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Performance Analysis of Double Pipe Helical Shaped Heat Exchanger for Different Elliptical Cross Section

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***Abstract* - The mechanism for improvement of the heat transfer performance in the passive method is by promoting turbulence near the tube wall surface to reduce the thermal boundary layer thickness. Another mechanism is based on intense fluid mixing by modified tubes such as finned tube, tube with rib, tube with spirally roughened wall, corrugated tube, fluted tube, helical tube, elliptical axis tube and micro-fin tube. Among the modified tubes, the different cross section tube has become important for heat transfer enhancement in turbulent single-phase flow as the pressure drop increment is reasonable. The water cooling/heating coil, commonly used as condenser or evaporator in water source heat pumps, is a double tube heat exchanger that employs a refrigerant on the annulus side and water on the tube side. The heat transfer enhancement on either side of the inner tube is the subject of the present study.**

For the present analysis the cross section of inner tube of a double tube heat exchanger has been changed considering the reduction of y axis and increment of x axis dimension of circular cross section.

The aim of this study is "To access the effect of reduction of one axis and increment of other axis (changed from circular to elliptical shape) on the heat transfer performance of double pipe helical shaped heat exchanger with the help of finite element analysis."

***Index Terms* - Double pipe heat exchanger, LMTD, NTU, CFD analysis, etc.**

INTRODUCTION

Several passive enhancement techniques have been introduced to improve the overall thermal performance of heat exchangers, resulting in the reduction of the heat exchanger size and the cost of operation. The mechanism for improvement of the heat transfer performance in the passive method is by promoting turbulence near the tube wall surface to reduce the thermal boundary layer thickness. Another mechanism is based on intense fluid mixing by modified tubes such as finned tube, tube with rib, tube with spirally roughened wall, corrugated tube, fluted tube, helical tube, elliptical axis tube and micro-fin tube. Among the modified tubes, the different cross section tube has become important for heat transfer enhancement in turbulent single-phase flow as the pressure drop increment is reasonable. The water cooling/heating coil, commonly used as condenser or evaporator in water source heat pumps, is a double tube heat exchanger that employs a refrigerant on the annulus side and water on the tube side. The heat transfer enhancement on either side of the inner tube is the subject of the present study.

Heat Exchangers

A heat exchanger is a device that facilitates the process of heat exchange between two fluids that are at different temperatures. Heat exchangers are used in many engineering applications, such as refrigeration, heating and air conditioning systems, power plants, chemical processing systems, food processing systems, automobile radiators, and waste heat recovery units. Air preheaters, economizers, evaporators, superheaters, condensers, and cooling towers used in a power plant are a few examples of heat exchangers.

Classification of heat exchangers

Heat exchangers can be classified based on different criteria, as listed below.

Based on the nature of the heat exchange process

1. Direct contact–type heat exchanger

In this type, both fluids are from the same substance and a schematic is shown in Figure. 1.1A. For example, the hot fluid is water vapor, and the cold fluid is water.

The limitation of a direct contact–type heat exchanger is that both the fluids must be of the same substance, like hot water and cold water, steam and water, etc.

2. Regenerator type of heat exchanger

In this type of heat exchanger, the hot and cold fluids flow through the heat exchanger alternately and a schematic is shown in Fig. 1.1 B. When the hot fluid flows through the heat exchanger, heat is transferred from the hot fluid to the heat exchanger wall (matrix). The hot fluid is then stopped, and the cold fluid is sent so that the heat is transferred from the heat exchanger wall (matrix) to the cold fluid. This is called a fixed matrix regenerator. A rotary regenerator employs a matrix in the form of a wheel that rotates continuously through the counterflowing streams of the hot and cold fluids.

