Design of Shell and Tube Type Heat Exchanger using CFD Tools

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Abstract

In present day shell and tube heat exchanger is the most common type heat exchanger widely used in oil refinery and other large chemical process, because it suits high pressure application. The process in solving CFD consists of modeling and meshing the basic geometry of shell and tube heat exchanger using CFD package ANSYS 13.0. The objective of the project is design of shell and tube heat exchanger with helical baffle and study the flow and temperature field inside the shell using ANSYS software tools. The heat exchanger contains 7 tubes and 800 mm length shell diameter 90 mm. The helix angle of helical baffle will be varied from 00 to 20°. In CFD will show how the temperature varies in shell due to different helix angle and flow rate. The flow pattern in the shell side of the heat exchanger with continuous helical baffles was forced to be rotational and helical due to the geometry of the continuous helical baffles, which results in a significant increase in heat transfer coefficient per unit pressure drop in the heat exchanger. There is a wide application of coiled heat exchanger in the field of industrial applications for its enhanced heat transfer characteristics and compact structure. Lots of researches are going on to improve the heat transfer rate of the helical coil heat exchanger. Here, in this work, an analysis has been done for a tube-in-tube helical heat exchanger with constant heat transfer coefficient with parallel flow. There are various factors present that may affect the heat transfer characteristics of the heat exchanger. The flow pattern in the shell side of the heat exchanger with continuous helical baffles was forced to be rotational and helical due to the geometry of the continuous helical baffles, which results in a significant increase in heat transfer coefficient per unit pressure drop in the heat exchanger. There is a wide application of coiled heat exchanger in the field of industrial applications for its enhanced heat transfer characteristics and compact structure. Lots of researches are going on to improve the heat transfer rate of the helical coil heat exchanger. Here, in this work, an analysis has been done for a tube-in-tube helical heat exchanger with constant heat transfer coefficient with parallel flow. There are various factors present that may affect the heat transfer characteristics of the heat exchanger.
Keywords: Heat Exchanger, Mass Flow Rate, Baffles Spacing, Heat Transfer Coefficient, LMTD, ANSYS Software and CFD

I. INTRODUCTION

Shell and tube heat exchanger design is normally based on correlations, among these, the Kern method and Bell-Delaware method are the most commonly used correlations. Kern method is mostly used for the preliminary design and provides conservative results. Whereas, the Bell-Delaware method is more accurate method and can provide detailed results. It can predict and estimate pressure drop and heat transfer coefficient with better accuracy. The Bell-Delaware method is actually the rating method and it can suggest the weaknesses in the shell side deign but it cannot indicate where these weaknesses are. Thus in order to figure out these problems, flow distribution must be understood. For this reason, several analytical, experimental and numerical studies have been carried out. Most of this research was concentrated on the certain aspects of the shell and tube heat exchanger design. These correlations are developed for baffled shell and tube heat exchangers generally.

R. Hosseini, A. Hosseini-Ghaffar, M. Soltani experimentally obtained the heat transfer coefficient and pressure drop on the shell side of a shell-and-tube heat exchanger for three different types of copper tubes (smooth, corrugated and with micro-fins). Also, experimental data has been compared with theoretical data available. Experimental work shows higher Nusselt number and pressure drops with respect to theoretical correlation based on Bell's method.

Resat Selbas, Onder Kızılkan, Marcus Reppich: Applied genetic algorithms (GA) for the optimal design of shell-and-tube heat exchanger by varying the design variables: outer tube diameter, tube layout, number of tube passes, outer shell diameter, baffle spacing and baffle cut. From this study it was concluded that the combinatorial algorithms such as GA provide significant improvement in the optimal designs compared to the traditional designs. GA application for determining the global minimum heat exchanger cost is significantly faster and has an advantage over other methods in obtaining multiple solutions of same quality.

