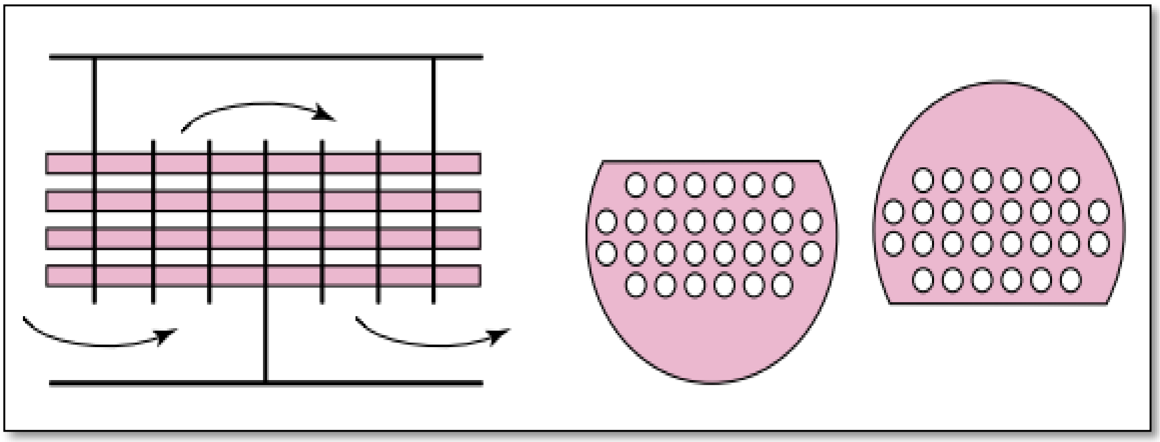


Figure 1.11 Baffles.

"Figure 1.12" shows the baffle spacing, which is distance between two adjacent baffle.

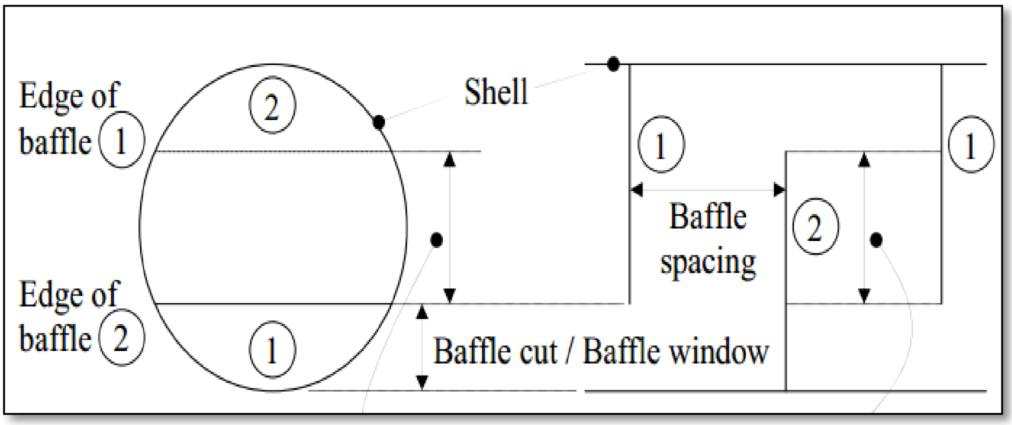


Figure 1.12 Baffle cut and Spacing

“Figure 1.13” shows the typical shell and tube heat exchanger and its various components.

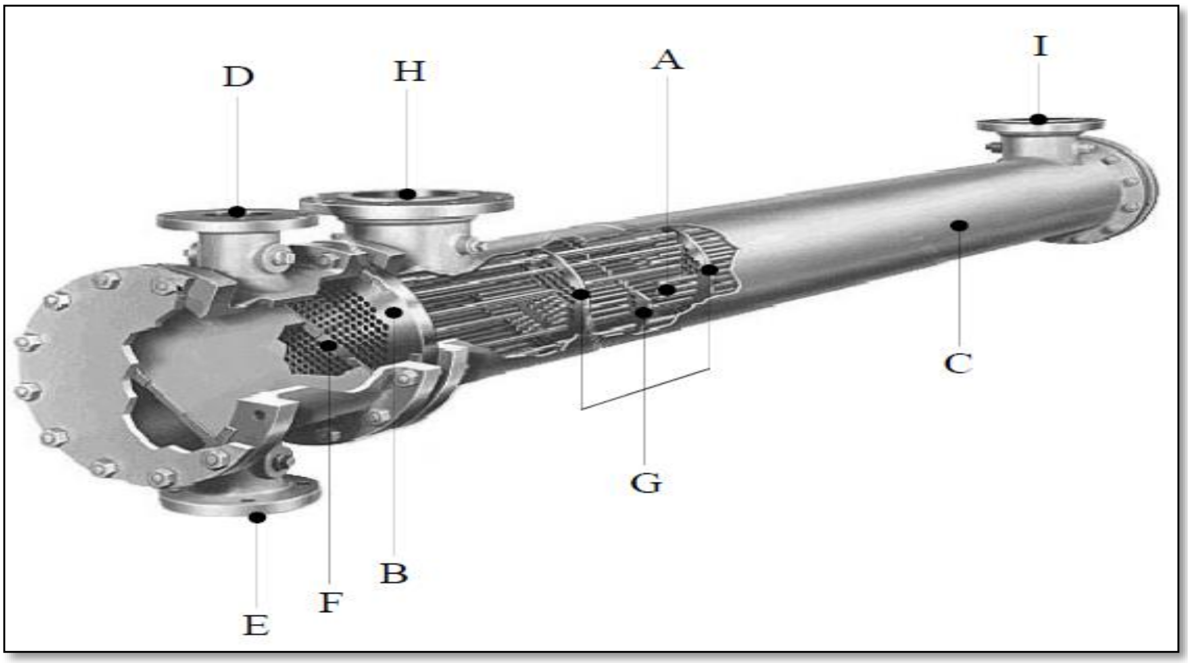


Figure 1.13 Components of Shell and Tube Heat Exchanger

A-tubes	D-tube side inlet	I-shell side outlet
B-tube sheets	F-pass divider	E-tube side outlet
C-shell	G-baffles	H-shell side inlet

Heat Exchanger: It is an equipment which is built for efficient transfer of heat between two mediums. Heat transfer media can be a direct contact type or can be separated by a wall. Heat exchangers are widely used in refrigeration & air conditioning, power plants, petroleum refiners, natural gas processing and in many more applications. A heat exchanger categorize in general three types, namely:

1. Transfer type HE.
2. Storage type HE.
3. Direct contact type HE.

Transfer Type HE: In this type of HE_X fluids are kept separate and they do not mix as the flow through it. Heat is transferred through the separating walls. A concentric double pipe heat exchanger is an example of this type. Present study is based on analysis of transfer type heat exchanger.

Shell-and-Tube HE: It consists tubes in series. The heated or cooled water flows through one set of pipe. The second fluid runs in other set of tubes which are being cooled or heated, so that first set of tube can absorb or transfer the heat to second set of tubes according to requirements. There are some technical terms which are used in present study as follows:

Reynolds Number (Re): Reynolds number of airflow is calculated by knowing velocity, density, hydraulic diameter of duct and viscosity. Reynolds number is important parameter which decides the turbulence of fluid through duct. If Re ≥2300 then flow is turbulent, otherwise it is laminar flow. Re is calculated by

$$Re = \frac{\rho V D_h}{\mu} \qquad (2.1)$$

Where D_h is the hydraulic diameter and calculated by

$$D_h = \frac{4A_C}{P} \qquad (2.2)$$

Nusselt Number: It is a dimensionless form of heat transfer coefficient which is the ratio of rate of heat transfer through convection to the rate of heat transfer through conduction.

$$Nu = \frac{hL}{K} \qquad (2.3)$$

Heat transfer rate Q

Heat loss by hot water

$$Q_h = m_h \times C_{ph} \times (T_{hi} - T_{ho}) \quad (2.4)$$

Heat gained by cold water

$$Q_C = m_c \times C_{pc} \times (T_{ci} - T_{co}) \quad (2.5)$$

Where, $Q = Q_c = Q_h$ (kw)

Logarithmic mean temperature difference (LMTD): It is defined as average driving temperature difference for heat transfer between two fluids flowing at different temperature. Given as

$$LMTD = \frac{\Delta T_1 - \Delta T_2}{\ln(\Delta T_1/\Delta T_2)} \quad (2.6)$$

Where $\Delta T_1 = T_{hi} - T_{co}$ & $\Delta T_2 = T_{ho} - T_{ci}$

Effectiveness (ϵ): It's a ratio of actual heat transfer to the maximum heat transfer. Given as below

$$\epsilon = \frac{Q_a}{Q_{max}} \quad (2.7)$$

Overall Heat Transfer Coefficient (U): It can used to calculate the total heat transfer through heat exchangers or walls. Given as

$$U = \frac{Q}{A_s \times \Delta T_{ln}} \quad (2.8)$$

Tube Clearance (C): It is distance between two successive tubes which is given by

$$C = P_t - D_{out} \quad (2.9)$$

Where, P_t =Tube pitch, D_{out} = Outer tube diameter.

Cross Flow area: The cross flow area along the centerline of flow in shell given as

$$S_s = \frac{D_s \times C \times L_B}{P_t} \quad (2.10)$$

Where D_s = Shell diameter, L_B = Baffle spacing.

Equivalent Diameter: It is defined as total wetted are to the volume available to the flow.

$$D_e = 4 \times \left(\frac{\text{Flow Area}}{\text{Wetted Perimeter}}\right) \quad (2.11)$$

$$D_e = \frac{4 \times \left({P_t}^2 - \pi {D_o}^2/4 \right)}{\pi D_o} \tag{2.12}$$

Maximum Velocity: It is given by

$$V_{max} = \frac{Q_s}{A} \ (m/s) \tag{2.13}$$

Prandtl Number:

$$Pr = \frac{\mu C_p}{K} \tag{2.14}$$

Where C_p = Specific heat (KJ/kg. k), μ=Dynamic Viscosity, K=thermal conductivity (W/m. K)

Pressure Drop (ΔP**):** It signifies the drop in pressure due to fiction losses in heat exchanger. Given as

$$\Delta P_s = \frac{4 \times f \times {G_s}^2 \times D_s \times (N_B + 1)}{2 \times \rho \times D_e \times {(\mu/\mu_w)_s}^2} \tag{2.15}$$

Where N_B = no. of tubes, ρ =density (kg/m^3).

$$N_B = \frac{L_s}{L_B + t_b} - 1 \tag{2.16}$$

Shell and tube heat exchanger is a huge topic for discussion, serval papers have been published regarding designs, optimization, enhancement techniques, parameters and etc. Every aspects have been explained in many times but still there are enough to find. On the basis of my literature study, brief summary is reviewed here.

Kumar et al. [12] analyzed the performance of heat exchanger with helix baffle and gives the comparative analysis between segmental baffle and helix baffle heat exchanger. He concluded that in helix-changer, performance of heat exchanger increases by increasing of overall heat transfer and decreasing of pressure drop. According him, helix baffle provides a smooth helical passage which gives more contact time with proper mixing of fluid without any fouling and tube bundle vibration. They concluded that pressure drop in helical baffle heat exchanger in much lower in compared to conventional segmental heat exchanger.

