DESIGN AND ANALYSIS OF HELICAL COIL HEAT EXCHANGER

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Abstract. Heat exchangers has been widely used in power plants and industries for heating or cooling applications. Heat is transferred from one medium to another medium by using heat exchangers. Helical coil heat exchangers with two different shell configurations are designed. First shell configuration with a central core and second without a central core. Both the configurations has a copper helical coil. Designing of heat exchangers is done with counter flow arrangement by using CATIA V5 R2015. The performance of both the configurations are analysed and compared by using Fluid flow (Fluent) in ANSYS WORKBENCH 18.1 for CFD simulations. Further the helical tube materials Copper and Aluminium which are widely used in heat exchangers are also analysed in shell with core configuration and heat transfer rates are also compared using CFD (Fluent) analysis.

1. Introduction
The main objective of heat exchangers is to enhance the heat transfer between two fluids. The helical coil heat exchanger is designed with a helix angle of 13° which makes it compact and the heat transfer is greatly improved when compared to straight tubes. Due to the curved geometry of helical coil a centrifugal force is induced on the moving fluid. This results in development of a secondary flow. This secondary flow is the reason for increased heat transfer rates in helical coils.

Two types of shell configurations are designed one with a core and another without a core. Both these configurations has a common material copper as inner tube material. Both the shell and tube fluids is water flowing in a counter flow arrangement. Performance of both the configurations are analysed.

Aluminium is also widely used as a tube material in heat exchangers. So copper is replaced by aluminium as tube material and the configuration used is shell with core. The heat transfer rates of copper and aluminium are analysed and compared.

Amitkumar S Putterwar, A.M.Andhare has designed and thermally evaluated helical coil heat exchanger experimentally in a counter flow arrangement and how the heat transfer is improved due to secondary flow development [1]. Mr. M.D.Rajkamal et al has studied the use of POCO HTC graphite, ASTM SA 179 carbon steel and copper as inner tube materials in a shell with no core configuration using Ansys CFX 15.0 software and the results were compared [2]. Devendra Borse, Jayesh V. Bute has studied the helical coil heat exchanger on the basis of Dean Number, heat transfer coefficient and
Reynolds number and it infers that helical coiled tube heat exchanger is a promising modification over conventional type of heat exchanger [3]. Sreejith K, Jaivin A Varghese et al experimentally found that the effectiveness of helical coil heat exchanger is found to be higher than that of the straight tube heat exchanger for all the inlet temperatures of water. They have studied the variation of effectiveness with inlet temperature of hot water for both helical coil and straight tube heat exchangers. From the results obtained they have concluded that helical coil heat exchanger is having better effectiveness than straight tube heat exchanger [4]. Subin Michael has studied the changes in temperature profiles for different tube materials and the effectiveness of heat exchangers are calculated. CFD simulations are done for different industrial materials [5]. Shiva Kumara and K. Vasudev Karanth has studied the performance helical coiled tubular heat exchanger used for cooling water under constant wall temperature conditions by CFD simulations. CFD results of helical coiled tubular heat exchanger are compared with the results of straight tubular heat exchanger of the same length under identical operating conditions. Results showed increase in heat transfer and increase in nusselt number when compared to straight tubular heat exchanger [6].

2. MATERIAL PROPERTIES
Two commonly used materials in heat exchangers are aluminium and copper. These materials are used as inner tube materials and Mild steel is used as shell material
The properties of materials used are:

| MATERIAL | DENSITY (kg/m³) | SPECIFIC HEAT (J/kg-K) | THERMAL CONDUCTIVITY (W/m-K) |
|----------|----------------|------------------------|-----------------------------|
| Copper   | 8978           | 381                    | 387.6                       |
| Aluminium| 2719           | 871                    | 202.4                       |

