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ENHANCEMENT OF HEAT TRANSFER IN HELICAL COIL HEAT EXCHANGER FOR COUNTER FLOW ARRANGMENT

M.Sireesha, M.Ganesh Kumar, Ch.Kiran Kumar
Mechanical department, Sanketika Institute of Technology and Management,
P.M Palem, Visakhapatnam, Andhra Pradesh, India

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ABSTRACT
Heat recovery is the capture of energy contained in the fluids otherwise that would be lost from the facility. The heat exchangers are the important in the engineering system with wide variety of applications including power plants, nuclear reactors, refrigeration, air conditioning system, heat recovery systems, chemical processing and food industries. Helical tube heat exchanger (HTHE) is a device which is used for heat recovery system because of fluid dynamics inside the pipes of a helical coil heat exchanger offers certain advantages over the straight tubes. The experimental set up of the heat exchangers consist of a shell through which cold water flows and the hot water flows through the tube which configured in helical tube in the set up. The centrifugal force developed due to the helical curvature of tubes resolve in the secondary flow development, which may be the key factor enhancements of heat transfer. The present project work is to investigate the performance of the counter flow heat exchanger experimentally, analytically by using CREO & solid works for enhancement heat transfer coefficients of fluid in helical tube for pitch and curvature ratio and compare the experimental and analytical values of helical coil heat transfer coefficient for counter flow arrangement.

KEYWORDS: Helical coil heat exchanger, rotameter, effectiveness, overall heat transfer coefficient.

INTRODUCTION
Using passive techniques in order to enhance heat transfer characteristics in heat exchanger has been an interesting topic for scientists and researchers during recent decades. Numerical and experimental studies have been conducted in order to improve heat transferred by these techniques. The demand of reduction of the cost and dimensions of heat exchanger has motivated the searchers to investigate different ways of heat transfer enhancement. Passive heat transfer enhancement techniques are mostly preferred due to their simplicity and applicability in many applications. Furthermore, in passive techniques, there is no need of any external power input except to move the fluid.

HEAT EXCHANGER
A heat exchanger as shown in figure 1 is a piece of equipment built for efficient heat transfer from one medium to another. The media may be separated by a solid wall to prevent mixing or they may be in direct contact. They are widely used in space heating, refrigeration, air conditioning, power plants, chemical plants, petrochemical plants, petroleum refineries, natural gas processing, and sewage treatment. The classic example of a heat exchanger is found in an internal in which a circulating fluid known as engine coolant flows through radiator coils and air flows past the coils, which cools the coolant and heats the incoming air.

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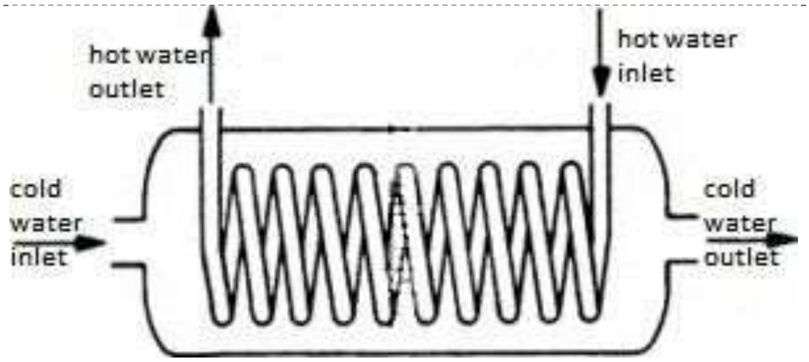

Fig 1: Schematic diagram of shell and tube heat exchanger

Heat transfer enhancement, augmentation or intensification deals with the improvement of thermo hydraulic performance of heat exchangers. Different enhancement techniques have been identified which can be broadly classified as **passive** and **active techniques**. The primary distinguishing feature is that unlike active methods passive techniques do not require direct input of external power. They generally use surface or geometrical modifications to the flow channel, or incorporate an insert, material, or additional device. Except for extended surfaces, which increase the effective heat transfer area, these passive schemes promote higher heat transfer coefficients by disturbing or altering the existing flow behavior. This is however accompanied by an increase in the pressure drop. In case of active techniques the addition of external power essentially facilitates the desired flow modification and the concomitant improvement in the heat transfer rate. The use of two or more techniques (passive and/or active) in conjunction with the purpose of further enhancement of heat transfer constitutes **compound enhancement.** The effectiveness of any of these methods is strongly dependent on the mode of heat transfer (single-phase free or forced convection, pool boiling, forced convection boiling or condensation, and convective mass transfer) and type and process application of the heat exchanger.

