Experimental and Numerical Analysis of Helical Coil Heat Exchanger by varying Curvature Ratio

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ABSTRACT— In the following paper an experimental analysis of heat transfer in helical coil heat exchanger is carried out for varying curvature ratio and validation is carried out numerically. The reason for the study is to compare the heat transfer in simple straight helical coil and helical coil heat exchanger with varying curvature ratio. The volume of both the coils and shell are kept same for comparison purpose. The solution has been formed at the steady state condition and experiment was conducted for different flow rates in laminar flow regime. The coil side flow rate is kept varying while the shell side flow rate is kept constant. It is found that the heat exchanger with varying curvature ratio is more efficient than simple straight helical coil. Observations shows that the heat transfer rates for varying curvature ratio helical coil is more than that of the simple straight helical coil heat exchanger.

Keywords— Helical coil,curvature ratio,Dean No.,Nusselt No., secondary flow

I. INTRODUCTION

Helical coiled heat exchangers are used in a variety of applications like food processing, nuclear reactor, compact heat exchangers, heat recovery systems and chemical processing. Helical coil heat exchanger can be used ,

- Where space is limited, so that enough straight pipe cannot be laid.
- laminar flow or low flow rates where shell and tube heat exchanger would become uneconomical because of the resulting poor heat transfer coefficients.
- Under the conditions of development of secondary flow which enhances heat transfer and temperature uniformity.

Though the advantages of helical coil over straight tube heat exchangers have been investigated and heat transfer relationships have been developed for helical coil, majority of studies have been limited to straight helical coil with tube in tube and concentric coil configurations only. Also very few investigations are carried out on shell side heat transfer coefficients. In spite of having better performance, conical spiral coil have received little attention due to its complex structure in both experimental investigation and numerical simulation. If geometry of helical coil is varied it will have advantages of:

- Secondary flows which depends upon curvature.
- Helical geometry which has significant effect over inside heat transfer.
- Heat transfer coefficient of shell side as it depends upon coil surface area, and geometry.

Therefore it is decided to go through literature to collect maximum information about various factors associated with heat transfer characteristics of helical coil heat exchanger. Thermal performance of helical coil will be studied to obtain flow & dimension parameters and their relationships with the heat transfer coefficients related with different geometries. It is also intended to compare these results with the available results of other types of heat exchangers.

II. LITERATURE REVIEW

D. G. Prabhanjan et al [1] experimentally studied advantage of helically coil heat exchanger against a straight tube heat exchanger for heating of coil liquids. Length of helical coil and straight tube was same. The rise in temperature of coil fluid is significantly affected by both coil geometry and flow rate; however it was not significantly changed by outside water bath temperature. Increase of coil fluid temperature for helical coil was greater compared to straight tube. Heat transfer coefficient for helical coil was 1.16 and 1.43 times larger than for straight pipe heat exchanger. This is due to increased mixing of fluid as secondary flow takes hotter fluid and passes it through center of tube. Also heat transfer coefficient increases for higher bath temperature due to increase in buoyancy effect on the outside of coil.N.Ghorbani et [2]Experimentally studied helical coil heat exchanger for different characteristic length upon which the correlation between Nusseltno.and Rayleigh no.is studied. P. Naphon et al [3] experimentally and numerically (Fluent software) studied horizontal spiral coil tube. The effects of curvature ratios on coil exit temperature, heat transfer rate, Nusselt number and pressure drop were studied. The outlet temperatures of cold coil fluid at lower curvature ratios were higher than those at higher curvature ratio because tube length for lower curvature ratio was higher. Nu for lower curvature ratio was higher than those at higher curvature ratio. Also Nu for spiral coil was 1.49 times higher than straight tube. Yan Ke et al [4] investigated heat transfer characteristic of conical spiral tube with numerical simulation method for variation of cross section, upper radius, helical pitch and cone angle (55°C to 85°C). Heat transfer coefficient of circular section of conical tube is more than the elliptical section. As curvature increases main fluid flow (axial fluid flow) increases. The secondary fluid flow becomes intensive when tube curvature increased; hence heat transfer coefficient of circular section is better than elliptical section.

