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Design and Simulation of Counter Flow Heat Exchanger with Fins and Internal Ribs

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Abstract: A Heat Exchanger is a device to transfer heat from fluid at higher temperature to fluid at lower temperature with highest efficiency. Designed for various applications such as preheating the water before sending it into boiler for generation of steam. This work is carried out with the primary objective of increasing the thermal efficiency of the procedure heat transfer process. There are different types of heat exchangers from which shell and tube heat exchanger is considered for this present work. High temperature water passes through the copper tubes and low temperature water flows outside the copper tubes. To enhance the rate of heat, transfer the modified design is implemented. The design consists of fins outside the copper tubes to increase the surface area in contact with outside fluid. Also, ribs are provided inside the copper tubes for increasing the turbulence along with more area of contact. This paper mainly deals with design, modelling and CFD analysis of the heat exchanger. Overall heat transfer coefficient of the fins and internal ribs of heat exchanger is based on the results of effectiveness-NTU approach and LMTD approach. Modelling of various components are presented with the help of standard modelling software, solid works. Simulation of the process is done using ANSYS. The simulated results obtained in the software are compared with the published experimental results which are very close to our modified design heat exchanger and it is found that the results are very close to experimental results.

Keywords: Heat Transfer, Surface Modification, Heat Exchanger, ANSYS, SolidWorks

I. INTRODUCTION

Heat exchanger, a device to exchange of heat between two fluids at different temperatures. Heat exchangers can be divided into types depending on both, their construction and type of fluid flow. In this work analysis is on counter flow heat exchanger with fins and internal ribs. It consists of two pipes of different diameters. Water is used as a fluid between pipes having different hot and cold temperatures at inlet. The heat is exchanged as the fluids flow across the pipes. For the present work counter flow heat exchanger is considered, so flow direction is counter in nature which means hot and cold water will enter from opposite directions. Inner pipe carries hot water while outer pipe carries cold water. The outer layer of outer pipe acts as an adiabatic wall.

Heat exchanger is an important and expensive item of equipment that is used almost in every industry (oil and petrochemical, food, sugar, pharmaceutical and power industry). A better understanding of the basic principles of heat transfer and fluid flow and their application to the design and operation of heat exchangers will enable us to improve their efficiency and extend their life.

II. WORKING PRINCIPLE

Heat exchanger facilitates heat transfer from one medium to another as shown in Figure 1. Often these media are two process fluid streams such as - oil, water, steam, gas, air etc. In general, one fluid has to be significantly hotter than the other. So, we have a hot and a cold fluid. And a heat exchanger enables the heat to flow from hot fluid to cold through a metallic wall.

Heat exchanger channels the flow of hot and cold streams through passages separated from each other by metal surface. Thanks to the high heat conductivity of the metal, heat flows from hot stream to the cold one. So, the hot fluid exits the heat exchanger, a little colder. And cold stream goes out a little hotter [1].

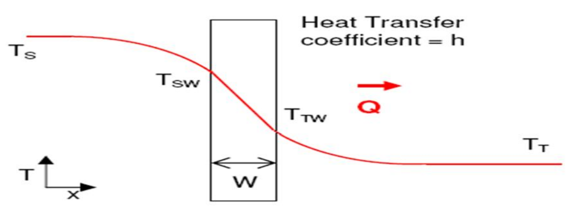

Fig. 1 Basic representation of heat transfer through a medium

The overall heat transfer rate required in a heat transfer operation is calculated using the following equation -

$$Q = W_{Tube} \times C_{pT} \times \Delta T_{Tube} = W_{Shell} \times C_{pS} \times \Delta T_{Shell}$$

where, Q = overall heat transfer rate
W_{Tube} and W_{Shell} are mass flow rates for tube side and shell side respectively
C_{pT} and C_{pS} are specific heat capacities for tube side and shell side respectively
ΔT_{Tube} is the temperature difference in tube side (between tube side inlet/outlet)
ΔT_{Shell} is the temperature difference in shell side (between shell side inlet/outlet)

III. DESIGN OF HEAT EXCHANGER

A. Dimension Description

As there are two pipes in the heat exchanger, so there are two different diameters and two different inlets and outlets.

