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A Review on Helical Coil Heat Exchanger

Devendra Borse[1], Jayesh V. Bute[2]
[1]*Student (Mechanical Engineering)/Pimpri Chinchwad College Of Engineering & Research, Pune, India)*
[2]*Asst. Prof./Pimpri Chinchwad College Of Engineering & Research, Pune, India)*

Abstract: A heat exchanger is a device that is used to transfer thermal energy between two or more fluids, between a solid surface and a fluid, or between solid particulates and a fluid, at different temperatures and in thermal contact without mixing of the fluids. As heat exchangers are used in many applications, the efficient heat exchangers have tremendous demand from industries. Since global industrialization, efforts have been made to increase the heat transfer, increase the rate of heat transfer, minimize size of heat exchangers, and mainly increase the effectiveness. Enhancing the heat transfer by the use of helical coils has been studied and researched by many researchers, because of the fluid dynamics inside the pipes of a helical coil heat exchanger. The centrifugal force due to the curvature of the tube results in the secondary flow development. The curvature of the coil governs the centrifugal force while the pitch or helix angle influences the torsion subjected to the fluid. Due to the curvature effect, the fluid streams in the outer side of the pipe moves faster than the fluid streams in the inner side of the pipe. The difference in velocity sets-in secondary flows which enhances the heat transfer rate. The main purpose of this study is to analyze the helical coil heat exchanger on the basic of Dean Number, heat transfer coefficient and Reynolds number. Based on the analysis, it is found that the performance of heat exchanger is improved with use of helical coil tube structure and it infers that the helical coiled tube heat exchanger is a promising modification over conventional type of heat exchanger.
Keywords: Helical Coil Heat Exchanger, Dean number, LMTD, Fouling Factor

I. INTRODUCTION

Heat exchange between flowing fluids is one of the most important physical process and a variety of heat exchangers are used in different industrial applications, as in process industries, compact heat exchangers nuclear power plant, refrigeration, power plants, chemical processing and food industries, etc. The main purpose of constructing a heat exchanger is to get an efficient method of heat transfer from one fluid to another, by direct contact or by indirect contact. The heat transfer occurs by three modes which are: conduction, convection and radiation. In a heat exchanger, the heat transfer through radiation is not taken into consideration as it is negligible in comparison to conduction and convection. Conduction takes place when the heat from the high temperature fluid flows through the surrounding solid wall. The conductive heat transfer can be enhanced by selecting minimum thickness of wall of a highly conductive material. But convection plays a major role in the performance of a heat exchanger. Helical coil configuration is very effective for heat exchangers because they can accommodate a large heat transfer area in a very small space, with very high heat transfer coefficients.

The flow through a curved pipe has been attracting much attention of researchers. The fluid flowing through curved tubes induces secondary flow in the tubes.

The curved shape of the tube causes the flowing fluid to experience centrifugal force. The extent of centrifugal force experienced by flowing fluid depends on the local axial velocity of the fluid particle and radius of curvature of the coil. The fluid particles flowing at the core of the pipe have higher velocities than those flowing near to the pipe wall. Thus the fluid particles flowing close to the tube wall experience a lower centrifugal force than the fluid particles flowing in the tube core. This causes the fluid from the core region to be pushed towards the outer wall. This stream bifurcates at the wall and drives the fluid towards the inner wall along the tube periphery, causing generation of secondary flows which produce additional transport of the fluid over the cross section of the pipe. This additional convective transport increases heat transfer and the pressure drop when compared to that in a straight tube. This secondary flow in the tube has significant ability to enhance the heat transfer due to mixing of fluid. Forced convection in a heat exchanger transfers the heat from one moving stream to another stream through the wall of the pipe. The cooler fluid removes heat from the hotter fluid as it flows along or across it.

