A Review on Investigation of Performance of Pipe in Pipe Helically Coil Heat Exchanger

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Abstract— Enhancing the heat transfer by the use of helical coils has been studied and researched by many researchers, because the fluid dynamics inside the pipes of a helical coil heat exchanger offer certain advantages over the straight tubes, shell and tube type heat exchanger, in terms of better heat transfer and mass transfer coefficients. This configuration offers a high compact structure and a high overall heat transfer coefficient; hence helical coil heat exchangers are widely used in industrial applications. Convective heat transfer between a surface and the surrounding fluid in a heat exchanger has been a major issue and a topic of study in the recent years. In this particular study, an attempt has been made to experimental work of various parameters like radius of tubes, pitch of coil, pitch circle diameter, number of turns of helical coil, flow rate and temperature that affect the effectiveness of a heat exchanger and increases heat transfer rate at two different flows (parallel and counter-flow)on the total heat transfer from a helical tube, where the cold fluid flows in the outer pipe and the hot fluid flowing in the inner pipes of the pipe in pipe helical coiled heat exchanger. This paper focus on the review on helically coiled heat exchanger.

Key words: Helical Coil Heat Exchangers, Parallel Flow And Counter Flow, Coil Configuration, CFD

I. INTRODUCTION

Heat exchangers serve a straight forward purpose controlling a system’s or substance’s temperature by adding or removing thermal energy. Although there are many different sizes, levels of sophistication, and types of heat exchangers, they all use a thermally conducting element usually in the form of a tube or plate to separate two fluids, such that one can transfer thermal energy to the other. Home heating systems use a heat exchanger to transfer combustion - gas heat to water or air, which is circulated through the house. Power plants use locally available water or ambient air in quite large heat exchangers to condense steam from the turbines.

Many industrial applications use small heat exchangers to establish or maintain a required temperature. In industry, heat exchangers perform many tasks, ranging from cooling lasers to establishing a controlled sample temperature prior to chromatography.

A. Helical Coil Heat Exchanger

Helically coiled tubes fig-1 can be found in many applications including food processing, nuclear reactors, compact heat exchangers, heat recovery systems, chemical processing, low value heat exchange, and medical equipment. Curved tubes are of interest to the medical community as blood flow occurs in many arteries that are curved.

Helical coils are very alluring for various processes such as heat exchangers and reactors because they can accommodate a large heat transfer area in a small space, with high heat transfer coefficients and narrow residence time distributions. Due to the extensive use of helical coils in these applications, knowledge about the pressure drop, flow patterns, and heat transfer characteristics are very important.

Pressure drop characteristics are required for evaluating pump power required to overcome pressure drops to provide the necessary flow rates. These pressure drops are also functions of the curvature of the tube. The curvature induces secondary flow patterns perpendicular to the main axial flow direction.

Typically, fluid in the core of the tube moves towards the outer wall, then returns to the inner portion of tube by flowing back along the wall, as shown in figure-2.

Secondary flow can be expected to enhance heat transfer between the tube wall and the flowing fluid. Another advantage to using helical coils over straight tubes is that the residence time spread is reduced, allowing helical coils to be used to reduce axial dispersion in tubular reactors. Thus, for design of heat exchangers that contain curved tubes, or helically coiled heat exchangers, the heat transfer and hydrodynamic characteristics need to be known for different configurations of the coil, including the ratio of tube radius to coil radius, pitch, and Reynolds and Prandtl numbers and Dean Number (De).

Fig. 1: Diagram of Helical Coil

Fig. 2: Secondary flow for low and high Dean Numbers

The fluid motion in curved pipes was first observed by Eustice in 1911. Since then numerous studies have been reported on the flow fields that arise in curved pipes (Dean, 1927, 1928; White, 1929; Hawthorne, 1951; Horlock, 1956;
Barua, 1962; Austin and Seader, 1973) including helical coils, which is a subset of curved pipes. The flow fields have been observed experimentally and numerically. These studies have shown that the secondary flow pattern can change substantially in form as some of the parameters are changed (in this case the Dean number).