Outer diameter of outer pipe	=	70mm
Outer diameter of inner pipe	=	42mm
Inner diameter of outer pipe	=	66mm
Inner diameter of inner pipe	=	34mm
Length of outer pipe	=	1250mm
Length of inner pipe	=	1500mm
Length of fin on the pipe wall	=	2mm
Height of fin on the tube wall	=	0.25mm
Length of rib in the inner wall	=	2mm
Depth of rib on the inner wall	=	0.25mm

Cross-sectional view is shown in Figure 2.

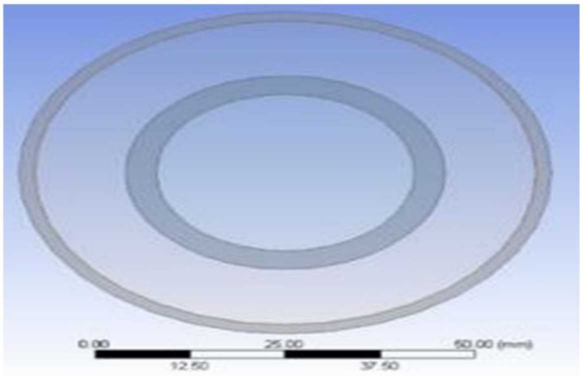

Fig. 2 Cross-sectional view heat exchanger arrangement

B. Material selection

Heat exchangers are used to achieve desired heating or cooling. Selection of appropriate materials to conduct and transfer heat efficiently and fast is a most important aspect in designing heat exchanger[2], [3].

In this work Copper has been considered as it has many desirable properties such as high thermal conductivity, corrosion resistance, maximum allowable stress and internal pressure, biofouling resistance, creep rupture strength, tensile strength, fatigue strength, hardness, thermal expansion, specific heat, antimicrobial properties, yield strength, high melting point, alloy ability, ease of joining and fabrication.

IV. MODELLING

A. Plane Copper Tubes

In the first case, use of copper pipes as they have significant adiabatic flow properties and also hold great weightage in the heat transfer process. We have used the Solidworks software in order to stimulate the geometric modelling of the copper pipe as shown in the Figure 3.

Case 1 consists of plain copper tubes as shown in Figure 3 and 4 which are used as a principle for comparison for the other two cases.

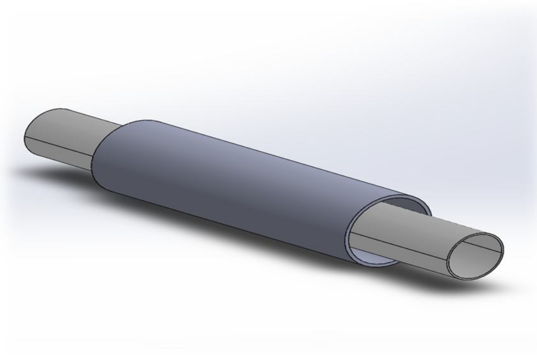

Fig. 3 Isometric view of plane copper tubes

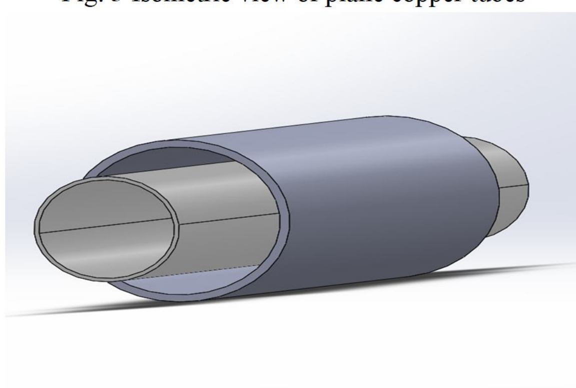

Fig. 4 Elaborated view of plane copper tubes

B. Copper Pipes with Fins over the Internal Tube

The second case consists of employing fins onto the copper pipe, which basically acts as an extended surface and therefore aids in the heat transfer process. Our geometric model, as shown in the Figure 5, consists of copper pipes with fins over the internal tube. As the surface area is extended, it assists the overall heat transfer coefficient to increase and eventually increases the efficiency of the heat exchanger by increasing the heat transfer significantly.

