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A Review on CFD Analysis of Tubular and Sector-By-Sector Helical Coil Heat Exchanger

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Abstract- A heat exchanger may be defined as an equipment which transfers the energy from a hot fluid to a cold fluid, with maximum rate and minimum investment and running cost. The rate of transfer of heat depends on the conductivity of the dividing wall and convective heat transfer coefficient between the wall and fluids. The heat transfer rate also varies depending on the boundary conditions such as adiabatic or insulated wall conditions. Heat exchange between flowing fluids is one of the most important physical processes of concern, and a variety of heat exchangers are used in different type of installations, as in process industries, compact heat exchangers nuclear power plant, HVACs, food processing, refrigeration, etc. The 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.

Keywords-Tubular, sector-by-sector helical coil heat exchanger, heat transfer.

I. INTRODUCTION

Tubular heat exchangers are built of mainly of circular tubes although some other geometry has also been used in different applications. This type of construction offers a large amount of flexibility in design as the designing parameters like the diameter, length and the arrangement can be easily modified. This type is used for liquid-to-liquid (phase changing like condensing or evaporation) heat transfer. Again, this type is classified into shell and tube, double pipe and spiral tube heat exchangers.

Heat exchange between flowing fluids is one of the most important physical processes of concern, and a variety of heat exchangers are used in different type of installations, as in process industries, compact heat exchangers nuclear power plant, HVACs, food processing, refrigeration, etc. The 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 principles: conduction, convection and radiation. The double pipe or the tube in tube type heat exchanger consists of one pipe placed concentrically inside another pipe having a greater diameter.

The flow in this configuration can be of two types: parallel flow and counter-flow. It can be arranged in a lot of series and parallel configurations to meet the different heat transfer requirements. Of this the helically arranged stands out as it has found its place in different industrial applications. As this configuration is widely used, knowledge about the heat transfer coefficient, pressure drop, and different flow patterns has been of much importance. The curvature in the tubes creates a secondary flow, which is normal to the primary axial direction of flow. This secondary flow increases the heat transfer between the wall and the flowing fluid. And they offer a greater heat transfer area within a small space, with greater heat transfer coefficients. Study has been done on the types of flows in the curved pipes, and the effect of Prandtl and Reynolds number on the flow patterns and on Nusselt numbers. The two basic boundary conditions that are faced in the applications are constant temperature and the constant heat flux of the wall.

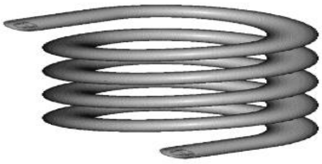

Fig. 1: Double pipe helical coil

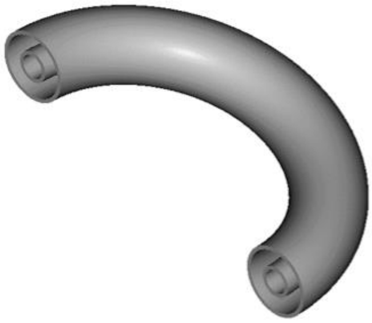

Fig.2: Close-up of double pipe coil

2. Advantages & Disadvantages

Advantages of coils

- Coils give better heat transfer performance, since they have lower wall resistance & higher process side coefficient.
- The whole surface area of the curved pipe is exposed to the moving fluid, which eliminates the dead-zones that

are a common drawback in the shell and tube type heat exchanger.
- A coil can provide a large surface area in a relatively small reactor volume.
- The heat exchanger's spring-like coil eliminates thermal expansion and thermals hock problems, which helps in high pressure operations.
- Fouling is comparatively less in helical coil type than shell and tube type because ofgreater turbulence created inside the curved pipes.

Disadvantages of coils
- For highly reactive fluids or highly corrosive fluid coils cannot be used, instead jackets are used.
- Cleaning of vessels with coils is more difficult than the cleaning of shells and jackets.
- Coils play a major role in selection of agitation system. Densely packed coils cancreate unmixed regions by interfering with fluid flow.
- The design of the helical tube in tube type heat exchanger is also a bit complex andchallenging.

III. REVIEW OF PAST STUDIES

Amini et al. (2018) Thermal performance of a shell-and-tube heat exchanger is investigated numerically using ANSYS FLUENT software under various conditions. Before proceeding with simulations, sensitivity analysis is performed for both mesh grid and turbulence model and the results are compared and validated with results obtained from Bell-Delaware method. The numerical study is consisted of three parts: First the effect of tubes wall relative roughness and Reynolds number on total heat transfer and pressure drop is investigated.

