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Design and Analysis of Helical Coiled Heat Exchanger

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Abstract

Heat exchangers are the important engineering systems with wide variety of applications including power plants, nuclear reactors, refrigeration and air-conditioning systems, heat recovery systems, chemical processing and food industries. Helical coil configuration is very effective for heat exchangers and chemical reactors because they can accommodate a large heat transfer area in a small space, with high heat transfer coefficients. This project deals with the analysis of the helical coiled heat exchanger with various correlations given by different papers for specific conditions. Although various configurations are available, the basic and most common design consists of a series of stacked helically coiled tubes placed in a cylindrical outer cover. The inner tube ends are connected to manifolds, which act as fluid entry and exit locations. And the outer tube is also provided with inlet and outlet manifolds so that cooling fluid can be passed through it. The tube bundle is constructed of a number of tubes stacked atop each other, and the entire bundle is placed inside a helical casing, or shell. The complex fluid-dynamic inside curved pipe heat exchangers gives them important advantages over the performance of straight tubes in terms of area/volume ratio and enhancing of heat transfer and mass transfer coefficient. Convective heat transfer between a surface and the surrounding fluid in a heat exchanger has been a major issue and a topic of study for a long time. The analysis of these various correlations with certain defined data is presented in this project.

In this study, an attempt has been made to analyze the effect of counter-flow on the effectiveness from a helical tube. The heat exchanger was modeled in CATIA, grid was generated i.e. meshed in ANSYS WORKBENCH and the temperature contours, velocity vectors was calculated and plotted using FLUENT. Copper and Aluminum was chosen as the metal for the construction of the helical tube. The fluid flowing through the inner tube and outer casing was taken as water, benzene, kerosene.

Introduction

The heat is a form of energy that transfers from the hot object to the cold object, and it transferred through the conduction, the convection and the radiation**.** The heat energy has many usages in the industry as making metals, chemicals, refining oil and processing the food. The shortage of heat energy leads to conserve or to make best use of it. In several industrial processes there is waste of energy or a heat stream that being exhausted in atmosphere. The heat exchangers plays important role to recover this heat and place it to use by heating a different stream within the process. This practice saves a lot of money in industry, as the heat supplied to other streams from the heat exchangers would otherwise come from an external source that is more expensive and more harmful to the environment. The purpose of constructing a heat exchanger is to get an efficient technique of heat transfer from one fluid to another, by direct contact or by indirect contact. In a heat exchanger the heat transfer through radiation is negligible in comparison to conduction and convection. But convection plays the major role in the performance of a heat exchanger. There are numerous applications of heat exchangers such as heat recovery

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systems, refrigeration, waste water treatment plants, pharmaceuticals, oil and gas industries, HVAC, food & beverage processing industries. In addition to these applications heat exchangers are also used in large scale chemical and process industries for transferring the heat between two fluids which are at a single or two states.

In general, the heat transfer techniques can be divided into two groups: active and passive. The active techniques need external forces like fluid vibration, electric field and surface vibration whereas passive techniques requires special surface geometries like varied tube inserts. The straight tube heat exchanger has been the oldest type of heat exchanger that has been in use.

The research work has been performed by various investigators on enhancing the performance of straight tube heat exchanger by changing geometric such as baffle arrangement, types of tube arrangement, length of the pipe etc. The main challenge in heat exchanger design is to make it compact and to get maximum heat transfer in minimum space. However, it was found that straight tube heat exchangers have restriction in terms of sizing and space which are significant parameters while designing industrial heat exchangers. In 1970 Charles Boardman and John Germer introduced helical coil tube heat exchanger as one of the best passive heat transfer enhancement techniques. The various experimental research work have indicated that helical coil tube heat exchangers are the most useful because of its spiral coil configuration which provides more heat transfer area and better flow in minimum space. This configuration leads higher heat transfer coefficient as compared to straight tube heat exchanger under the same experimental conditions.

Literature Review

J.S. Jayakumaret.al.[1]observed that the use of constant values for the transfer and thermal properties of the fluid resulted in inaccurate heat transfer coefficients. Based on the CFD analysis results a correlation was developed in order to evaluate the heat transfer coefficient of the coil. In this study, analysis was done for both the constant wall temperature and constant wall heat flux boundary conditions. The nusselt numbers that were obtained were found to be highest on the outer coil and lowest in the inner side. Various numerical analyses were done so as to relate the coil parameters to heat transfer. The coil parameters like the diameters of the pipes, the Pitch Circle Diameters have significant effect on the heat transfer and the effect of the pitch is negligible.

