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A COMPARATIVE STUDY OF HEAT EXCHANGER EFFECTIVENESS FOR DOUBLE HELICAL AND STRAIGHT CIRCULAR GEOMETRY

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Abstract-Heat exchanger is very important part of any heat processing equipment as it is used to transfer the heat from one media to another media. The performance of the heating equipment depends upon the effectiveness of the heat exchanger. The effectiveness of any heat exchanger depends upon several conditions or factors. In the present paper, the effectiveness of heat exchanger has been studied for the helical cross sectional and straight cross sectional geometry. Further, three different materials have also been included for the research. The results obtained shows that helical circular geometry has higher effectiveness than that of straight circular geometry.

Keywords—Heat exchanger, helical, circular, effectiveness.

I. Introduction

Heat exchanger is an important engineering device of any heat generation or power generation process. These are mostly used in real practice for the wide range of applications such as heating, refrigeration, air conditioning systems, chemical processing plant, electrical and power electronic sectors and power generation in large thermal plants [1]. Heat exchangers are mainly used for the heat transfer from hot fluid to cold fluid. According to the flow arrangement, heat exchanger can be categorized as parallel flow and counter flow heat exchanger [2]. Higher efficiency of heat exchanger is desirable and it depends upon the surface area available to exchange the heat transfer. The design of heat exchanger should be such that it should offer minimum resistance to the flow of fluid. In order to get better heat exchanging capacity, heat exchangers are constructed with shell and tube, plates, plates and shell, plate and fins etc. Among the different types of heat exchangers, shell and tube heat exchangers are preferred for space heating, power production, and chemical processing applications. The main advantage of shell and tube type of heat exchanger is the flexibility regarding their material. However, this heat exchanger requires more space. In case of helical tube heat exchanger, helical tube in the form of coil is rounded over the shell, as shown in Fig. 1. The main advantage of helical tube heat exchanger is that it is space efficient, espically when not enough space is available.

Several research works have been reported on different design of heat exchanger to increase the efficiency of heat transfer. Verma et al. [3] studied the heat transfer of concentric tube with corrugated inner tube. Authors have achieved maximum heat transfer coefficient and Nusselt number with helical shaped ribs. Mimura et al. [4] investigated the effect of the shape of corrugated tubes with different relative depths and pitches on heat transfer and pressure drop characteristics. The tube side heat transfer co-efficient obtained from the two start corrugated tubes were slightly smaller than those from single start tube. Ganeshan et al. [5] studies the effect of single and multi-start corrugates tubes in heat transfer and friction factor characteristics. Srinivasan et al. [6] have conducted an experiment for designing tubular heat exchangers using spirally fluted tubes for studying the heat transfer and pressure drop characteristics. Based on the measured data, the correlation of heat transfer coefficient and friction factor were proposed. Kara et al. [7] created 240 alternative exchanger configurations and the computer program that they developed selects the optimum configuration among the all possible exchanger configurations. The shell diameter, baffle spacing, number of pass are the parameters that can be changed in this program. The results of their study showed that triangular tube pitch layout with one or two tube pass yields the best performance. Walraven et al. [8] investigated the different tube configurations. Their study concluded that the 30° and 60° tube configurations should be used for the single phase and two phase heat exchangers, respectively. Kurnia et al. [9] numerically investigated the effect of various cross sections geometries (i.e. circular, ellipse and square) on the heat transfer rate and entropy generation in a shell and helically coiled tube heat exchange. Authors found that coiled tube heat exchanger provides higher heat transfer rate. Jamshidi et al [10] experimentally investigated heat transfer performance of shell and helical tube heat exchanger. They reported that the higher coil diameter, coil pitch and mass

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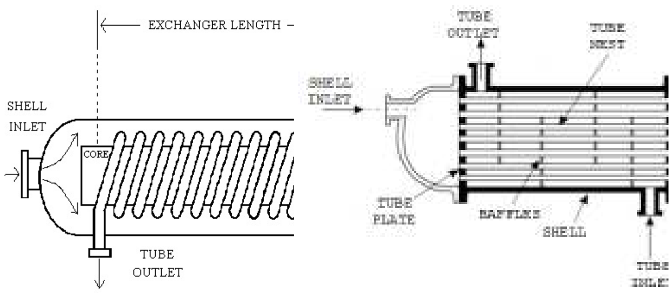


(a) (b)

Fig. 1 Heat exchanger (a) Helical tube heat exchanger (b) Straight tube heat exchanger

flow rate in shell and helical tube can enhance the heat transfer rate. By using Taguchi analysis, they found that coil diameter, tube side flow rate and coil pitch are the most important design parameters in coiled heat exchangers.