The next logical step in observing the flow patterns was to study the patterns in heat transfer applications. The heat generation of the heating element is temperature dependant, as the temperature will not be uniform over the length of the heating coil. Pipe in pipe helical coil heat exchanger design is based on correlations between the Kern method and Bell-Delaware method

- In Bell’s method the heat-transfer coefficient and pressure drop are estimated from correlations for flow over ideal pipes, and the effects of leakage, bypassing and flow of fluid in the pipe zone are allowed for by applying correction factors. This approach will give more satisfactory predictions of the heat-transfer coefficient and pressure drop than Kern’s method; and, as it takes into account the effects of leakage and bypassing, can be used to investigate the effects of constructional tolerances. Bell-Delaware method is more accurate method and can provide detailed results.

In Kern's method is based on experimental work on commercial exchangers with standard tolerances and will give a reasonably satisfactory prediction of the heat-transfer coefficient for standard designs. The prediction of pressure drop is less satisfactory, as pressure drop is more affected by leakage and bypassing than heat transfer. The shell-side heat transfer and friction factors are correlated in a similar manner to those for tube-side flow by using a hypothetical shell velocity and shell diameter.

Some of the works carried out by researchers are as follows:-

Rahul Kharatet. al.[1] analyzed the heat transfer coefficient correlation for concentric helical coil heat exchanger. Their result is based on two most important design parameters such as coil gap and tube diameter which affect the heat transfer performance. It was observed that the heat transfer coefficient decreases with the increase in gap.

The heat transfer coefficient increases with the increase in tube diameter. This is due to reduction in coil gap with increasing tube diameter and the effect of tube diameter is not dissociated with the effect of coil gap.

Mohamed A. AbdRabohet. al. [2] carried out an experimental study for condensation heat transfer inside helical coil. Appropriate analysis of the experimental measurements leads to heat flux and condensation heat transfer coefficient for different operating parameters. The operating parameters were pipe diameter, coil diameter, coil pitch, and coil orientations.

Condensation heat transfer coefficient increases first with the decrease in pipe diameter and coil diameter then it decreases. Also condensation heat transfer coefficient increases with the increase of coil pitch up to a certain value (p>40 mm) then it decreases. Heat transfer coefficient takes higher values for inclined position with angle 45° than the vertical and other inclination angles.

Kapil Devt. al.[3] carried out an empirical study of helical coil heat exchanger used in liquid evaporation and droplet disengagement for a laminar fluid flow. They focussed on design parameters and heat transfer conditions of a generator of a simple vapour absorption refrigeration system with flow condition of refrigerant taken as laminar flow.

If the required design parameters would be changed, then the effectiveness of heat exchanger remains same by increasing the surface area of helical coils. It is also found that the heat transfer coefficient could be increased with the mass flow rate.

Pablo Coronel et. al. [4] has carried out experiments to study heat transfer coefficient in helical heat exchanger under turbulent flow conditions. His study involved the determination of convective heat transfer coefficient in both helical and straight tubular heat exchangers under turbulent flow conditions.

Experiments were conducted in helical heat exchangers, with coils of two different curvature ratios (d/D = 0.114 and 0.078), and in straight tubular heat exchangers at various flow rates (0.00189 - 0.00631 m³/s) and for different end-point temperatures (92 - 149°C). The results show that the overall heat transfer coefficient (U) in the helical heat exchanger is much higher than that in straight tubular heat exchangers. The inside (hi) and outside (ho) convective heat transfer coefficients were determined based on the overall heat transfer coefficient and a correlation to compute the inside convective heat transfer coefficient (hi) as a function of NLRe, NPr, and d/D (dean number) was developed.

Timothy J. Rennieet. al. [5] has carried out experimental studies of a double-pipe helical heat exchanger using two differently size heat exchanger. The mass flow rates in the inner tube and in the annulus were both varied as well as both parallel and counter flow configuration were tested and both parallel flow and counter-flow configurations were tested.

It was observed that there were little differences in overall heat transfer coefficient between parallel and counter flow configurations. Heat transfer rates were found much higher in counter flow configuration than in parallel one. Nusselt number in the inner tube was compared with literature values and found to be in good agreement.