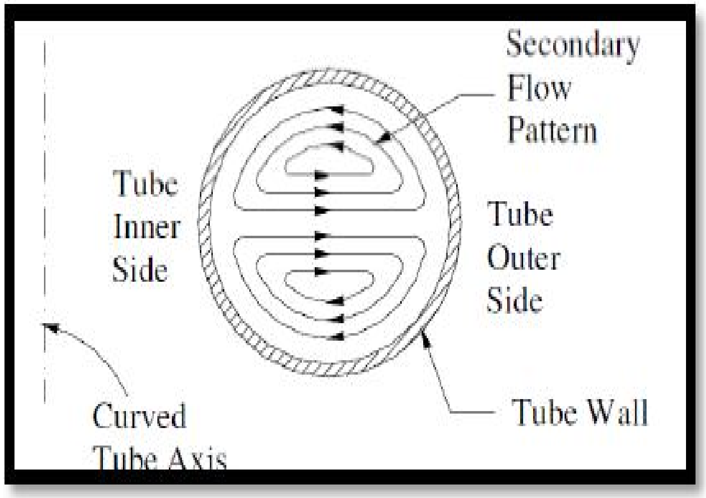

Figure: Fluid flow in curved tubes

A. Heat Transfer Enhancement

For well over a century, efforts have been made to produce more efficient heat exchangers by using various methods of heat transfer enhancement. The study of enhanced heat transfer has gained serious momentum during recent years, however, due to increased demands by industry for heat exchange equipment that is less expensive to build and operate heat exchangers than standard heat exchanging devices. Savings in materials and energy use also motivates researchers for the development of improved methods of heat transfer enhancement. When designing cooling systems for automobiles, it is important to design the heat exchangers which are are especially compact, lightweight and easily maintainable. These applications, as well as numerous others, have led to the development of various design modifications in heat exchanging devices.

B. Log Mean Temperature Difference

Heat flows between the hot and cold streams due to the temperature difference existing between two sides. From the heat exchanger equations, it can be shown that the integrated average temperature difference (for either parallel or counter flow) may be written as:

$$\Delta\theta = LMTD = \frac{\theta_1 - \theta_2}{\ln\left(\frac{\theta_1}{\theta_2}\right)}$$

The effective temperature difference calculated from this equation is known as the log mean temperature difference, abbreviated as LMTD, based on the type of mathematical average that it describes.

While the equation applies to either parallel or counter flow, it can be seen that effective LMTD will always be greater in the counter flow arrangement.

C. Type of Flow [Counter Flow or Parallel Flow or Cross Flow]

There are major two advantages of counter flow, (A) Larger effective LMTD and (B) greater potential energy recovery. The advantage of the larger LMTD is that, a larger LMTD permits a smaller heat exchanger area, Ao, for a given heat transfer, Q. Sometimes, however, parallel flows are desirable where the high initial heating rate may be used and where it is required the temperatures developed at the tube walls are moderate. In heating very viscous fluids, parallel flow provides for rapid initial heating and consequent decrease in fluid viscosity. In cross flow, the fluid flow occurs in perpendicular direction. From the LMTD point of view, counter flow is best, cross flow is better and parallel flow is good.

D. Design Parameters of Helical Coil Heat exchanger

General parameters of designing a helical coil heat exchangers are as follows:

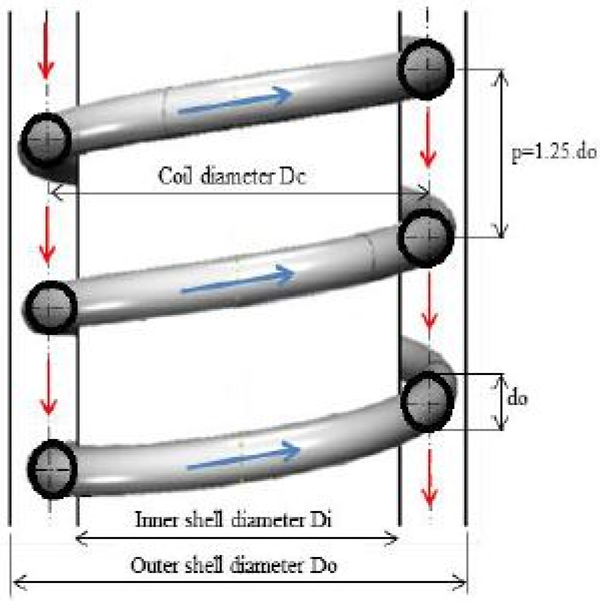

Figure : A Schematic cut-away view of a helical coil heat exchanger.