Timothy J. Rennieet.al.[2] studied the heat transfer characteristics of a double pipe helical heat exchanger for both counter and parallel flow. Both the boundary conditions of constant heat flux and constant wall temperature were taken. The study showed that the results from the simulations were within the range of the pre-obtained results. For dean numbers ranging from 38 to 350 the overall heat transfer coefficients were determined. The results showed that the overall heat transfer coefficients varied directly with the inner dean number but the fluid flow conditions in the outer pipe had a major contribution on the overall heat transfer coefficient. The study showed that during the design of a double pipe helical heat exchanger the design of the outré pipe should get the highest priority in order to get a higher overall heat transfer coefficient.

Usman Ur Rehmanet.al.[3] studied the heat transfer and flow distribution in a shell and tube heat exchanger and compared them with the experimental results. The model showed an average error of around 20% in the heat transfer and the pressure difference. The study showed that the symmetry of the plane assumption worked well for the length of the heat exchanger but not in the outlet and inlet regions. The model could be improved by using Reynold Stress models instead of k-ε models. The heat transfer was found to be on the lower side as there was not much interaction between the fluids. The design could be improved by improving the cross flow regions instead of the parallel flow.

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Nawraset.al.[4] studied on the mechanical and thermal performance of elliptical tubes used for polymer heat exchangers. The mechanical analysis showed that the streamlined shape of the outer tube had an optimal thermal performance. A set of design curves were generated from which a number of geometries of the tube and different materials can be easily selected in order to meet the deformation constraints. A Finite element solution was determined for strain as a function of the material of the tube.

Daniel Flórez-Orregoet.al.[5] have worked on the single phase cone shaped helical coil heat exchanger. The study showed the flow and the heat transfer in the heat exchanger. An empirical correlation was proposed from the experimental data for the average nusselt number and a deviation of 23% was found. For the cone shaped helical coils an appreciable inclination of the velocity vector components in the secondary flow was seen, even though the contours of velocity were similar. The study showed that some of the deviations and errors were due to the non-uniform flame radiation and condensed combustion products which modified the conditions of the constant wall heat flux assumptions. The correlations for the nusselt number values were not totally reliable. There was no proper data available for the effect of the taper in the local nusselt number and also the effect of curvature ratio, vertical position and the pitch of the heat exchanger.

Modeling And Meshing

Heat exchanger is built in the CATIA. It is a counter-flow heat exchanger. The design specifications of the helical coil heat exchanger are shown below and later the geometric model is imported to Ansys for CFD analysis

- Inner Tube Inner Diameter : 13.843mm
- Inner Tube Outer Diameter : 15.875mm
- Outer Tube Inner Diameter : 19.939mm
- Outer Tube Outer Diameter : 22.225mm
- Helical Diameter : 152.4mm
- Helical Pitch : 50.8mm
- Tube Length : 963mm