The present study investigates the effect of geometry of tube on effectiveness of the heat exchanger. The performance of heat exchangers in terms of effectiveness has been evaluated and compared. The effectiveness of double helical circular tube and double straight circular tube has been calculated for both types of fluid flow i.e. parallel and counter flow. The effectiveness study has been carried out for three different materials namely, Copper, Aluminium and Steel.

II.Modeling of Heat Exchanger

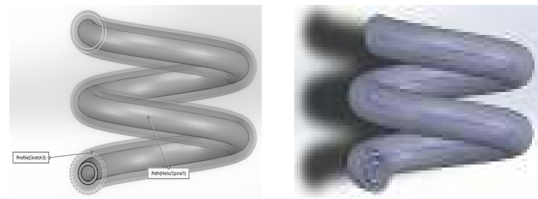
Double Helical Circular and double straight circular tubes are designed using trial version of Solidworks software and 3D model is saved in IGES format. Ansys fluid flow (FLUENT) module is used to simulate the boundary conditions.

A. Modeling of Double Helical Circular Tube

Double helical circular tube consists of two concentric tubes. The dimensions of the double helical tube are shown in table 1.

TABLE I. Geometrical parameters for double helical circular tube

S.N.	Items	Dimension
1	Inner Tube Diameter	20 mm
2	Outer Tube Diameter	24 mm
3	Pitch	40 mm
4	No. of Revolutions	2
5	Thickness of Tubes	2 mm



(a) (b)

Fig. 2 Double Helical Circular Tube

Figure 2 shows the model of double helical circular tube.

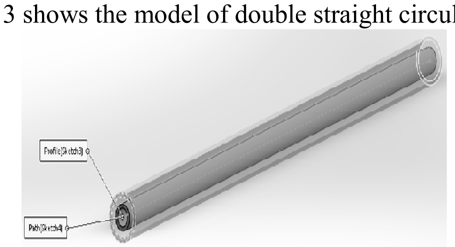
B. Modeling of Double Straight Circular Tube

Double straight circular tube is two concentric circular tubes. The dimensions of the double straight tube are shown in table 2.

TABLE II. Geometrical parameters for double straight circular tube

S.N.	Items	Dimension
1	Inner Tube Diameter	20 mm
2	Outer Tube Diameter	24 mm
3	Length	633 mm
4	Thickness of Tubes	2 mm

Figure 3 shows the model of double straight circular tube.



(a)

(b)

Fig. 3 Double Straight Circular Tube

The boundary conditions for the analysis have been shown in table 3.

TABLE III. Boundary conditions for analysis

S.N.	Items	Value
1	Cold Inlet velocity	0.1 m/s
2	Hot Inlet velocity	0.1 m/s

S.N.	Items	Value
3	Cold inlet Temperature	303 k
4	Hot inlet Temperature	353 k
5	Cold outlet	Pressure-outlet
6	Hot outlet	Pressure-outlet
7	Hot and Cold fluid	Water
8	Tube material	Steel, Aluminium, Copper

III. Heat Transfer Analysis

Logarithmic mean temperature difference (LMTD) is a function of the temperature difference of the hot and cold fluid. It indicates the rate of heat transfer of the heat exchanger. The mathematical expression of LMTD is given in equation 1.

$$LMTD(\theta_m) = \frac{\theta_1 - \theta_2}{\ln\left(\frac{\theta_1}{\theta_2}\right)} \tag{1}$$

where, θ_1 is temperature difference between hot water inlet temperature and cold water inlet temperature; θ_2 is hot water outlet temperature and cold water outlet temperature.

The rates of heat transfer to the cold fluid and from hot fluid are shown in equations 2 and 3 respectively.

$$Q_{cf} = m_{cf} C_p \left(T_{c1} - T_{c2}\right) \tag{2}$$

$$Q_{hf} = m_{hf} C_p \left(T_{h1} - T_{h2}\right) \tag{3}$$

where, Qcf and Qhf are the heat transfer rate (kW) to cold and hot fluid respectively, mcf and mhf are mass flow rate of cold and hot fluid (kg/s), Cp is specific heat (kJ/kgºC), T is temperature (K).