Also heat transfer enhancement mainly takes place near outer surface of tube. The secondary fluid flow of conical spiral tube is complicated than a straight tube or a curved tube because there exist four independent part of secondary flow and flow directions are different from each other. Therefore the heat transfer enhancement is much better. In the investigations of Yan Ke et al [4] mathematical correlations are not obtained for non dimensional parameters and only inside heat transfer coefficient is emphasized. Also optimum effect of cone angle is not found. So it is necessary to study conical spiral coil experimentally and numerically to understand inside and outside heat transfer and fluid flow characteristics. Abo Elazm M.M. et al [5] studied experimental and numerical comparison between the performance of conical spiral and ordinary helical coils, and exit temperature of coil fluid was the parameter studied. The heat transfer characteristics of the conical spiral tube were found to be better than the heat transfer characteristics of ordinary coils. The geometry of coil was found to have a significant effect on coil exit temperature. Investigations are carried out on shell side heat transfer coefficients.

1. Significance of the study in the context of current status

Most of research work is dealing with typical applications of straight helical coil heat exchangers. The design of helical coil heat exchanger with variation in geometries requires information that is not found in literature. There is urging to develop a methodology that will give significant ease for improvements in heat transfer in helical coil heat exchangers. This research will help to put forth different probabilities to improve heat transfer rate by changing geometries of helical coil heat exchangers. The suggested correlations will be helpful in designing efficient heat exchangers.

This research will also help to develop the methodology to obtain flow and dimension parameters and its relationships with the heat transfer coefficients, and its comparison with the available results of other types of heat exchangers. This research requires development and manufacturing of helical coil heat exchanger experimental set up. This developed experimental set up can be used for further studies by students and faculties of Mechanical, Chemical and Instrumentation & control and relevant disciplines. Future students will be able to use their data to calculate heat transfer coefficient and pressure drop.

2. Experimental Setup

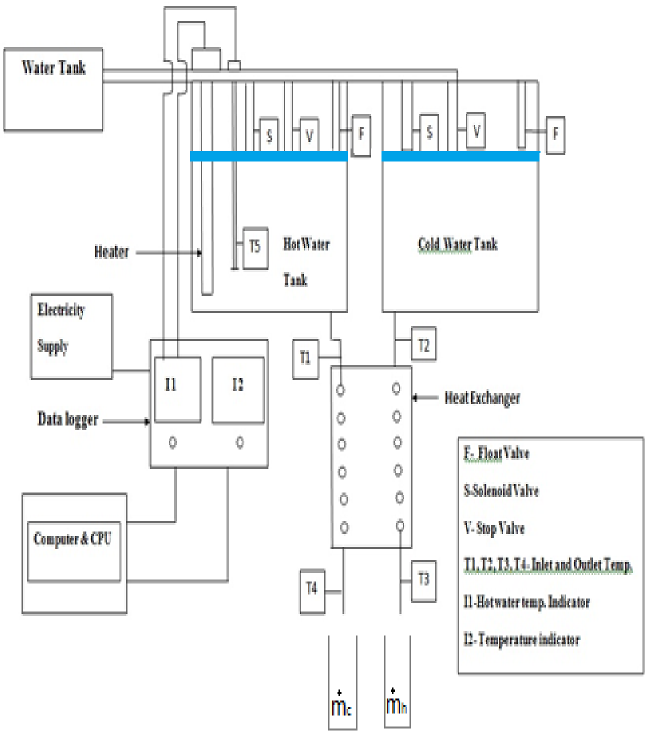

Fig. 1. Experimental Setup

Prof.S.M.Magarhas installed a Heat exchanger test rig. At PDVVP college of EngineeringAhmednagar,which is extensively used for testing and trial purpose on various types of heat exchangers which facilitates computerized interface of major thermal parameters like Thi, Tci, Tho ,Tco, mci, msi at synchronized time intervals which leads ease of observations and mathematical calculations using MS-Excel also data logger extends graphical representation.