Pramod S. Purandarea et.al.[6] carried out a parametric analysis of helical coil heat exchanger with various correlations given by different researchers for specific conditions.

It was found that helical coils are efficient in low Re. The analysis also shows that, as tube diameter (d) increases with constant coil diameter (D), the curvature ratio (δ) increases, which increases the intensity of secondary developed in fluid flow. The increase in the intensity of secondary developed influid flow increases Nu. Hence, it is desirable to have small coil diameter (D) and large tube diameter (d) in helical coil heat exchanger, for large intensities of secondary in tube.

B. ChinnaAnkanna et.al.[7] carried out a performance analysis of fabricated helical coil heat exchanger”. He investigated the effect of various parameters that affect the effectiveness of a heat exchanger like number of coils, flow rate and temperature. After conducting the
experiments and comparing the results obtained on helical (parallel and counter flow) and straight (parallel and counter flow) tube, the following results are drawn:

- The helical pipe is having the greater surface area which allows the fluid to be in contact for greater period of time period so that there is an enhanced heat transfer compared to that of straight pipe.
- The inside over all heat transfer coefficient for helical pipe is approximately 0.35 of that straight pipes.
- The temperature of cold water coming from the helical tube in counter flow arrangement is (38°C - 52 °C) i.e. a rise in the temperature of water is between 7°C to 21°C.It implies that for the same surrounding area the helical pipe absorbed is more than that of straight copper tube.
- The effectiveness of pipes either helical or straight in counter flow is greater than parallel configuration.
- From the above one can realize the fact that for the same space or volume in industry the helical heat exchangers are more efficient than normal straight heat exchangers.
- The influencing parameters on effectiveness and overall heat transfer coefficient in the decreasing order are: Flow rate, Hot water inlet temperature and number of turns.

Ashok Reddy K et. al. [8] studied the effect of Dean number on heating transfer coefficients in an flat bottom agitation vessel. In this study, the effect of impeller speed, discharge, flow behavior index (n) and consistency index (K) of test fluids with dimensionless curvature of the helical coil based on characteristic diameter was analyzed. It was found that the with the increase in impeller speed, the Dean number values also increasing.

Neerajkumar Nagayachet. al. [9] reviewed the research work carried out on the heat transfer growth in circular and non-circular tubes. Active as well as passive methods are employed for increasing the heat transfer coefficient in heat exchanger; Passive methods do not require application of external power such as active method require.

The effectiveness of both active and passive methods depends strongly on the mode of heat transfer, which might range from single phase free convection to dispersed flow film boiling. He reviewed the work dealing with displaced insert into circular tubes (twist tap insert, screw tap insert, helical tap insert, wire mesh tape insert), non-circular tubes (triangular, rectangular duct) and CFD based analysis in laminar and turbulent flow.

Some kind of internal inserts are placed in the flow passage of a tube to augment the heat transfer rate like twist taps insert, screw tap insert, helical tap insert, wire mesh tape insert etc. Hence it is concluded that inserts are effective in laminar flow. Inserts used in turbulent flow is effective up to a certain Reynolds number because more Reynolds number block the flow and increase the pressure drop.

Turbulent flow is more frequently encountered than laminar flow so a great change of local heat transfer rate in separated flow region is achieved and considerable heat transfer augmentation may result up to reattachment region. Heat transfer of non-circular tube was found considerably higher than the circular tube because of non-circular tube which has a high surface to volume ratio.

H. S. Patel et.al.[10] carried out a review on the “performance evaluation and CFD analysis of double pipe heat exchanger”. They described the different techniques which may help to enhance the heat transfer rate. Heat exchangers are modified in space of annular, also using Nano particle in water and compared with the conventional heat exchanger.

Results shows that heat transferrate of modified heat exchanger are higher than the conventional heat exchanger. Nano particles dispersed in water can signficantly enhance heat transfer rate and also heat transfer rate increase with increase of mass flow rate.

It may conclude that heat transfer augmentation techniques are successful to increaseheat transfer performance of double pipe heat exchanger.