A. *Heat Exchanger Classification:*

At present heat exchangers are available in many configurations. Depending upon their application, process fluids, and mode of heat transfer and flow, heat exchangers can be classified. Heat exchangers can transfer heat through direct contact with the fluid or through indirect ways. They can also be classified on the basis of shell and tube passes, types of baffles, arrangement of tubes

(Triangular, square etc.) and smooth or baffled surfaces. These are also classified through flow arrangements as fluids can be flowing in same direction (Parallel), opposite to each other (Counter flow) and normal to each other (Cross flow). The selection of a particular heat exchanger configuration depends on several factors. These factors may include, the area requirements, maintenance, flow rates, and fluid phase.

B. Shell & Tube Heat Exchanger:

A typical heat exchanger, usually for higher Temperature 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. Generally, it is cylindrical in shape with a circular cross section, although shells of different shape are used in specific applications. For this particular study shell is considered, which a one pass shell is generally. A shell is the most commonly used due to its low cost and simplicity, and has the highest log-mean temperature-difference (LMTD) correction factor. Although the tubes may have single or multiple passes, there is one pass on the shell side, while the other fluid flows within the shell over the tubes to be heated or cooled. The tube side and shell side fluids are separated by a tube sheet. Baffles are used to support the tubes for structural rigidity, preventing tube vibration and sagging and to divert the flow across the bundle to obtain a higher heat transfer coefficient. Most of the researches now a day are carried on helical baffles, which give better performance than single segmental baffles but they involve high manufacturing cost, installation cost and maintenance cost. The effectiveness and cost are two important parameters in heat exchanger design. So, in order to improve the thermal performance at a reasonable cost of the Shell and tube heat exchanger, baffles in the present study are provided with some inclination in order to maintain a reasonable pressure drop across the exchanger. The complexity with experimental techniques involves quantitative description of flow phenomena using measurements dealing with one quantity at a time for a limited range of problem and operating conditions. Computational Fluid Dynamics is now an established industrial design tool, offering obvious advantages. In this study, a full 360° CFD model of shell and tube heat exchanger is considered. By modeling the geometry as accurately as possible, the flow structure and the temperature distribution inside the shell are obtained.

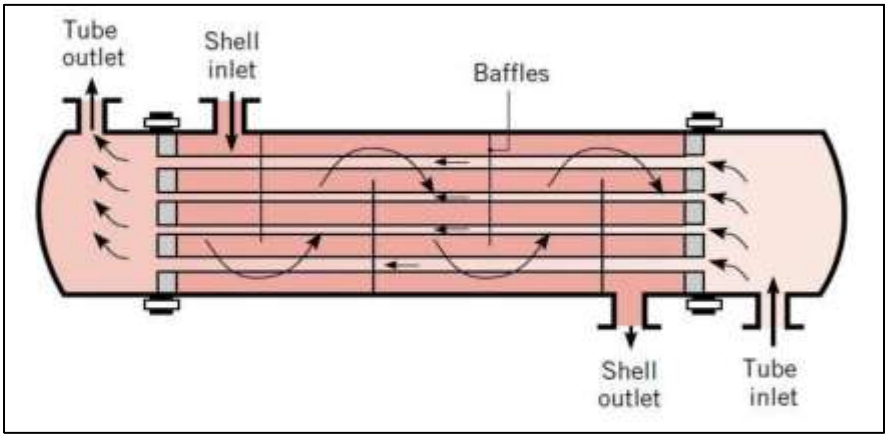

Fig. 1: shell and tube type heat exchanger

II. OBJECTIVE

The main objective of this project is designing and simulation of shell and tube heat exchanger with helical baffle using ANSYS tools. The helix angle of helical baffle will be varied from 20°. In CFD will show how the temperature vary in shell due to helix angle and flow rate.

A. Purpose of Use of Helical Baffle:

A new type of baffle, called the helical baffle, provides further improvement. This type of baffle was first developed by Lutcha and Nemcansky. They investigated the flow field patterns produced by such helical baffle geometry with different helix angles. They found that these flow patterns were very close to the plug flow condition, which was expected to reduce shell-side pressure drop and to improve heat transfer performance. An experimental setup was made for studying the heat transfer and also CFD was used for the simulation of the heat transfer. The CFD simulation results were reasonably well within the range of the experimental results. Based on both the experimental and simulation results a correlation was established for the inner heat transfer coefficient.