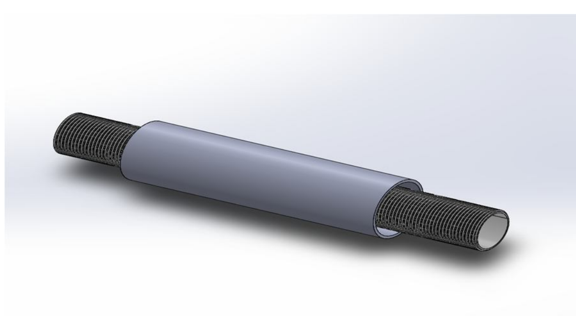

Fig. 5 Isometric view of copper tube with fins

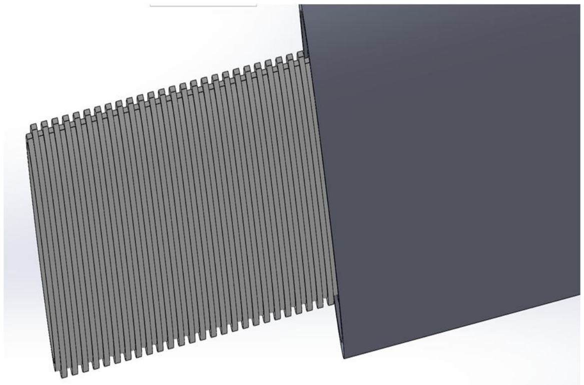

Fig. 6 Elaborated view of copper tube with fins

C. Copper Tubes with Fins and Internal Ribs

The third case, as shown in the figure, the copper pipes are incorporated with fins and also, internal ribs. As we know that, because of the employment of fins, we have increased the surface area which in turn helps in increasing the heat transfer rate due to surface extension. The installation of ribs consists of formation of internal groves in the pipe which also altogether increase the surface area. Therefore, adds an advantage to the overall heat transfer rate.

As shown in the Figure 6, 7 and 8 the geometric model represents the copper pipes with fins and internal ribs. Various Solid works commands such as Sketch, line, circle, smart dimensions, add relation, extrude, boss extrude, extruded cut, mirror etc. are used in order to achieve the geometric model.