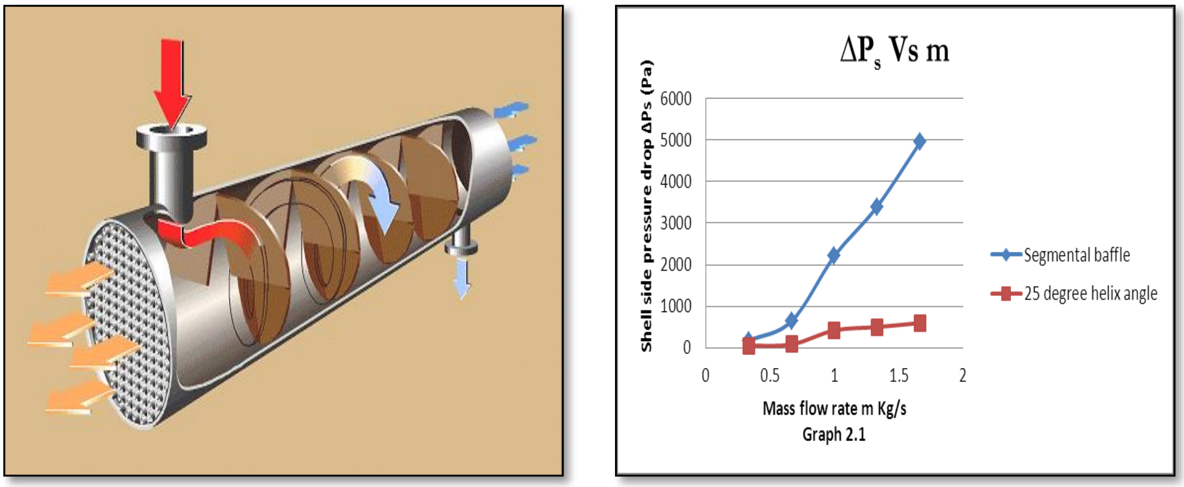


Figure 3.1 Helical baffle heat exchanger & Chart representing Pressure v/s Mass flow rate.

Pravin et.al [6] worked on the physical importance of helix baffle in heat exchanger and what should be the optimum angle for the helix changer. They examined helix-changer over segmental heat exchanger and found that running time foe helical baffle is 3 times more than segmental baffle. It is clear from picture that fouling is more in segmental baffle than helical baffle. He compared results of heat transfer and pressure drop for different helix angle and gives the conclusion that for lower helix angle heat transfer coefficient will be more. They got the heat transfer to pressure drop maximum for helix angle >35 degree. The figures given below presents that fouling effect on segmental baffle and helical baffle. “Figure 3.3” shows the graph between running time and efficiency. “Figure 3.4” shows the pressure drop as a function of helix angle.

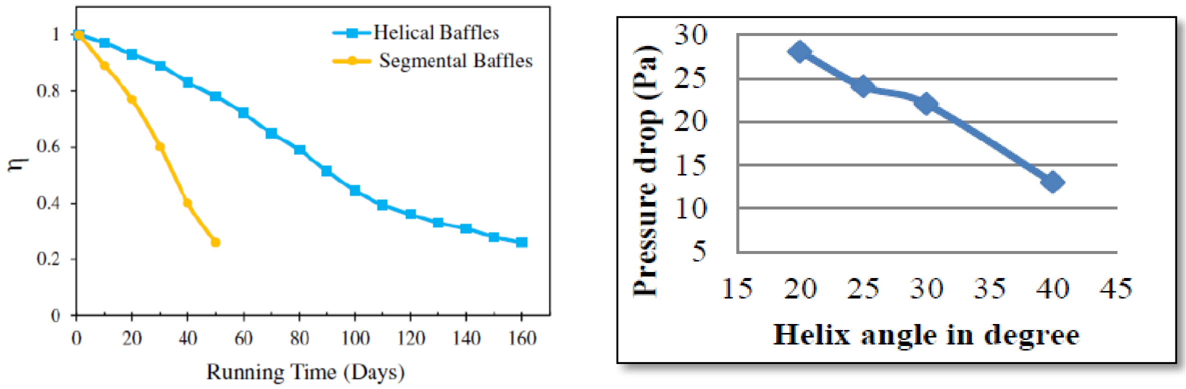


Figure 3.2 Running time of helical and segmental baffle   Pressure drop for one cycle

Mohammadi [7] investigated the effect of baffle orientation on the performance of heat exchanger. He used vertical and horizontal orientation of baffles for testing in CFD. The shell-side pressure drop and average Nusselt number are calculated at different Reynolds numbers for a typical shell and tube heat exchanger. The shell and tube heat exchanger considered is an ideal heat exchanger without leakages. The shell-side pressure drop and heat transfer coefficient for the vertical baffle orientation is greater than the shell-side pressure drop and heat transfer coefficient for the horizontal baffle orientation

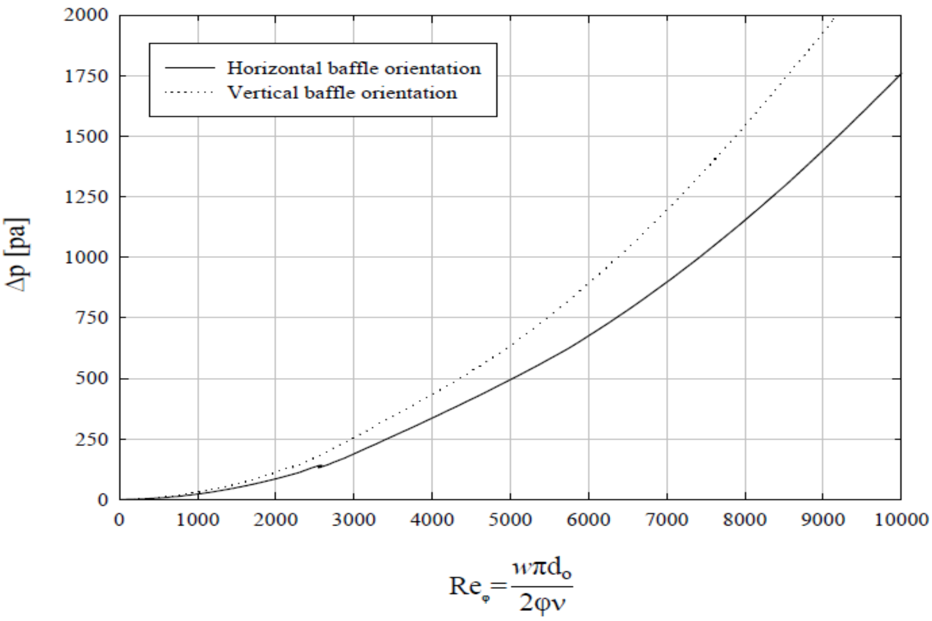


Figure 3.3 Pressure drop Vs. Reynolds no.

Lin et al [2] analyzed and calculated the design parameter for effective heat transfer area and pressure drop and confirming that expected design fulfils all the obligation. The principal goal of this design is to accomplish the higher heat transfer deprived of increasing the pressure drop. Decreasing pattern of curve of Reynolds no. with increasing effective length shows that there is a significant pressure drop.

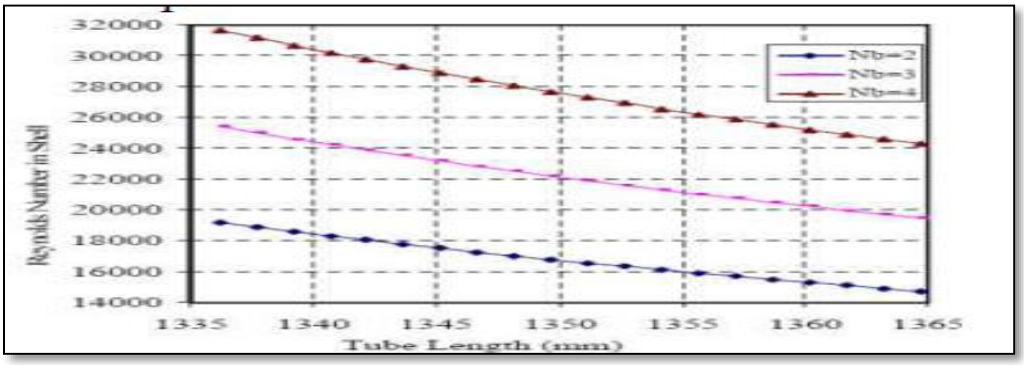


Figure 3.4 Reynolds no. Vs. tube length

Pancha et al [8] analyzed the conventional segmental baffle heat exchanger using the Kern method with varied shell side flow rates. This is a proven method used in design of Heat Exchangers with a baffle cut of 25%. They have done thermal analysis of a helix-changer (Continuous Helical baffled Heat Exchanger) using the Kern method to estimate the results for different flow rates at a fixed helical angle of 25˚. Graphs have been plotted on the basis of result And from graph it is very clear that helical baffles have better thermal performance like heat transfer coefficient and pressure drop over segmental baffle heat exchanger.

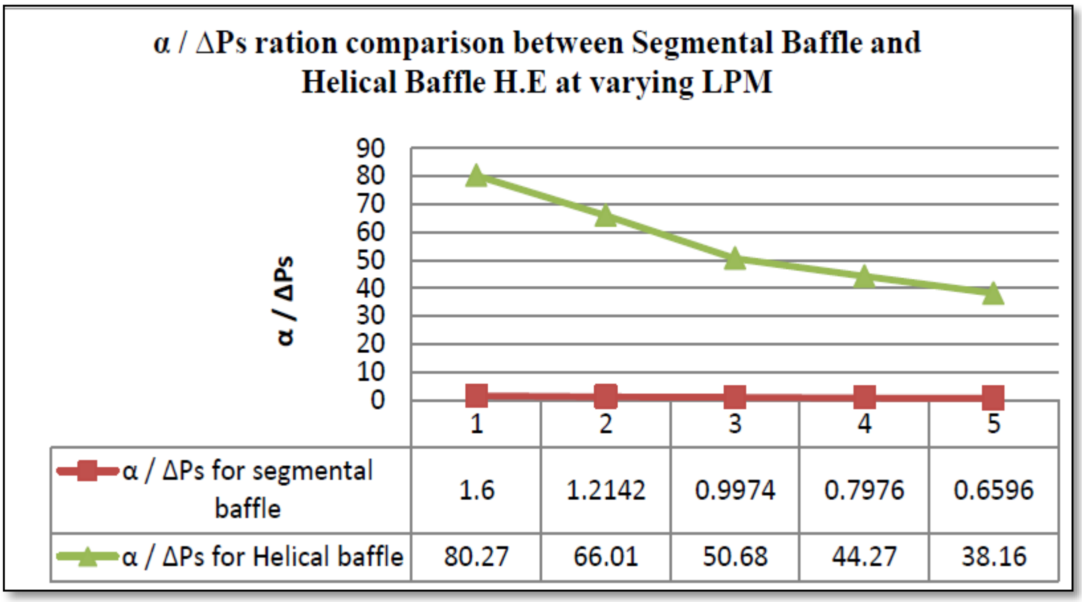


Figure 3.5 Helical baffle vs. Segmental baffle

Mohammadi [9] explained the parameters which affects the design of heat exchanger. There are two major design consideration, heat transfer rate and pumping power required to overcome the friction and make it possible to flow fluid into the heat exchanger. He gave the idea by performing different experiments on every possible parameter and concluded that for higher dense fluid the pumping power required is less compared to heat transfer, but for lesser dense fluid the flow friction will me more which results in higher pumping power. It is shown by results that for any flow passage heat transfer/ area can be increased by increasing the flow velocity. If we increases the velocity, heat transfer rate increases but the friction will increases more rapidly than heat transfer. If friction become much higher than velocity should be decreased by giving no. of flow passage. It will decrease the heat transfer rate but the reduction would be compensated by no. of tubes which give more surface area.