FABRICATION OF HELICAL TUBE HEAT EXCHANGER

Initially copper tube of length 4m is filled with sand and ends of the tube is closed with caps. This is done to prevent crimpling of tube while bending the tube in making process of helical form. The tube with sand is now enough heated to make it soft and malleable to bend. Now the tube is bent for a core diameter of 35mm by maintaining the pitch of 20mm in between helixes by using wood inserts to maintain the required pitch for a total number of 12 turns. Now the hollow helical tube is tested for any leakages with water by providing end caps. The helical tube is concentrically inserted in PVC shell of 75mm diameter and1.5 ft length by providing shell end caps. The concentric shell and tube heat exchanger is provided with hot water and cold water entrance and exit trough helical tube. It is also arranged for temperature measuring digital probes to measure inlet and outlet temperatures of hot and cold water. The hot water pump (0.5 HP) is arranged for the supply of hot water through copper tube from hot water tank. The water tank is provided with 4 numbers of immersion heaters for a total heat load of 3000Watts. So the required geometrical configuration of heat exchanger is fabricated shown in fig 2.

Fig 2: fabrication of helical coil heat exchanger

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EXPERIMENTAL SETUP

Figures 3 show the experimental setup. It is a helical tube heat exchanger consisting of a test section, a constant temperature bath (nearly 180 liters capacity) for supplying hot water, heaters, pump, control systems & temperature indicators. The test section is a helical tube with dimensions of 250mm length, Inner tube 8.3mm ID, and 9.8mm OD; Outer shell pipe 71mm ID, and 75mm OD. The outer pipe is well insulated using 15mm diameter asbestos rope to reduce heat losses to the atmosphere. Measuring jar of 1 liter capacity and stop watch to set the flow by regulating it using control valve to required flow rate. The heater coils (generally known to be immersion rods) is placed in lower tank filled with water. Motor of 0.5 HP is arranged in experimental setup as shown in below diagram. The by-pass valve is arranged because the copper tube diameter is small; the tube couldn't hold the discharge of pump. The outlet of helical tube is directed to small tank so that lower tank maintained at constant temperature. The inlet of shell is connected to ambient water supply and outlet is left to the environment after measuring its temperature.

Fig 3: Experimental setup of helical coil heat exchanger with supporting instrumentation.

MODELING IN CREO SOFTWARE

The helical tube heat exchanger design is modeled in the CREO software and is exported to SOLIDWORKS for thermal analysis. The design specifications considered in the fabrication of helical coil heat exchanger are followed for modeling in CREO software. Figure 4 shows the final assembled model of helical tube heat exchanger.

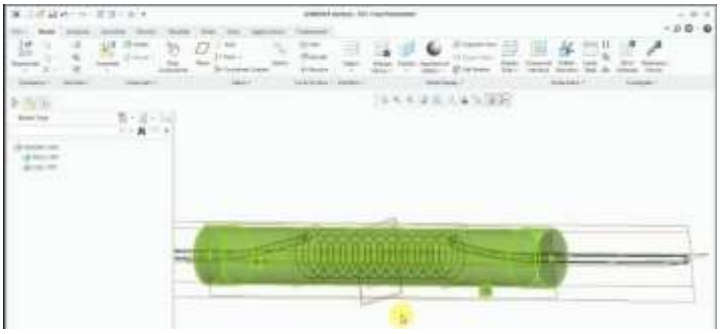

Fig 4 Assembly of the shell and the helical coil

COUNTER FLOW HEAT EXCHANGER FLOW SIMULATION IN SOLID WORK

The obtained results can also be shown in the pictorial representation of color indications for the highest and the lowest temperatures. The highest temperature of 60^0C and the lowest temperature of 32^0C are observed from the figures 5 and 5.1 the stream lines of the shell side and tube side flows are indicated with the colors according to the temperature scale. In the same manner the temperature variations are observed from the screenshots for the

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various flow rates of both the shell side and tube side fluids Also it is observed the gradual decrease of hot fluid temperature and increase of shell fluid temperature along the length of heat exchanger as shown in figures 5 and 5.1. Similarly the shell side flow is indicated with the colored gradient lines changing from the inlet to the outlet of heat exchanger, varying from 32^0C to 46^0C.

