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Comparison of Heat Transfer between a Helical and Straight Tube Heat Exchanger

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Abstract

Helical pipes are universally used for heat transfer enhancement in heat exchangers. In the present work, CFD simulations are carried out for a counter flow double pipe helical heat exchanger by varying the flow rates of a single fluid (water). The heat transfer characteristics of the same are compared with that of a counter flow double pipe straight tube heat exchanger for the same flow rates. The results were interpreted by developing correlations between Nusselt number and Dean Number for both the inner and outer helical pipes which shows a strong linear relationship.

KEYWORDS: Double-Pipe, Heat exchanger, Helical, Nusselt Number, Dean Number

1. INTRODUCTION

Helical tubes are universally used in chemical reactors, ocean engineering, heat exchangers, piping system and many other engineering applications. It has been long recognized that heat transfer characteristic of helical tubes is much better than the straight ones because of the occurrence of secondary fluid flow in planes normal to the main flow inside the helical structure. The secondary fluid flow of helical tubes was first studied by Dean with toroidal system. Based on the perturbation method, Germano solved the fluid flow equations of a helical duct with elliptical cross section. The subsequent work by Zhang and Zhang indicated that the torsion has no effect on the secondary fluid flow and heat transfer enhancement in a helical tube with a circular cross section in laminar fluid flow.

Helical tubes show great performance in heat transfer enhancement, while the uniform curvature of spiral structure is inconvenient in pipe installation in heat exchangers. A new conical spiral tube bundles was proposed by Yan et al. which is feasible to a nested installation via its conical structure. The tube bundles consist of two pipes, which are conical spiral structure and connected via a rigid body. Different bundles are fixed as a nested structure in the shell-side of heat exchangers via its conical spiral structure. Conical spiral tube bundles are widely used in heat transfer enhancement of flow-induced vibration.

The work conducted by Naphon and Suwagrai discussed the heat transfer and pressure drop of a horizontal spirally coiled tube with both experimental analysis and numerical simulation. Ho et al. investigated the heat transfer performance of spiral coil heat exchanger with relevant correlations of tube-side and air-side heat transfer coefficients in different conditions. A subsequent work was done in the study of the fin efficiency of spiral coil, which can be seen in Naphon and Wongwises.

The pipe curvature causes centrifugal forces to act on the flowing fluid, resulting in a secondary flow pattern perpendicular to the main axial flow. This secondary flow pattern generally consists of two vortices, which move fluid from the inner wall of the tube across the center of the tube to the outer wall. Upon reaching the outer wall it travels back to the inner wall. The secondary flow increases heat transfer rates as it moves fluid across the temperature gradient. Thus, there is an additional convective heat transfer mechanism, perpendicular to the axial flow, which does not exist in straight tube heat exchangers (except when produced by buoyancy forces).

2. OBJECTIVE

The objective of this work is to determine the heat transfer characteristics for a helical double-pipe heat exchanger by varying the flow rates of a single fluid in both the inner and outer tubes for counter flow and to compare the same with the double-pipe straight tube heat exchanger. Correlations between Nusselt number and Dean number for the helical coiled heat exchanger are also developed. The problem is defined and meshing is done in GAMBIT 2.4.6 and FLUENT 6.3.26 is used to predict the flow and temperature contours of both the heat exchangers.

3. METHEDOLOGY

3.1. Modelling

Geometries for the heat exchangers were created in AutoCAD 2010 as shown in Figure 1 and Figure 2. Then it is exported as ACIS (.sat) files to GAMBIT 2.4.6 for mesh generation. After generating mesh for both the heat exchangers, the meshed models are then exported as mesh (.msh) files to FLUENT 6.3.26 for analysis.

