International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Index Copernicus Value (2013): 6.14 | Impact Factor (2013): 4.438

Parametric Comparison of Heat Transfer in Helical and Straight Tube-In-Tube Heat Exchanger

Suraj R. Gurav

B.E. Mechanical, Modern College of Engineering, Pune University, 411020, India

Abstract: ***Helical pipes can be used for heat transfer enhancement in heat exchangers. The purpose of this work is to compare tube-in-tube helically coiled heat exchanger with a straight tube heat exchanger. In current work the fluid to fluid heat exchange is taken into consideration. The actual experimentation is carried out on tube-in-tube helical coil heat exchanger and tube-in-tube straight heat exchanger by keeping mass flow rate constant for both the fluids. The results were plotted graphically for comparison of heat transfer in both heat exchangers.***

Keywords: Dean number, pressure drop, heat transfer coefficient, secondary turbulence, fouling, Tube-in-tube helical coil, Nusselt number.

1. Introduction

Heat exchangers are used in variety of applications including power plants, nuclear reactors, refrigeration and air-conditioning systems, automobile industries, chemical processing, and food industries. Besides improving the performance of heat exchanger, heat transfer enhancement techniques affect the heat exchanger size. In general, the enhancement techniques can be divided into two groups - active and passive techniques. The active techniques require external forces like fluid vibration, electric field, and surface vibration. The passive techniques require special surface geometries or fluid additives like tube inserts. Helically coiled tubes have been introduced as one of the passive heat transfer enhancement techniques and are widely used in various industrial applications. Many studies by various scientists have indicated that helically coiled tubes are superior to straight tubes when employed in heat transfer applications .The centrifugal force due to the curvature of the tube results in the secondary flow development which enhances the heat transfer rate.

2. Literature Survey

Pramod S. Purandare[1] did the analysis of Helical Coil Heat Exchanger. The range of *Re* considered for the analysis is about 100 to 6000 and the analysis is carried out for laminar and turbulent region separately for tube side heat transfer coefficient (*hi*) and Nusselt number(*Nu)*. He used four different correlations for calculating Nusselt number given byy M.R. Salimpour, Kalb et al, Roger et al and Xin et al. The analysis also showed that, as tube diameter increases with constant coil diameter (*D*), Nusslet number also increases.

B. Chinna Ankanna et al.[2] focused on an increase in the effectiveness of a heat exchanger and analysis of various parameters affecting it.

J. S. Jayakumar[3] continued to study a number of numerical experiments to find the influence of coil parameters, such as pitch circle diameter, coil pitch and pipe diameter on heat transfer.

N. D. Shirgire et al.[4] considered the fluid to fluid heat exchange. Wilson plot method was used to calculate inner heat transfer coefficient. The result proved that heat transfer coefficient is affected by the geometry of the heat exchangers.

Earlier Dittus-Boelter correlation[10]

$$\mathrm{Nu} = 0.023\mathrm{Re}^{0.8}\mathrm{Pr}^{n}$$

was being used for turbulent flow in tubes. Different values of 'n' were needed because of variation of viscosity with temperature. Instead of using different exponents for heating and cooling, direct correlation for viscosity can be used. This takes the form of ratio of viscosity at bulk fluid temperature to viscosity at wall temperature –

$$\varnothing_v = \left(\frac{\mu}{\mu_w}\right)^{0.14}$$

With addition of this, a standard equation – Sieder Tate correlation[10] is put forth for general use.

