Heat Transfer Analysis of a Helical Coil Heat Exchanger by using CFD Analysis

Dr. B. Jayachandraiah\(^1\), H.S.S.K. Praveen\(^2\)

Abstract

Helical Coil Heat Exchangers (HCHE) are widely used in industrial applications because they can accommodate a large heat transfer area in a small space, with high heat transfer coefficients. An attempt is made in this paper to evaluate the thermal performance of HCHE through CFD analysis. The modeling is done by using CATIA V5 software. The model contains the Coiled tube and Shell having an inner diameter of 8.41 mm and 260 mm respectively. The height of the shell is 250 mm. The material of the Shell and Coil is made up of Steel and Copper respectively. Computational Fluid Dynamics (CFD) Analysis is performed for different flow rates of 40, 60, 80, 100, 140 LPH at Coil side and constant flow rate of 200 LPH at Shell side in both laminar and turbulent flow regime under steady state conditions. It was found that the heat transfer characteristics were found better at the flow rate of 80 LPH and it is well desired to be maintained in the coil.

Keywords

Helical Coil Heat Exchanger, CATIA V5 software, Computational Fluid Dynamics (CFD) Analysis, Heat transfer.

1 Introduction

Heat Exchangers are the most widely used equipment in power stations and petro-chemical industries. A Heat Exchanger is a contrivance designed to transfer thermal energy between two or more fluids over solid surface at different temperatures and when they are in thermal contact. The wall temperature also gets changed along the length of Heat Exchanger as temperature of each fluid changes during the passage through the Exchangers.

A Shell and tube heat exchanger consists of series of tubes. They are typically used for high-pressure applications (with pressures greater than 30 bar and temperatures greater than 260 °C). There can be many variations on the shell and tube design. Although Double-Pipe Heat Exchangers are the simplest to design, the better choice would be the Helical Coil Heat Exchanger (HCHE).

The Helical coils of circular cross section have been used in wide variety of applications due to easy to manufacture. Flow in curved tube is different from the flow in straight tube because of the presence of the centrifugal forces. These centrifugal forces generate a secondary flow, normal to the primary direction of flow with circulatory effects that increases both the friction factor and rate of heat transfer coefficients.
2. Literature Review

2.1 Introduction

Literature survey of past research effort such as journals or articles related to Shell and Helical Coil Heat Exchanger and Computational Fluid Dynamics (CFD) analysis. Moreover, review of other relevant research studies are made to provide more information in order to understand more on this research. Timothy John Rennie [1] has studied the heat transfer characteristics of a double pipe helical heat exchanger for both counter and parallel flow. The results showed that the overall heat transfer coefficients varied directly with the inner dean number ranging from 38 to 350 but the fluid flow conditions in the outer pipe had a major contribution on the overall heat transfer coefficient. J. S. Jayakumar et al [2] have studied the constant thermal and transport properties of the heat transfer medium and their effect on the prediction of heat transfer coefficients. An experimental setup was made for studying the heat transfer coefficients and also compared with the CFD simulation results and the correlation was established for the inner heat transfer coefficient. Nasser Ghorbani et al [3] have experimentally conducted for mixed convection heat transfer in a Coil-in-Shell Heat Exchanger for various Reynolds numbers, Rayleigh numbers, tube-to-coil diameter ratios and dimensionless coil pitch. The calculations have been performed for the steady-state. Results observed that the mass flow rate of tube-side to shell-side ratio was effective on the axial temperature profiles of heat exchanger. Jundika C. Kurnia et al [4] have completed the Evaluation of the heat transfer performance of Helical coils of non-circular tubes. They have performed for the three configurations-Conical, Helical, and Spiral. It was found that even though coiled ducts give higher heat transfer rates, they also impose a higher pressure drop penalty. Shinde Digvijay D and Dange H. M [5] have conducted the experimental research on Helical Coil Heat Exchangers considering the counter flow. The conditions of hot water and cold water mass flow rates were taken. For the flow rates ranging from 60 LPH and 280 LPH characteristics were determined. It was observed that the Coils side flow rate has significant impact on the performance of Heat Exchanger.

2.2 Objective Of The Paper

An attempt is made in this paper to design and analysis of Helical Coil Heat Exchanger. The modeling is done by using CATIA V5 software which is a parametric solid modeling system with many extended design and manufacturing applications. CATIA represents the leading edge of CAD/CAE/CAM technology. This paper explains about the effective performance of Cone shaped HCHE over Simple HCHE.

3. Modeling

The Modeling of Helical Coil Heat Exchanger is created by using CATIA V5 software which is a parametric solid modeling system with many extended design and manufacturing applications. CATIA represents the leading edge of CAD/CAE/CAM technology. This paper explains about the effective performance of Cone shaped HCHE over Simple HCHE.