III. PRINCIPLE

A shell and tube heat exchanger is a class of heat exchanger designs. It is the most common type of heat exchanger in oil refineries and other large chemical processes, and is suited for higher-pressure applications. As its name implies, this type of heat exchanger consists of a shell (a large pressure vessel) with a bundle of tubes inside it. One fluid runs through the tubes, and another fluid flows over the tubes (through the shell) to transfer heat between the two fluids. The set of tubes is called a tube bundle, and may be composed of several types of tubes: plain, longitudinally finned, etc.

A. Baffle:

Baffles are placed within the shell of the heat exchanger firstly to support the tubes, preventing tube vibration and sagging, and secondly to direct the flow to have higher heat transfer coefficient. The distance between two baffles is baffle spacing.

B. Baffles Serve Two Purposes:

- Divert (direct) the flow across the bundle to obtain a higher heat transfer coefficient.
- Support the tubes for structural rigidity, preventing tube vibration and sagging.
- When the tube bundle employs baffles.

C. Type of Baffles:

Baffles are used to support tubes, enable a desirable velocity to be maintained for the shell side fluid, and prevent failure of tubes due to flow-induced vibration. There are two types of baffles: plate and rod. Plate baffles may be single-segmental, double-segmental, or triple-segmental, as shown in Figure.

D. Baffle Design:

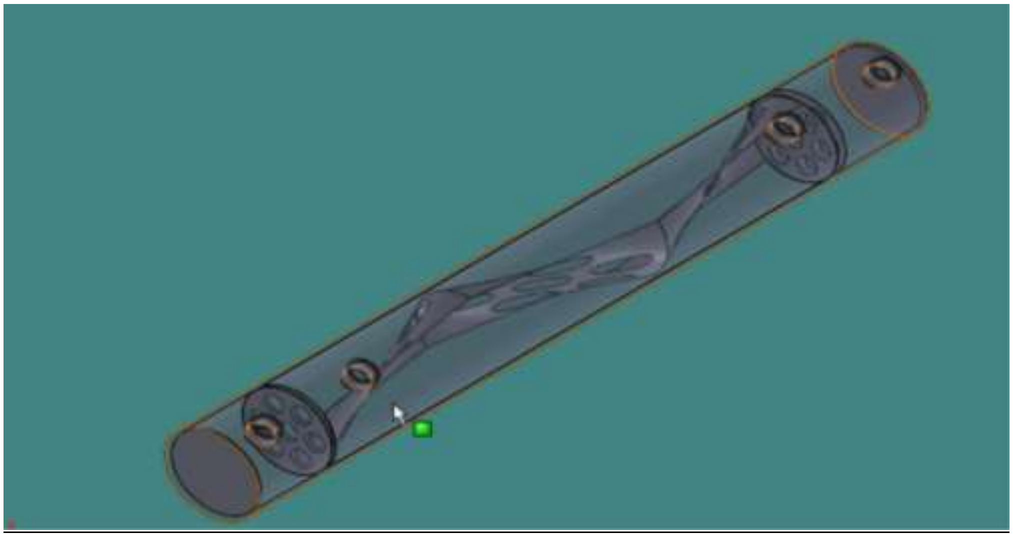

Fig. 2: Baffle Design

E. Variation of Temperature:

The temperature Contours plots across the cross section at different inclination of baffle along the length of heat exchanger will give an idea of the flow in detail. Three different plots of temperature profile are taken in comparison with the baffle inclination at 20^0.