Heat exchanger with the modification of extended surfaces, twisted tape, and louvered strips are resulted greater heat transfer rate as compared to heat exchanger without modification.

Alok Vyas et.al.[11] has studied the various experimental research work on performance of tubular heat exchangers. The tubular heat exchanger is used throughout various industries because of its inexpensive cost and handiness when it comes to maintenance. Their study was focused on tube diameter, tube length, number of tubes, number of baffles, & baffles inclination. They concluded that heat transfer coefficients coming out by use of 30˚ baffles are more efficient than 0˚ baffles.

S. Laohalertdecha et. al. [12] studied the heat transfer performance and pressure drop characteristics of various enhanced tube. It was found that different types of the enhanced tubes (corrugated tube, ribbed tube, grooved tube and fluted tube) have great potential for heat-transfer enhancement and are highly suited to applications in practical heat-transfer processes.

Pardeep Kumar et.al. [13] carried out an experimental investigation to study the Heat transfer Enhancement of Helix-changer with Grooved Tube. It was found that results of heat transfer enhancement of helix-changer assisted by grooved tubes over plain tubes at same operating conditions, heat transfer enhancement by using grooves on tubes, which is a passive heat enhancement technique, is still far from the practical application with helix baffle. The groove pattern on tubes will increase turbulence, degree of movement of fluid which leads to better heat enhancement over the plain tube helix-changer.

II. COMPUTATIONAL MODELING

Computational Fluid Dynamics (CFD) provides a qualitative (and sometimes even quantitative) prediction of fluid flows by means of

- mathematical modelling (partial differential equations)
- numerical methods (discretization and solution techniques)
- software tools (solvers, pre- and post-processing utilities)
CFD enables scientists and engineers to perform “numerical experiments” (i.e., computer simulations) in a “virtual flow laboratory”.

Governing equations:

\[
\begin{align*}
\text{X momentum:} & \quad \nabla (\rho u v) = \frac{\partial (\rho + u v)}{\partial x} + \frac{\partial (\rho u v)}{\partial y} + \frac{\partial (\rho u v)}{\partial z} \\
\text{Y momentum:} & \quad \nabla (\rho u v) = \frac{\partial (\rho v u)}{\partial x} + \frac{\partial (\rho v v)}{\partial y} + \frac{\partial (\rho v v)}{\partial z} \\
\text{Z momentum:} & \quad \nabla (\rho u v) = \frac{\partial (\rho u z)}{\partial x} + \frac{\partial (\rho u z)}{\partial y} + \frac{\partial (\rho u z)}{\partial z} \\
\text{Energy:} & \quad \nabla (\rho u v) = -p v + \nabla (k u v) + \varphi
\end{align*}
\]

Above equation, \( \varphi \) is the dissipation function that can be calculated from

\[
\begin{align*}
\varphi & = \mu \left[ 2 \left( \frac{\partial u}{\partial x} \right)^2 + \left( \frac{\partial u}{\partial y} \right)^2 + \left( \frac{\partial u}{\partial z} \right)^2 \right] + \frac{\partial u}{\partial y} \frac{\partial u}{\partial y} \\
& \quad + \frac{\partial u}{\partial z} \frac{\partial u}{\partial z} + \frac{\partial u}{\partial x} \frac{\partial u}{\partial x} \\
& \quad + \lambda (\nabla u)^2
\end{align*}
\]

A. A Turbulence Model:

A turbulence model is a computational procedure to close the system of means flow equations. For most engineering applications it is unnecessary to resolve the details of the turbulent fluctuations. Turbulence models allow the calculation of the mean flow without first calculating the full time-dependent flow field.

We only need to know how turbulence affected the mean flow. In particular we need expressions for the Reynolds stresses. For a turbulence model to be useful it: – must have wide applicability, – be accurate, – Simple, – Economical to run.