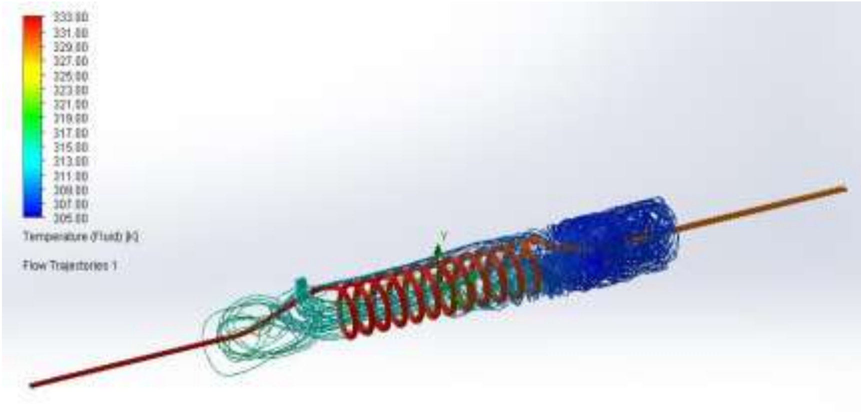

Fig 5: Showing the stream flow lines of the hot and cold water

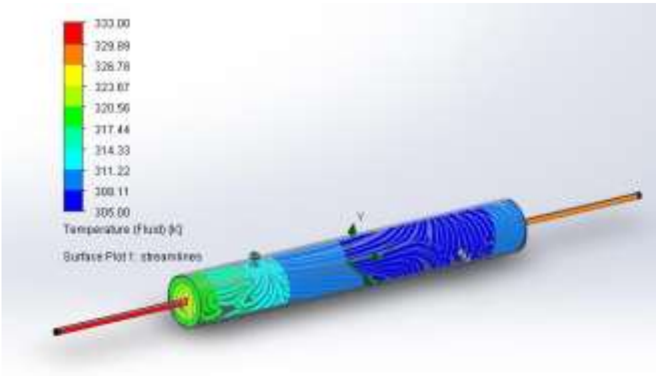

Fig 5.1: Variation in the temperatures in the shell and tube

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CALCULATIONS

Volume flow rate for tube water, m_h = 0.0657 lit/sec

Volume flow rate for shell water, m_c = 0.025 lit/sec

Tube water inlet temperature, T_{hi} = 59.03 ^{0}C

Tube water outlet temperature, T_{ho} = 55.37 ^{0}C

Shell water inlet temperature, T_{ci} = 31.27^{0}C

Shell water outlet temperature, T_{co} = 39.98^{0}C

The amount of heat transfer rate,

For tube side water, $Q_h = m_h\, C_h(T_{hi} - T_{ho})$

= 0.0657×4183× 985× 10^{-3}(59.03-55. 37)

= 990.76475 J/sec

For shell side water, $Q_c = m_c\ C_c(T_{co} - T_{ci})$

= 0.025×4178× 985× 10^{-3} (39.98-31.27)

= 896.1131J/sec

Average heat transfer rate, $Q_{avg} = (Q_h + Q_c)/2$

= (990.7647+896.1131)/2

= 943.4389 J/sec

Difference between inlet temperatures, $\Delta T_i = T_{hi} - T_{co}$

= 59.03-39.98

= 19.05 ^{0}C

Difference between outlet temperatures, $\Delta T_o = T_{ho} - T_{ci}$

= 55.37-31.27

= 24.1 ^{0}C

LMTD, $\Delta T_{lmtd} = \frac{\Delta T_i - \Delta T_o}{\ln(\frac{\Delta T_i}{\Delta T_o})}$

$= \frac{24.1 - 19.05}{\ln(\frac{24.1}{19.05})} = 21.47\ ^0C$

Cross-sectional area of tube, $A_o = \pi DL$

= π×0.0083×3.010

= 0.07848 m^2

Overall heat transfer coefficient, $U_o = \frac{Q_{avg}}{A_0\ \Delta T_{lmtd}}$

$= \frac{943.4389}{0.07848 \times 21.47} = 559.91 W/m^2\ ^0C$

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Reynolds number for hot fluid, Re= $\frac{\rho VD}{\mu} = \frac{VD}{\nu}$

$= \frac{0.8245 \times 0.0083}{0.478 \times 10^{-6}}$

= 14316.6318

Reynolds number for cold fluid, Re=5447.092

Prandtl number, Pr= $\frac{C_p \mu}{K}$

$= \frac{4183 \times 985 \times 0.478}{0.6513}$

= 3.02

Dean number for hot fluid, De= $Re\left(\frac{d}{D}\right)^{0.5}$

$= 14316.6318\left(\frac{0.0083}{0.496}\right)^{0.5}$

= 1851.991

Dean number for cold fluid, De= 704.6329

Nusselt number hot fluid, Nu= 0.152 $De^{0.431} Pr^{1.06} \gamma^{-0.277}$

$=0.152(1851.991)^{0.431}(3.02)^{1.06}(0.0205)^{-0.277}$

= 22.3059

Nusselt number cold fluid, Nu=24.707

Helix number for hot fluid, He = $\frac{De}{(1+r^2)^{0.5}}$

= 1540.49

Helix number for cold fluid, He =586.118

RESULTS AND DISCUSSION

Table: 1 comparison of experimental & analytical values of counter flow helical coil heat exchanger