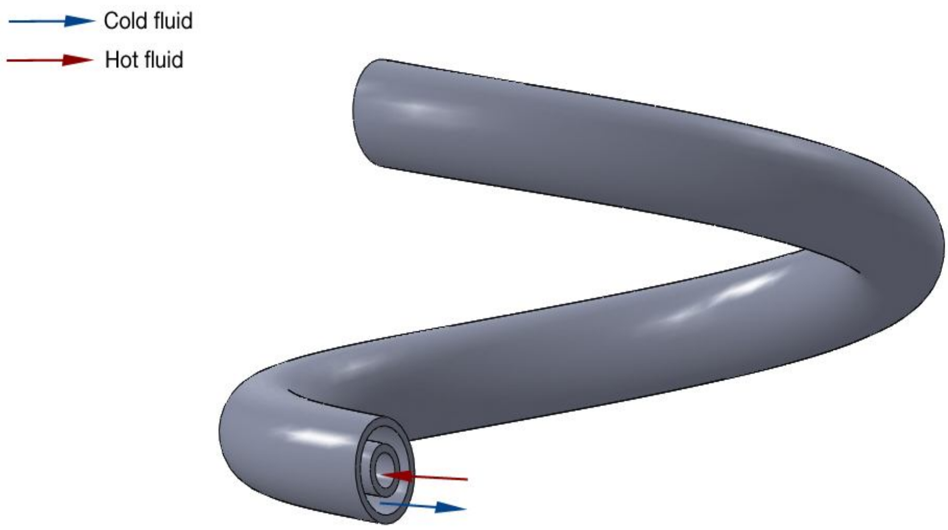

Figure 1. Schematic Diagram of the geometry of helical tube heat exchanger

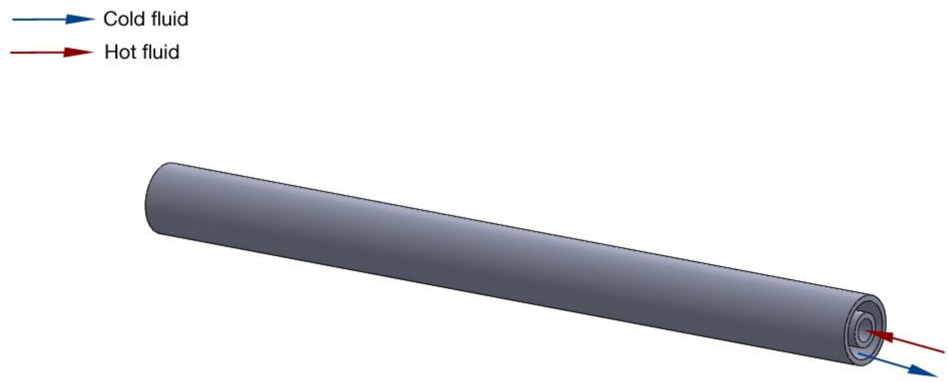

Figure 2. Schematic Diagram of the geometry of straight tube heat exchanger

3.2 CFD Analysis

The k-ε standard turbulence model suggested by Wang and Chen is used as the viscous model. In the simulation of the laminar fluid flow, the flow and pressure equations were solved with SIMPLE algorithm, which is one of the three widely used velocity-pressure coupling algorithm in FLUENT 6.3.26. The assumptions made for simplifying the problems are:

1. Radiation and natural convection effects are ignored.
2. The fluid is assumed to be incompressible.
3. Flow is assumed to be steady and turbulent.

Mass flow rate is given at the inlet whereas pressure value is given at outlet as the inlet and outlet boundary conditions for both the heat exchangers. For outermost walls of the heat exchangers the boundary condition given is that the wall is adiabatic. Hot water enters through the inner tube at 370K for both the heat exchangers and cold water at 280K enters through the outer tube in the opposite direction. Inlets and outlets were located at each end of the coil. The boundary conditions associated with the inlets specify the inlet velocities in the axial direction. The outer surface of the heat exchanger was set to be adiabatic and the inner coil was set to allow conductive heat flow through the tube. Simulations were performed using water for four different mass flow rates in the inner and outer tubes (0.8 kg/s, 1.1 kg/s, 1.4 kg/s and 1.7 kg/s). The material for the pipes is taken as copper.

3.3 Calculation of Heat Transfer Coefficients

The heat transfer coefficient was found by using the equation,

$$h = \frac{Q}{A.\Delta T} \tag{1}$$

Q = heat transfer (W),

h = heat transfer coefficient (W/m^2K),

A = area of heat transfer (m^2),

ΔT = difference between bulk average fluid temperature and average coil temperature (K)

Heat transfer coefficients were calculated for both the inner and outer tubes. For these calculations, average bulk temperatures were used.

