Heat Transfer Enhancement Using Helical Coil Heat Exchanger

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***Abstract*:- Helical coil configuration is very effective for heat exchanger, because they can accommodate a large heat transfer area in small space, with high heat transfer coefficients. This project focus on an increase in the effectiveness of a heat exchanger using water and analysis of various parameters that affect the effectiveness of a heat exchanger and also deals with the performance analysis of heat exchanger by varying various parameters like flow rate and temperature. The results of the helical coil heat exchanger are compared with the straight tube heat exchanger in both parallel and counter flow by varying parameters like temperature, flow rate of fluid and number of turns of helical coil. The fluid flow analysis was done by ANSYS CFD (Computized Fluid Dynamics) software.**

Keywords: Helical Coil, parallel and counter flow

I. INTRODUCTION

. 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. In a heat exchanger the heat transfer through radiation is not taken into account 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 maximised by selecting a minimum thickness of wall of a highly conductive material. But convection is plays the major role in the performance of a heat exchanger.

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.

Helical coils of circular cross section have been used in wide variety of applications due to simplicity in manufacturing. Flow in curved tube is different from the flow in straight tube because of the presence of the centrifugal forces. These centrifugal forces generate a secondary flow, 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). Due to enhanced heat transfer in helical coiled configuration the study of flow and heat transfer characteristics in the curved tube is of prime importance. Developing fluid-to- fluid helical heat exchangers (fluid is present on both sides of the tube wall) requires a firm understanding of the heat transfer mechanism on both sides of the tube wall. Though much investigation has been performed on heat transfer coefficients inside coiled tubes, little work has been reported on the outside heat transfer coefficients.

(e)

Abbreviations

A	Area
D	Mean diameter
d	Inner diameter of copper tube.
F	Fouling factor
h_i	Inlet heat transfer coefficient
h_o	Outlet heat transfer coefficient
K	Thermal conductivity
l	Length of heat exchanger
m	Mass flow rate.
Nu	Nusselt number
Pr	Prandtl number
Q	Heat transfer rate
Re	Reynolds number
T	Hot fluid inlet temperature
ΔT_m	Logarithmic mean temperature difference
U_o	Overall heat transfer coefficient
u	Fluid velocity
ε	Effectiveness

II. MATERIALS AND METHODS

Although various configurations are available, the basic and most common design consists of a series of stacked helically coiled tubes. The tube ends are connected to manifolds, which act as fluid entry and exit locations. The tube bundle is constructed of a number of tubes stacked a top each other, and the entire bundle is placed inside a casting or a shell. Here the material of coil is copper.

Shell and Helical Tube Heat Exchanger

COMPONENTS

- Flow rate
- Pump
- Heater
- Temperature indicator
- Thermocouple
- Helical coil

1. *Flow rate*

The flow rate has been calculated by using measuring jar (liters) and stop watch. It belongs to a class of meters called variable area meters, which measure flow rate by allowing the cross-sectional area the fluid travels through to vary, causing some measurable effect.

2. *Pump*

A **pump** is a device that moves fluids (liquids or gases), or sometimes slurries, by mechanical action. Pumps can be classified into three major groups according to the method they use to move the fluid: direct lift, displacement, and gravity pumps. Pumps operate by some mechanism (typically reciprocating or rotary), and consume energy to perform mechanical work by moving the fluid. Pumps operate via many energy sources, including manual operation, electricity, engines, or wind power.

3. *Heater*

A **heater** is an object that emits heat or causes another body to achieve a higher temperature. In a household or domestic setting, heaters are usually appliances whose purpose is to generate heating (i.e. warmth). Other types of heaters are Ovens and Furnaces. Heaters exists for all states of matter, including solids, liquids and gases and there are 3 types of heat transfer: Convection, Conduction and Radiation.

4. *Temperature indicator*

A temperature data logger, also called temperature monitor, is a portable measurement instrument that is capable of autonomously recording temperature over a defined period of time. The digital data can be retrieved, viewed and evaluated after it has been recorded. A data logger is commonly used to monitor shipments in a cold chain and to gather temperature data from diverse field conditions.