3. HEAT EXCHANGER DIMENSIONS
3.1 Shell dimensions
| S. No | DIMENSIONAL PARAMETERS | DIMENSIONS (mm) |
|-------|------------------------|-----------------|
| 1.    | Inner diameter (D_o)   | 220             |
| 2.    | Shell length(L)        | 295.625         |
| 3.    | Core diameter(D_i)     | 110             |
| 4.    | Shell thickness        | 4               |

3.2 Helical coil dimensions
| S. No | DIMENSIONAL PARAMETERS | DIMENSIONS (mm) |
|-------|------------------------|-----------------|
| 1.    | Tube outer diameter(d_o)| 12.5           |
| 2.    | Tube inner diameter(d_i)| 10             |
| 3.    | Tube thickness(t)       | 1.25            |
| 4.    | Mean coil diameter(D_m)| 165             |
| 5.    | Coil outer diameter     | 177.5           |
| 6.    | Pitch(p)                | 18.75           |
| 7.    | No of turns(n)          | 12              |
Fig. 1 CATIA 3D model of heat exchanger

Fig. 2 CATIA 3D model of helical tube
4. MESH DETAILS

3D Model designed and assembled in CATIA is imported to Ansys Workbench and the volume extract feature available in SpaceClaim modeling is used to fill tube fluid volume and shell fluid volume before meshing.

Smoothing: High and Fine

| PART NAME      | NODES   | ELEMENTS          |
|----------------|---------|-------------------|
| Shell          | 23760   | 73161             |
| Helical tube   | 166980  | 91056             |
| Shell fluid    | 370661  | 2000359           |
| Tube fluid     | 192426  | 888060            |
| All domains    | 753827  | 3052636           |

Fig. 3 Mesh cross section of shell without core

Fig. 4 Mesh cross section of shell with core
5. CALCULATIONS

5.1 Fluid flow volume calculations

Length of coil (L_{coil}) = n \sqrt{(\pi D_o)^2 + p^2} \\
= 8598.34 \text{mm}

Volume occupied by coil = (\pi d_o^2/4) \times L_{coil} \\
= 1067794.2 \text{mm}^3

Volume of shell (with core) = (\pi * (D_o^2 - D_i^2) / 4) \times L \\
= 8428254.95 \text{mm}^3

Volume of shell fluid (with core) = 8428254.9 - 1067794.2 \\
= 7360460.7 \text{mm}^3

Volume of shell (without core) = (\pi * D_o^2/4) \times L \\
= 11237673.27 \text{mm}^3

Volume of shell fluid (without core) = 10169879.07 \text{mm}^3

5.2 Heat transfer calculations

\[ Q = m_h \times C_{ph} \times (t_2 - t_1) = m_c \times C_{pc} \times (T_1 - T_2) \]

Mass flow rate of hot fluid (m_h) = 0.045 \text{kg/s}
Mass flow rate of cold fluid (m_c) = 0.050 \text{kg/s}
Specific heat of hot fluid (C_{ph}) = 4182 \text{J/kg-K}
Specific heat of cold fluid (C_{pc}) = 4182 \text{J/kg-K}

Inlet and outlet temperatures:
T_1 – Entry temperature of hot fluid (K)
T_2 – Exit temperature of hot fluid (K)
t_1 – Entry temperature of cold fluid (K)
t_2 – Exit temperature of cold fluid (K)

5.2.1 Shell with core and copper tube:
T_1 = 323 \text{ K}
T_2 = 307.4 \text{ K}
t_1 = 293 \text{ K}
t_2 = 305.3 \text{ K}
Q = 0.050 \times 4182 \times (305.3-293) \\
= 2571.93 \text{ J/s}

5.2.2 Shell without core and with copper tube:
T_1 = 323 \text{ K}
T_2 = 309.9 \text{ K}
t_1 = 293 \text{ K}
t_2 = 303.2 \text{ K}
Q = 0.050 \times 4182 \times (303.2-293) \\
= 2132.82 \text{ J/s}
5.2.3 Shell with core and aluminum tube:

\[ T_1 = 323 \text{ K} \]
\[ T_2 = 312.8 \text{ K} \]
\[ t_1 = 293 \text{ K} \]
\[ t_2 = 301.2 \text{ K} \]
\[ Q = 0.045 \times 4182 \times (323-312.8) \]
\[ = 1919.53 \text{ J/s} \]

6. ANALYSIS AND RESULTS

For viewing the temperature contour plots and velocity profiles at the inlets and outlets two clip planes are used.
Clip plane 1 – To view the shell inlet and outlet
Clip plane 2 – To view the tube inlet and outlet
Volume Rendering is done to both shell fluid and tube fluid with transparency of 0.2.

