Performance Analysis of Triple Concentric Tube Heat Exchanger with Ribs

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***Abstract*— Present study includes the performance analysis of triple concentric tube heat exchanger with ribs using ANSYS Fluent 15. Water is used as working fluid. The inner most tube provides passage for the flow of water at room temperature. The intermediate tube encloses the innermost tube and also provides passage for hot water. The outermost tube encloses both the tubes and also provides passage for cold water. This arrangement is called N-H-C arrangement and the flow of all fluid is co-current. The intermediate tube consists of ribs having length of 4 mm and 8 mm and a width of 1 mm. The results are presented in the form of temperature at the inlet and outlet of tube and also the effectiveness of heat exchanger with and without ribs are shown. The result obtained is better with 8 mm rib.**

***Keywords*— Triple concentric tube heat exchanger, Rib, C-H-N, co-current flow, ANSYS Fluent**

I. INTRODUCTION

Heat exchanger is a device which is used to transfer heat between a solid object and a fluid, or between two or more fluids separated by a wall to prevent mixing of the fluid. The performance of the heat exchanger generally depends on the various physical characteristics of the fluid and the material. There are several kinds of heat exchangers are used in industry such as plate type heat exchanger, shell and tube heat exchanger, double pipe heat exchanger, helical tube heat exchanger etc. The type of heat exchanger to be used is determined by the process and product specification. Nevertheless, concentric tube heat exchanger plays a major role in fulfilling the needs of heat exchanger in food industry. The most commonly used heat exchanger is double pipe heat exchanger which consists of one pipe inside another pipe placed concentrically. It is used in different products such as dairy, food, beverage and pharmaceutical industries. There are some disadvantages of this exchanger and to overcome this, there is need to enhance the performance of double pipe heat exchanger. Adding an intermediate tube to a double pipe heat exchanger converts it to a triple pipe heat exchanger (figure 1). Triple concentric tube heat exchanger has better heat transfer efficiencies and performs better as compared to double pipe heat exchanger. It has larger area per unit length for heat transfer and better overall heat transfer coefficient due to higher fluid velocities in the annular regions. To study the temperature distribution along the length of heat exchanger with ribs (N-H-C) arrangement of fluid is used which means that the normal water flows through the innermost pipe, hot water through the inner annulus and cold water flows through the outer annulus.

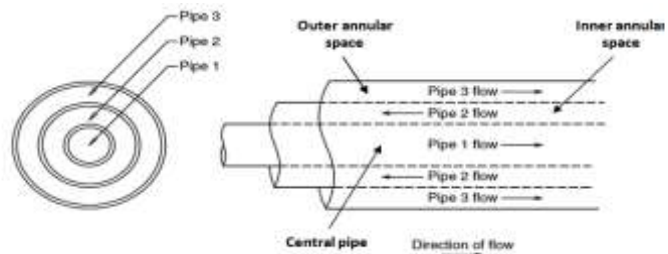

Figure 1: Triple concentric-tube heat exchanger [5]

II. LITERATURE REVIEW

Quadir et. al. [1] studied triple concentric tube heat exchanger experimentally under steady state conditions for two different flow arrangements, called N-H-C and C-H-N, and for insulated as well as non-insulated conditions of the heat exchanger. The results are presented in terms of temperature distribution of the three fluids along the length of the heat exchanger under co-current parallel flow, both insulated as well as non-insulated conditions, and for different fluid flow rates. It is observed that the heat transfer between the three fluids considered is more effective in N–H–C arrangement of the heat exchanger as compared to that in C–H–N arrangement.

Sahoo et. al. [2] carried out experiment for helical triple concentric tube heat exchanger with different flow arrangements i.e. N-H-C and C-H-N with parallel and counter flow types. The temperature distribution of fluids with respect to length of the heat exchanger was observed. Effectiveness calculated for parallel and counter flow in N-H-C and C-H-N arrangements. The triple concentric helical tube heat exchanger proved to be effective and of compact design for heat exchange between the fluids.

Dilpak et. al. [3] carried out CFD analysis of triple concentric tube heat exchanger by using previous research's mathematical model, experimental model and correlation .Here mainly focused on two conditions, $V_n = V_h = V_c = 35$ l/min and V_h=20 l/min; V_n=V_c=35 l/min. The flow analyzed was co current parallel flow with N-H-C arrangement. Neglecting small difference, CFD results are close to the experimental results.

Pravin et. al. [4] carried out experiment for the heat transfer performance and pressure drop of triple concentric pipe heat exchanger. The mass flow rate of hot water in the inner annulus and normal water in the inner pipe are varied during experiment. Effect of mass flow rate on heat transfer characteristics and pressure drop are considered. With increase in hot water Reynolds number, both normal and cold side overall heat transfer coefficient increases.