$$\varepsilon = \frac{1 - e^{\{-NTU(1+R)\}}}{1 + R} \tag{4}$$

where, ε is the effectiveness,

$$NTU = \frac{UA}{C_{\min}} \text{ and } R = \frac{C_{\min}}{C_{\max}}$$

IV.Results and Discussions

Heat transfer from the hot fluid flowing inside the helical tube to the cold fluid flowing through the tank is modelelled using FLUENT. In order to study the effect of fluid properties on the modelling of heat transfer, the boundary conditions have been selected as inlet velocity 0.1 m/s and inlet temperature 353 K and outlet velocity has been selected as 0.1 m/s and outlet temperature as 303 K. The geometry has been created using Solidworks and mesh has been created using FLUENT. Initially a relatively coarse mesh is generated. This mesh contains mixed cells (Tetra and Hexahedral cells) having both triangular and quadrilateral faces at the boundaries. Care has been taken to use structured hexahedral cells as much as possible. This has been done to reduce the numerical diffusion as much as possible by structuring the mesh in a good manner, particularly near the wall region. After this, a fine mesh has been generated. For this fine mesh, the edges and regions of high temperature and pressure gradients are finely meshed as shown in fig 4 and 5.

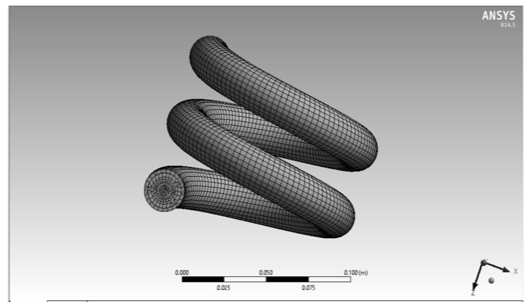


Fig. 4 Meshing of double helical tube

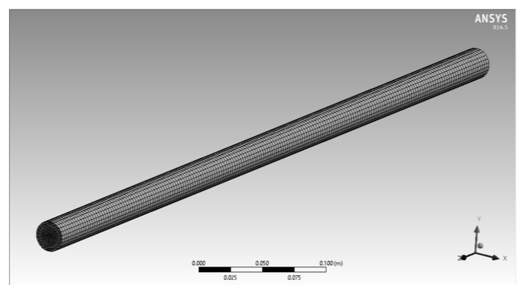
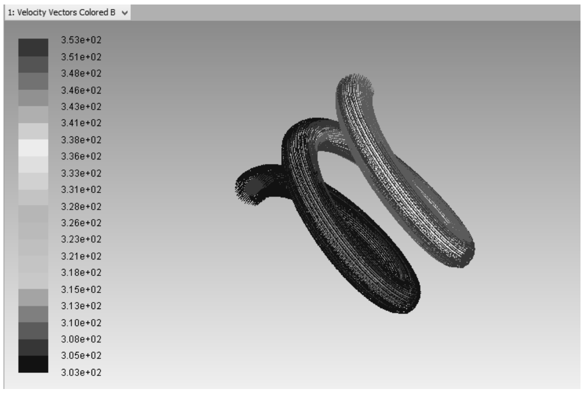
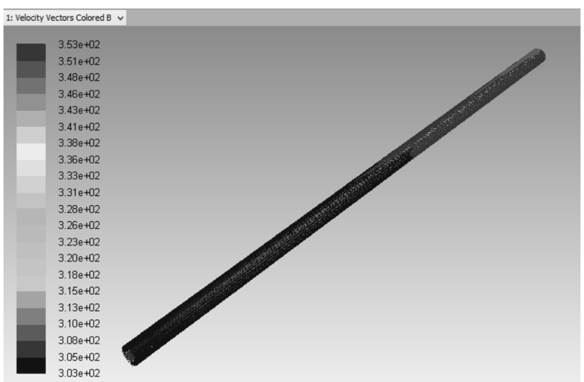


Fig. 4 Meshing of straight tube

The Realisable k–ε turbulence with standard wall functions was used in this analysis. It is the most common model used in Computational Fluid Dynamics (CFD) to simulate mean flow characteristics for turbulent flow conditions. It is a two equation model which gives a general description of turbulence by means of two transport equations (PDEs). That means, it includes two extra transport equations to represent the turbulent properties of the flow. The first transported variable is turbulent kinetic energy, k. The second transported variable in this case is the turbulent dissipation, ε. It is the variable that determines the scale of the turbulence, whereas the first variable k, determines the energy in the turbulence.) The boundary conditions have been applied on each part. The inlet and outlet conditions have been defined as velocity inlet and pressure outlet. The walls have been separately specified by respective boundary conditions. No slip condition was considered for each wall. Except for tube walls, each wall was set to zero heat flux condition. The solution has been computed by fixing the number of iterations to 500. Various contours, vectors, and plots have been obtained from the results under both types of flows i.e. parallel and counter flow for three materials namely steel, aluminium and copper. Figures 6 to 9 show the simulated results under different conditions.