In the second part, effect of simple segmented tube fins on heat transfer is studied under two independent adjustable parameters, namely fin pitch and fin height while surface roughness is fixed. Finally, a novel design of fins (helical fin) is proposed and its influence on thermal performance of the heat exchanger is investigated and results are compared to no-fin and segmented fin configurations. It is found that tube fins in general enhance overall efficiency of the heat exchanger. The efficiency is increased by 9.5% and 6% when the proposed helical fins and segmented fins are used respectively. CFD results purpose the efficiency is increased by increasing fin height, but decreased by increasing fin pitch. Helical fins increase effectiveness of heat exchanger by 17% compared to plain tubes. Although increasing surface roughness increases the efficiency, it leads to faster corrosion which means higher maintenance costs and is not desirable. The efficiency of the heat exchanger therefore can be prominently increased when combination of low surface roughness and helical fins with smaller pitch and larger height are used.

Wang et al. (2017)A heat exchanger is an apparatus used for effective heat transfer between two fluids. Heat is transferred through both conduction and convection processes. Based on the flow configuration, heat exchangers are classified in the four groups of parallel-flow, counter-flow, cross-flow and hybrid. Aside from classification, heat exchangers have numerous types including shell and tube, double pipe, plate fin, adiabatic wheel etc. Amongst these types, Shell-and-tube heat exchangers are used in a wide range of industrial applications such as oil, gas, HVAC, food and beverage industries.

Particularly for higher pressure applications like latent thermal energy storage in concentrated solar power systems, it is the most promising technology due to its low cost. Analyzing the fluid flow around the shell-and-tube heat exchangers and design process may be truly complicated due to various possible geometric arrangements of the shell side and numerous leakages in fluid channels, resulting complicated flow structures. The mentioned fluid channels and their corresponding leakages would be different, considering the dissimilar sizes and designs of these kinds of heat exchangers. Significant efforts have been made to address this problem. For instance, considered installing sealers inside shell-and-tube heat exchanger which effectively could block the baffle-shell gap and decrease the circular leakage flow which consequently increased the overall coefficient of heat transfer. However, in small exchangers, leakage is not present at all or it might be negligible compared to main fluid flow.

Jia et al.(2017) studied the thermal performance and flow characteristics of a fin-tube heat exchanger in low pressure environments numerically and found out that the interaction between temperature and velocity is different at various pressures due to the change in the thermal boundary layer thickness caused by the fins. They introduced an innovate design of a finned double pipe heat exchanger and performed a full CFD analysis; their results indicated that the newly introduced parameter, i.e. the ratio of tip to base angles play a significant role in the design of a double-pipe heat exchanger in improving the heat transfer rate and making the exchanger energy-efficient.

Gorman et al. (2016) investigated the fluid and thermal design principals of a single double-pipe heat exchanger at various Reynolds values numerically with the inner pipe having fins to produce swirl flow and they have shown that heat transfer is nearly tripled comparing to a plain pipe with no fins. While they have investigated effect of fin pitch on heat transfer and pressure drop, no study of fin height has been done. The experimentally investigated the performance of a single internal helically-finned tube at constant fin pitch and height and various Re values. They found out that comparing to a plain tube, thermal performance of the helically-finned tube is much higher (j-factor 3.5 times bigger for finned-tube vs. plain tube). They also pointed out that the enhancement of the internal helically-finned tube is decreased as Re is increased. Effect of fin geometry in shell-and-tube heat exchangers have been also investigated. It carried out a parametric study of a longitudinal-finned tube with two different cross-sectional shape in an unbaffled shell-and-tube heat exchanger and found that heat transfer rate is increased by going from rectangular to trapezoidal shape baffle.

Yehia et al. (2016) proposed employing a set of swirl vanes on the tubes in a shell-and-tube heat exchanger and the numerically investigated effect of blade angle and vane diameter on total heat transfer rate. They showed that by using the vanes heat transfer is enhancing with the highest swirl diameter and blade angle leading to highest heat transfer rate compared to plain tubes.

Reddy, K. V. K., (2017)A helical coil tube heat exchanger is generally applied in industrial applications due to its compact structure, larger heat transfer area and higher heat transfer capability etc. The importance of compact heat exchangers has been recognized in many industrial applications ranging from chemical and food industries, power production, electronics, environmental engineering, manufacturing industry, air conditioning, waste heat recovery, cryogenic processes and space applications for the last six decades. However, flow and helical coils are extensively used as heat exchangers and reactors due to higher heat and mass transfer coefficients, narrow residence time distributions and compact structure. In the present study a tube in tube helically coiled heat exchanger has been modeled for fluid flow and heat transfer characteristics for different fluid flow rates in the inner as well as outer tube. A CFD analysis has been conducted for a TTHC heat exchanger. The geometry was developed in PRO-E 5.0 with meshing performed in ICEM-CFD and was exported to Fluent 14.0.