Zhang [10] developed the rating and designing method for heat exchanger with helical baffle based on the present Bell-Delaware method. He developed correlation for finding the pressure drop and heat transfer rate. The accuracy of present method is validated with experimental data four designing purpose. And the result outcomes is much better.
Correlation obtained

$$N_{tub} = \frac{0.037 \times Re^{0.7} \times P_r}{1 + 2.433 Re^{-0.1}(Pr^{0.67} - 1)}$$

$$H_s = \frac{N_u \times \gamma_s}{l}$$

$$\text{Where } l = \frac{\pi \times D_o}{2}$$

Gowthaman et al [11] modeled the shell and tube heat exchanger with helical baffle and segmental baffle and done the analysis on CFD fluent for the defining the flow pattern induced by the using of helical baffle. Helical baffle reduced the pressure loss by directing the flow in a unique way basically helical. This pattern makes reduction in dead zone and by pass flow which is a main reason for pressure drop. It was completely simulation work.

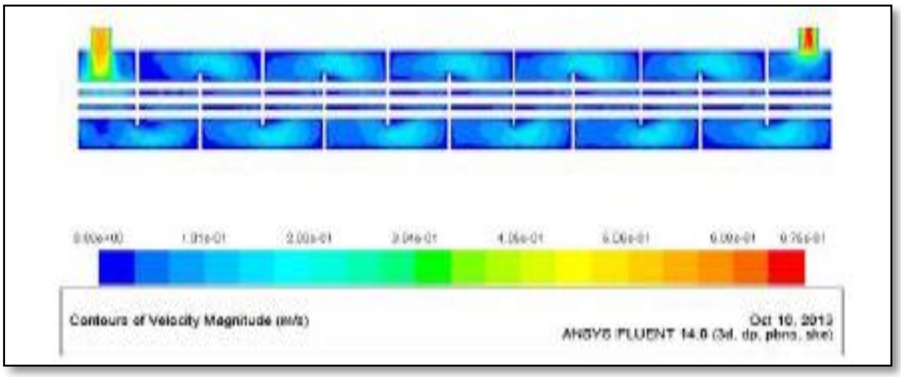


Figure 3.6 Velocity at mid plane

Dhamane et al [12] have done the experiment on the tube in which twisted tape was inserted. Authors had done experiment with taking air as working medium and twist angle of the tape was 8.33. They have found that using twisted tape increases the heat transfer rate and this increases with increasing the number of twist. There was 18-38% in increment in heat transfer.

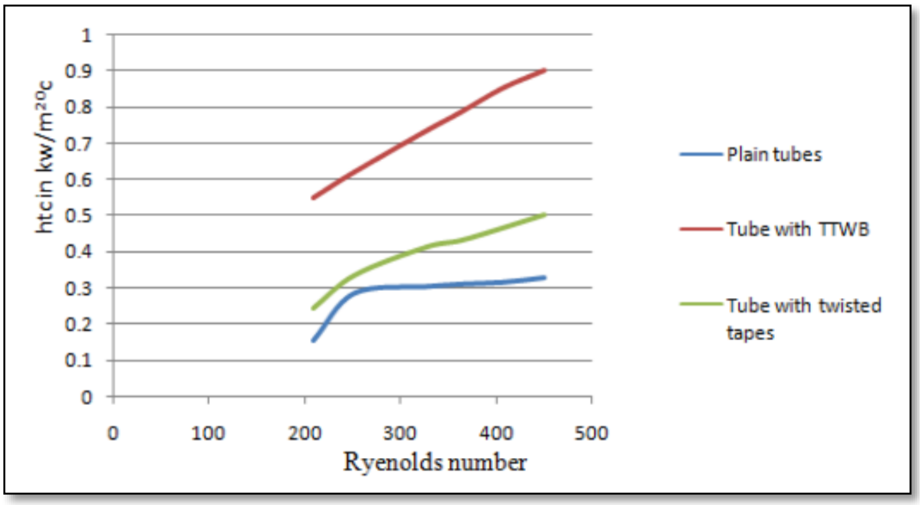


Figure 3.7 Reynolds number v/s heat transfer coefficient

Ard et al. [13] explained the result of experiment done using delta-winglet twisted tape with typical twisted tape, and compare the results. He found that Nussle's number value and friction factor are much higher in case of delta twisted tape in tube compared to typical twisted tape in same tube. Authors found that Nusselt no. value and friction factor increases with decreasing the twist ratio. He concluded that delta twist tape gives batter heat enhancement compare to simple twist tape.

Figure 3.8 Twisted tap

Chand et al. [14] investigated the thermal performance of water and oil type shell and tube heat exchangers. These type of heat exchange mostly used in oil coolers, pre heaters and condensers etc. The high pressure can be done in shell and tube heat exchanger due to its robustness and medium weight. They have done the thermal analysis of these heat exchangers by using theoretical formulae. By using Floefd software they did the thermal analysis of water and oil type shell and tube heat exchanger. Theoretical results are compared with predicted results, which is calculated by Floefd software. They found a very good agreement between these results.

Ozden et al. [15] have been done the investigation of small shell and tube heat exchange by using CFD software. They found how the heat transfer coefficient and the pressure drop depends on shell diameter, baffle cut and baffle spacing dependence. Numerical modelling also have been done by them. The shell and single tube pass heat exchanger, which is having variable number of baffles are analyzed by CFD software for turbulent flow. The results are validated by the comparison of outlet temperature, heat transfer coefficient and pressure drop for their model with two baffle cut values. They discussed how the heat exchanger performance affected by the baffle spacing to shell diameter ratio at varying mass flow rate. The results are shown in figure below.

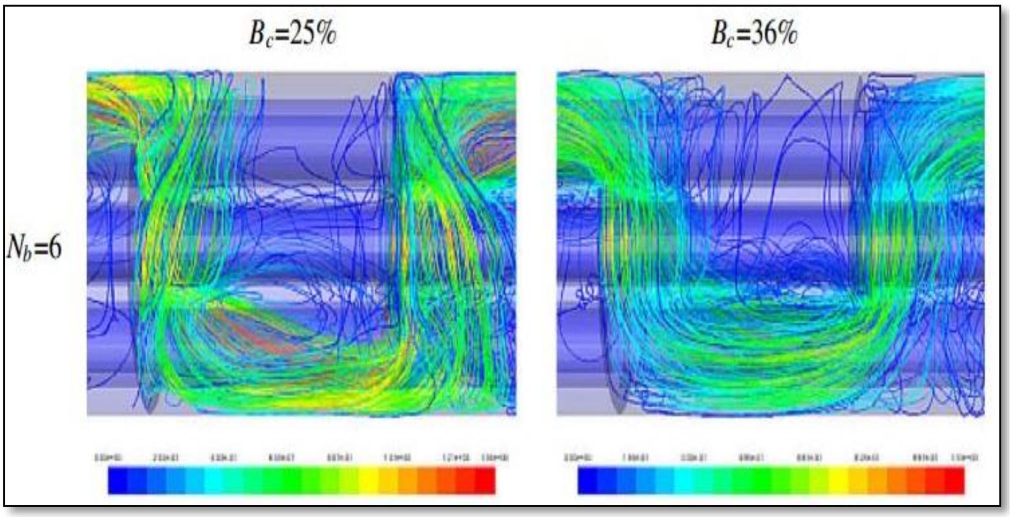


Figure 3.9 CFD analysis of baffle

Wen et al. [16] have been studied the heat transfer enhancement in fin and tube heat exchanger with improved fin design. In a wind tunnel three different types of fins they were used. They analyzed hew the drop of pressure for air side (), heat transfer coefficient (h), fanning friction factor (f) and the Colburn factor (j) get affected by air velocity (V) and Reynolds number (Re). They found that wavy fin as compare to flat fin show heat transfer coefficient (h), pressure drop, Colburn factor and friction factor are increases about 11.8-24.0%, 10.9–31.9%, 0.5–2.7% and 2.2–26.5% respectively. The compounded fin as compare to flat fin show heat transfer coefficient (h), pressure drop, Colburn factor and friction factor are increases about 28.0–45.5%, 33.6–63.1%, 9.4–13.2% and 6.9–71.1% respectively. They suggest to use the heat exchanger having compounded fins.

Yang et al. [23] have been studied a comparison of four numerical modeling approaches for enhanced shell-and-tube heat exchangers with experimental validation. They studied four different modeling approaches of a rod-baffle heat exchanger, which are the unit model, the periodic model, the porous model, and the whole model. The experiments validate the precision of each model in predicting heat transfer and pressure drop with the experimental validation. It is concluded that the periodic model, porous model and whole model have a high accuracy on predicting heat transfer performance, while the unit model has a relatively low accuracy. It is concluded that the porous model and whole model has high accuracy on predicting pressure drop, while unit model and periodic model are unable to directly predict hydraulic performance. Trade-offs between computational resources and accuracy are analyzed. The whole model with highest accuracy consumes largest resources on geometrical modeling, grid generation, and numerical calculations. The porous model with relatively high precision consumes medium numerical resources. However, it requires extra codes and is not applicable for new designs; the periodic model consumes relatively low resources and the unit model consumes the lowest.

Serna et al. [25] they have presented a compact formulation to relate the shell-side pressure drop with the exchanger area and the film coefficient based on the full Bell–Delaware method. In addition to the derivation of the shell side compact expression, they have developed a compact pressure drop equation for the tube-side stream, which accounts for both straight pressure drops and return losses. They have shown how the compact formulations can be used within an efficient design algorithm. They have found a satisfactory performance of the proposed algorithms over the entire geometry range of single phase, shell and tube heat exchangers.

Sepehr et al. [17] considered seven design parameters namely tube arrangement, tube diameter, tube pitch ratio, tube length, tube number, baffle spacing ratio as well as baffle cut ratio. Fast and elitist non-dominated sorting genetic algorithm with continuous and discrete variables were applied to obtain the maximum effectiveness (heat recovery) and the minimum total cost as two objective functions.

Patel et al. [18] explores the use of a nontraditional optimization technique; called particle swarm optimization (PSO), for design optimization of shell-and-tube heat exchangers from economic view point. Minimization of total annual cost is considered as an objective function. Three design variables such as shell internal diameter, outer tube diameter and baffle spacing are considered for optimization. Two tube layouts viz. triangle and square are also considered for optimization. The presented PSO technique's ability is demonstrated using different literature case studies and the performance results are compared with those obtained by the previous researchers. PSO converges to optimum value of the objective function within quite few generations and this feature signifies the importance of PSO for heat exchanger optimization.

Kara et al. [19] prepared a computer based design model for preliminary design of shell and tube heat exchangers with single phase fluid flow both on shell and tube side. The program determines the overall dimensions of the shell, the tube bundle, and optimum heat transfer surface area required to meet the specified heat transfer duty by calculating minimum or allowable shell side pressure drop. He concluded that circulating cold fluid in shell-side has some advantages on hot fluid as shell stream since the former causes lower shell-side pressure drop and requires smaller heat transfer area than the latter and thus it is better to put the stream with lower mass flow rate on the shell side because of the baffled space.

Fawal et al. [20] in this paper a computer program for economical design of shell and tube heat exchanger using specified pressure drop is established to minimize the cost of the equipment. The design procedure depends on using the acceptable pressure drops in order to minimize the thermal surface area for a certain service, involving discrete decision variables. Also the proposed method takes into account several geometric and operational constraints typically recommended by design codes, and provides global optimum solutions as opposed to local optimum solutions that are typically obtained with many other optimization methods.

Selvam et al [21] performed Experimental investigations of heat transfer and friction factor characteristics of a circular tube fitted with full-length twisted tape with pins of different twist ratios have been studied in tube in tube heat exchangers for the turbulent flow of Re ranging between 10000 to 23 000.Author suggested that use of bonded twisted tape with pins in the tube in tube heat exchanger enhances the heat transfer with significant pressure drop.

Bhuiya et al. [22] experimentally studied influence of triple helical tapes inserted for turbulent flow through a tube on heat transfer enhancement. Triple helical tapes with different helix (α=90 130 170) are used for experiment, author observed that, the helical tape with helix angle 90 gives maximum heat flux compared to other helical tapes.