3. Methodology

The experiment on tube-in-tube heat exchanger was performed for both – straight as well as helical configuration. In experiment, all the possible flow arrangements such as counter flow and parallel flow were analyzed. The temperature difference and flow rates of fluids are recorded and all the fluid properties were taken at bulk average temperature which is arithmetic mean of inlet and outlet temperature. As each flow geometry requires different correlations be used to obtain heat transfer coefficients, further calculations of Nusselt number are carried out using the correlations given by Salimpour, Kalb, Xin and Roger for helical coil arrangement. Correlation given by Roger[1],

$$\mathrm{Nu} = 0.023\mathrm{Re}^{0.85}\mathrm{Pr}^{0.4}\delta^{0.1}$$
$$\text{for Re} > 2000$$

While, Nusselt number was calculated using Sieder Tate correlation for straight tube configuration.

$$Nu = 0.023Re^{0.8}Pr^{\frac{1}{3}}(\frac{\mu}{\mu_v})^{0.14}$$

For 0.7< Pr < 160

Specifications of tube-in-tube helical coil heat exchanger:

Table 1: Specification of Helical coil

Parameters	Dimensions
Inner tube diameter, d_i	6 mm
Outer tube diameter, d_o	12 mm
Coil diameter, D	165.2 mm
Length of coil, L	3260 mm
Pitch, b	25 mm

4. Parameters affecting Heat transfer

4.1 Parameters common to straight and helical tube-in-tube arrangement

i. Reynolds Number- Reynolds number expresses the ratio of inertial forces (resistance to motion) to viscous forces (heavy and sticky). Higher values of this parameter indicate that flow is invicid. Reynolds number is deciding factor for type of flow- whether laminar or turbulent. The value of this parameter depends on density, viscosity of fluid and tube diameter. In experiment, as mass flow rate of fluid is kept same for both helical and straight tube-in-tube arrangement, the Reynolds number remained same. The experiment was conducted by keeping Reynolds number range from 2900 to 18000.

ii. Hydraulic diameter- In order to calculate velocity of fluid flowing through annular space, it is necessary to calculate hydraulic diameter. Hydraulic diameter can be calculated by dividing four times cross-sectional area of tube by its circumference.

$$D_h = \frac{4\,A}{P}$$

Where, D_h = hydraulic diameter, (m)
A = cross sectional area, (m^2)
P = perimeter, (m)

iii. Pressure Drop – As friction takes place between fluid and tube walls, pressure drop takes place. The pressure drop depends on friction factor which ultimately depends on relative roughness of material. Correlation given by B.S.V.S.R. Krishna[8]

$$\Delta p = \frac{2f_c L \rho V^2}{d}$$

As per following correlation, the friction factor for helical tube in tube configuration is higher than straight tube in tube arrangement.

Correlation is given by White (1932),

$$f_c = f_s(1 + 0.033(\log_{10} De)^{4.0})$$

$$\text{for } De > 1$$

Where, De = Dean number

The pressure drop occurring in helical curved tube is found to be always higher than that of straight tubes for same flow rates.

4.2 Parameters for Helical Tube-In-Tube Arrangement

i. **Curvature Ratio –** curvature ratio establishes relation between tube diameter and coil diameter. After several studies Dean put forth a number called as Dean Number which is calculated as,

$De = Re *(d/D)^{0.5}$

Where,
d = tube diameter (m)
D = coil diameter (m)
r = tube radius (m)
R = coil radius (m)

While calculating dean number for fluid flow in annular space, ‘d’ is the hydraulic diameter. The ratio ‘r/R’ is the curvature ratio. Its effect on heat transfer is studied experimentally and theoretically.

ii. **Secondary Turbulence –** Turbulence is random movements of fluid particles. Turbulence is the flow regime that greatly influences the heat transfer rates and require power for pumping. The centrifugal force due to curvature of tube results in the development of secondary turbulence. The centrifugal force experienced by fluid flowing through inner tube is higher than the centrifugal force experienced by fluid flowing through annular space. This intensity of secondary turbulence is function of tube diameter (d) and coil diameter (D). This secondary turbulence developed in helical coil allows better mixing of fluid as compared to simple turbulence in straight tube. Dean was the first person to study the flow patterns in curved pipes using toroidal co-ordinate system.