Vimal Kumar et al., (2008) numerically modeled Tube in Tube Helical Coil (TTHC) Heat Exchanger for fluid flow and heat transfer characteristics at different fluid flow rates in inner as well as outer tube. New empirical correlation was developed for hydrodynamic and heat transfer prediction in the outer tube of Tube in Tube Helical Coil (TTHC) Heat Exchanger. It was observed that when the inner coil tube flow rates increases then the overall heat transfer coefficient is increases at constant wall temperature at that time the overall heat transfer coefficient were observed for different flow rates in the annulus region for a constant flow rates in inner coiled tube. it was also observed that while increasing the operating pressure in the inner tube , the result is rise in overall heat transfer coefficient . Also the heat transfer in inner and outer tube of Tube in Tube Helical Coil (TTHC) Heat Exchanger was higher. Prabhanjan et al, studied the relative advantage of using a helical coiled heat exchanger over a straight tube heat exchanger for heating liquids. They reported that the particular difference in the study was the boundary conditions for the helical coil, and results showed that the heat transfer coefficient was affected by the geometry of the heat exchanger and the temperature of the water affects both heat exchangers. It was also reported that the helical coil heat exchanger increased the heat transfer coefficient when compared to a similarly dimensioned straight tube heat exchanger.

Kharat et al. (2009) had done the experiments to study the heat transfer rate on a concentric helical coil heat exchanger and develop the correlation for heat transfer coefficient. Heat transfer coefficient has improved for the tube containing flue gas of the heat exchanger by using CFD simulation and the experimental study. The effect of Vijaya Kumar Reddy K et al / Materials Today: Proceedings 4 (2017) 2341–2349 2343 different operating variables was studied. The variables they had considered are gap between the concentric coils, diameter of tube and coil diameter. The heat transfer coefficients are affected by the coil gap and the tube diameter. They found that the heat transfer coefficient decreases with the increase in coil gap. With increase in tube diameter the heat transfer coefficient increases.

Mishra, T. N. (2015).A helical coil heat exchanger has a wide range of application in industries over the straight and shell type heat exchangers because of its greater heat transfer area, mass transfer coefficient and higher heat transfer capability, etc. The relevance of helical coil heat exchanger has been identified in industrial application like turbine power plants, automobile, aerospace, etc. because of above mentioned factors. In this thesis we model a tube in tube helical coil heat exchanger using CATIAV5r18 and done CFD analysis using ANSYS. The thesis shows the deviation of Nusselt Number for different curvature ratio(D/d ratio) and Reynolds Number.CFD analysis has been done for varying inlet condition keeping the heat flux of outer wall constant.

The turbulent flow model with counter flow heat exchanger is considered for analysis purpose. Copper was used as the base metal for both inner and outer pipe and simulation has been done using ANSYS 13.0.The software ANSYS 13.0 was used to plot the temperature contour, velocity contour. pressure contour taking cold fluid at constant velocity in the outer tube and hot fluid with varying velocity in the inner one. We also find out the wall shear stress on both inner and outer tube. Water was taken as the working fluid for both inner and outer tube. Result after analysis shows that temperature, pressure velocity contour in the heat exchanger were similar to literature data and It is also visible from the results that Nusselt Number depends on curvature ratio. It is increasing with increase in curvature ratio. In addition, the value of Nu no. was found to increase with increase in mass flow rate (i.e. inlet velocity), with increases in D/d ratio (inverse of curvature ratio) the Nusselt number will decreases; for a particular value of Reynolds number. Nusselt number has maximum value for D/d=10.

Aly et al.(2014) had done the numerical study to find the heat transfer and pressure drop of nano fluid in coiled tube-in-tube heat exchangers for turbulent flow condition. The numerical study was carried out by computational fluid dynamics (CFD) analysis to find the heat transfer rate and pressure drop characteristics of water-based Al2O3 nano-fluid flowing inside coiled tube-in-tube heat exchangers. The overall performance the heat exchangers was assessed based on the thermo-hydrodynamic performance index. Nanofluid flows inside inner tube side. When he compared the result for the same Re or Dn, the heat transfer coefficient or the rate of heat transfer was increased by increasing the coil diameter and nanoparticles volume concentration. Also, he found that the friction factor increases with the increase in curvature ratio and the pressure drop penalty is negligible with increasing the nano-particles volume concentration up to 2%.For the nano fluid the correlations for predicting average heat transfer and friction factor in turbulent flow regime such as Gnielinski correlation and Mishra and Gupta correlation, respectively, for helical tubes are also valid. In results they found that nano fluids behave like a homogeneous fluid.