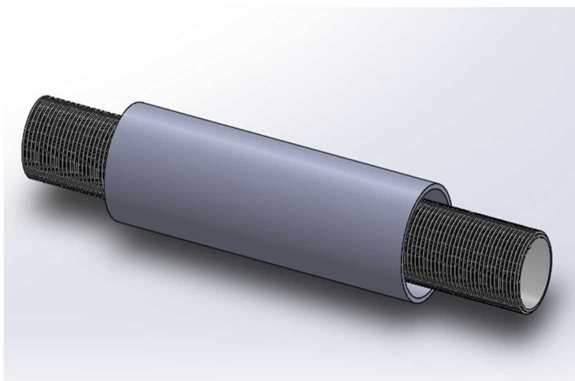

Fig. 7 Isometric view of copper tube with fins and internal ribs

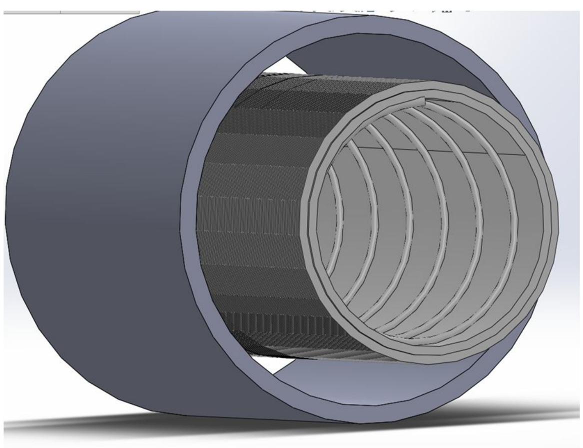

Fig. 8 Elaborated view of copper tube with fins and internal ribs

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V. RESULTS AND DISCUSSIOS

A. Meshing

Ansys Mechanical finite element analysis software is used to simulate computer models of structures, electronics, or machine components for analyzing strength, toughness, elasticity, temperature distribution, electromagnetism, fluid flow, and other attributes. Figure 9 shows the Isometric view of edge sizing Mesh, Figure 10 Isometric view of Face Mesh, Figure 11 shows Front view of Mesh, and Figure 12 shows the Isometric view of complete Mesh.

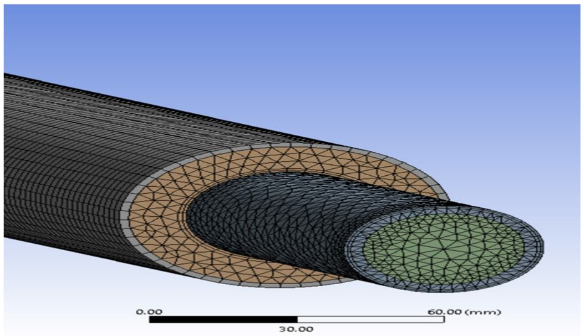

Fig. 9 Isometric view of edge sizing Mesh

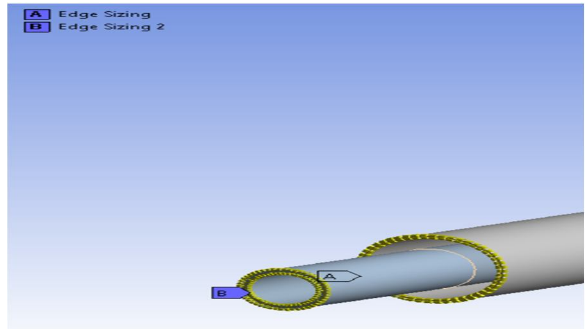

Fig. 10 Isometric view of Face Mesh

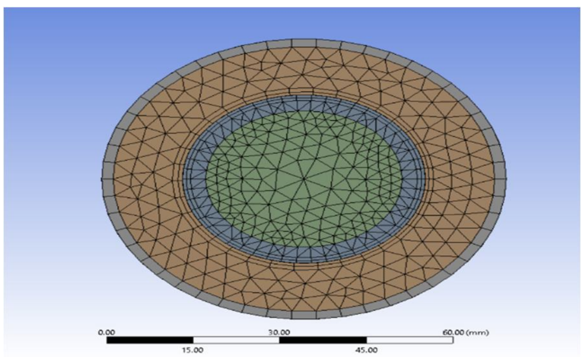

Fig. 11 Front view of Mesh

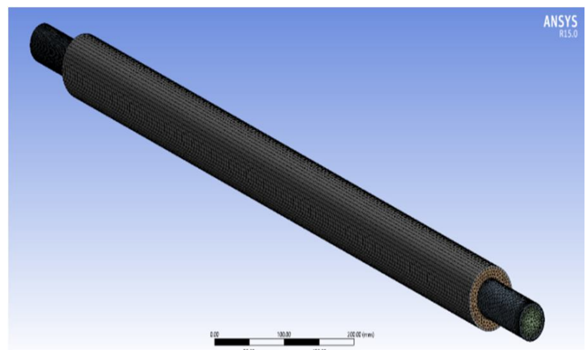

Fig. 12 Isometric view of complete Mesh

B. Boundary Conditions

Following boundary conditions have been used [4]-[6]. Boundary conditions specify the value of one variable and other unknowns are calculated depending on these values. These can be applied to any of the zones of the geometry.