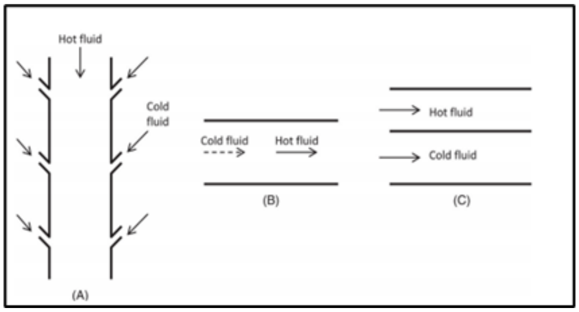


Figure 1.1 Schematic representation of (A) direct contact–type heat exchanger, (B) regenerator type of heat exchanger, and (C) recuperator type of heat exchanger.

3. Recuperator type of heat exchanger

In this type of heat exchanger, both the hot and cold fluids flow through the heat exchanger simultaneously and are separated by a thin wall, as shown in Figure. 1.1C.

Based on the direction of fluid flow

1. Parallel flow

In a parallel-flow heat exchanger, both the hot and cold fluids move in the same direction, as shown in Figure. 1.1A.

2. Counterflow

In a counterflow heat exchanger, the hot and cold fluids move in opposite directions, as shown in Figure. 1.1B.

3. Cross flow

In a crossflow heat exchanger, the hot and cold fluids move in perpendicular directions, as shown in Figures. 1.2A and B.

Based on the mechanical design

1. Concentric tube heat exchanger

Also called a double pipe heat exchanger, it is one wherein one fluid flows through the inner tube, and the other fluid flows through the annulus, as shown in Figures. 1.2A and B.

2. Shell and tube heat exchanger

In this type of heat exchanger, one of the fluids flows through a number of tubes stacked in a shell, and the other fluid flows outside the tubes. Depending on the requirement, there can be multiple tube or shell passes. Flow conditions in a shell and tube heat exchanger are neither parallel flow nor counter flow.

3. Multipass heat exchanger

Shell and tube heat exchangers and crossflow heat exchangers can be of multipass type to enhance their heat transfer capability. Multiple tube passes or shell passes are chosen based on the velocity consideration, the total heat transfer area requirement, and the space (the heat exchanger length) constraints.

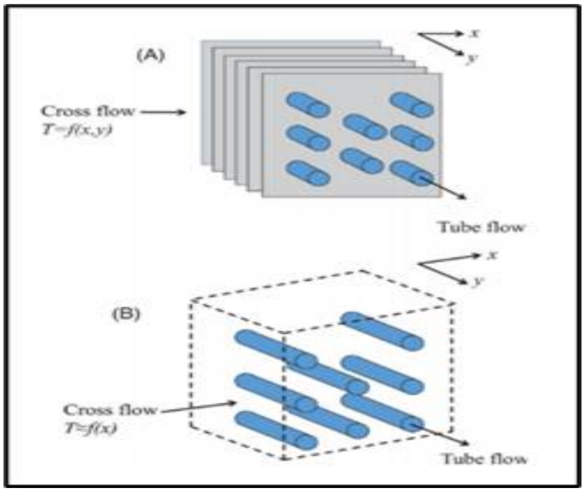


Figure 1.2 Cross-flow heat exchanger with (A) both fluids unmixed and (B) one fluid mixed and the other unmixed.

II-METHODOLOGY

Modes of Heat Transfer

There are two fundamental modes of heat transfer—namely, conduction and radiation. Both of these are independent and are based on completely different mechanisms. Convection is an enhanced or modified form of conduction, in which a bulk motion of the medium is additionally present. Convection has its underpinnings in conduction and thermodynamic laws applicable to bulk transport. Because of its importance in heat transfer engineering, it is common to declare convection as the third mode of heat transfer.

- Conduction
- Convection
- Thermal radiation

Finite Element Analysis

ANSYS Workbench is used for Finite element analysis. In ANSYS software the Computational Fluid Dynamics (CFD) is used as platform for the study.