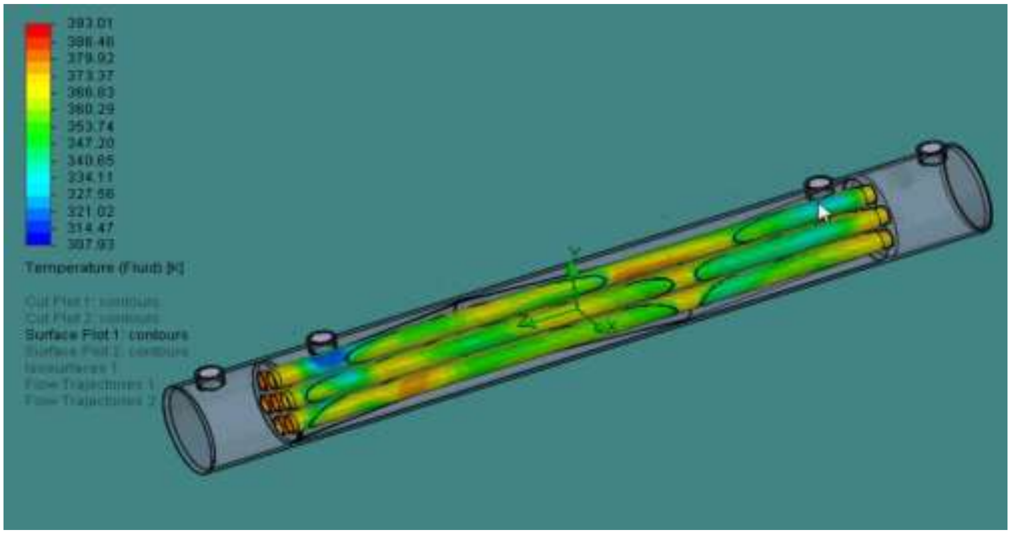

Fig. 3: Variation of Temperature

IV. FORMULA USED

A. Hot fluid flow:

$$Q_h = (m_h Cp_h)(T_{ho} - T_{hi})$$

B. Cold fluid flow:

$$Q_c = (m_c Cp_c)(T_{co} - T_{ci})$$

C. One shell pass and multiple tubes:

$$Q_h = Q_c = Q$$

D. Heat exchanger:

$Q = FUA(\Delta T_m)$

E. Effectiveness of a Heat exchanger:

– Ratio of the actual heat transfer rate to maximum available heat transfer rate.

$$\varepsilon = Q_{act.} \div Q_{max.}$$

F. Specific Heat:

For Hot
$C_{Ph} = 4.250$ KJ/Kg-K

For Cold
$C_{Pc} = 4.178$ KJ/Kg-K

G. For Parallel Flow:

$$\theta_m = \frac{\theta 1 - \theta 2}{\log\frac{\theta 1}{\theta 2}}$$

H. Heat Exchanger Surface Area:

$$A = \pi d_i l$$

I. Overall Heat Transfers Co-Efficient:

$$U = \frac{Q_h}{FA(\Delta T_m)}$$

V. CFD RESULT

20° Baffle inclination:
CFD of 20° baffle inclination is converged. The following figure shows the residual plot:

A. Shell Fluid Flow

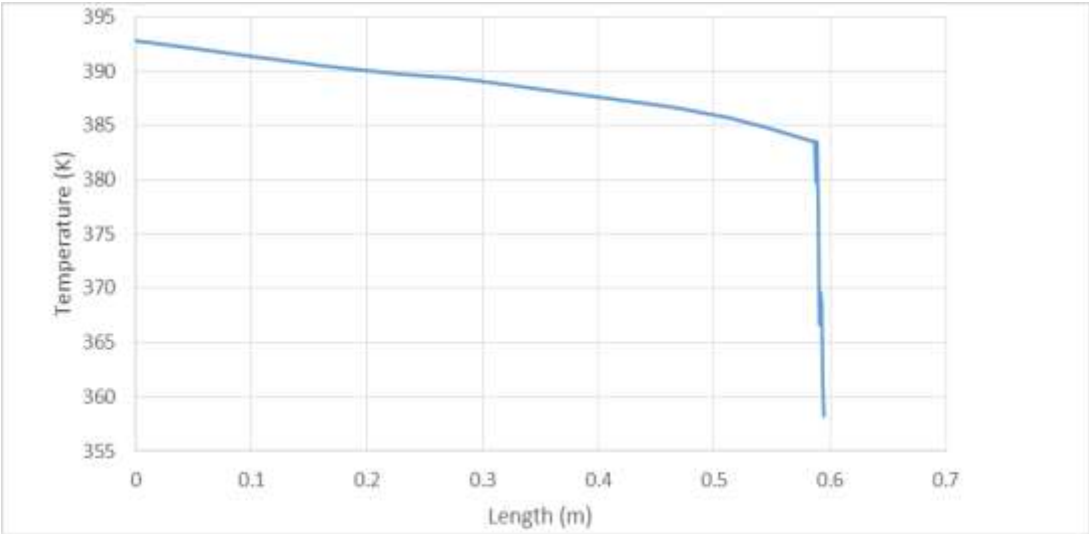

Fig. 5.1: T-L Profile

B. Tube Flow Fluid

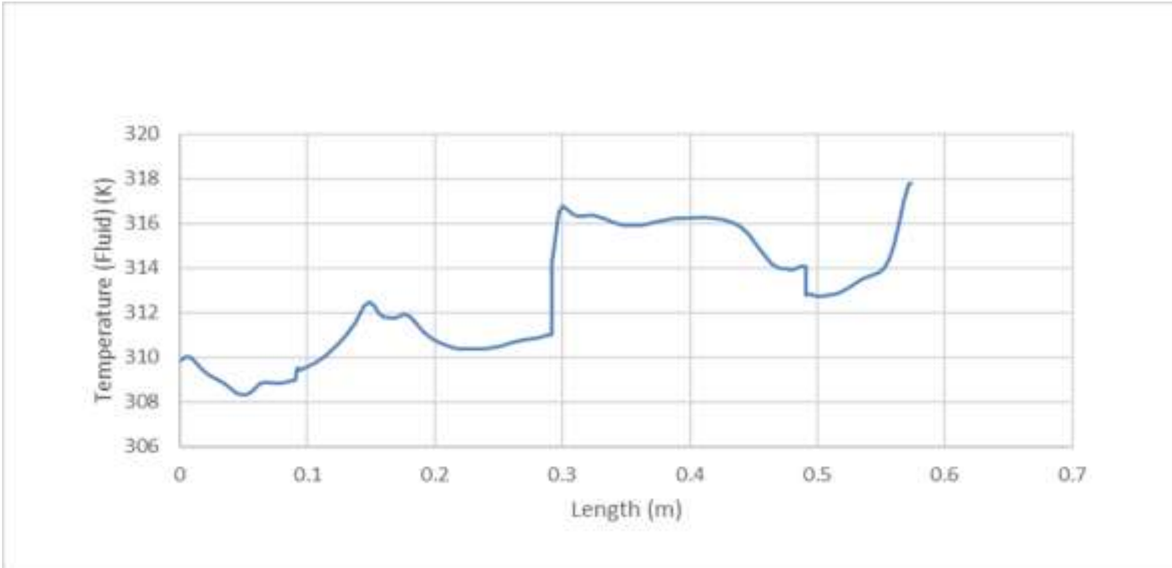

Fig. 5.2: T-L Profile

Table - 5.1
For The Outlet Temperature of the Shell Side and Tube Side

Baffle Inclination Angle (Degree)	*Outlet Temperature Of Shell side*	*Outlet Temperature Of Tube side*
0	*346*	*317*
10	*347.5*	*319*
20	*349*	*320*