Bahiraei, M., Naseri, (2021) The present study aims to research the thermohydraulic characteristics and performance index for flow of the nanofluids containing varied particle shapes including cylinder, blade, brick, platelet, and Oblate Spheroid (OS) in a shell and tube heat exchanger (STHX). The STHX is equipped with new unilateral ladder-type helical baffles to develop spiral stream inside the shell side. The nanofluid is assumed as the hot fluid that passes inside the tube side. Water is selected for the cold fluid that flows within the shell side with Reynolds numbers of 5000 to 20,000. The flow pattern developed by the baffles has noticeable impacts on the STHX performance. By the rise in the Reynolds number of the shell side, the heat transfer rate, overall heat transfer coefficient, effectiveness, Number of Transfer Unit (NTU), and pressure drop increase, whereas the performance index decreases. Moreover, the highest heat transfer rate, overall coefficient, and pressure loss belong to the nanofluid containing the platelet additives, while the greatest effectiveness, NTU, and performance index happen for the nanofluid with the OS additives. The severe cross and secondary flows are completely obvious in the shell side due to the existence of the new baffles, specially at high Reynolds numbers.

Flórez-Orrego, D., (2012) The complex fluid-dynamic inside curved pipe heat exchangers gives them important advantages over the performance of straight tubes in terms of area/volume ratio and enhancing of heat transfer and mass transfer coefficient. In this is work, heat transfer in a non-previously implemented coneshaped helical prototype with 15cm in maximum diameter, 7.5cm in minimum diameter, 3/8" pitch and 40cm in axial length was studied. An empirical correlation for the determination of average Nusselt number along the duct, with Reynolds ranging between 4300 and 18600 has been developed. The experimental results have been compared with those obtained with the correlation proposed by Seban-McLaughlin and XinEbadian for curved pipes. Also, numerical simulations were performed using ANSYS FLUENT 12.1 software, where the governing equations of mass, momentum and heat transport were solved simultaneously, using realizable k-e two equations turbulence model. The velocity profiles in cross sectional area were obtained and compared with those of conventional helical tube configurations (non-conical). It was found there are similarities in terms of the main flow skewness, but there were slight differences on the path that follows the fluid particles in the secondary flow. Finally, the results for pressure gradient were calculated using Ito and White correlations and were compared with those obtained in computer simulations, obtaining a good agreement.

Kareem, R. (2017) Optimization of double pipe helical coil heat exchanger with various optimizing parameters and its comparison with double pipe straight tube are the prime objectives of this paper. Numerical studies were performed with the aid of a commercial computational fluid dynamics package ANSYS FLUENT 14. In this paper the double pipe helical coil is analysed under turbulent flow conditions for optimum heat exchanger properties. The parameters used for optimization are cross-sectional shape and taper angles. Optimization analysis is being carried out for finding best cross sectional shape of heat exchanger coils by using rectangular, square, triangular and circular cross-sections. The tapered double pipe helical coil is then analysed for best heat transfer and pressure drop characteristics by varying the angle of taper. Finally, an optimum coil on the basis of all the analysis is selected. This optimized double pipe helical coil is compared with double pipe straight tube of equivalent cross-sectional area and length as that of unwounded length of double pipe helical coil.

4. Conclusion

Heat transfer in helical coils is higher than as compared to straight coils. Because of its compact size, higher film coefficient, they are widely used in industrial applications like power generation, nuclear industry, process plant, heat recovery system, chemical process industries etc. These heat exchangers are used to control the temperature of the reactors for exothermic reactions.

They have less expensive design. Helical geometry allows the effective handling at higher temperatures and extreme temperature differentials without any highly induced stress or expansion of joints. Helical coil heat exchanger consists of series of stacked helical coiled tubes and the tube ends are connected by manifolds, which also acts as fluid entry and exit locations.Natural convection is a process or type of heat transfer, in which the fluid motion is caused by density differences in the fluid occurring due to temperature gradients. Here the fluid which surrounds a heat source receives heat, becomes lessdense and rises. The fluid that is surrounding the hot fluid is cooler and then moves in to replace it. Then further that cooler fluid gets heated and the process continues, forming convection current. The driving force for this process is buoyancy, a result of difference in the fluid density. Natural convection has attracted a great deal of attention from researchers because of its presence both in nature and engineering applications.Forced convection in a heat exchanger is the transfer of 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. If it moves along the hot stream then it’s called parallel flow and if they are across then its counter flow.

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