6.1 Shell with core and copper tube:
Fig. 6 Temperature contour plot at clip plane 2

Fig. 7 Copper tube temperature contour plot
6.2 Shell without core and with copper tube:

Fig. 8 Shell fluid velocity with streamlines (no of visible lines is 200)

Fig. 9 Temperature contour plot at clip plane 1
Fig. 10 Temperature contour plot at clip plane 2

Fig. 11 Shell fluid velocity with streamlines (no of visible lines is 200)
6.3 Shell with core and aluminium tube:

Fig. 12 Temperature contour plot at clip plane 1

Fig. 13 Temperature contour plot at clip plane 2
Fig. 14 Temperature contour plot of aluminium tube

Chart 1 Heat transfer rates of different shell configurations
7. CONCLUSION
Thus the design and analysis is helical coil heat exchanger is done and has the following conclusions.

- The performance of both the shell configurations are analysed. The heat transfer to shell fluid in configuration 1 (shell with core) is higher than configuration 2 (shell without core). This is due to the reduced volume of fluid flow in configuration 1, whereas in configuration 2 the volume through which the fluid flows is 38% higher than configuration 1 and the velocity of flow is much better in configuration 1. This is concluded by comparing the velocity streamline plot in figures 8 and 11. Due to the economic use of cold fluid and increased heat transfer rates observed in configuration 1 it is preferred over configuration 2.

- Even though copper has a better thermal conductivity aluminium has better specific heat and less weight in comparison to copper. Thus aluminium is also preferred in various applications. The increased thermal conductivity of copper can be observed in figure 7 and 14 where the tube temperature distribution is much higher in copper tube than aluminium and the heat transfer rates are also much higher in copper tube than aluminium.

REFERENCES

[1] Amitkumar S Putterwar, A.M. Andhare-“Design and thermal evaluation of shell and helical coil heat exchanger”, International journal of research in engineering and technology. eISSN: 2319-1163

[2] Mr. M.D. Rajkamal, M. Mani Bharathi, Shams Hari Prasad M, Santhosh Sivan M, Karthikeyan S, R. H. Bahruteen Ali Ahamadu, S. KALIAPPAN, Dr. T. Mothilal – “Thermal analysis of shell and tube heat exchanger”, International Journal of Pure and Applied Mathematics Volume 119 No. 12 2018, 14299-14306.

[3] Devendra Borse, Jayesh V. Bute- “A Review on Helical Coil Heat Exchanger”, International Journal for Research in Applied Science & Engineering Technology (IJRASET), Volume 6 Issue II, February 2018.
[4] Sreejith K., T.R. Sreesastha Ram, Jaivin A. Varghese, Manoj Francis, Mossas V.J., Nidhin M.J., Nithil E.S., Sushmitha S.- “Experimental Investigation of a Helical Coil Heat Exchanger”, International Journal of Engineering And Science, Vol.5, Issue 8 (August 2015), PP -01-05.

[5] Comparative CFD Analysis of Shell and Serpentine Tube Heat Exchanger by Subin Michael , International Research Journal of Engineering and Technology (IRJET),e-ISSN: 2395 -0056 ,Volume: 04 Issue: 02, Feb -2017.

[6] Shiva Kumara and K.Vasudev Karanth – “Numerical Analysis of a Helical Coiled Heat Exchanger using CFD” ,International Journal of Thermal Technologies ,ISSN 2277 – 4114.