4. Meshing

The meshing of Shell and Helical Coil Heat Exchanger is done using Steady state Solution mode and Turbulence Model Equation. Number of elements- 28,77,318
5. CFD Analysis

5.1 Introduction
A continuity equation is a differential equation that describes the conservative transport of some kind of quantity. In fluid dynamics, the continuity equation is a mathematical statement that, in any steady state process, the rate at which mass enters a system is equal to the rate at which mass leaves the system. The differential form of the continuity equation is:

\[
\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{v}) = 0
\]  

(1)

5.2 Turbulence Model
The model is one of the most common turbulence models. It is a two equation model, which 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. The model has been useful for free-shear layer flows with relatively small pressure gradients.

For flow rates of 40, 60, 80, 100 and 140 LPH, Reynolds Number for HCHE are observed as 1421, 2082, 2844, 3470 and 4859.5. At the flow rate of 40 LPH, laminar flow is observed while for the remaining flow rates, turbulence condition is observed during the flow of fluid. A sample analytical calculation at the flow rate of 80 LPH is given below based on the results obtained from CFD analysis.

5.3 Mathematical Analysis

At Flow Rate of 80 LPH:

1. Heat Transfer Rate (Q_{Avg})

\[
Q_{avg} = m \cdot C_p \cdot (T_{in} - T_{out})
\]

For flow rates of 40, 60, 80, 100 and 140 LPH, Reynolds Number for HCHE are observed as 1421, 2082, 2844, 3470 and 4859.5. At the flow rate of 40 LPH, laminar flow is observed while for the remaining flow rates, turbulence condition is observed during the flow of fluid.

2. Overall Heat Transfer Coefficient (U)

\[
U = \frac{\Delta T_{avg}}{LMTD}
\]

Where, \( \Delta T_{avg} = \frac{\Delta T_{in} + \Delta T_{out}}{2} \)

LMTD = \frac{\Delta T_{in} + \Delta T_{out}}{2}

\[
U = \frac{m \cdot C_p \cdot (T_{in} - T_{out})}{\Delta T_{avg} \cdot \Delta T_{in} \cdot \Delta T_{out}}
\]

3. Dean Number (De)

\[
De = Re \cdot \sqrt{D/D}
\]

where: \( Re \) is the Reynolds Number, \( D \) is the tube diameter \( d \) is the tube diameter

4. Effectiveness

\[
\varepsilon = \frac{Q_{avg}}{Q_{max}} = \frac{1709.04}{3083.325} = 0.55
\]
Table 3. Temperature Results of HCHE considering Velocity

<table>
<thead>
<tr>
<th>S.No</th>
<th>Flow Rate (LPH)</th>
<th>Shell Side Temperature (°C)</th>
<th>Coil side Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Inlet</td>
<td>Outlet</td>
<td>Inlet</td>
</tr>
<tr>
<td>1.</td>
<td>40</td>
<td>25</td>
<td>30.56</td>
</tr>
<tr>
<td>2.</td>
<td>60</td>
<td>25</td>
<td>32.09</td>
</tr>
<tr>
<td>3.</td>
<td>80</td>
<td>25</td>
<td>33.52</td>
</tr>
<tr>
<td>4.</td>
<td>100</td>
<td>25</td>
<td>35.24</td>
</tr>
<tr>
<td>5.</td>
<td>140</td>
<td>25</td>
<td>36.91</td>
</tr>
</tbody>
</table>

The Critical Reynolds number, $Re_{cr}$ for laminar to turbulent flow transition is calculated by the below equation considering curvature ratio for the coil:

$$Re = d/D = 0.04 \quad Re_{cr} = 2100 \left(1 + 12 \lambda^{0.5}\right)$$

It is found as $7140$

(6)

6. Results

The below table shows the CFD temperature results in Coil and Shell sides for various flow rates. The below table shows the results of Heat transfer Rate, Overall heat transfer coefficient, Dean Number and Effectiveness at various flow rates of hot water in HCHE.

**Velocity Contours**

The Velocity profile at hot water inlet is 500.35 mm/s. Maximum Velocity obtained inside the Shell is 1208.39
mm/s and turbulence occurs in the shell region. The Velocity profile at hot water inlet is 700.628 m/s. Maximum Velocity obtained inside the Shell is 1200.02 mm/s and turbulence occurs in the shell region. From the above figure, it is observed that the temperature profile is getting varied to a greater extent at the flow rate of 140 LPH.

7. Conclusions

1. From the analysis, it gives us a clear idea that hot fluid temperature is reduced to a great extent at the flow rate of 40 LPH and 80 LPH compared to other flow rates. Hence these are suggested as better flow rates to be maintained in the Coil.
2. The Heat transfer rate increases with increase in Flow rate at Coil side.
3. The Overall Heat transfer Coefficient increases with increase in Flow rate at Coil side. At 80 LPH, the deviation occurred which indicates the optimal flow rate in the coil.
4. Dean Number increases with increase in Coil side flow rate.
5. The Heat Exchanger Effectiveness is decreased consid-
erably with increase in Coil side flow rate. The greater Effectiveness of 0.80 was obtained at 40 LPH.

8. Future Work

In the present paper, the CFD analysis is carried out in order to evaluate the thermal performance of Helical Coil Heat Exchanger considering the Volume Flow rate boundary conditions. The extension of this work can be done considering other boundary conditions like Pressure and Wall heat flux etc.

References


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