They are used to predict the effects of turbulence in fluid flow without resolving all scales of the smallest turbulent fluctuations there are several turbulence models available in CFD-software including the Large Eddy Simulation (LES) and Reynolds Average Navier-Stokes (RANS). There are several RANS models available depending on the characteristic of flow, e.g., Standard k- \( \varepsilon \) model, k- \( \varepsilon \) RNG model, Realizable k- \( \varepsilon \), k-\( \omega \) and RSM (Reynolds Stress Model) models.

1) k-\( \varepsilon \) turbulence model: -

The k-\( \varepsilon \) (k-epsilon) model has been implemented in most general purpose CFD codes and is considered the industry standard model. It has proven to be stable and numerically robust and has a well-established regime of predictive capability. For general purpose simulation, the model offers a good compromise in term of accuracy and robustness.

2) k-\( \omega \) turbulence model: -

One of the advantages of the k-\( \omega \) formulation is the near wall treatment for low Reynolds number computations. The model does not involves the complex nonlinear damping functions required for the k-\( \omega \) model and is therefore more accurate and more robust. The models assume that the turbulence viscosity is linked to the turbulence kinetic energy and turbulent frequency via the relation.

3) k-\( \omega \) SST turbulence model: -

The k-\( \omega \) SST model is a two equation model. This model is known because it uses both k- \( \omega \) and k- \( \varepsilon \) models. SST models stands for Shear Stress Transport model. k- \( \varepsilon \) is a high Reynolds number model thus in the near wall region k- \( \omega \) model is used. Whereas, in the region away from the walls, k- \( \varepsilon \) model is used. The SST model uses a blending function whose value depends upon the distance from the walls. Near the wall, in viscous sub-layer, this blending function is one and only k- \( \omega \) model is used. The regions away from the wall this function is zero and uses only k- \( \omega \) model.

The standard k-\( \varepsilon \) model is a semi-empirical model based on model transport equations for the turbulence kinetic energy k and its dissipation rate \( \varepsilon \). For steady state, k and \( \varepsilon \) are obtained from the following transport equations:

\[
\begin{align*}
\frac{\partial (\rho k)}{\partial t} + \nabla (\rho u k) & = \nabla \left( \frac{\mu_{t}}{\sigma_{k}} \nabla k \right) + 2\mu_{t}S_{ij} - 2\rho \varepsilon \\
& \quad + \nabla (\rho \varepsilon U) \\
= & \nabla \left( \frac{\mu_{t}}{\sigma_{k}} \nabla k \right) + 2\mu_{t}S_{ij} - 2\rho \varepsilon \\
& \quad + \nabla (\rho \varepsilon U)
\end{align*}
\]

and the turbulent viscosity is defined by the following equation:

\[
\mu_{t} = \rho c_{\mu} \frac{K^{2}}{\varepsilon}
\]

III. CONCLUSION

Helical coil heat exchangers have great potential for heat transfer enhancement and are highly suited to applications in practical heat-transfer processes. This brings an opportunity for engineers to develop highly compact and effective heat-transfer equipment.

Several published articles show that the heat-transfer coefficients of the helical coil are 15 to 20% higher than simple shell and tube heat exchanger.

Further research on heat transfer enhancement of helical coil heat exchanger can be carried out by experimentally and validation with computational fluid dynamics on following points:-

- By modifying Dean Number (like- tube diameter, pitch length and pipe diameter), which causes increase in the turbulence mixing intensity in the flow field, and also by limiting the growth of surface area of the helical coil. This may leads to increase in heat-transfer performance.
- Enhancement in effectiveness can be investigated by varying the hot fluid and cold fluid flow rate.
- Heat transfer enhancement in pipe in pipe heat exchanger can be investigated by inserting helical tape using cold water and hot air as the test fluids.
- For Concentric pipe in pipe heat exchanger, investigation can be carried out on enhancement in heat transfer using different types of helical pipe construction in the inner tube.
- Investigation can be carried out on flow conditions based on varying Reynolds Number to find the heat transfer rate in turbulent and laminar condition as many researchers carried out the experiments under limited Reynolds number of 2000 to 4500.

Research can be carried out on compactness of the heat exchanger in order to reduce the size of the heat exchangers, so that helical coil heat exchangers can be used in refrigeration and air conditioning equipment.
REFERENCES