Introduction to Computational Fluid Dynamics

The flows and related phenomena can be described by partial differential (or integro-differential) equations, which cannot be solved analytically except in special cases. To obtain an approximate solution numerically, we have to use a discretization method which approximates the differential equations by a system of algebraic equations, which can then be solved on a computer.

Components of a Numerical Solution Method

Mathematical Model

The starting point of any numerical method is the mathematical model, i.e., the set of partial differential or integro-differential equations and boundary conditions. One chooses an appropriate model for the target application (incompressible, inviscid, turbulent; two- or three-dimensional, etc.). As already mentioned, this model may include simplifications of the exact conservation laws. A solution method is usually designed for a particular set of equations. Trying to produce a general-purpose solution method, i.e., one which is applicable to all flows, is impractical, if not impossible and, as with most general-purpose tools, they are usually not optimum for any one application.

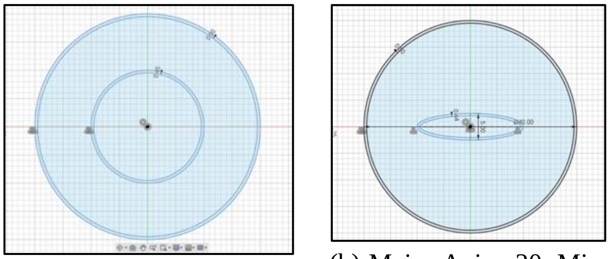
Geometry

As shown in Figure. 3.1, the simulated double tube type heat exchanger has different geometrical cross sections. The whole computation field is covered or bounded by the inner surfaces of tubes of heat exchanger contained in the domain or field. The inlet and outlet of the domain are connected with the consequent tubes. The mild steel shell is placed and allowed to flow cold fluid. Hot fluid is allowed to flow in tubes.

To simplify numerical simulation problems and for some basic distinctiveness of the processes, the following assumption are made:

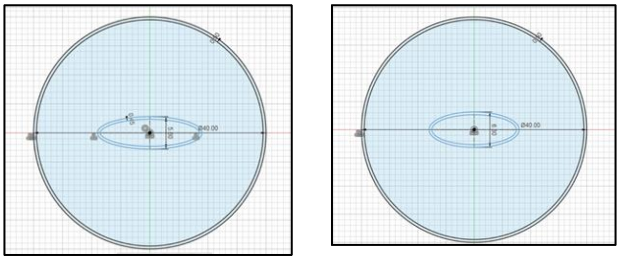
- Thermal properties of the fluid should be constant in the whole analysis.
- The fluid flow and heat transfer processes should be turbulent and in steady state.
- The leaks between tubes are neglected.
- The natural convection induced by the fluid density variation is neglected.
- The tube wall temperature is kept constant in the whole.

The heat exchanger is well insulated; hence, the heat loss to the environment is totally neglected.



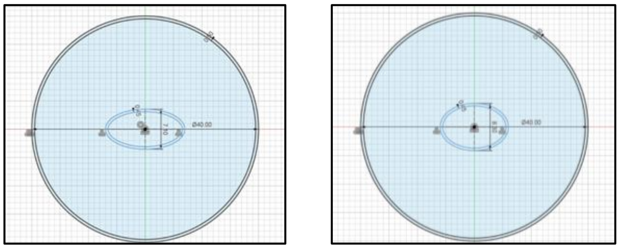
(a) Circular Shaped

(b) Major Axis= 20, Minor Axis=5,



(c) Major Axis= 18, Minor Axis=5.6

(d) Major Axis= 16, Minor Axis=6.3



(e) Major Axis= 14, Minor Axis= 7.1

(f) Major Axis= 12, Minor Axis=8.3

Figure 3.1 Geometry of the heat exchanger

Discretization Method

After selecting the mathematical model, one has to choose a suitable discretization method, i.e., a method of approximating the differential equations by a system of algebraic equations for the variables at some set of discrete locations in space and time. There are many approaches, but the most important of which are: finite difference (FD), finite volume (FV) and finite element (FE) methods.