The coil length L_{coil}, needed to make N_{coil} turns:

$$L_{coil} = N_{coil}\sqrt{(\pi d_o)^2 + p_{itch}^2}$$

The volume occupied by the coil:

$$V_c = \frac{\pi}{4} {d_o}^2 L_{coil}$$

The volume of the shell-side (annulus):

$$V_a = \frac{\pi}{4}\left(D_{o\_in}^2 - D_{i\_out}^2\right) p_{itch} N_{coil}$$

The volume available for the flow of fluid in the annulus

$$V_f = V_a - V_c$$

The shell-side equivalent diameter of the coiled tube:

$$D_e = 4V_f / \pi d_o L_{coil}$$

E. Dean Number

The Dean number represents the ratio of the viscous force acting on a fluid flowing in a curved pipe to the centrifugal force. Dean number is used to characterise the flow in a helical pipe. The Dean number will never be larger than the Reynolds number for the same flow. As the Dean number approaches that of the Reynolds number, the effects of centrifugal force dominate the flow. From study [8], it is found that a larger heat transfer coefficient is obtained in case of helical coil due to the geometry of helical coil.

$$De = \frac{\rho V d}{\mu}\sqrt{\frac{d}{D}} = Re\sqrt{\frac{d}{D}}$$

F. Heat Transfer Coefficient

In case of convective heat transfer from surface to fluid, in the immediate vicinity of the surface and film of fluid which is free of turbulence, covers the surface. Through this film heat transfer takes place by thermal conduction and as thermal conductivity of most fluids is low. Therefore increase in velocity of fluid over the surface results in improved heat transfer mainly because of reduction in thickness of film. The equation for rate of heat transfer by convection under steady state is given by,

$$\mathbf{Q = h.\ A.\ \Delta T}$$

Where 'h' is the film coefficient or surface coefficient.

The value of 'h' depends upon the properties of fluid within the film region, hence it is called 'Heat Transfer Coefficient'. It depends on various properties of fluid, linear dimensions of surface and fluid velocity (i.e. nature of flow).

Numerically, Heat Transfer Coefficient (h) is the quantity of heat transferred in unit time through unit area at a temperature difference of one degree between the surface and the surrounding. Its SI unit is (W/m2K). The term 1/h is the thermal resistance. The 'overall Heat Transfer Coefficient' can be in terms of thermal resistances. The summation of individual resistances is the total thermal resistance and its inverse is the overall Heat Transfer Coefficient, U. That is,

$$\frac{1}{U} = \frac{1}{h_o} + \frac{A_o}{A_i}\frac{1}{h_i} + R_{fo} + \frac{A_o}{A_i}R_{fi} + R_w$$

Where,

U = overall heat transfer coefficient based on outside area of tube wall

A = area of tube wall

h = convective heat transfer coefficient

Rf = thermal resistance due to fouling

Rw = thermal resistance due to wall conduction

and suffixes 'i' and 'o' refer to the inner and outer tubes respectively.

Due to presence of secondary flows, the heat transfer rates and the fluid pressure dropare higher in helical tubes.

II. LITERATURE REVIEW

A. Dravid, A. N., Smith., K. A., Merrill, E.A., and Brian, P.L.T.[1],

In their research they have presented that, The Helical coils of circular cross section have been used in wide variety of applications due to its simplicity in case of manufacturing. Flow in case of curved tube is different than the flow in straight tube because of the presence of the centrifugal forces. These centrifugal forces generate secondary flows, normal to the primary direction of flow with circulatory effects that increases both the friction factor and rate of heat transfer. The intensity of secondary flow developed in the tube is the function of tube diameter (d) and coil diameter (D).

B. Jaivin A. Varghese[2],

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. Following graph presented in their study gives the variation of effectiveness with inlet temperature of hot water for both helical coil and straight tube heat exchangers. From this result it is found that the helical coil heat exchanger is having better effectiveness than straight tube heat exchanger.