Temperature at the inlet of cold pipe = 303 k
Temperature at the inlet of hot pipe = 333 k
Mass flow rate in hot pipe = 0.048Kg/s
Mass flow rate in cold pipe = 0.10Kg/s
Pressure is kept constant throughout the analysis

In this analysis 1000 iterations are performed keeping the flow of the fluids in laminar flow as shown in figure 13. Wall heat flux is shown in Figure 14. Temperature gradient and temperature volume rendering is shown in Figure 15 and 16 respectively.

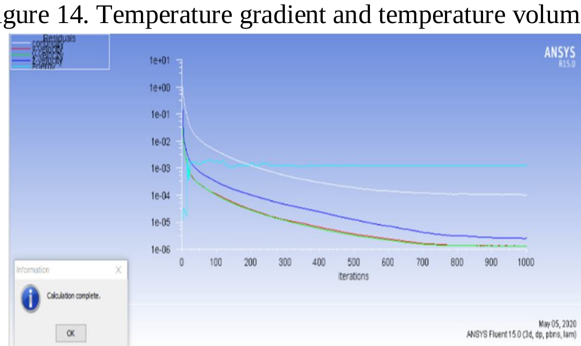

Fig. 13 Iterations graph laminar conditions

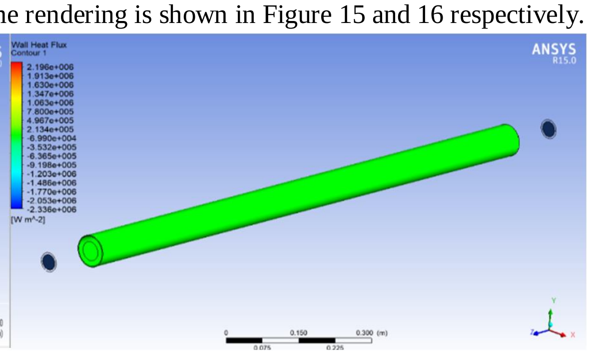

Fig. 14 Wall heat flux

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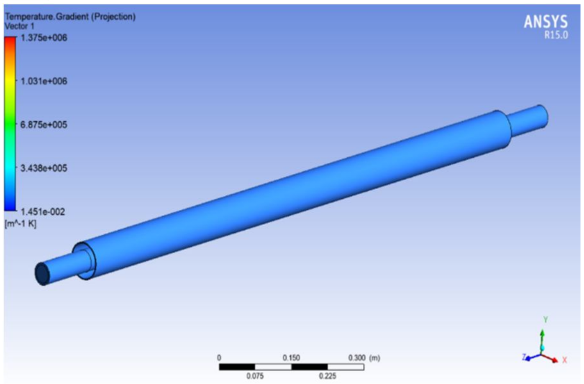

Fig. 15 Temperature gradient

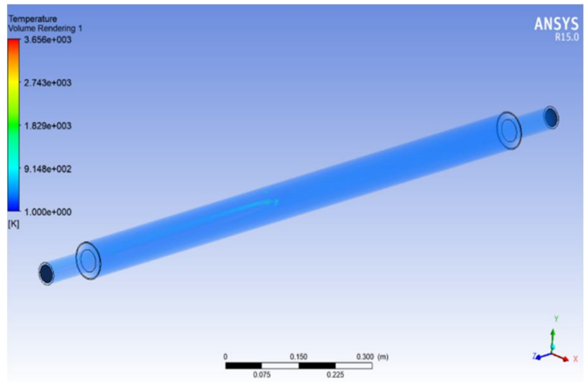

Fig. 16 Temperature Volume rendering

C. Heat Flux Contour

Heat (Thermal) flux is a flow of energy per unit of area per unit of time, also known as heat flux density, heat-flow density or heat flow rate intensity.