4.1 Performance of Heat Exchanger Depends Upon

- Flow arrangement
- Temperature distribution
- Heat transfer coefficient
- Fouling factor
- Heat transfer area
- Pressure drop

4.2 Factors Affecting the Performance of STHE

- Fouling
- Leakage
- Tube vibration
- Dead zone

4.2.1 Fouling

Fouling is defined as the hail of undesirable material like rusting and impurities inside the exchanger over time which effects the performance of heat exchanger.

Types

- Chemical fouling
- Biological fouling
- Corrosion fouling
- Particulate fouling
- Crystallization fouling

For continuous performance of exchangers cleaning should be done perilously. The best way is to use mechanical methods. In which high pressure water is used for cleaning Chemicals also used for off line cleaning of tubes.

4.2.2 Leakage

In heat exchangers sometimes the fluid of shell can leak to tube or vice versa. This kind of situation can cause huge losses and sometimes risky to human life. Normally tubes are attached to tube sheet at the end but leakage can occur their due to week welding or due to porosity in welding. This situation can be handled by using double tube sheet. Using of double tube sheet cause considerable maintenance.

4.2.3 Tube vibration

In heat exchangers there is a tube bundle and sometimes system fails due to extreme vibration. This occurs mainly in cross flow exchangers where high velocity fluid strikes the tube. To reduce this kind of failure velocity reducer and supported pan will be required.

4.2.4 Dead zone

Areas that have the flow to minimal or even nonexistent and usually produce poor heat transfer and can lead ultimately to excessive fouling. Existing shell and tube heat exchangers suffer from the fact that they must typically use baffles to maintain the required heat transfer. This, however, results in “dead zones” within the heat exchanger where flow is minimal or even nonexistent. These dead zones generally lead to excessive fouling. Other types of heat exchangers may or may not employ baffles. If they do, the same increased fouling problem exists. Further, in heat exchangers fitted with baffles, for example, the cross flow implementation results in the additional problem of potential damage to tubes as a result of flow induced vibration. In the case of such damage, processes must often be interrupted or shut down in order to perform costly and time consuming repairs to the device.

4.3 Heat Transfer Enhancement Technique

Heat transfer enhancement technique are classified into three groups:

- Active technique
- Passive technique
- Combined technique

Active technique

In this method some external power inputs are required for the enhancement of heat transfer. Example are fluid vibration (tube side), surface vibration, electrostatic field, suction and injection jets are required some external source.

Passive technique

In this method geometric modification takes place for enhancement of heat transfer, by inserting extra component, rough surfaces, and extended surfaces.

Combined technique

Combination method is a combination of two above method like rough surface with fluid vibration or with twisted tapes. [4]

4.3.1 Passive Technique

Conventional method for enhancement of convective heat transfer were based on the increasing the effective heat transfer area/surface and resistance time of heat transfer. Passive methods uses geometric modification like inserting devices or extending surfaces. Due to this geometric modification turbulence and boundary layer are break down to near localized surface and it accelerate the existed heat transfer rate. Some of methods for increasing heat transfer rate. [13]

4.3.1.1 Ribs

Introducing the ribs in a suggested pattern on the heat transfer surface increases the turbulence without disturbing the flow because of size of the ribs are very small. Ribs gives great heat transfer without increasing successive amount of pressure drop and friction.

4.3.1.2 Baffle

Using baffle in heat exchanger promotes the proper mixing of fluid and gives the increased contact time which leads to higher heat transfer.

4.3.1.3 Extended surface

Extended surface like fins increases effective surface area. Increased surface area leads to higher heat transfer.

4.3.1.4 Twisted Tape and Wire Coils

Twisted tapes are metallic strips, which are inserted in the flow. These strips are twisted by some angle and this angle are known as twist angle.

4.3.1.5 Surface Modification

Surface modification involves fins, continuous or discontinuous surfaces, rough surface which crate turbulence and this turbulence leads to higher heat transfer rate.

4.3.1.6 Coiled flow

These methods are appropriate for very compact exchanger. Using of coiled tubes generates the secondary flow and vortices which causes high heat transfer. Second thing coiled tubes provides greater surface area then straight tube so contact time and contact surface area increases.

5.1 Conclusion from Literature Review

Following conclusion are obtained from the literature review

In order to achieve the maximum performance of heat exchanger at lowest possible running cost without compromising the reliability, some of features are required for a heat exchanger.

1. **Higher heat transfer coefficient and larger effective heat transfer area**

Higher heat transfer is a principal requirement of any heat exchanger, it can be achieved by using heat transfer surface which promotes turbulence for single phase flow and with some external arrangement for double phase flow. The best way is to use larger area density per unit exchanger volume.

2. **Lower pressure drop**

In conventional exchangers segmental baffles were used causes high pressure drop which leads to higher pumping cost. So the pressure drop is directly proposal to the running cost of heat exchanger. So it is required to minimize the pressure drop by using inclined baffle or helical baffle.

From these two requirement we came to know that for any heat exchanger $\propto/\Delta P$ heat transfer to pressure drop should be maximize.so my objective is in this research is same .

5.2 Principle Objective

As discussed above we need to maximize the $\propto/\Delta P$, for this we have to increase the heat transfer rate and Need to decrease the pressure drop.

5.2.1 Enhancement of heat transfer rate

Heat enhancement methods are

- Active method
- Passive method
- Compound method

The present work is based on the use of passive methods for enhancement in heat transfer rate. It's a quite easier and effective method. Providing the extended surface like ribs and fins in heat exchanger can increase the heat transfer rate. Fins and ribs are small is size but provides sufficient effective surface area so that more fluids comes in contact and it gives very positive results in heat transfer rate. The present works shows the new techniques for enhancement of shell-side-heat transfer coefficient by using of circular fins on the long tubular copper tubes.

5.2.2 Reduction in pressure drop

In normal heat exchangers with segmental baffle having a problem of pressure drop and dead zones in between two adjacent baffles which would lead to fouling resistance and zig-zag motion of fluid causes high risk of vibration.

Helical baffle heat exchanger or generally called a helix-changer was introduced in Czechoslovakia. It is a special kind of exchanger which was designed for the elimination of draw backs of conventional heat exchangers. It is a very real where pressure drop and fouling factors are major concern. ([5]Mr. Pravinkumar). It consist a series of baffle so that it can resist the bundle vibration. For effective performance of exchanger it is very essential to minimize the pressure losses it can be achieved by continuous helical baffle. “Manufacturing of these baffles are very hard. Helical baffle offers a near plug flow which results in less particle impurities collection near dead jone.” ([14]Patel)].

Helical baffle offers: -

- Higher shell side heat transfer
- Lower Pressure drop
- Lower fouling resistance
- High thermal effectiveness
- No bundle vibration
- Less By- pass effect
- Reduced operating cost
- High thermal effectiveness
- It helps to improve capacity of plant
- Increased $\alpha/_{\Delta P}$ for same mass flow rate
- Lower maintenance cost

The experiment comprising helical baffle heat exchanger. Copper tubes have 13.5 mm outer diameter. The Plexiglas shell has 20 cm inner and 22 mm outer diameters and 50 cm length. Total 12 baffles are used in this. The experimental setup and its schematic diagram are shown in Figure 6.1. The setup is a well instrumented heat exchanging system in which a hot water stream flowing inside the copper tube is cooled by a cold stream flowing in the shell side. Two 2000 W parallel electric heaters were placed in the hot water storage tank; reach the hot water temperature to the desired value. The hot water is then pumped to the copper tube which is placed in the heat exchanger. The mass flow rate is measured by two flow meters placed in the way of hot and cold waters. As the hot water exits the heat exchanger, its temperature reduces so the hot flow returns back to the hot water storage tank to have the constant hot water temperature at the entrance of tube. The cold water has the same closed cycle but the difference is that the cold water temperature increases as it passes through the heat exchanger so a cooling unit placed in cold water cycle fixes the cold water temperature at the entrance of shell. The inlet and outlet temperatures of hot and cold water were recorded manually using 4 RTD PT 100 sensors inserted in the small holes made in the inlet and outlet tubes of each heat exchanger and sealed to prevent any leakage. Shell is covered by the glass wool and aluminum foil for the proper insulation Tests were conducted with varying different parameters such as different flow rates in tube and shell side, different inlet fluid temperature to study the effect of these parameters in heat transfer rate.

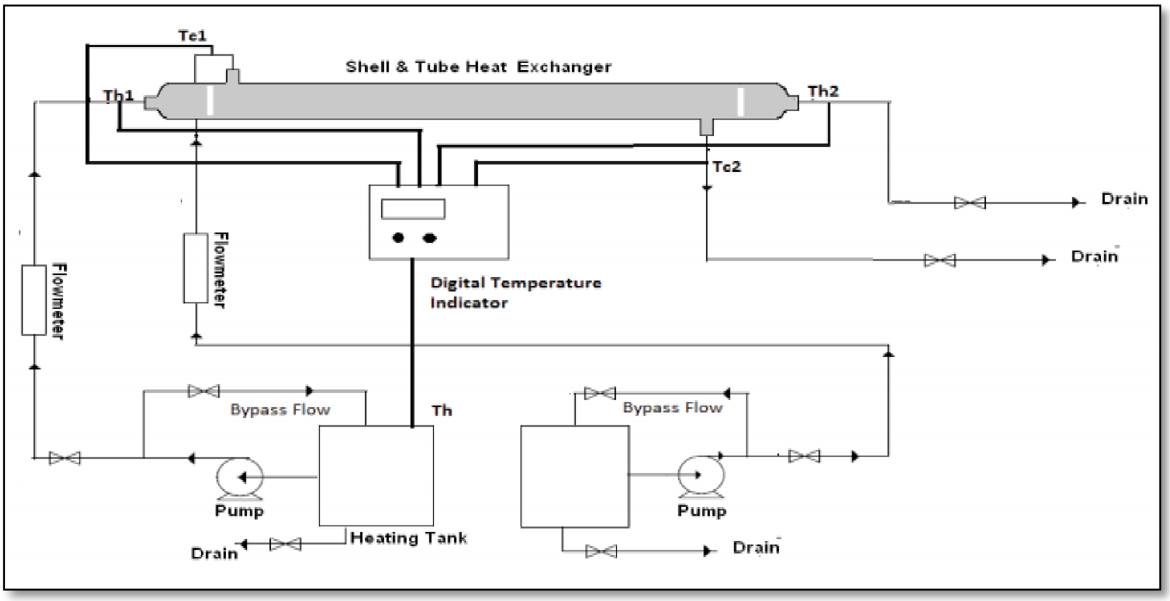


Figure 6.1 Symmetric view of experimental apparatus.

6.1 Component of Apparatus

6.1.1 Shell

The shell is in circular shape made of cast iron having inside diameter 0.153 m and length of 0.5 m. tubes will be inserted in the shell.at both ends it consist sups which have same diameter as shell having and cups are connected by means by flange coupling with the help on nut bolts. Outer body of shell is insulated by means of insulating material. In this apparatus cotton wolves are used, so that no heat is dissipated in atmosphere.

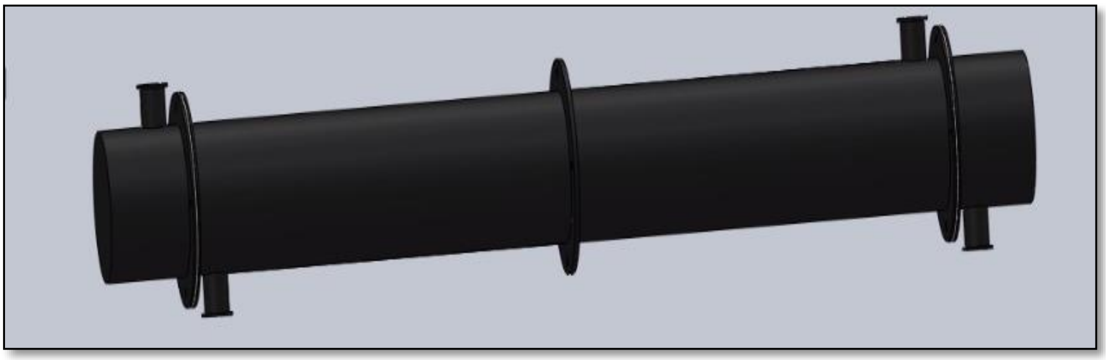


Figure 6.2 Shell and Cups.