4. MODEL VALIDATION

The model was validated by comparing the results of a double-pipe helical heat exchanger modeled using the same software with that of literature of Timothy J. Rennie et al.The model consisted of a concentric coil heat exchanger (an inner coil surrounded by an annulus, surrounded by an outer coil). Geometries for the heat exchanger were created in AUTOCAD 2010 and exported as sat files to GAMBIT 2.3 for meshing. The heat exchanger had a length of 2π (one full revolution) and the pitch was 0.115 m. The analysis was done in Fluent 6.3.26. The material used was Iron for the coils and the fluid through the exchanger was water. A flow rate of 0.00835 kg/s was given to both the fluids through inner coil and annulus. The graph in figure 3 shows the matching characteristics between the literature and present study with an accuracy of 98.6%.

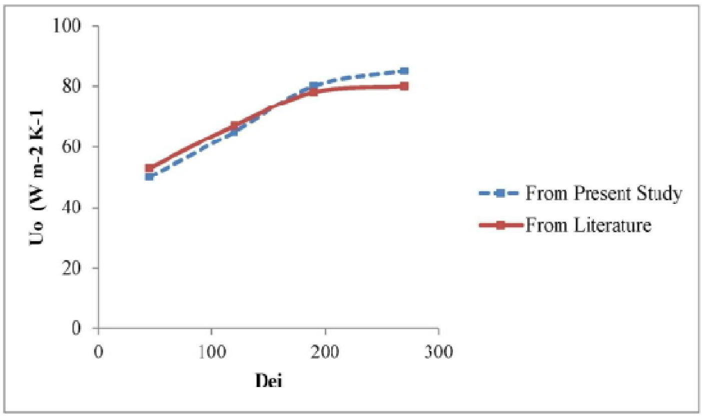

Figure 3. Overall heat transfer coefficient versus the inner Dean number

5. RESULTS AND DISCUSSION

Figure 4.(a) and Figure 4.(b) illustrates the inner tube temperature contours of both helical and straight heat exchangers for various mass flow rates and for an inlet temperature of 370K. The same are shown in Figure 5.(a) and Figure 5.(b) for the outer tube of both the heat exchangers. The temperature contours of the inner tube indicates that the hot water enters the tube from one end and releases heat to the cooling water circulating in the outer tube and thus water exits the tube at a lower temperature. And consequently, the cooling water enters the outer tube from the opposite end and gets heated up. From Figure 4.(a) and Figure 4.(b) it is evident that for the inner tube, the hot water gets cooled up more for helical geometry than that for the straight geometry. It is also evident from Figure 5.(a) and Figure 5.(b) that the cooling water carries away more heat in the case of helical tube than in the straight tube. From the contours given in Figure 4.(a) and Figure 4.(b) it is clear that there is a significant decrease in temperature along the length of the duct in the case of helical tube as compared to the straight geometry for various mass flow rates.

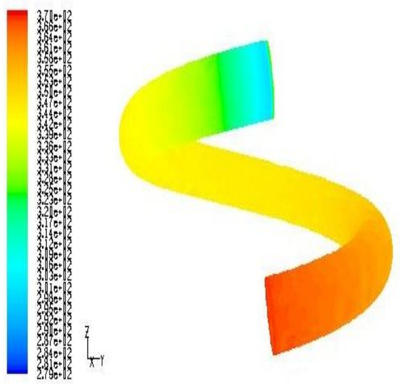

Figure 4.(a)

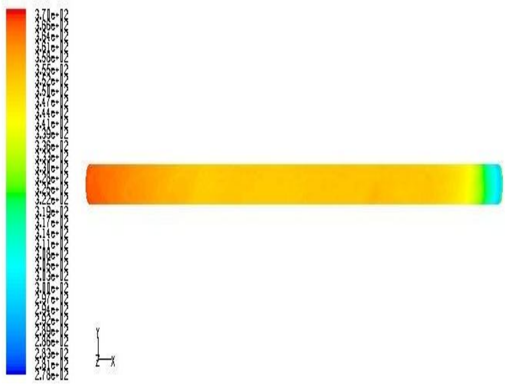

Figure 4.(b)

Temperature contours of the inner helical and straight tube heat exchangers for a mass flow rate of 0.8kg/s