This consists of heat exchanger, hot water tank and cold water tank (water cooler). A heat exchanger is a device which consists of helical coil made up of copper material, it is enclosed in shell. Shell is made up of PVC material and having metallic flange at one end and other end is closed by PVC cap. Shell has four openings two for coil fluid inlet and outlet and two for shell fluid inlet and outlet. Hot water is stored in hot water tank at atmospheric pressure which flows through coil. The cold water tank is used to store cold water from the cooler which flows through shell. Six Thermocouples are used to measure coil fluid and shell fluid temperature. It is used for parallel flow arrangement. The mass flow rate of cold and hot fluid is measured with help of measuring flask. This experimental set up is developed for simple helical coil heat exchanger.

A schematic diagram of the experimental set up for helical coil heat exchanger with varying curvature ratio is shown in fig. 1. The area of testing is coil with changing curvature ratio consisting of shell. The shell having circular cross section with 250mm diameter & the height of the shell is kept 250mm. The cold fluid will flow from shell while hot water from coil. Observations are taken for parallel flow arrangementThe cold water flow to the shell is provided by the pumping of the cold water from the cold water tank. The centrifugal pump is used to lift the water from the cold water tank. As the cold water passes through the shell, its temperature increases. So instead of supplying this cold water to the tank it is fed to the atmosphere so that the temperature of the cold water will not increase. The hot water flow is entered to the coil with the help of centrifugal pump from the hot water tank. Both the tanks have dimensions as 460mm * 410 mm * 410 mm. The hot water tank consists of two immersion type heaters having capacity 1500 watt each to heat the water in the tank. The two flowmetersare connected series with each of the two pumps to measure the mass flow rate of the cold & hot water respectively. Both the Rota meters are calibrated & having the range of 60 to 600 LPH. The flowmeters are mounted on a fabricated stand for the support. The connections of the water flow to both the shells & coils are made by using the T joints which are connected between Rota meters and test sections. All these connections are made with PVC piping. Total 7 thermocouples are used for measurement of the inlet & outlet temperatures of shell and tube side for both the coils. All the thermocouples are calibrated and connected to the 12 channel temperature indicator. Mass flow rate on shell side is kept constant and the flow on tube side loop is varied by using the valve.Temperature range from 25°C to 40°C .were considered for the mass flow rate of the coil. All the tests were performed under the steady state conditions. The inlet and outlet connections to the shells & coils are made with the piping. All the assembly of the helical coil heat exchanger is placed on the mild steel fabricated structure.

3. Experimentation

Experiment was performed for different inlet temperatures conditions and flow rates of hot water entering the coil. The hot water flows though the copper coil and cold water flows through the shell with constant flow rate. The inlet hot water temperatures were kept constant by using electric heaters controlled by temperature controllers. The waited for steady state before data was recorded. The flow rates were controlled by adjusting the valve and measured by the two calibrated thermocouples having range 60 to 600 LPH.

Experimental procedure is as follows:

a) First fill the both hot and cold water tanks and switch on the electric supply to the heater for heating water in hot water tank

b) After reaching the required temperature of hot water, start the centrifugal pump of hot water so that hot water will flow from copper coil. The mass flow rate of hot water is controlled by FCV and measured by the flowmeter.

c) At the same time cold water is circulated through shell. The flow rate of cold water is controlled by flow ctrl valve kept in cold water line and measured by the flowmeter..

d) Water temperatures for both shell side and coil side is measured by the temperature indicator after the steady state is reached.

e) Take the reading for different mass flow rates for hot water while for cold side it is kept constant.

f) Repeat the procedure for simple helical coil.

4. Heat Transfer Analysis.[2]

- Natural Convection

  $Q = A * h (Ts - Tf)$ [1]

Where Ts = Temperature of solid surface &

Tf = Temperature of fluid

Under this framework convection problem reduce to estimation of convective coefficient (h).