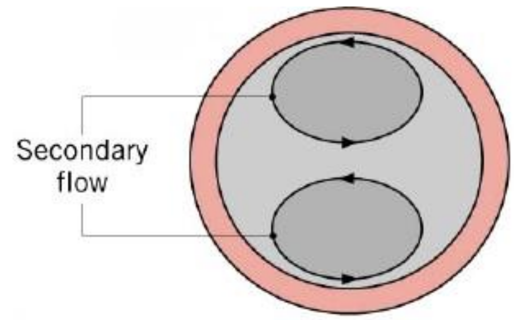


Figure 1: Secondary flow pattern in single tube helical coil[9]

4.3 Parameters for straight tube-in-tube arrangement

1) Fouling – In straight tube-in-tube heat exchanger, due to absence of any obstruction to fluid flow, there are chances of slag deposition on walls of heat exchanger in contact with fluid. This deposition reduces the heat transfer rate. Most of the times deposition of slag near valves and joints leads to leakages. The similar problem is absent in helical tube-in-tube arrangement. Due to secondary turbulence the

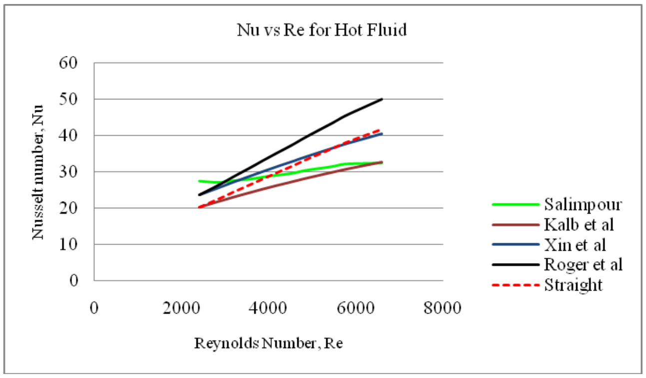
helical arrangement can be said as self cleaning heat exchanger.
2) No Secondary turbulence – due to absence of curvature there is no secondary turbulence in straight tube-in-tube configuration. As stated earlier, this gives poor mixing of fluids and hence heat transfer is affected.

5. Results and Discussions

Based on observations, the effectiveness for all the flow arrangements are calculated and it is found that Counter flow arrangement with cold water flowing through inner tube and hot water flowing through annular space is most effective. It gives the effectiveness of 0.6767 for the mass flow rate of 210 lph.

5.1 Effect on Nusselt number

Next two graphs show the effect of Reynolds number on Nusselt number. Correlations given by different scientists consider various parameter while calculating Nusselt number. Hence, four different curves for each correlation were plotted.



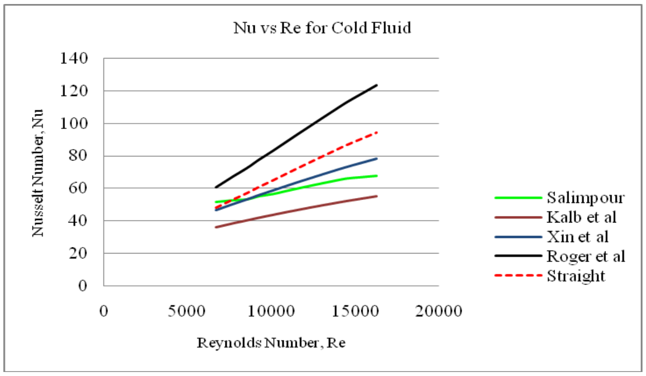


Figure 2: Nusselt number, Nu Vs Reynolds number, Re

From above graphs it can be seen that, for same Reynolds number, value of the nusselt number given by Roger for helical tube in tube arrangement is higher than straight tube arrangment. As the Roger considered curvature ratio for calculation of nusselt number, it results into increased heat transfer due to secondary turbulence. Thus, values given by Roger are considered for comparison.