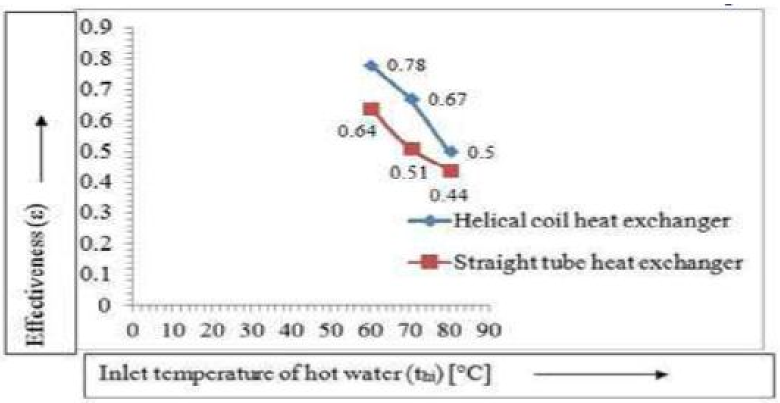

Figure: Variation of Effectiveness with Inlet temperature of hot water

C. Chinna Ankanna, B. Sidda Reddy.[3

In their research they have analyzed the helical coil heat exchanger. They mainly focused on increasing the effectiveness of a heat exchanger and analysing various parameters that affect the effectiveness of a heat exchanger. They also deal with the performance analysis of heat exchanger by varying various parameters like number of coils, flow rate and temperature. The results of the helical tube heat exchanger are compared with the straight tube heat exchanger in both parallel and counter flow by varying parameters like temperature, flow rate of cold water and number of turns of helical coil. They found that Heat transfer in case of helical coil heat exchanger is more than that of straight tube helical coil heat exchanger.

D. A. Chaves, D. R. F. de Castro, W. Q. Lamas, J. R. Camargo and F. J. Grandinetti [4],

in their study they have concluded that, The flowing fluid experiences centrifugal force because of curved shape of the helical tube. The local axial velocity of the fluid particle and the radius of curvature of the coil affects the magnitude of centrifugal force experienced by fluid. The velocity of fluid particles flowing at the core of the tube is higher than those flowing near to the tube wall. Thus, less centrifugal force will be experienced by the fluid particles flowing close to the tube wall than in the tube core. This pushes the fluid from the central or core region towards the outer wall (away from the coil axis). This stream bifurcates at the wall and drives the fluid towards the inner wall generating counter-rotating vortices referred as secondary flows. This secondary forces developed help in increasing the heat transfer rate and the pressure drop in case of helical coil.

E. Jung-Yang San, Chih-Hsiang Hsu and Shih-Hao Chen[5],

Heat transfer characteristics of a helical heat exchanger", found that the impact of coil curvature is to suppress turbulent fluctuations arising within the flowing fluid and smoothing the appearance of turbulence. Thus it will increase the value of the Reynolds number (Re) needed to attain a fully turbulent flow, as compared to it of a straight pipe. The impact of turbulent fluctuations suppression enhances as the curvature ratio of coil increases.

F. Jian Wen, Huizhu Yang, Simin Wang, Yulan Xue and Xin Tong[6],

In their research they have presented that, Fouling could be a dynamic development that changes with time and that will increase thermal resistance and lowers the heat transfer coefficient of heat exchangers. It also obstructs the fluid flow, accelerates corrosion and increases pressure drop across heat exchangers. Helical coil heat exchangers have shown significance enhancements in fouling behaviour of heat exchange. Because of helical flow pattern in case of helical tubes, it provides low fouling characteristics. It also increases the schedule cleaning period of tubes.

G. Rahul Kharat, Nitin Bhardwaj, R.S. Jha[7],

carried out a comparative study between helical coil heat exchanger and straight tube heat exchanger, and found that the effectiveness of heat exchanger is greatly affected by hot water mass flow rate and cold water flow rate. When cold water mass flow rate is constant and hot water mass flow rate increased the effectiveness decreases. Increase in cold water mass flow rate for constant hot water mass flow rate resulted in increase in effectiveness. For both helical coil and straight tube heat exchangers with parallel and counter flow configuration this result obtained. Helical coil counter flow is effective in all these conditions than the straight tube parallel flow heat exchanger. Overall heat transfer coefficient on other hand increases with increase in hot water mass flow rate and cold water mass flow rate. Use of a helical coil heat exchanger was seen to increase the heat transfer coefficient compared to a similarly dimensioned straight tube heat exchanger.

III. CONCLUSION

From above study, it is clear that helical coil heat exchangers offer more effectiveness than conventional heat exchangers like straight tube, shell and tube, etc. Due to secondary flow development inside the helical tube, it offers more heat transfer and also increases the rate at which heat transfer takes place. It also increases the friction factor which eventually increases the effectiveness of helical coil heat exchanger per unit pressure drop. It is also seen that the impact of coil curvature is to suppress turbulent fluctuations arising within the flowing fluid and smoothing the appearance of turbulence. Thus it will increase the value of the Reynolds number (Re) needed to attain a fully turbulent flow which results in enhanced effectiveness. Fouling obstructs the fluid flow, accelerates corrosion and increases pressure drop across heat exchangers. Because of helical flow pattern in case of helical tubes, it provides low fouling characteristics. It also increases the schedule cleaning period of tubes.

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