Fluid sections are inlet fluid, outlet fluid, and fluid at inner and outer tube. In current analysis, finer elements (element size=100 µm) are chosen for fluid section.

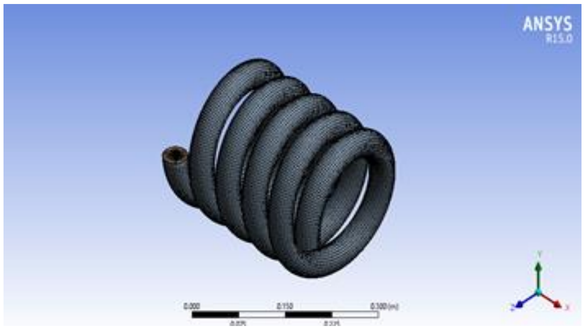


Figure 3.2 Mesh model of the heat exchanger

The meshed model consisted of both tetrahedral and hexahedral elements with triangular as well as quadrilateral faces near to the boundaries. The special consideration is taken to use more structured element (hexahedral). For this purpose, the geometrical model is considered as many parts of integral model to adapt automatic techniques offered by ANSYS (ANSYS release version 15) so that the analysis time is drastically reduced by well mesh configuration.

Boundary Conditions

The following boundary conditions are considered:

1. Velocity is defined as inlet boundary condition.
2. Hot fluid inlet velocity and temperature is taken as 0.75 m/s and 350K.
3. Cold fluid inlet velocity and temperature is taken as 0.5 m/s and 285 K.
4. Water is considered as working fluid.

III-RESULT ANALYSIS

There are several augmentation techniques for enhancing the effectiveness of the tubular heat exchanger, namely active and passive techniques. Recently, passive techniques have become a promising method as it does not need any external power, easy and low-cost implementation. At present the changes in cross sectional shape have been implied.

Results for circular cross sectional inner tube of 10mm diameter

Figure 3.1 to 3.2 shows the cold and hot fluid inlet outlet temperature, pressure and heat flux, respectively.

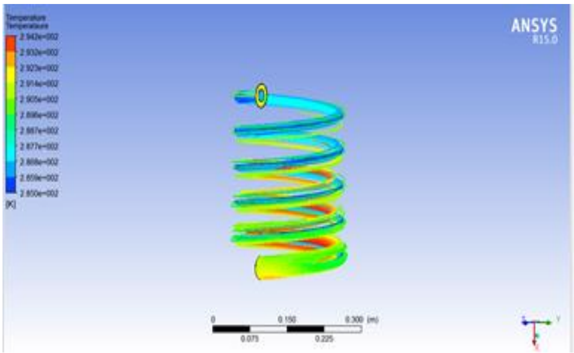


Figure 3.1 Cold Fluid inlet outlet temperature for circular cross sectional shaped inner tube of 10 mm diameter

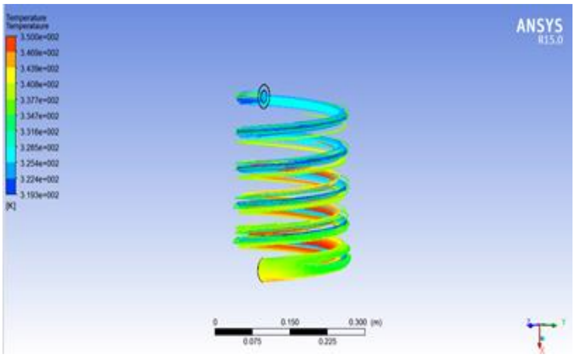


Figure 3.2 Hot Fluid inlet outlet temperature for circular cross sectional shaped inner tube of 10 mm diameter