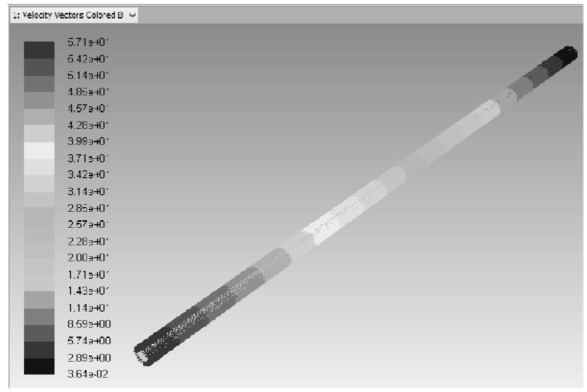
(a)



(b)

Fig. 6 Contours of temperature (a) Helical (b) Straight tube for parallel flow

(a)



(b)

Fig. 6 Contours of pressure (a) Helical (b) Straight tube for parallel flow

From the simulated results as shown in the Fig. 6, it can be observed that the temperature of the inside fluid is more at the the begning of the tube, indicated using red color, and is decreasing with the length of tube. At the end of the tube, temperature of the hot fluid is received by the cold fluid and is indicated using blue color.

Pressure variation inside the tubes has been shown in Fig. 7. Pressure at the begning of the tube is higher and is decreasing with increase in length of the heat exchanger. The results of the analysis of the CFD simulation are used to estimate the effectiveness of heat exchangers. Table 4 shows the effectiveness of heat exchangers under different flow and materials.

TABLE IV. Effectiveness of heat exchangers

S.N.	Geometry	Material	Effectiveness	
			Parallel Flow	Counter Flow
1	Helical Circular Tube	Steel	0.3681	0.6650
		Aluminium	0.3870	0.6650
		Copper	0.3879	0.6677
2	Straight Circular Tube	Steel	0.3259	0.5051
		Aluminium	0.3406	0.5440
		Copper	0.3411	0.5453

Based on the table 4, the various plots have been plotted and shown in Fig. 8 to 13.

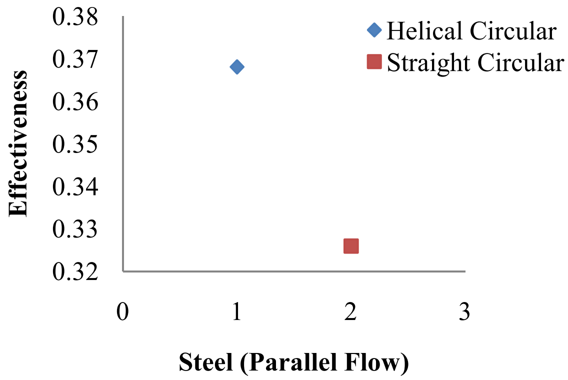


Fig. 8 Effectiveness in parallel flow for steel material

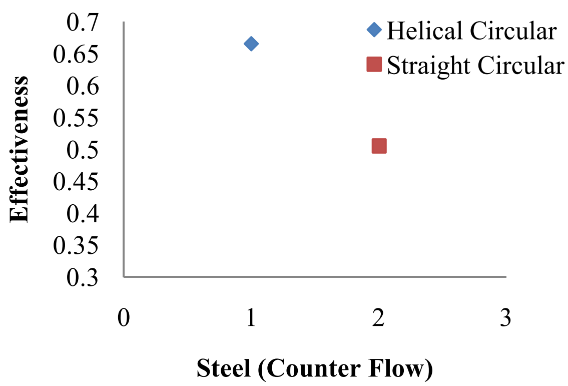


Fig. 9 Effectiveness in counter flow for steel material

The effectiveness of heat exchangers has been calculated using equation 4 and shown in Fig. 8 in parallel flow for steel material. It can be observed that effectiveness in case of helical circular geometry is 11.46 % more than that of straight circular geometry. However, in counter flow, the effectiveness of helical circular is 24 % higher than that of straight circular geometry. This can be observed from the Fig. 9. Further, it can be observed that effectiveness of helical circular cross sectional tube is higher irrespective of flow type for steel material.

Heat exchanger effectiveness of helical circular and straight circular tube using aluminium material is shown in Fig. 10 and 11. Effectiveness is observed higher in case of helical circular cross sectional geometry for both types of flow. As indicated in Fig. 10, effectiveness is 12 % higher than straight circular heat exchanger for parallel flow. Whereas, Effectiveness of helical circular tube is 18 % more than that of straight circular tube under counter flow, as shown in Fig. 11. In case of aluminium also, effectiveness is observed higher than that of straight circular type.