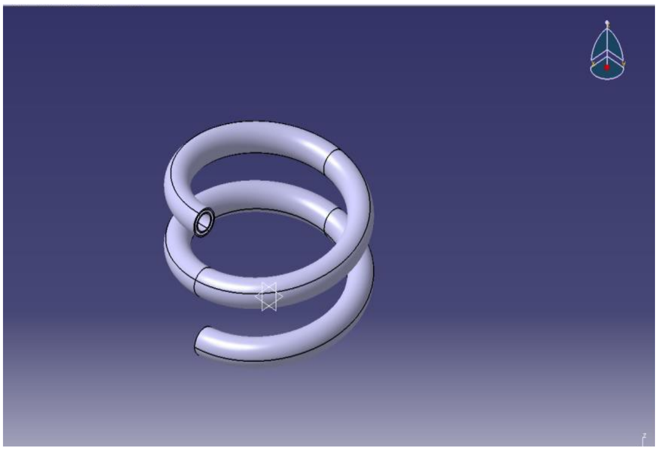

Fig 1 Catia Model of Helical Tube Heat Exchanger

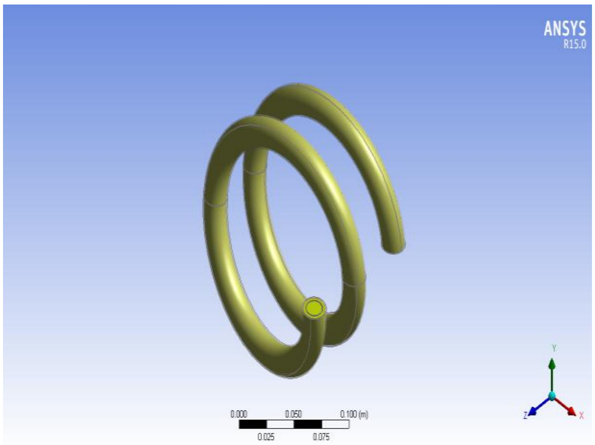

Fig 2 Imported Geometric model in Ansys

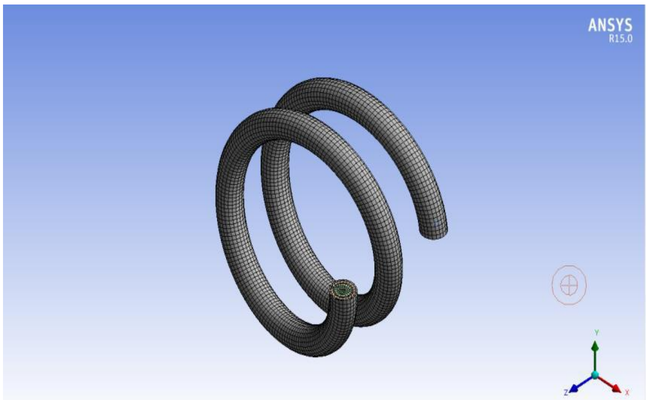

Fig 3 Meshed model

Results and Discussion

The details about all boundary conditions can be seen in the following table as given below.

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Table 1 Boundary Conditions

	Boundary Condition Type	Velocity Magnitude	Turbulent Kinetic Energy	Turbulent Dissipation Rate	Temperature
InnerInlet	Velocity Inlet	0.9942 m/s	0.01 m2/s2	0.1 m2/s3	348 K
InnerOutlet	Pressure Outlet	-	-	-	-
OuterInlet	Velocity Inlet	1.8842 m/s	0.01 m2/s2	0.1 m2/s3	283 K
OuterOutlet	Pressure Outlet	-	-	-	-