- Heat transfer for coil fluid, Qc

  $Qc = mcCp,c\ (Tc,i – Tc,o)$ [2]

- Heat transfer for shell fluid, Qs

  $Qs = msCp,s\ (Ts,o – Ts,i)$

- Average heat transfer, Qave

  $Qave = (Qc + Qs) / 2$ [3]

- Inside tube heat transfer coefficient, hi

  $hi = Qave /Ai(T1 –T2)$

- Logarithmic temperature difference for parallel flow, (ΔTLMTD) PF

  $(\Delta TLMTD)\ PF = [(Tc,i-Ts,i)-(Tc,o-Ts,o)]/ \log[(Tc,i-Ts,i)/(Tc,o-Ts,o)$ [4]

- Logarithmic temperature difference for parallel flow, (ΔTLMTD) CF

$(\Delta TLMTD)\ CF = [(Tc,i-Ts,o)-(Tc,o-Ts,i)]/ \log[(Tc,i-Ts,o)/(Tc,o-Ts,i)]$ [5]

- If parallel flow arrangement Overall heat transfer coefficients, Ui&Uo and outside shell side heat transfer coefficient, ho is obtained as:

  $Ui = Qave / Ai\ (\Delta TLMTD)\ PF$

  $Uo = Qave / Ao\ (\Delta TLMTD)\ PF$

  $ho = 1/\{ [Ao/UiAi]-[Ao(\log (do/di))/ 2\ \Pi\ L\ kt]-[Ao/hiAi]\}$
- If counter flow arrangement Overall heat transfer coefficients, Ui&Uo and outside shell side heat transfer coefficient, ho is obtained as:

  $Ui = Qave / Ai\ (\Delta TLMTD)\ CF$

  $Uo = Qave / Ao\ (\Delta TLMTD)\ CF$

  $ho = 1/\{ [Ao/UiAi]-[Ao (\log (do/di))/ 2\ \Pi\ L\ kt]-[Ao/hiAi]\}$
- Nusselts Numbers, Nu

  $(Nu)i = hi\ di / kc$

  $(Nu)o,Dhx = ho\ Dhx / ks$

  $(Nu)o,Deq = ho\ Deq / ks$
- Effectiveness of heat exchanger, ϵ

  $\epsilon = Qave / \{(mCp)min\ (Tc,i - Ts,i)\}$ [6]

- Modified Effectiveness of heat exchanger, ϵ`

  $\epsilon` = (Tc,i - Ts,o)/ (Tc,i - Ts,i)$ [7]

Fig.2Helical coil Heat Exchanger

5. Numerical Analysis

Various commercial CFD packages available are FLUENT, ANSYS CFX, STAR CCM+, UH 3D etc.
CFD analysis isclassified into three main steps: preprocessing, solution, and post processing.

5.1 CFD modeling

Preprocessing involves identifying the flow region of interest, geometrically representing the region, defining a suitable grid, and then applying the principles of flow physics. Following are steps carried out in CFD software.

- Import of Geometric Model
- Creation of heat transfer regions and Interfaces ,Meshing
- Boundary Conditions

5.2 Import of Geometric Model

Geometric Model is created in CAD software and imported in STAR CCM+ in .igs format.

5.3 Creation of heat transfer regions and Interfaces

Afterwards four heat transfer regions are created. If hot water is flowing through tube then heat transfer takes place from hot water to copper tube and from copper tube to cold water flowing in shell. Shell is considered as adiabatic. Therefore four heat transfer regions are copper tube, cold water, hot water and shell. These four regions are sown in Fig. Also following three contact type interfaces are created through which energy transfer takes place.

- Inplace interface1: Interface between Hot water and Copper tube region

- Inplace interface 2: Interface between Copper tube and Cold water region
- Inplaceinterfacec 3:Interface between Cold water region and Shell region