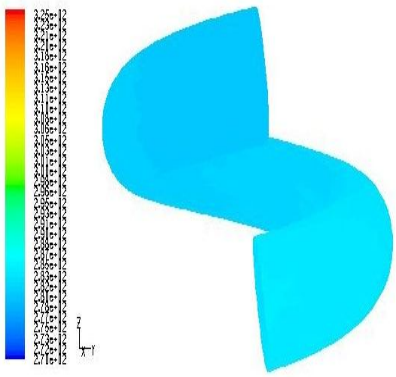

Figure 5. (a)

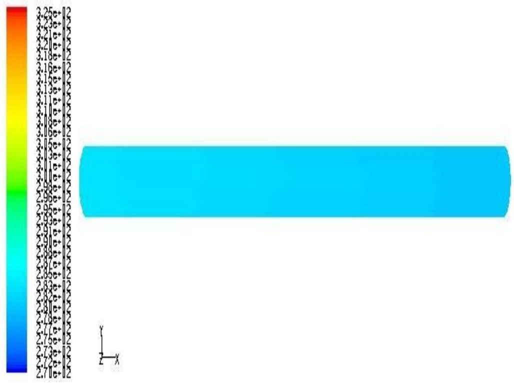

Figure 5. (b)

Temperature contours of the inner helical and straight tube heat exchangers for a mass flow rate of 0.8kg/s

From the various flow rates tested, it is found that as the flow rate increases the wall temperature decreases, resulting in an increase in heat transfer coefficient at the interface. Figure 6 depicts the variation of heat transfer coefficient for both the helical and straight tube heat exchanger for various mass flow rates which shows a remarkable increase of heat transfer coefficient by 10% for the helical tube heat exchanger when compared to the straight tube heat exchanger, indicating that a helical tube heat exchanger is efficient than a straight tube heat exchanger.

Figure 7 and Figure 8 illustrates the variation of Nusselt number versus the Dean number for the helical tube heat exchanger. Nusselt number and Dean number where calculated by using the relations.

$$Nu = (hD_h)/k \qquad (2)$$

and

$$De = Re\sqrt{\delta D_h} \qquad (3)$$

h= heat transfer coefficient.

D_h= hydraulic diameter

k= thermal conductivity

Re= Reynolds number

δ = curvature of helix

It shows that Nusselt number is varying linearly with that of Dean number for different values of mass flow rates. Regression analysis was used to find out the correlations between the both as $Nu = 0.0271\ De^{0.9949}$ for the inner tube and $Nu = 0.1407\ De^{1.0092}$ for the outer tube respectively.

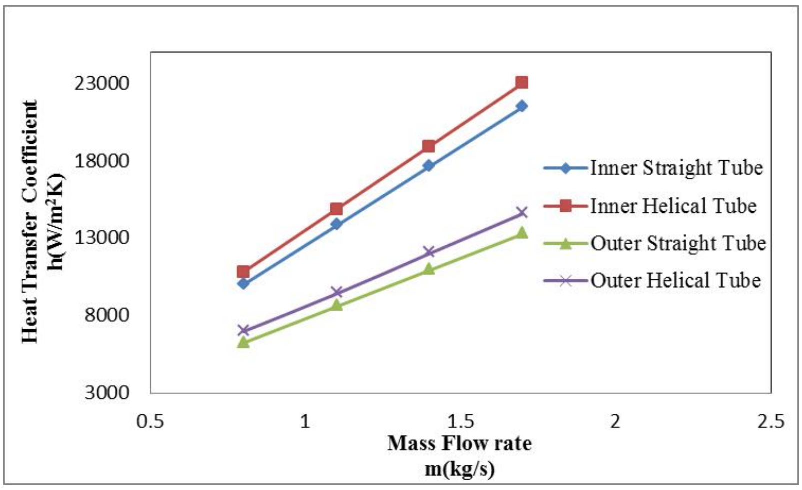

Figure 6. Heat transfer coefficient versus Mass Flow rate for both helical and straight heat exchangers