Ganesh et. al. [5] carried out experiment on performance analysis of triple tube heat exchanger with dimple tubing. It is observed that for the same Reynolds number effectiveness of triple tube heat exchanger is 60% more than double tube heat exchanger. Friction factor on hot fluid side is decreases as ‘Re’ increases and hence pumping power is reduced.

Tejas et. al. [6] studied sizing of triple concentric pipe heat exchanger. It involves the sizing of triple concentric pipes heat exchanger where in two cold water streams flow through the central tube and outer annular space at same mass flow rates and same inlet temperatures in co-current direction while hot water flows through inner annular space in counter-current direction. A basic procedure is used for calculating overall heat transfer coefficients and length of triple concentric pipes heat exchanger. Length of triple pipe heat exchanger is computed for a required temperature drop of hot water with available dimensions of three pipes by LMTD method. Overall heat transfer coefficient and length of the equivalent double pipe heat exchanger are compared with that of the triple pipe heat exchanger. The theoretical analysis shows that introducing an intermediate pipe to the double pipe heat exchanger reduces effective length of heat exchanger, which results in savings in material and space. **D. P. Sekulic et al. [7]** studied a detail review on thermal design theory of three fluid heat exchanger, where they have allowed for third fluid temperature to vary according to main thermal communication while neglecting interaction with ambient. He used effectiveness- NTU (number of heat transfer units) approach and corresponding rating and sizing problems for the determination of the effectiveness or NTU for a three-fluid heat exchanger.

Quadir et. al. [8] studied performance of a triple concentric pipe heat exchanger numerically using finite element method (FEM) under steady state conditions for different flow arrangements and for insulated as well as non-insulated conditions of the heat exchanger. The three fluids being considered are hot water, cold water and the normal tap water. The results are presented in the form of the dimensionless temperature variations of the three fluids along the length of the heat exchanger for their different flow rates. He found that the numerical predictions of the temperature variations of the three fluids by using FEM follow closely to those obtained from experiments both in magnitude and trend provided correct overall heat transfer coefficients are used. Parametric studies are also carried out to show the effect of the individual design parameter on the performance of the heat exchanger.

Ahmet Unal et. al. [9] developed a mathematical model, consisting of the derivation and possible solutions of the governing equations for both counter-flow and parallel-flow arrangements. The equations derived in this study can be used for both design calculations and performance calculations, besides they can be used for the determination of bulk temperature variation along the exchanger.

Ahmet Unal et. al. [10] conducted several case studies for counter-flow arrangement. It has been demonstrated that the relative sizes of the tubes (the tube radii) play a very important role on the exchanger performance and/or on the exchanger length and optimizing triple tube heat exchanger effectiveness provides a considerable amount of increase in the exchanger performance

M.Suresh et. al. [11] in his work, a standard concentric tube heat exchanger has been modified such that the flow area of inner tube is continuously increased and reduced alternately; along the flow axis i.e. inner tube is a convergent- divergent tube. The outer tube is a constant area tube with same diameter along flow axis. Inner tube carries cooling water and outer tube carries hot water, which transfers heat to the cooling water. A convergent-divergent tube-in- tube heat exchanger has been fabricated and an experimental setup has been built. He found that modified heat exchanger increases the heat transfer rate due to increase in surface area and it could give better heat transfer enhancement when gases are used as heat transfer fluids.

III. PROCEDURE

The analysis of triple concentric tube heat exchanger is done by using ANSYS FLUENT 15.Geometric modeling of triple concentric tube heat exchanger with and without ribs is done by using CATIA Version 5 software. Outside diameters of the three pipes are 0.0508 m, 0.0762 m and 0.1016 m respectively with thickness of each pipe as 1.5 mm only and length of heat exchanger is 4 m. The normal water flows through the inner most pipe, hot water flows though the inner annulus formed between 0.0508 m pipe and 0.0762 m pipe and the cold water flows though the outer annulus formed between 0.0762 m and 0.1016 m pipe. This arrangement of flow of different fluids is called N–H–C configuration of the heat exchanger as shown in Fig. 1.

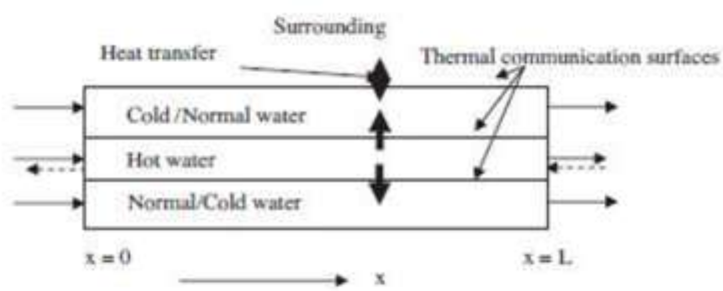

Figure 2: Flow directions of three fluids for N–H–C and C–H–N configurations of the triple concentric pipe heat exchanger [1]

The three pipes used for the heat exchanger are made of stainless steel and water is used as working fluid. The flow arrangement is co-current and the configuration is C-H-N.