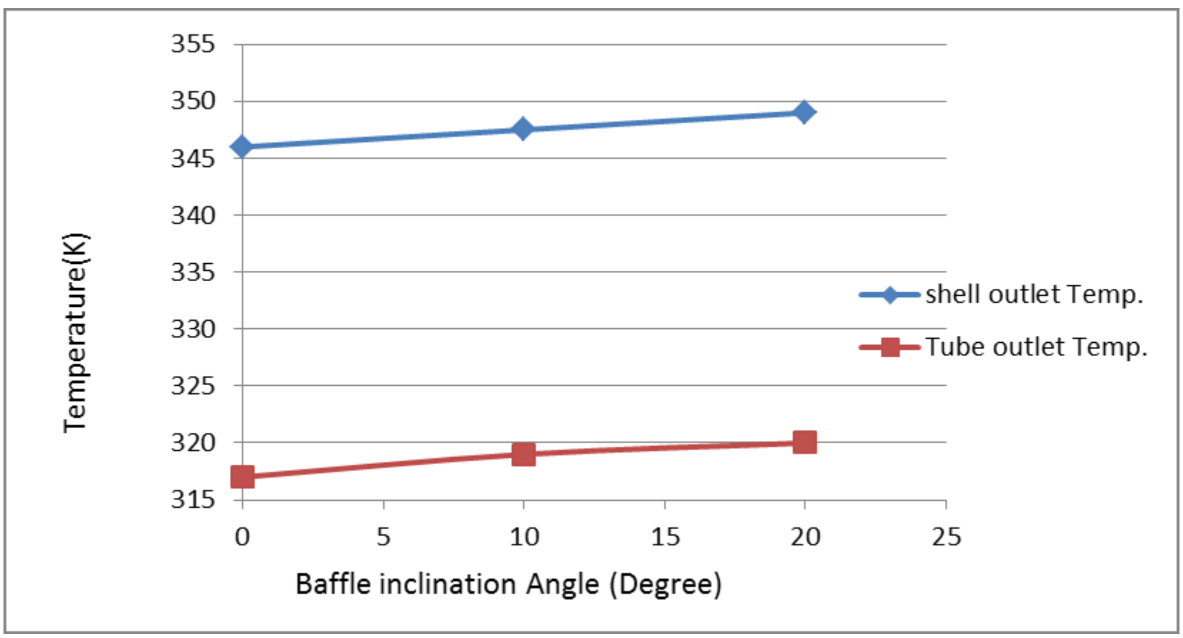

Fig. 5.3: Plot of Baffle inclination angle vs Outlet Temperature of shell and tube side

It has been found that there is much effect of outlet temperature of shell side with increasing the baffle inclination angle from 0^0 to 20^0.

Table - 5.2
For Velocity inside Shell

Baffle Inclination Angle (Degree)	*Velocity inside shell (m/sec)*
0	*4.2*
10	*5.8*
20	*6.2*

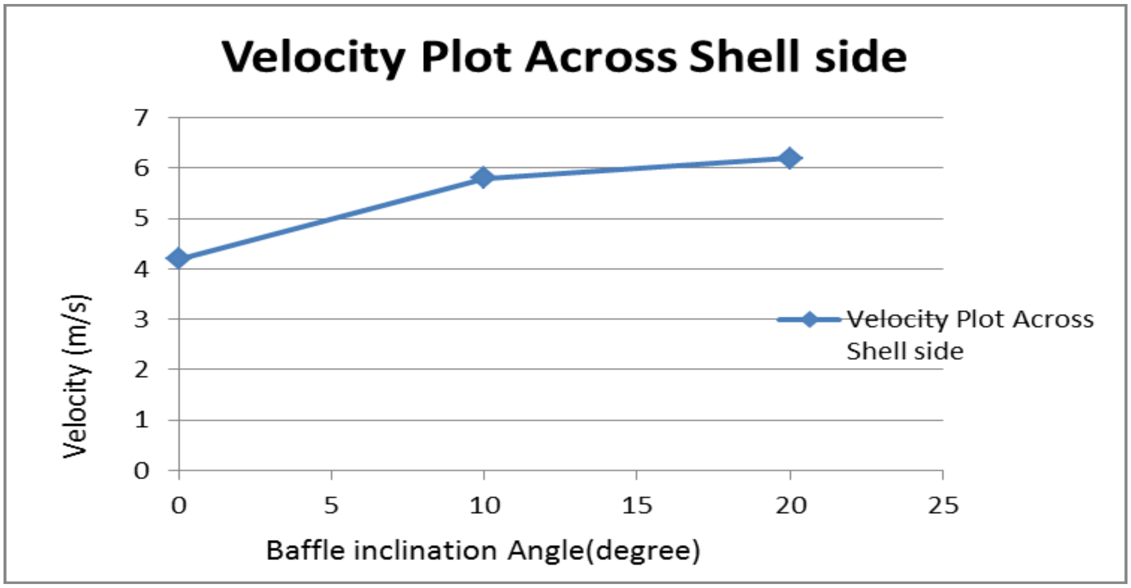

Fig. 5.4: Plot of Velocity profile inside shell

The outlet velocity is increasing with increase in baffle inclination. So that more will be heat transfer rate with increasing velocity.