5.2 Effect of Pressure drop

Next two graphs compare the effect of pressure drop on heat transfer coefficient for both straight and helical arrangements. With gradual increase in mass flow rate, pressure drop increases more rapidly in tube-in-tube helical coil heat exchangers as compared to straight tube-in-tube arrangement. Pressure drop acts like driving force for heat transfer. These graphs highlight this. The ratio of pressure drop to heat transfer coefficient for helical tube-in-tube arrangement is comparable with straight tube-in-tube arrangement. Pressure drop curve for straight tube-in-tube is steeper than helical tube-in-tube arrangement.

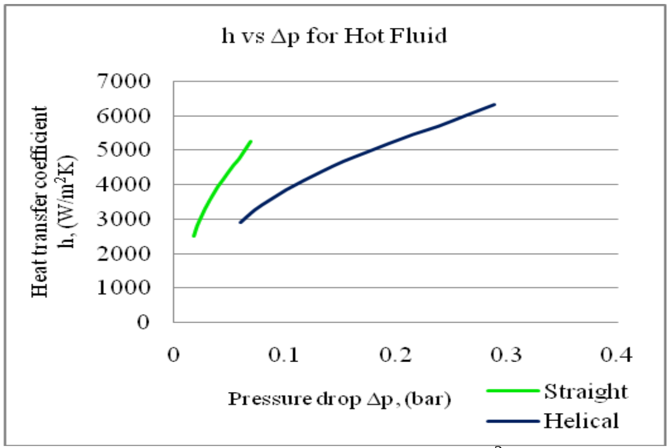
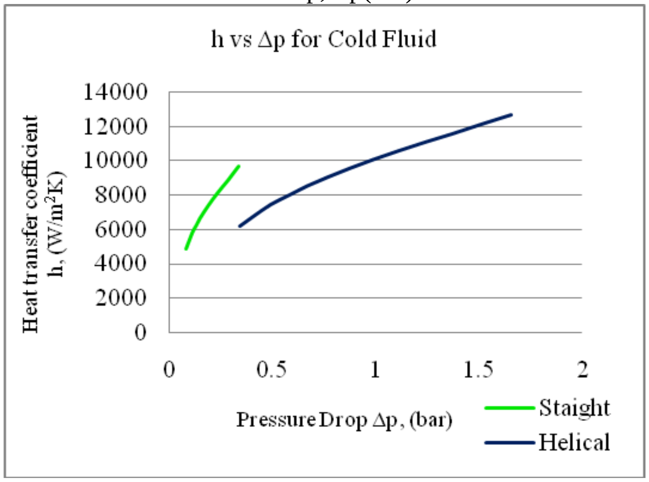


Figure 3: Heat Transfer coefficient, h (W/m^2K) Vs Pressure drop, Δp(bar)



6. Conclusion

Comparative experimentation and analysis is carried out between tube-in-tube helical coil heat exchanger and straight heat exchanger. The results of this analysis showed that previously published correlations yield similar results to the one obtained in this work. Based on the experiments, the following conclusions are drawn:
1) Intensity of secondary flow developed goes on increasing with increase in curvature ratio. This increase in turbulence causes significant mixing of fluid inside the tube which resultantly increases heat transfer coefficient.

2) The heat transfer coefficient in helical heat exchanger increased with flow rate and approached a maximum value at higher flow rates. It is observed that the heat transfer coefficient for helical tube-in-tube arrangement is approximately 10 to 20 times that of straight tube-in-tube arrangement.
3) This heat transfer is obtained on the expense of pressure drop which is 200-300% higher than straight tube in tube heat exchanger, which is within permissible limits as per earlier research in similar field.
4) For the same surface area, the heat energy absorbed by helical tube is more than that of straight copper tube. For same heat transfer rate of these heat exchangers, straight tube-in-tube heat exchanger is large in size and thus bulky. Thus compact size provides a distinct benefit of tube-in-tube helical coil heat exchanger.

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Author Profile

Suraj Gurav received B.E. degree in Mechanical Engineering, from Modern College of Engineering, Pune University in 2015. Currently working with Neilsoft Ltd. Pune.