Table1: Properties of material and fluid

Properties	Material (Steel)	Fluid (Water)
Density (kg/m^3)	8030	998.2
Specific heat (kJ/kg-k)	502.48	4.182
Thermal Conductivity (W/m-k)	16.27	0.6

Table 2: inlet parameters of Heat Exchanger

Condition	Inlet temperature (°C)	Inlet velocity (l/min)
Cold	10.23	35
Hot	52.11	35
Normal	28.23	35

IV. RESULTS AND DISCUSSION

CFD Analysis was done in ANSYS FLUENT SOLVER using k-Ɛ realizable model. After modeling, meshing and analysis using solver fluent we came up with the output readings. Some of the contours of temperature distribution in N-H-C arrangement for co-current flow with similar volume flow rate, i.e. 35 l/min is shown. The temperature of hot water drops to 33.696 °C from its inlet temperature of 52.11 °C; the cold water and the normal water temperature increases to 24.152 °C and 29.576 °C from its inlet temperature of 10.23 °C and 28.23 °C respectively for the heat exchanger without ribs. For the heat exchanger with 4 mm ribs the temperature of hot water drops to 32.597 °C from its inlet temperature of 52.11 °C; the cold water and the normal water temperature increases to 29.234 °C and 29.568 °C from its inlet temperature of 10.23 °C and 28.23 °C respectively. For the heat exchanger with 8 mm ribs the temperature of hot water drops to 31.107 °C from its inlet temperature of 52.11 °C; the cold water and the normal water temperature increases to 30.899 °C and 29.617 °C from its inlet temperature of 10.23 °C and 28.23 °C respectively. The effectiveness of heat exchanger without ribs, with 4 mm ribs and with 8 mm ribs are 0.43, 0.46 and 0.5 respectively. Temperature contour at the exit of pipe is shown in figure.

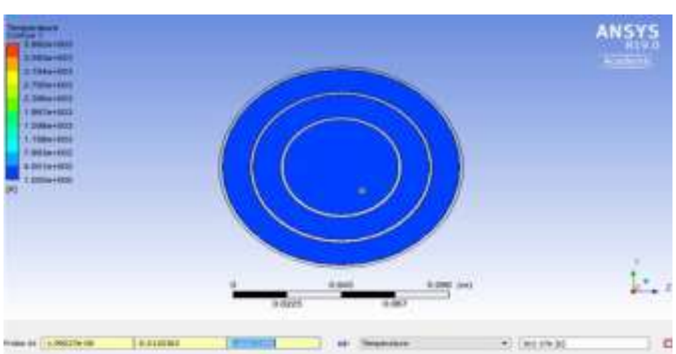

Figure 3: Temperature contour of Heat exchanger without Rib at outlet

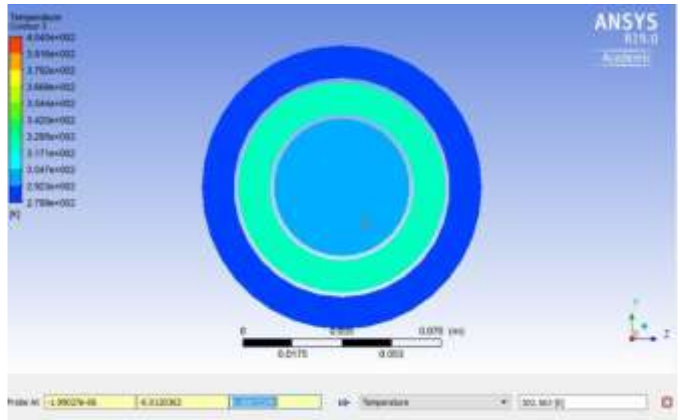

Figure 4: Temperature contour of Heat exchanger with 4mm Rib at outlet

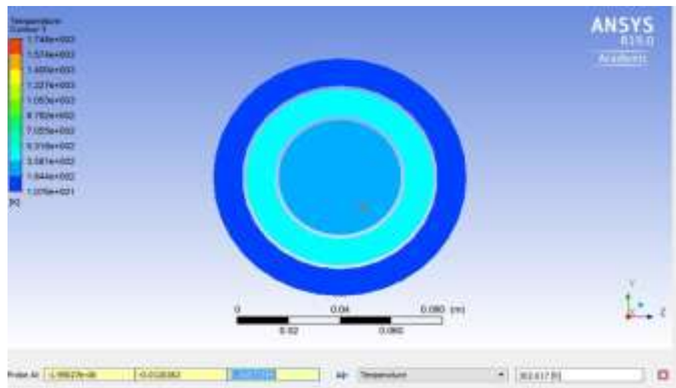

Figure 5: Temperature contour of Heat exchanger with 8mm Rib at outlet

Table 3: Comparison of temperature at outlet of Heat Exchanger

Condition	Without rib	With 4 mm rib	With 8 mm rib
Cold (°C)	24.152	29.234	30.899
Hot (°C)	33.696	32.597	31.107
Normal (°C)	29.576	29.568	29.617