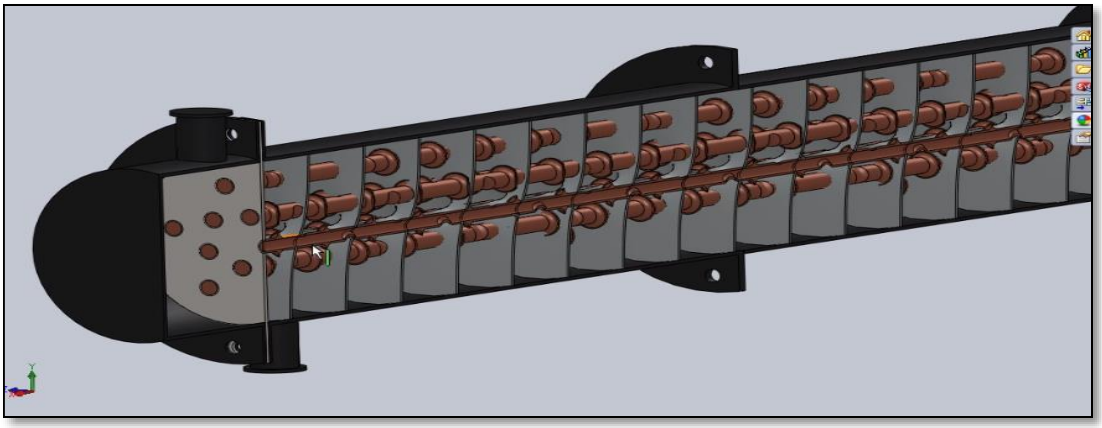


Figure 6.3 Cross section of shell

6.1.2 Tubes

This is already discussed that uses of tubes in STHExHB. Here copper tubes of outer diameter of 13.5 mm is used.

Having length same as shell. Here three types of tubes are used:

- Straight copper tubes
- Grooved copper tubes
- Finned copper tubes

6.1.2.1 Purpose of using Grooved and Finned tubes

It's a passive heat enhancement method when we change any geometry for heat enhancement to the flow. When we modify the geometry it leads the heat transfer enhancement due to disturbing the existing flow behavior. Here am proving two modification one is groove and another is a finned surface on the tube. When we introduce the grooves in the tubes it changes internal geometry of tubes and the flow I that region will be disturbed due to appearance of turbulence in some sight. Grooved offers helical pattern so every time when the hot fluid passes through the tubes, its velocity increases and flow will become turbulent and boundary layer will be end up at that sight this will help in increase in existing heat transfer rate.

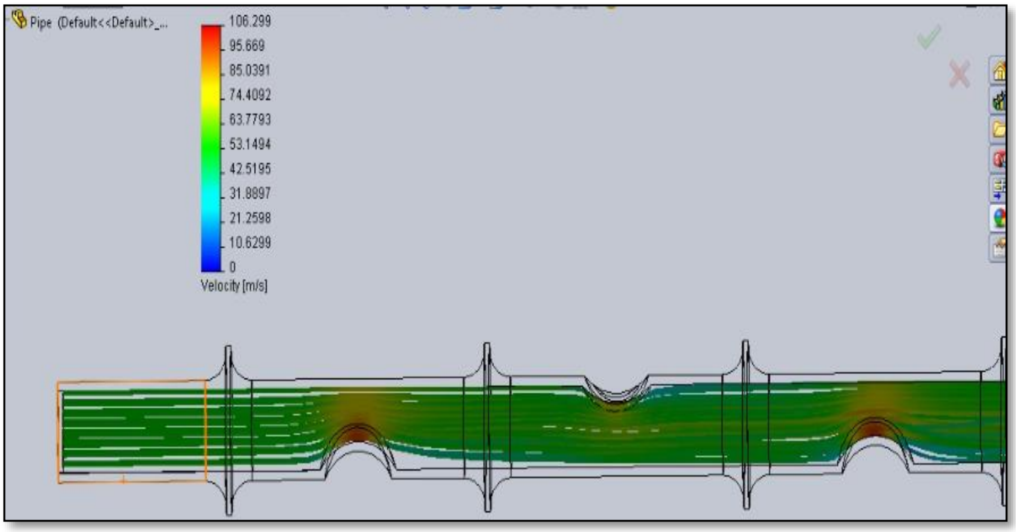


Figure 6.4 Velocity distribution

Groove alone is sufficient for the heat enhancement but for utilizing the heat generated near grooves fins are introduced between two adjacent grooved. Basically it increases the surface are of tube and utilizing the effect higher turbulence in that region so that overall heat transfer is increased.

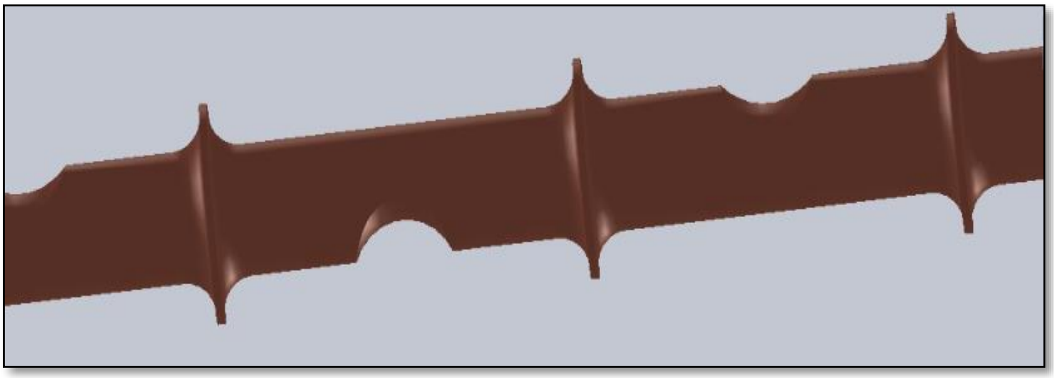


Figure 6.5 Finned and grooved tube.

Figure 6.6 Real time view

6.1.3 Baffle

Here baffle is made by GI sheet with helix angle $25°$. This is a continuous baffle, but at the level of fabrication single-single baffle is made by cutting of diameter lesser than shell inside diameter then radius is cut and this is folded at baffle angle $25°$. All the individual are joined by rivet joint and finally it takes shape of continuous baffle. Drills are done by punching machine. Total 9 tubes are using in this experiment so 9 drills have been done.

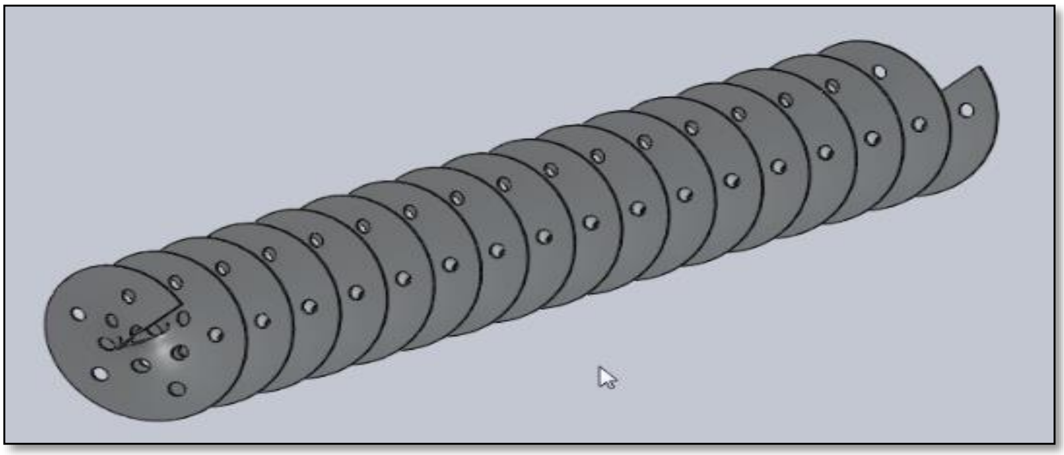


Figure 6.7 helical baffle (CAD model)

Figure 6.8 Helical baffle with tubes

6.1.4 RTD PT 100 Sensor

Thermocouples are used at appropriate position which carry the signals to the temperature indicator. A digital indicator with channel selector is provided to measure the temperature. In this experiment total 5 sensors are used and a 10 channel monitor box is used to measure the exact reading.

Figure 6.9 RTD PT-100 Sensor and Monitor

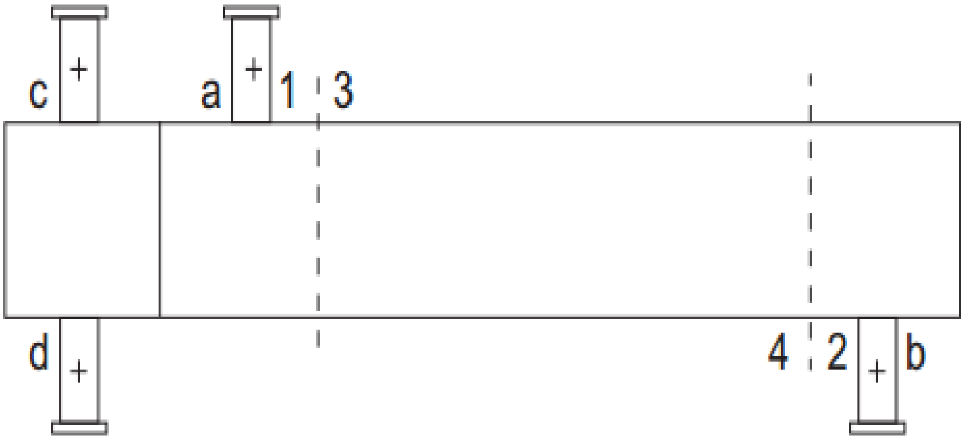


Figure 6.10 Arrangement of Test point

6.1.5 Pumps

Pumps are installed for the supplying the water into tubes and shell. Total 2 pumps of 0.5 HP are used here. All the connection are the shown in figure 6.1 symmetric diagram of system layout.

6.1.6 Rota meter

Rota meter are placed for the flow regulation and control in the heat exchanger. There are acrylic Rota meters which is used for range 180- 660 LPH. There are two rotameters installed, one for hot fluid and another for cold fluid. By-pass valves are provided with rotameters connection to avoid the pumps failure because pump compress the fluid at certain rate and we make this flow block, there will be problems like failure of pumps. By-pass are installed between the nozzles and motor.

6.1.7 Storage tanks

In this experiment two storage tank are used of size $45\times45\times30$ cm^3. One for cold fluid and another for hot fluid. In hot water container a heating coil is installed for the heating purpose. Sensor number 5 is in contact with this hot water tank and if the temperature of tank reached above 65^0, the cut of circuit automatically turn off the heaters.

6.2 Experimental Apparatus

"Figure 6.11" shows the complete assembly of shell and tube heat exchanger. It is a final experimental apparatus on which all the required experiments have been done. It is typical helical baffle shell and tune heat exchanger which is also known as helix-changer.