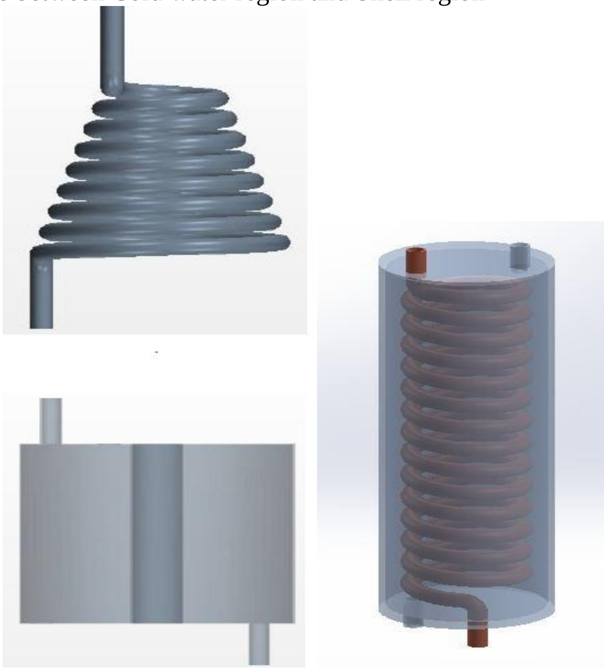

Fig.3 Interfacing Coil, Shell, Hot Water, Cold Water

5.4 Meshing,Boundary conditions

Two separate meshing parameters are used for solid regions and fluid regions.

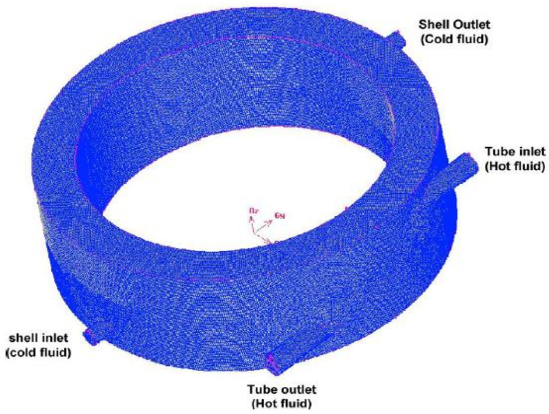

Fig.4 Meshing of Shell

- Polyhedral mesher : Base size- 3 mm
- Embeded thin layer: 3 thin layers are selected
- Boundary conditions applied in helical coil heat exchanger are 1.Coil and Shell fluid Inlet: Inlet Mass flow rate and Inlet temperature 2.Coil and Shell fluid Outlet: Pressure outlet

6. Result & Discussion

- **NuDt vs. ReDt**

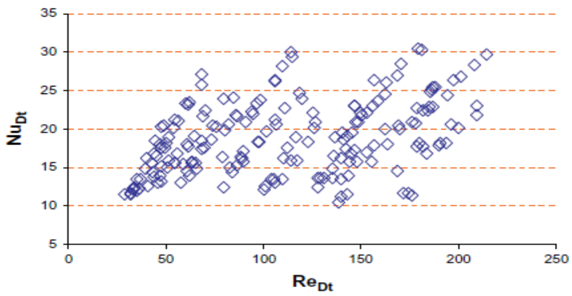

Fig.5 Result of Expt. Conducted by Gorbani

- **Nui vs. Rei**

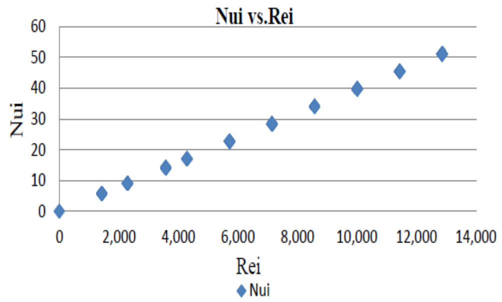

Fig.6Result for varying curvature ratio coil.

Fig. No. 6 indicate that inside Nusselt no. increases as inside Reynold no. increases. Thisshows agreement with results of Ghorbani shown in Fig. No. 5

III. CONCLUSION

In this work, the experimental analysis of helical coil heat exchanger with varying curvature ratio is carried out. The overall conclusion related with comparative analysis between the simple helical coil and coil with different curvature ratio it is found that the inner Nusselt number, inside Convective heat transfer coefficient and overall heat transfer coefficient increases when the coil curvature ratio changes. Also experimental results shows agreement with results of Ghorbani.

Symbol	Parameter
Q	Heat Transfer
h	Heat transfer coefficient
LMTD	Log mean temperature difference
m	Mass flow rate
Cp	Specific heat
Tci	Coil inlet temp.Coil
Tco	outlet temp.
Tsi	Shell inlet temp.
Tso	Shell outlet temp.
Nu	Nusselt Number
Re	Reynolds Number
Є	Effectiveness
U	Overall heat transfer coefficient

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