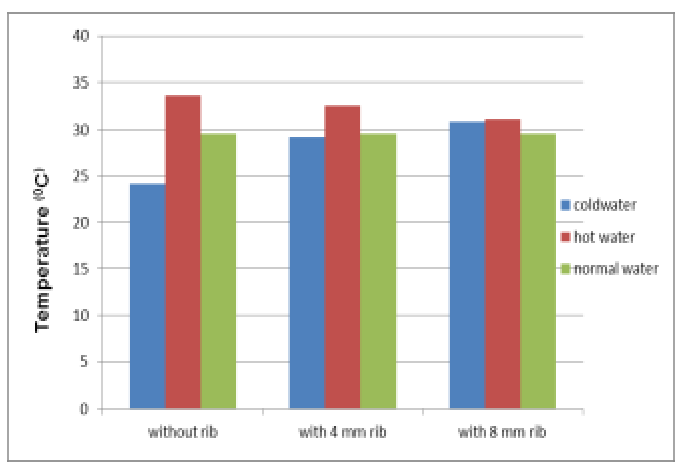

Figure 6: Temperature difference at outlet of pipe

. The effectiveness of the triple tube heat exchanger is calculated as:

$$\in = \frac{\dot{Q}}{Q_{max}} \qquad (1)$$

Is the actual heat transfer rate and Q_{max} is the maximum possible heat transfer rate of heat exchanger as per expression [10]

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$\dot{(Q)} = C_h (T_{hi} - T_{ho})$ (2)

$\dot{(Q)}_{max} = C_{min} (T_{hi} - T_{ci})$ (3)

$C_{min} = C_h$ if $C_h \le C_n + C_c$

$C_n + C_c$ if $C_n + C_c \le C_h$

Where Cc, C_h and Cn are the heat capacity rate of cold fluid side, hot fluid side and normal fluid side respectively and C_{min} is the minimum capacity rate. T_{hi} and T_{ho} are the temperatures of hot water inlet and hot water outlet respectively, T_{ci} is the temperature of cold water inlet where Cc, C_h and C_n are the heat capacity rate of cold fluid side, hot fluid side and normal fluid side respectively and C_{min} is the minimum capacity rate. T_{hi} and T_{ho} are the temperatures of hot water inlet and hot water outlet respectively, T_{ci} is the temperature of cold water inlet. Comparison of effectiveness of different heat exchanger is shown in figure.

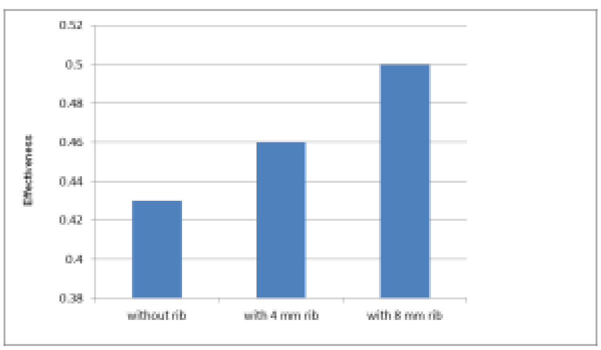

Figure 7: Comparison of effectiveness

V. CONCLUSION

- The flow analyzed was co-current flow with N-H-C arrangement (Cold water in the outermost tube, Hot in the intermediate and Normal in the inner most tube)
- For heat exchanger without rib the temperature at outlet of pipe for normal water, hot water temperature and cold water temperature is 29.576°C, 33.696 °C and 24.152 °C respectively.
- For heat exchanger with 4 mm rib the temperature at outlet of pipe for normal water, hot water and cold water is 29.568°C, 32.597 °C and 29.234 °C respectively.
- For heat exchanger with 8mm rib temperature at outlet of pipe for normal water, hot water and cold water is 29.617°C, 31.107 °C and 30.899 °C respectively.
- The maximum heat transfer rate and minimum temperature between hot and cold water at outlet of pipe is found in heat exchanger with 8 mm rib.
- The effectiveness of heat exchanger with 8 mm rib is more than that of with 4 mm and without rib.
- The best results are show in Heat Exchanger in 8mm Rib.

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