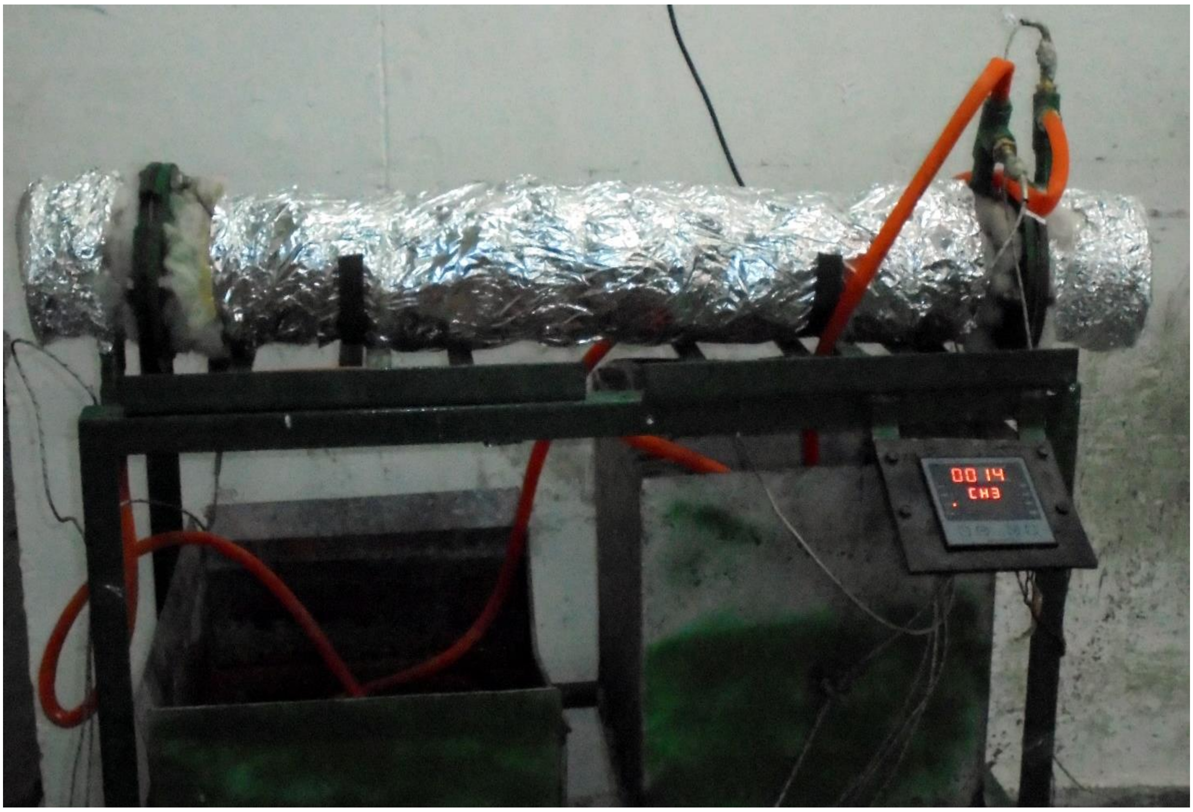


Figure 6.11 Experimental Apparatus

6.3 Methodology

Process flow chart

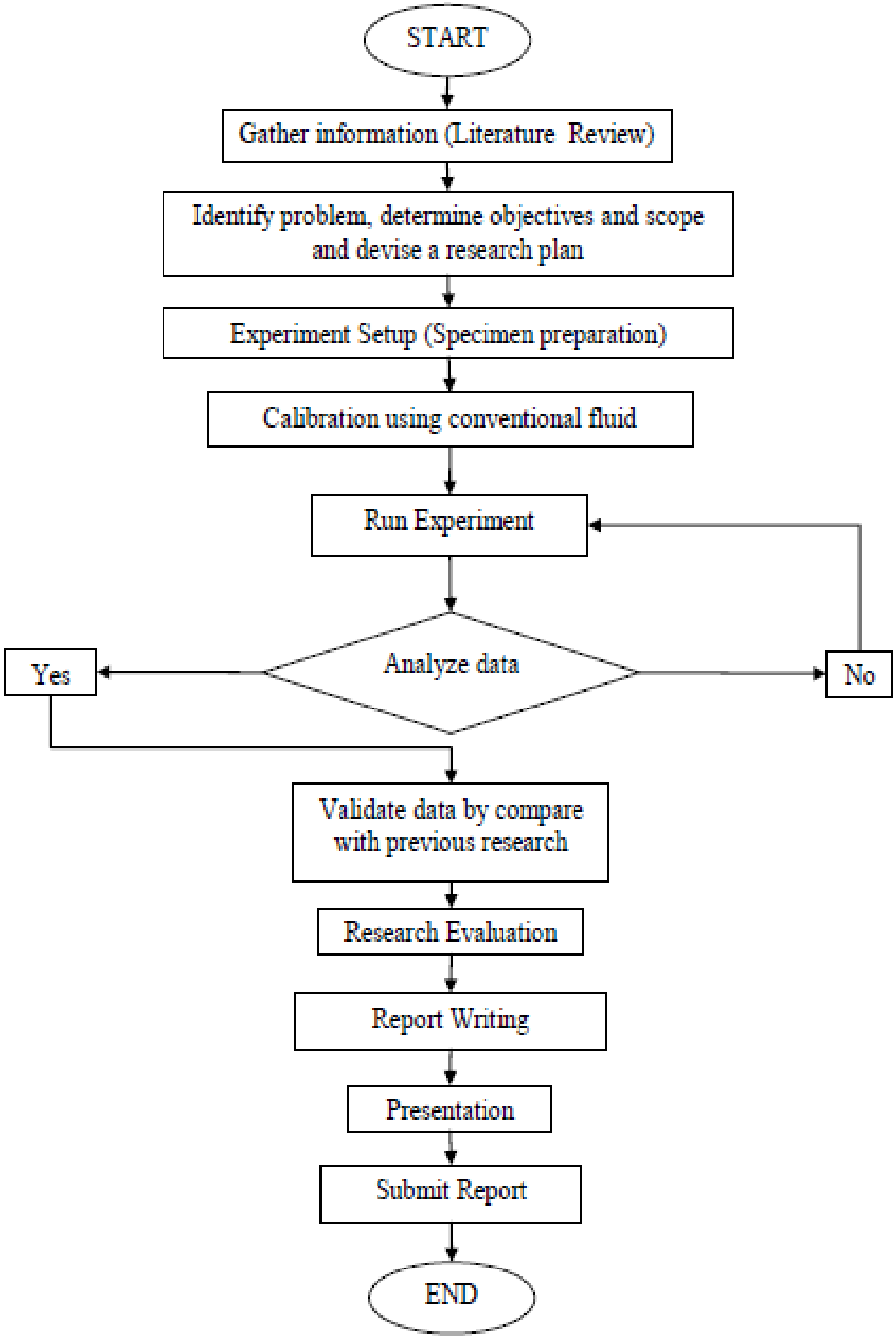


Figure 6.12 Process Flow Chart

6.4 Input Parameter

6.4.1 Helix-Changer Data at Shell Side:

"Table 6.1" shows the shell side parameters.

Table 6.1 Shell Side data

S. No	Quantity	Symbol	Value
1	Fluid	-	Water
2	Inner Diameter	D_{is}	0.2 m
3	Mass flow rate	M^*_s	0.05 to 0.183 kg/sec
4	Volume flow rate	Q^*_s	180 to 660 LPH
5	Shell Length	L_S	0.5 m
6	No. of passes	-	1
7	Tube Pitch	P_t	0.0225 m
8	Baffle cut	-	25%
9	Meant Bulk Temp	-	45^*C
10	Nozzle Id	-	0.023 m
11	No. of baffles	-	12
12	Baffle pitch	-	0.060 m

6.4.2 Helix-changer data at Tube side

"Table 6.2" shows the various data for tube side.

Table 6.2 Tube Side data

S. No.	Quantity	Symbol	Value
1	Fluid	-	Water
2	Volume flow rate	Q^*_t	420 LPH
3	Outer diameter	D_{ot}	13.5 m
4	No. of tubes	N_t	9
5	Mass flow rate	m^*_t	0.11667
6	Tube thickness	-	1.123 m
7	Nozzle inner diameter	-	0.225

6.4.3 Fluid Property

Table 6.3 Fluid Property

Property	Symbol	Unit	Cold water	Hot water
Density	ρ	kg/m^3	996	996
Thermal conductivity	K	W/m. K	0.6150	0.6150
Specific heat	C_p	KJ/kg. K	4.178	4.178
Prandl't no.	P_r	-	5,42	5,42
Viscosity	μ	kg/m. s	0.001	0.001

6.4.4 Flow Condition of fluid streams in heat exchanger

Table 6.4 Flow Condition of fluid

Serial No	Description	Shell side	Tube Side
1	Mass flow rate(LPH)	420	180-660
2	Inlet temperature (℃)	26	55
3	Outlet Temperature (℃)	51	36

6.4.5 Thermocouple connection

Table 6.5 Sensors Location

Serial No.	Sensor No.	Location
1	T-1	Hot inlet
2	T-2	Hot outlet
3	T-3	Cold inlet
4	T-4	Cold outlet
5	T-5	Heating tank

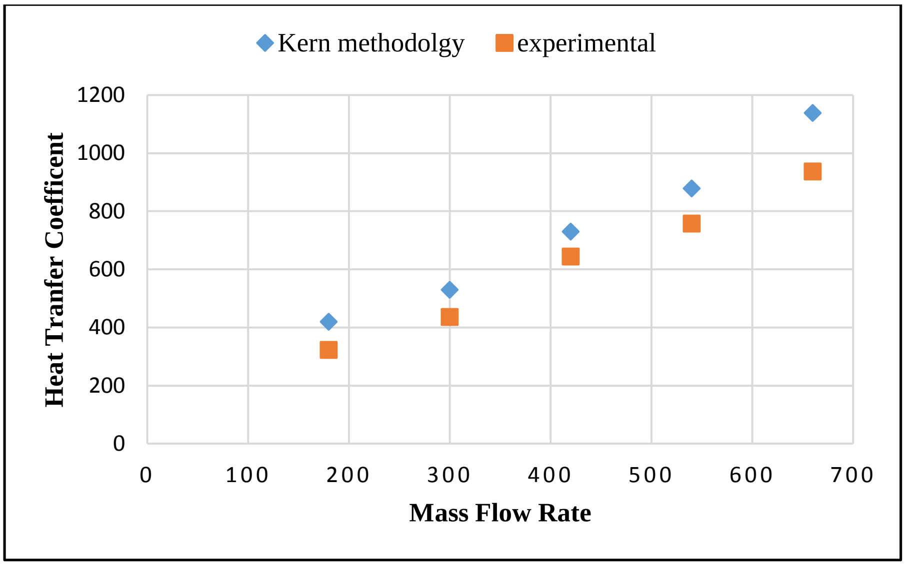
Performance test of the heat exchanger was carried out. Three parameters were studied to understand the performance of the heat exchanger. The heat transferred, overall heat transfer coefficient and shell side pressure drop within the exchanger. The shell and tube heat exchanger was having hot water in tube side and cold water in the shell side in counter flow configuration. Five experiments were conducted at different hot water mass flow rates in two phases.

In **primary phase** two experiments has been done on segmental baffle and helical baffle with simple copper tube at different mass flow rates.

In **Secondary phase,** next 3 experiments has been conducted with simple copper tube, grooved cooper tube and grooved-finned copper tube with helical baffle at 25° with different mass flow rates.

Results are plotted below:

7.1 Validation



For the validation purpose the experimental results are compared with the values calculated by Kern method. It is clear from graph that our experimental value is much closer to the values calculated by kern method which is proven and established method for heat exchanger design. At lower mass flow rate, the experimental result comes close to kerns result but at higher mass flow rate it a significant variation comes so this curve indicates that this result is quite good and acceptable for further research.