Discussion

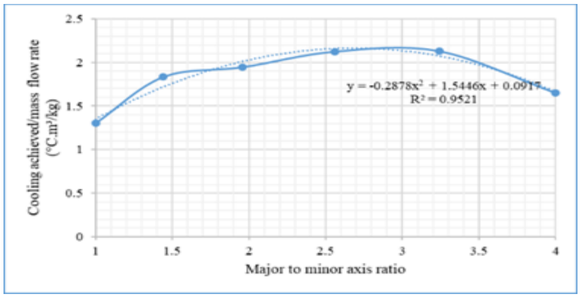


Figure 3.3 Cooling achieved/mass flow rate with respect to Major to minor axis ratio

Heat Flow Rate

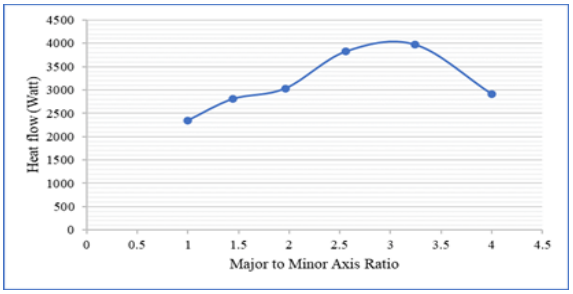


Figure 3.4 Heat flow with respect to Major to minor axis ratio

LMTD

The logarithmic mean temperature difference (LMTD) is cast-off to find out the temperature dependent force for heat transfer in dynamic condition, i.e., in heat exchangers. The LMTD is a logarithmic normal of the temperature variance amongst the hot and cold feeds at individual end of the double pipe exchanger. Heat exchanger with constant heat transfer surfaces and heat transfer coefficient, the larger the LMTD, the more heat is transferred.

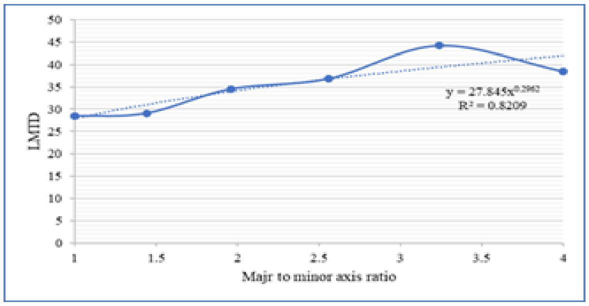


Figure 3.5 LMTD with respect to Major to Minor Axis ratio

Effectiveness – NTU method

Effectiveness is defined as the ratio of actual heat transfer in the heat exchanger to the maximum possible heat transfer. As can be seen, as increasing in the NTU, the effectiveness is also increased, which the maximal value is for major to minor axis ratio 3.2 heat exchanger.

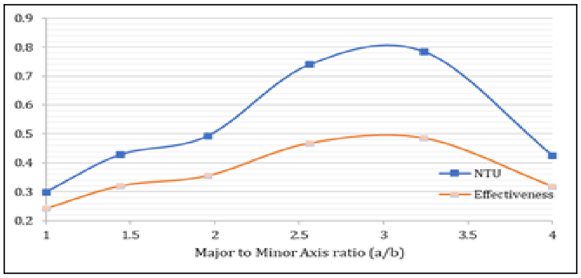


Figure 3.6 NTU and Effectiveness for heat exchangers with respect to Major to Minor Axis ratio

IV-CONCLUSION

A finite element analysis for the assessment of shape changes of inner tube with respect to heat transfer characteristics has been carried out. The following conclusions can be made:

- Cooling achieved per unit mass flow rate is maximum for major to minor axis ratio 3.2 i.e., when the elliptical shape having major axis 18 and minor axis 5.6mm.
- The use of the LMTD arises directly from the analysis of a heat exchanger with constant flow rate and fluid thermal properties. It can be observed that the LMTD is maximum for Major to minor axis ratio 3.2 i.e., when the elliptical shape having major axis 18 and minor axis 5.6mm
- Changing in Major to Minor Axis ratio cause increasing the effectiveness of the heat exchanger.
- As increasing in the NTU, the effectiveness is also increased, which the maximal value is for major to minor axis ratio 3.2 heat exchanger.

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