Pressure and velocity contours in section planes

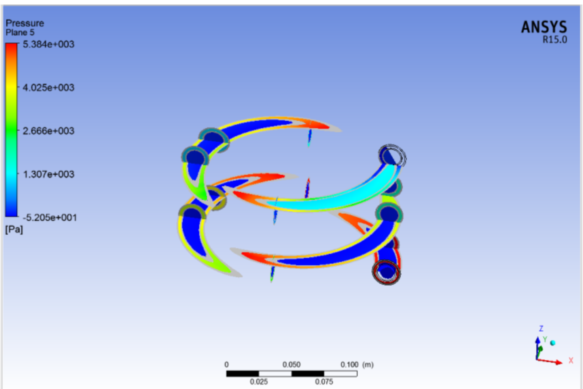

Fig 4 Section Planes for Pressure

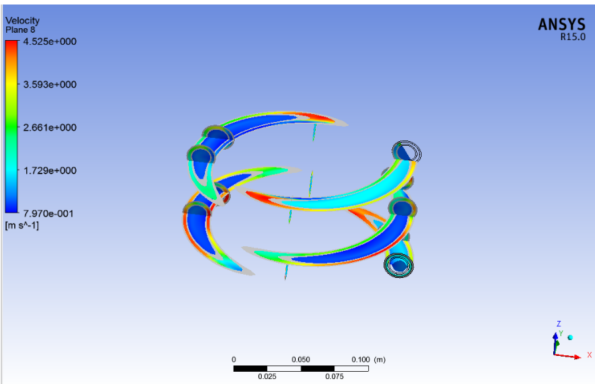

Fig 5 Section Planes for Velocity

Pressure and Velocity Vectors

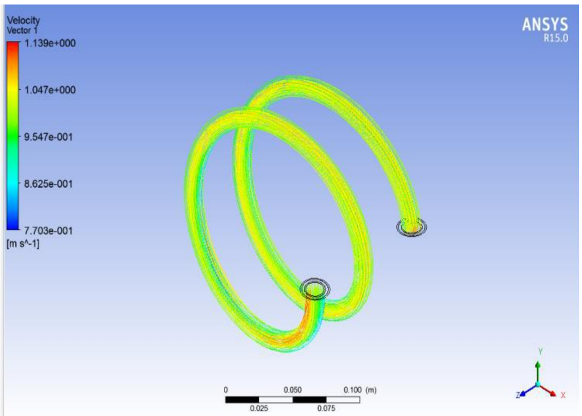

Fig 6Velocity Vector for Inner Fluid

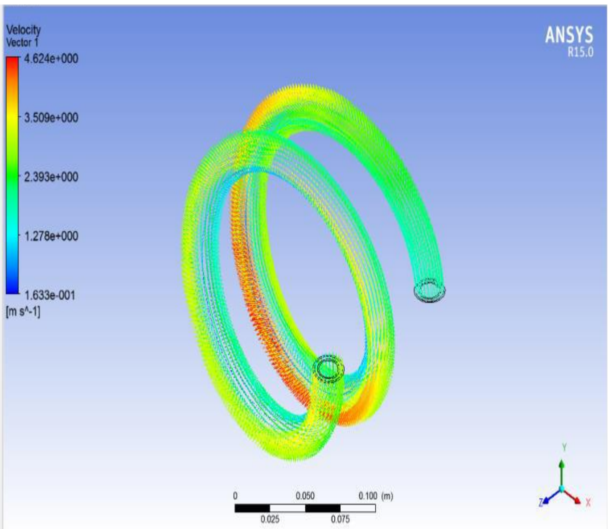

Fig 7Velocity Vector for Outer Fluid

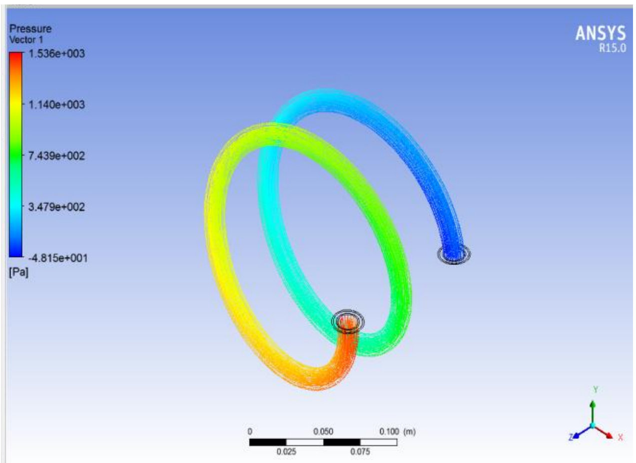

Fig 8Pressure Vector for Inner Fluid

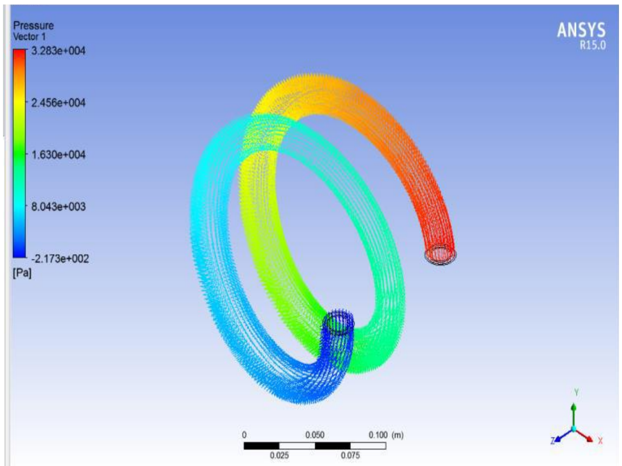

Fig 9 Pressure Vector for Outer Fluid

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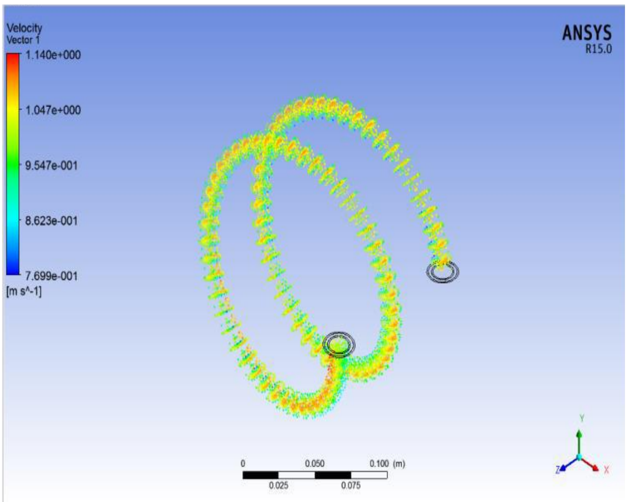