Kern Method, heat transfer coefficient

$$\propto = \frac{0.36 \times K \times Re^{0.55} \times Pr^{0.33}}{R \times R_E}$$

7.2 Effect of helical baffle on heat transfer coefficient

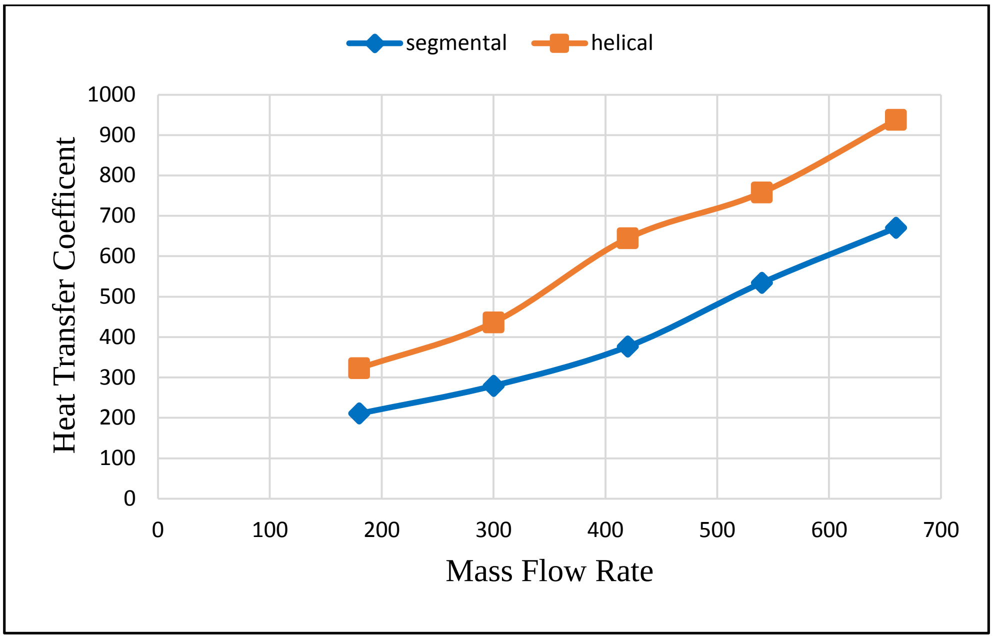


Figure 7.1 Mass flow rate v/s Heat transfer coefficient

Increase in the flow rate of hot water resulted in increase in the heat transfer coefficient as can be seen from curve in Figure 7.1. The curve shows that an increase of hot water flow coefficient from 180 LPH to 660 LPH, increased the heat transfer coefficient of the heat exchanger in both cases but it's much higher in helical baffle . This is because increase in the mass flow rate of hot water increases the heat energy transferred. Since the specific heat remains almost constant, hot water outlet temperature should decrease to comply with law of conservation of energy and hence as the flow rate of the hot water is increased, the tube side overall heat transfer coefficient also increases. And this transferred energy is adopted by helical flow because of its extreme contact timing of shell side fluid with tubes and proper mixing The performance test result indicated that the developed shell and tube heat exchanger performs satisfactorily under standard conditions and the variation of the overall heat transfer coefficient and total heat transferred with the mass flow rate of the hot water is analogous to similar heat exchangers.

7.3 Effect of helical baffle on pressure drop

It was observed that the pressure drop increases with increase in hot water flow rate in heat exchanger these result also indicate that the pressure drop ΔP_s in a helical baffle heat exchanger is appreciably lesser as compared to Segmental baffle heat Exchanger, figure 7.2 due to increased cross-flow area, resulting in lesser mass flux throughout the shell. Segmental baffle heat exchanger experience pressure drop mainly due to friction, and most of the its pressure part is wasted in changing the flow direction but in helical baffle, passage is very smooth so there is no fouling , no bypass flow. This pressure drop may increase pumping power and may affect the service time of structural components of the heat exchanger. However compared to rate of change of the heat transferred the rate of increase in pressure drop is reasonable.

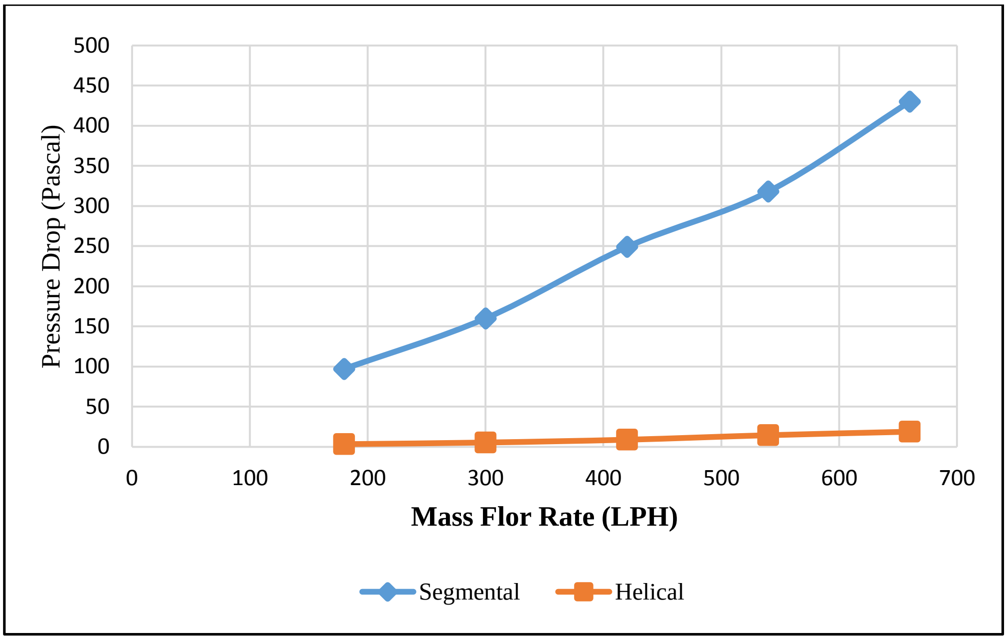


Figure 7.2 Mass flow rate v/s Pressure drop

7.4 Effect of Grooved and Finned Tune on Heat Transfer Rate

The heat enhancement brought by the grooved tubes may be influence by water flow rate passing through heat exchanger. In this experimental study, the hot water flow rate inside plain tube helix-changer or grooved tube helix-changer was changed to examine in figure 7.3. It is clear that the heat transfer has an obvious increase by using grooves. The results also show that the enhanced ratio of heat transfer due to grooves increasing with increasing mass flow rate of hot water (inside tubes). The enhanced ratio for the heat transfer is about 47% on different flow rates as the hot mass flow rate increase rate of heat transfer and overall heat transfer coefficient increase respectively. With grooved and finned tube this transfer rate is higher compared to grooved and simple tube due to increased effective heat transfer are.

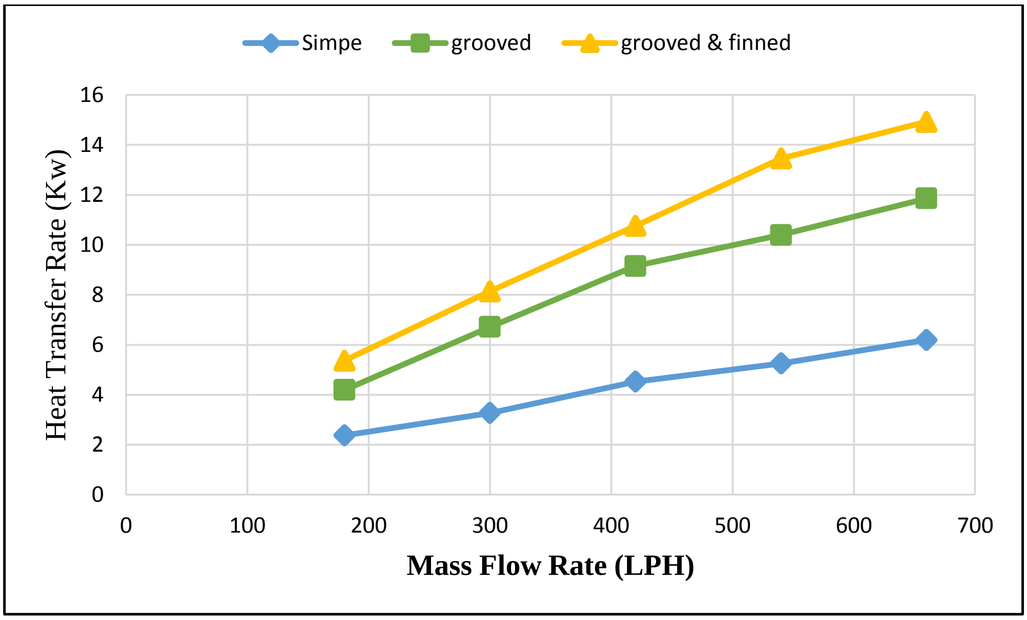


Figure 7.3 Mass flow rate v/s Heat transfer rate

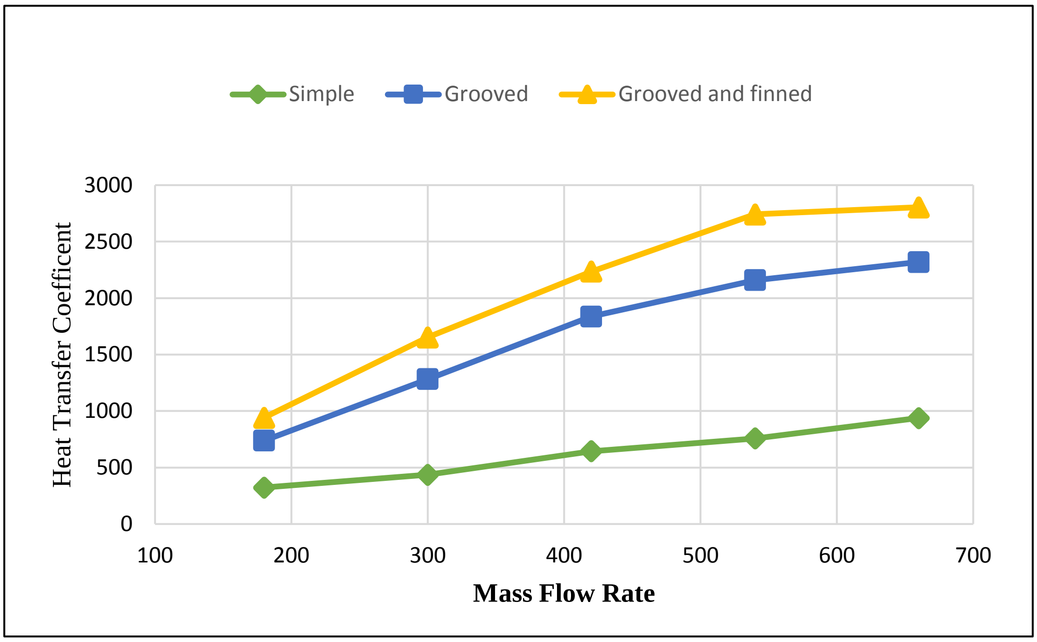


Figure 7.4 Mass flow rate v/s. Heat transfer coefficient

It is also concluded that there is significant temperature drop in grooved tube as compare to the plain tube helix-changer with the same operating conditions for both. It indicates that the effect of grooves produce turbulence in flowing fluid which leads to better heat enhancement over plain tube. Therefore it is reasonable to suppose that with the same operating condition heat enhancement of grooved tube helix-changer has better over plain tube helix-changer and it also concluded that heat transfer would increase with increasing flow rate. The concept of fines are same here.