The effectiveness of heat exchanger for aluminium material is higher than steel material. This may be due to the fact that the thermal conductivity of aluminium is higher than steel material. Therefore, heat transfer rate in aluminium material has been observed more and hence effectiveness is observed more.

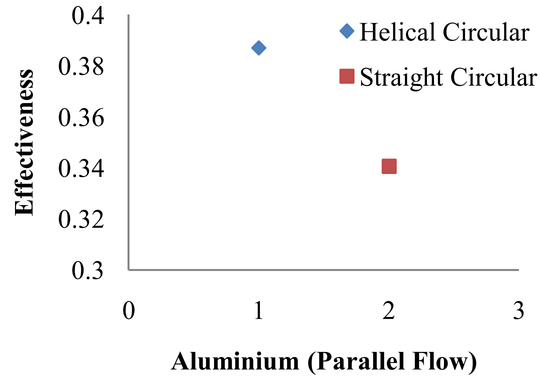


Fig. 10 Effectiveness in counter flow for aluminium material

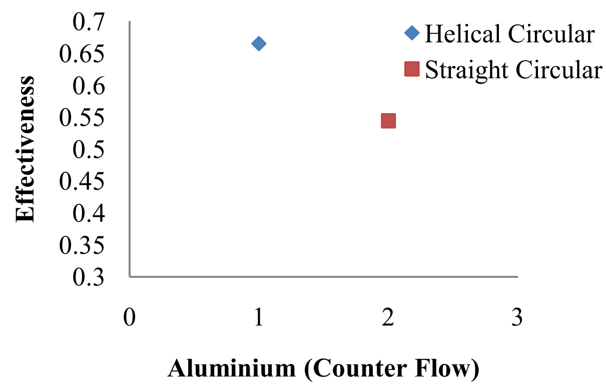


Fig. 11 Effectiveness in counter flow for aluminium material

The effect of heat exchanger geometry using copper material has been observed on effectiveness. Fig. 12 shows the variation in effectiveness in parallel flow. It can be observed that helical circular has 12 % more than that of straight circular pipe.

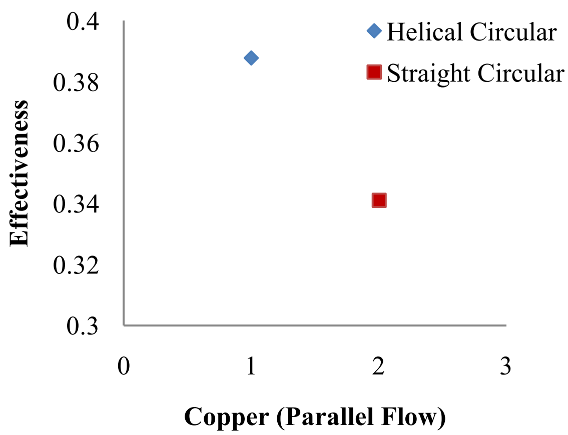


Fig. 12 Effectiveness in parallel flow for copper material

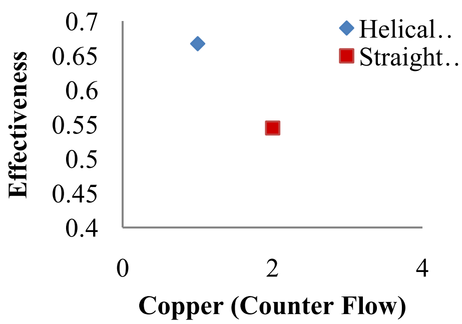


Fig. 13 Effectiveness in counter flow for copper material

Effectiveness for counter flow using copper material has been shown in Fig. 13. The effectiveness for helical circular tube is 18.3 % more than straight circular tube. Further, it can be observed that effectiveness in case of counter flow using helical circular tube is 42 % more than that of parallel flow for copper material. Whereas, the effectiveness using straight circular tube has yielded 37 % more for counter flow than parallel flow.

V.Conclusion

In the present research work, an attempt has been made to understand the effect of heat exchanger geometry, fluid flow types and materials on heat exchanger effectiveness. Helical circular and straight circular geometry with both types of flow i.e. parallel and counter has been considered for the study. The heat exchanger materials have been selected as steel, aluminium and copper. Simulation has been done using ANSYS software and following important conclusions have been drawn:

i. Helical circular cross sectional heat exchanger has yielded higher effectiveness than straight circular irrespective to materials and fluid flow.

ii. Counter flow is more effective than parallel flow.

iii. It has been observed that heat exchanger has higher effectiveness with copper material.

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