Fig 10Sectional Velocity Vector for Inner Fluid

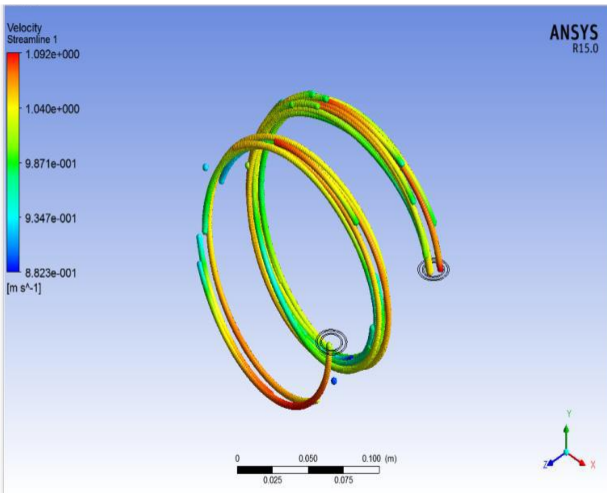

Fig 13 Velocity Streamlines 2

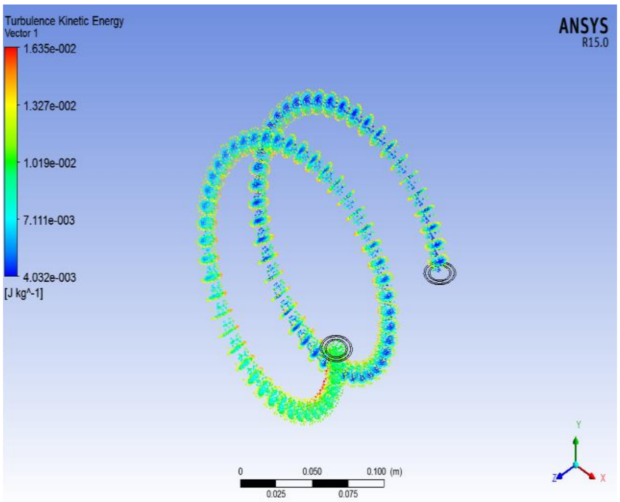

Fig 11 Turbulent Kinetic Energy Vector

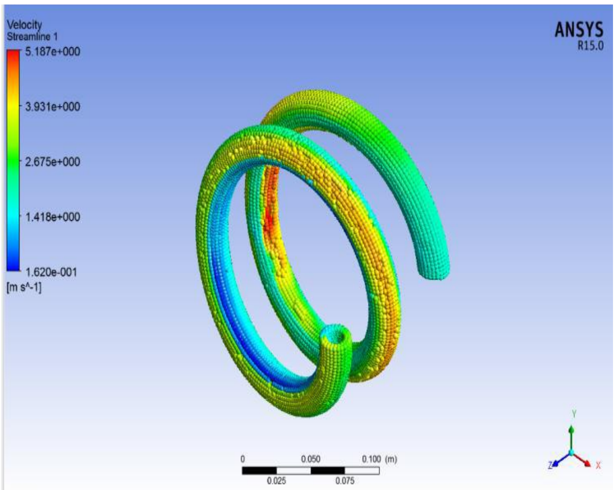

Fig 14 Velocity Stream Lines 3

Velocity Stream Lines

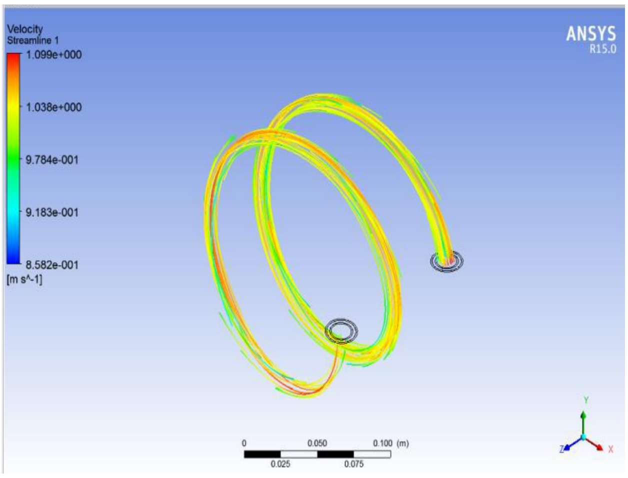

Fig 12Velocity Stream Lines 1

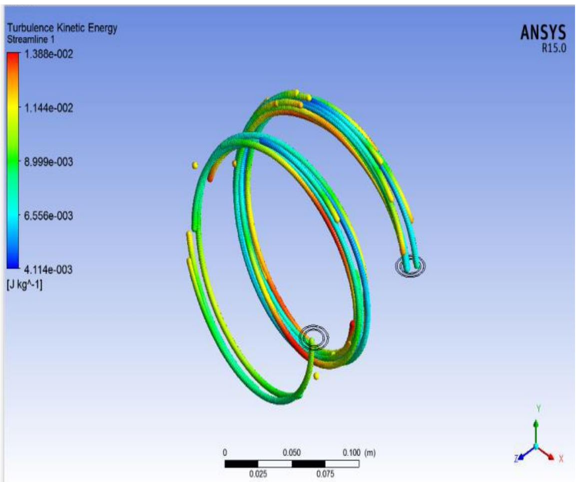

Fig 15 Turbulent Kinetic energy Streamlines

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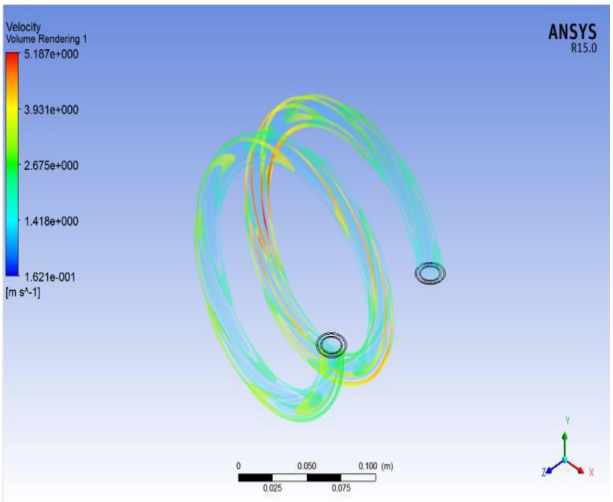
Volume Rendering



Numerical Calculations
Temperature Variations (in K)
Table 2: Copper as Solid

Fluid	inner inlet	inner outlet	outer inlet	outer outlet
Water	348	334.83502	283	293.61945
Benzene	348	335.71158	283	290.61935
Kerosene	348	342.86499	283	284.78473

Table 3: Aluminum as Solid

Fluid	inner inlet	inner outlet	outer inlet	outer outlet
Water	348	334.85919	283	291.75452
Benzene	348	335.21664	283	289.25629
Kerosene	348	341.82629	283	284.41977

Mass Flow Rates (in kg/s):

Mass flow rates in **kg/s** are calculated from the respective formulae and tabulated below

Table 4 Mass flow rates

	Inner fluid	Outer fluid
Water	0.1494	0.1134
Benzene	0.1309	0.0994
Kerosene	0.1167	0.0886

Effectiveness Calculation

The Effectiveness is acalculated by using the respective formulae

Table 5 Effectiveness

	copper	aluminum
Water	16.33	13.46
Benzene	11.72	9.62
Kerosene	2.7	2.1

Conclusion

A CFD package (ANSYS FLUENT 15.0) was used for the numerical study of heat transfer characteristics of a helical coiled double pipe heat exchanger for counter flow. The CFD results when compared with the results from different studies were well within the error limits. The study showed that the effective configuration of heat transfer performances of the counter-flow. The simulation was carried out for fluid to fluid heat transfer characteristics for different fluids, solids and different inlet temperatures were studied.

Effectiveness of Helical Tube Heat Exchanger is calculated on different fluids and solid configurations. Among different fluids and solid configurations copper-water combination gives more effectiveness 16.33% than other combinations.

From the velocity vector plot it was found that the fluid particles were undergoing an oscillatory motion inside both the pipes. From the pressure and velocity contours it was found that along the outer side of the pipes the velocity and pressure values were higher in comparison to the inner values.

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