7.5 Effect of Hot water temperature on heat transfer

Hot water temperature produces significant effect on heat transfer coefficient, which influences the efficiency of heat transfer. It is found that enhanced heat transfer efficiency of both, plain tube and grooved tube helix-changer changes with the inlet temperature of hot water. But grooved tube helix-changer has better heat transfer rate over plain tube helix-changer with same operating conditions. The peak point of enhanced ratio occurs at about 60^{0}C where enhanced ratio is about 18% for grooved tube and 28% for the grooved and finned tube. Temperature may be the most important parameter to be considered in maximizing heat transfer rate. This is because temperature affecting properties of liquid such as viscosity, thermal conductivity, and density & specific heat etc. Increasing liquid temperature, on one hand will decrease viscosity of liquid and make it easier to have good heat transfer rate. In this experimental study, temperature 60^{0}C exist a favorable liquid temperature that maximizes the enhanced ratio for grooved tube helix-changer over plain tube helix-changer. Further study ought to be made on this issue and reasonable model be established for guidance.

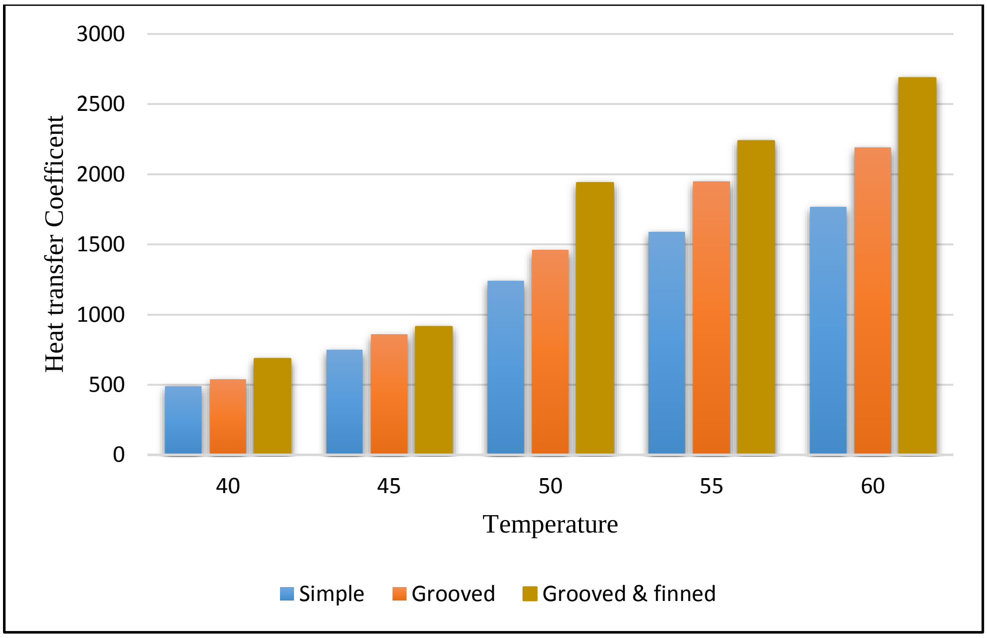


Figure 7.5 Temperature vrs Heat transfer coefficient

8.1 Conclusion

This study presents the effects of heat enhancement technique on the thermal performance of shell and tube heat exchanger. Our focus was on the passive technique so this is done by two ways, first changing the baffles offers a great result for pressure drop and fouling resistance and introducing the grooved and fined tube give better heat transfer and heat surface area.

The enhancement may be influence by conditions like the fluid temperature, the fluid mass flow rate as well as groove pattern. The effect of groove on the heat enhancement will be more evidence when the fluid mass flow rate is more. The influence of fluid temperature is mainly related to grooves as compare to plain tubes. It can also be concluded that grooves produces a significant drop in temperature of fluid by leading turbulence i.e. mixing of fluid which enhancing heat transfer rate. It is certain that higher the temperature, the higher enhanced ratio will be achieved. Fins provides effective heat transfer area in flow passage which utilize the generated heat by grooved and this heat is dissipated by the fins in surrounding fluid. The new technology of heat transfer enhancement by using grooves on tubes, which is a passive heat enhancement technique, is still far from the practical application with helix baffle. According to the experimental results, different flow behavior leads to different degree of heat transfer enhancement. The groove pattern on tubes will increase turbulence degree of movement of fluid which leads to better heat enhancement over the plain tube helix-changer and this is based on the size of groove which need to be optimized in future for making more effective heat exchanger. In this study helical baffle played an effective role for enhancing the performance of heat exchanger. Construction of continuous helical baffles are still tough and cost is also high but flapped helical baffle can be used in place of continuous helical baffle which gives almost same result.

8.2 Future Scope

In future, energy consumption will be critical parameter for any industrial development and for that thermal system must be effective and optimized. In this study, thermal performance of shell and tube heat exchanger has been improved by using of groove and finned tube. Result shows that there is a positive increment in heat transfer rate with grooves and fins which can be optimized for effective performance of heat exchanger in future.

REFERENCES

[1] Anil Singh Yadav, "Effect of half length twisted-tape turbulators on heat transfer and pressure drop characteristics inside a double pipe u-bend heat exchanger", *J J Mech and Ind Eng,* ISSN 1995-6665.

[2] Andre L.H. Costa, Eduardo M. Queiroz, "Design optimization of shell-and-tube heat exchangers", *Applied Thermal Engineering* 28 (2008) pp -1798–1805.

[3] Bashir Master, K.chunghad, "Fouling mitigation using helix changer heat exchanger," Conference on heat exchanger fouling and cleaning". *Fundamentals and application*.pp 312-317, (2003)

[4] B.I. Master,chungad,A.J Boxma,D.Kral,P.Stheik;"Most frequently used heat exchanger from pioneering research to world wide applications," vol.no.6, 2008 ppt-8.

[5] D. R. Pitts and L. E. Sissom, "Theory and Problems of Heat Transfer", *Schaum's Outline Series,* McGraw-Hill, 2nd Edition, 1998.

[6] Jian-Fei Zhang, Ya-Ling He and Wen-Quan Ta.,"A Design and Rating Method for shell and tubeand tube heat exchanger with helical baffle", *Journal of Heat Transfer,* 2010.

[7] Khin Aung Lin, Mi Sandar,Su Thet Mon Than,"Heat Exchangers Selection, Rating and thermal design". (2002).

[8] L. Gong, Z.Y. Li, Y.L. He, W.Q. Tao,"Discussion on numerical treatment of periodic boundary condition for temperature", *Numer. Heat Transfer* B 52 (5) (2007) 429–0448.

[9] Miguel Toledo-Velázquez1, Pedro Quinto-Diez, http://www.scirp.org/journal/eng, 2004

[10] Mohammadi, Koorosh,"Investigation of Baffle Cut and Fluid Viscosity", Abadam, 2011.

[11] Mustansir Hatim Pancha, Sunil Kumar Shinde and and S. Pavithran,"Improved perfomance of helix Changer over baffle heat exchanger using using Kern's method", *International Journal of Advances in Engineering & Technology*, 2012.

[12] M. B. Russell, P. N. Surendran and S. D. Probert, "Quantifying Acceptable Mesh Dependencies for Computational Investigations of Airflows within Rooms", *Applied Energy* Vol. 72, Issue 1, pp. 409-425, May 2002.

[13] M.Serna and A.Jimenez, "A compact formulation of the Bell Delaware method for Heat Exchanger design and optimization", Chemical Engineering Research and Design, 83(A5): 539–550.

[14] M. M. El-Fawal, A. A. Fahmy and B. M. Taher, "Modelling of Economical Design of Shell and tube heat exchanger Using Specified Pressure Drop", Journal of American Science.

[15] M.M.K. Bhuiya, J.U. Ahamed, M.S.U. Chowdhury, M.A.R. Sarkar, B. Salam, R. Saidur, H.H. Masjuki, M.A. Kalam, "Heat transfer enhancement and development of correlation for turbulent flow through a tube with triple helical tape inserts, *International Communications in Heat and Mass Transfer* 39 (2012) 94–101.

[16] N.B.Dhamane, D.B. Nalawade, M.M.Dange, "Experimental study of the Transfer for wavy twisted tape insert of various pitches in a circular tube", *International Journal of Innovative Research and Developmen*t, 2011

[17]] Patel, Sandeep K, "Shell & Tube Heat Exchanger Design with Optimization of Mass flow", *International Journal of Advanced Engineering Research and Studies*, 2012.

[18] Pravinkumar, V. Hadgekar, "Comparative thermal analysis of conventional tublar heat exchanger using Bell-delawaremethod", *International Journal of Scientific and Research Publications*, 2013.

[19] Rajeev Mukharji, "Effective design of shell and tube heat exchanger*", American Institute of Chemical Engineering*, 1988.

[20] Rehman,Usman Ur, "Heat Transfer Optimization of Shell-and-Tube Heat Exchanger through CFD studies, master's thesis", *Innovative and Sustainable Chemical Engineering,Goteborg*,2011.

[21] Sepehr Sanaye, Hassan Hajabdollahi, "Multi-objective optimization of shell and tube heat exchanger", *Applied Thermal Engineering* 30 (2010) 1937-1945.

[22] Sutapat Kwankaomeng, Sompol Skullong, "Thavee Teschareon and Pongjet Promvonge "Thermal Characteristics in Square Channel with 45° Staggered Baffle inserts", *PEA-AIT International Conference on Energy and Sustainable Development: Issues and Strategies* (ESD 2010) The Empress Hotel, Chiang Mai, Thailand. 2-4 June 2010.

[23] S.Eimsa-ard, K.Wongcharee, "P.Eimds-srd, Heat Transfer in a tube using delta winglet twisted tape inserts", *Applied Thermal Engineering* (2010) 310-318.

[24] S.Gowthaman, S. Satish., "Analysis of segmental and helical baffle in shell and tube heat exchanger", International journal of current engineering and Technology, 2014.

[25] S.K. Saha, A. Dutta, S.K. Dhal, "Friction and heat transfer characteristics of laminar swirl flow through a circular tube fitted with regularly spaced twisted: tape elements", *International Journal of Heat and Mass Transfer* 44 (2001) 4211–4223.

[26] S.Selvam, PR.Thiyagarajan, S. Suresh, "Experimental studies on effect of bonding the twisted tape with pins to the inner surface of the circular tube".

[27]] Shiv Kumar Rathore, Ajeet Bergaley, "Comparative Analysis of Finned Tube and Bared Tube Type Shell and Tube Heat Exchanger", *International Journal of Engineering and Innovative Technology* (IJEIT) Volume 2, Issue 1, July 2012.

[28] Vindhya Vasiny Prasad Dubey, Raj Rajat Verma, Piyush Shanker Verma, A. K. Srivastava, " Performance Analysis Of Shell & Tube Type Heat Exchanger Under The Effect Of Varied Operating Conditions", *International Organization of Scientific Researches*.

[29] V.K. Patel, R.V. Rao, "Design optimization of shell and tube heat exchanger using particle swarm optimization technique", *Appl. Therm. Eng* 30 (2010) 1417- 1425

[30] Vindhya Vasiny Prasad Dubey, Raj Rajat Verma, Piyush Shanker Verma, A. K. Srivastava, "Steady State Thermal Analysis of Shell and Tube Type Heat Exchanger To Demonstrate The Heat Transfer Capabilities Of Various Thermal Materials Using Ansys", Global Journals Inc., GJRE Volume 14, Issue 4, ISSN- 0975-5861

[31] Yusuf Ali Kara, Ozbilen Guraras, "A computer program for designing of Shell and tube heat exchanger", *Appl. Therm. Eng* 24(2004) 1797–1805.

[26] Y.L. He, M. Wu, W.Q. Tao, et al., "Improvement of the thermal performance of pulse tube refrigerator by using a general principle for enhancing energy transport and conversion processes", *Appl. Therm. Eng*. 24 (2004) 79–93.

[32] Zahid H. Ayub, "A new chart method for evaluating singlephase shell side heat transfer coefficient in a single segmental Shell and tube heat exchanger". *Appl. Therm. Eng* 25 (2005) 2412–2420.