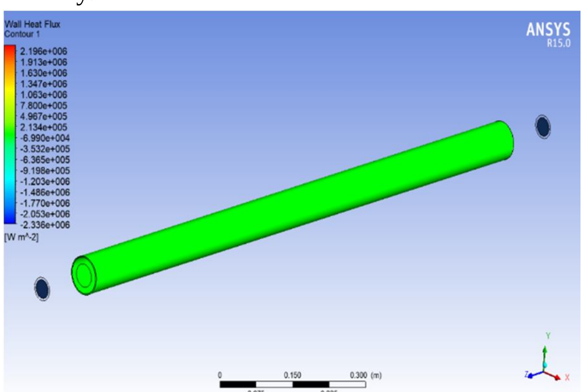

Fig. 17 Heat flux for plane wall copper tubes

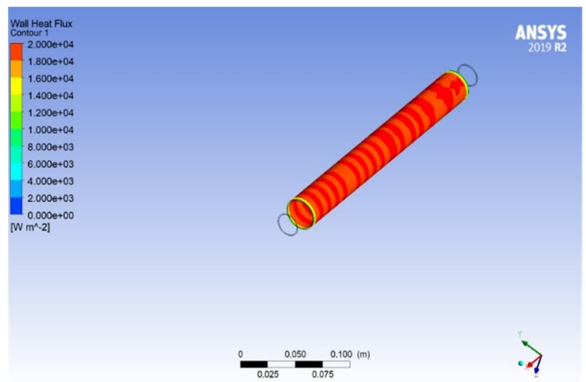

Fig. 18 Heat Flux for the finned wall copper tube

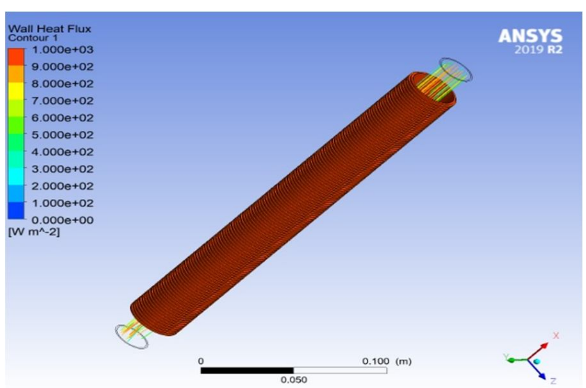

Fig. 19 Heat Flux for the finned + ribbed wall copper pipes

Figure 17 shows the heat flux through plane copper tube which is less, when finned copper tube wall is taken heat flux has increased substantially as shown in Figure 18, further on using ribbed and finned copper tube the heat transfer has further increased due to turbulence due to ribs and large surface area due to fins as shown in Figure 19.

Table 1 shows the in all the three cases as stated above and Table 2 shows the percentage of temperature increase in cold water and Percentage temperature decrease in hot water which is highest in finned + ribbed case showing high rate of heat transfer.

Table 1 Inlet and outlet temperatures of all the three systems

Type of tube	Inlet temp of cold water	Inlet temp of hot water	Outlet temp of cold water	Outlet temp of hot water
Plane copper tube	30°C	60 °C	46.7°C	41.44°C
Copper tube with fins	30 °C	60 °C	48.3°C	38.5°C
Copper tube with fins and internal ribs	30 °C	60 °C	50.1°C	37.53°C

Table 2 Change in percentages across all the three cases

Type of tube	Percentage of temperature increase in cold water	Percentage temperature decrease in hot water
Plane copper tube	55%	30.9%
Copper tube with fins	61%	35.8%
Copper tube with fins and internal ribs	67%	37.45%

VI. CONCLUSIONS

From the values of the maximum and minimum heat fluxes we conclude that the heat transfer is minimum when we used the plain pipes for the double pipe counter flow Heat Exchanger. While, outer surface with fins increased heat transfer rate due to the increased surface area. Moreover, when the ribs were introduced inside pipe surface, it increased the heat transfer rate further as the presence of ribs caused turbulence and hence the heat transfer rate increased in double pipe counter flow. So ribs increased turbulence which increased the heat transfer rate and fins increased surface area due to which rate of heat transfer increased.

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