Table - 5.4
For Heat Transfer Rate Across Tube Side

Baffle Inclination Angle (Degree)	*Heat Transfer Rate Across Tube side (W/m2)*
0	*3557.7*
10	*3972.9*
20	*4182*

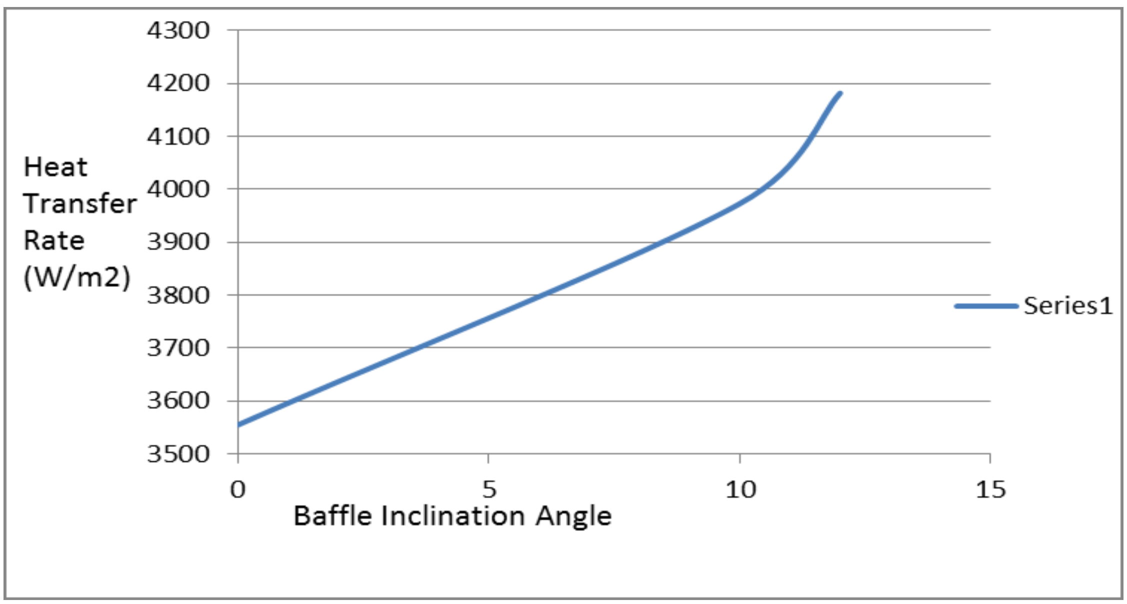

Fig: 5.5 Heat Transfer Rate along Tube side

The heat transfer rate is calculated from above formulae from which heat transfer rate is calculated across shell side. The Plot showing the with increasing baffle inclination heat transfer rate increase. For better heat transfer rate helical baffle is used and the resulting is shown in figure 20.

VI. CONCLUSION

The heat transfers and flow distribution is discussed in detail and proposed model is compared with increasing baffle inclination angle. The model predicts the heat transfer and pressure drop with an average error of 20%. Thus the model can be improved. The assumption worked well in this geometry and meshing expect the outlet and inlet region where rapid mixing and change in flow direction takes place. Thus improvement is expected if the helical baffle used in the model should have complete contact with the surface of the shell, it will help in more turbulence across shell side and the heat transfer rate will increase. If different flow rate is taken, it might be help to get better heat transfer and to get better temperature difference between inlet and outlet. The heat transfer rate is poor because most of the fluid passes without the interaction with baffles. Thus the design can be modified for better heat transfer in two ways either the decreasing the shell diameter, so that it will be a proper contact with the helical baffle or by increasing the baffle so that baffles will be proper contact with the shell. It is because the heat transfer area is not utilized efficiently. Thus the design can further be improved by creating cross-flow regions in such a way that flow doesn't remain parallel to the tubes. It will allow the outer shell fluid to have contact with the inner shell fluid, thus heat transfer rate will increase.

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