parameters	Experimental values	Analytical values
Shell inlet temperature	31.27^0C	32^0C
Shell outlet temperature	39.98^0C	41.48^0C
Tube inlet temperature	59.03^0C	60^0C
Tube outlet temperature	55.37^0C	56.64^0C
LMTD	21.4	21.434
Overall heat transfer coefficient	559.91 W/m^2 ^{0}C	560.264 W/m^2 ^{0}C
Reynolds number	14316.63	25525.10
Nusselt number	22.305	28.619
Dean number	1851.991	3301.91
Helix number	1540.49	2746.55

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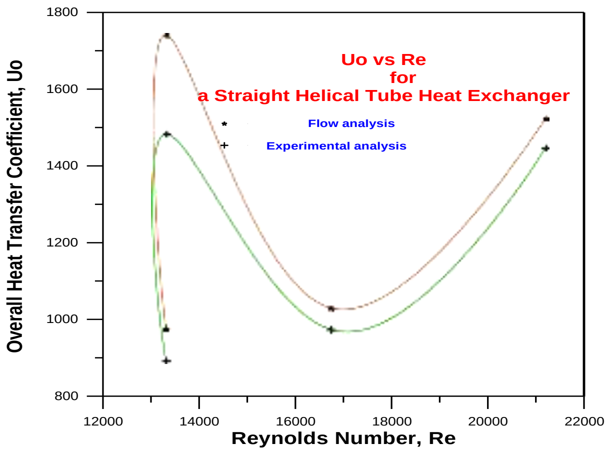
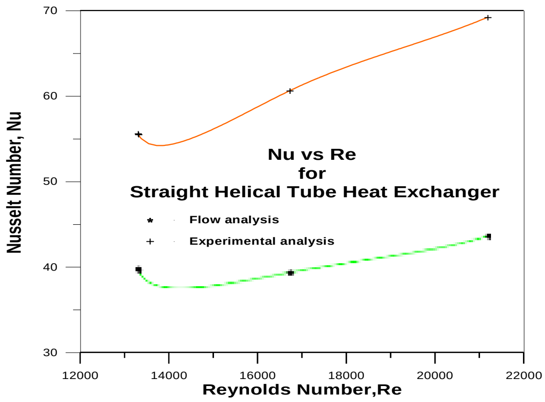
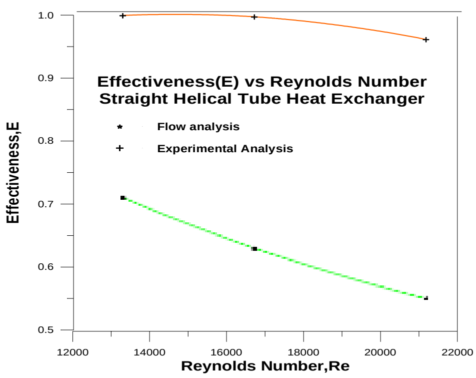
GRAPHS



Discussion: It is clear from the graph that the same trends are observed for the experimental and flow analysis having a deviation of 5.01%. The increase of overall heat transfer coefficient is observed with the increase of Reynolds number.



Discussion: The increasing trend of Nusselt number with the increase of Reynolds number is observed from the graph.



Discussion: The decreasing trend of effectiveness is observed with the increase of Reynolds number.

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CONCLUSION

1. When the flow rate is increased from an initial value of 0.020 m^3/sec to final value of 0.0025m^3/sec the Nusselt number is increased by 34.9%, Reynolds number is increased by 24.9% and the overall heat transfer rate increased by 43.47%.
2. Dean number is the property of fluid flowing in the curved tubes and shells. Its signifies the extent of turbulence obtained due to secondary flow as the turbulence increases the Reynolds number increases which inturn increases the dean number it is well known that heat transfer increases with Reynolds number and hence also increases with dean number and with 66 % of increasing dean number the Reynolds number increased by 66.3 % and the heat transfer rate was found to be increased by 43.47%.
3. An increase of 34.9% in Nusselt number was observed with an increase of 66% of dean number. The increase in Nusselt number was a result of increases in heat transfer coefficient. It is resulting due to turbulence increases in the helical tube due to pitch and curvature ratio.

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