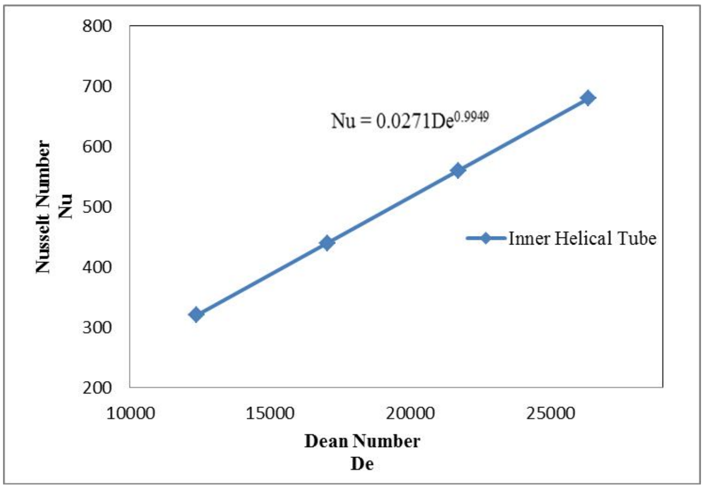

Figure 7. Nusselt Number versus Dean Number for inner helical tube

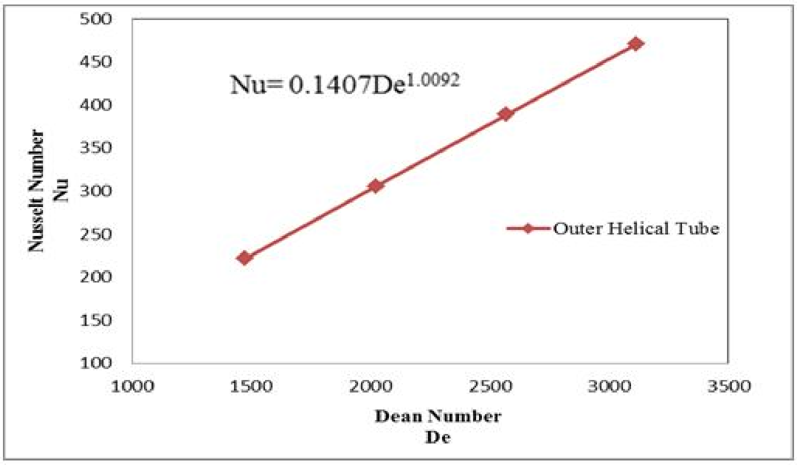

Figure 8. Nusselt Number versus Dean Number for outer helical tube

6. CONCLUSION

Comparison of heat transfer characteristics in helical tube heat exchanger and straight tube heat exchanger is carried out using computational method. Results show that the heat transfer characteristics of the helical tube heat exchanger is much better than that of straight tube heat exchanger, with remarkable increase in the heat transfer coefficient. For a particular mass flow rate, helical tube heat exchanger provides an increase in heat transfer coefficient by 10%. From the simulations made, it is also found that the heat transfer coefficient increases with the mass flow rate and the results are interpreted by predicting correlations between Nusselt number and Dean number as $Nu=0.0271De^{0.9949}$ for inner helical tube and $Nu=0.1407De^{1.0092}$ for the outer helical tube respectively.

7. REFERENCES

[1] T.S. Wang and Y.S. Chen, 1993, "Unified Navier–Stokes flow field and performance analysis of liquid rocket engines," AIAA Journal, vol. 9, pp. 678–685.

[2] C. X. Lin and M. A. Ebadian, 1997, "Developing turbulent convective heat transfer in helical pipes," International Journal of Heat and Mass Transfer, vol.40, 3861-3873.

[3] Timothy J. Rennie and Vijaya G.S. Raghavan, 2005, "Experimental studies of a double-pipe helical heat exchanger," Experimental Thermal and Fluid Science, vol. 29, pp. 919–924.

[4] Timothy J. Rennie and Vijaya G.S. Raghavan, 2006, "Numerical studies of a double-pipe helical heat exchanger," Applied Thermal Engineering, vol. 26, 1266–1273.

[5] I. Conte and X.F. Peng, 2008, "Numerical investigations of laminar flow in coiled pipes," Applied Thermal Engineering, vol.28, 423–432.

[6] Yan Ke, Ge Pei-qi, Su Yan-cai and Meng Hai-tao, 2011, "Numerical simulation on heat transfer characteristic of conical spiral tube bundle," Applied Thermal Engineering, vol. 31, 284-292.