5. *Thermocouple*

A thermocouple is an electrical device consisting of two dissimilar conductors forming electrical junction at differing temperatures. A thermocouple produces a temperature-dependent voltage as a result of the thermoelectric effect, and this voltage can be interpreted to measure temperature. Thermocouples are widely used type of temperature sensor. Here thermocouples are used to measure the temperature the temperature of water. This thermocouple are capable to measure upto 100 degree Celsius.

6. *Helical coil*

The present analysis considers the following dimensional and operating parameters.

Description	value
Outer diameter	38mm
Inner diameter	25.2mm
Tube diameter	6.4mm
Tube length	76cm
Pitch	15mm
Number of turns	35

III. EXPERIMENTAL SETUP

The experimental test rig is properly set up for parallel flow arrangement or counter flow arrangement. Set the volume flow rate of both hot water and cold water to a suitable value using measuring jar and stop watch. Measure the inlet and exit temperatures of hot and cold water using digital thermometer. Observations are noted and results are calculated. The test section comprising helically coiled heat exchanger is shown in Fig. Copper helical tubes have 5.4 mm inner diameter and 6.4 mm outer diameter. The coil diameter (Dc) is 38mm and pitch (Pc) is 15mm. The fiberglass shell has 44mm inner and 50mm outer diameters and 76cm length. Helical tube in this study has 45 turns. The experimental setup and its schematic diagram are shown in Fig. The setup is a well instrumented heat exchanging system in which a hot water stream flowing inside the coiled tube is cooled by a cold stream flowing in the shell side.
One 1500 watt parallel electric heater is placed in the hot water storage tank; reach the hot water temperature to the desired value. The hot water is then pumped to the helical tube which is placed in the heat exchanger. The cold water has the open cycle because the difference is that the cold water temperature increases as it passes through the heat exchanger. The inlet and outlet temperatures of hot and cold water were recorded manually using 4 thermocouples inserted in the small holes made in the inlet and outlet tubes of each heat exchanger and sealed to prevent any leakage. Tests were conducted with varying different parameters such as different flow rates in tube and shell side, volume fraction to study the effect of these parameters in heat transfer rate.

IV. CALCULATION

Length of copper tube in one coil = π*D

Total coil length=Tube length in one coil * Number of turns

$Q = F\, U_o\, A\, (\Delta T_m)$

(From HMT Data Book Page no. 152)
Logarithmic mean temperature difference,

$$(\Delta T_m) = \frac{(T_1 - t_1) - (T_2 - t_2)}{\ln\left((T_1 - t_1) / (T_2 - t_2) \right)}$$

(From HMT Data Book Page no.152)

$$P = \frac{(t_2 - t_1)}{(T_1 - t_1)}$$

(From HMT Data Book Page no.159)

$$R = \frac{(T_1 - T_2)}{(t_2 - t_1)}$$

(From HMT Data Book Page no.159)

By using P and R value find correction factor.

(From HMT Data Book Page no.159)

Area A = Π x d x l

Reynolds number for Hot water,

$$Re = \frac{u \times d}{\gamma}$$

(From HMT Data Book Page no. 112)
Find prandtl number from HMT Data book.
Nusselt number for Hot water,

$$Nu = 0.023\, (Re)^{0.8}\, (Pr)^{0.4}$$

(From HMT Data Book Page no. 126)

Nu $= \frac{h_i\, l}{K_W}$

(From HMT Data Book Page no. 112)

Find Heat transfer co-efficient (h_i) for Hot water using above formula,

Then find Nusselt number for cold water,

Nu $= \frac{h_o\, l}{K_W}$

(From HMT Data Book Page no. 112)

Then find Overall Heat transfer co-efficient,

$U_o = \frac{1}{\frac{1}{hi} + \frac{1}{hO} + Rf}$

Heat transfer rate when water is used in inlet,

Q $= F\, U_o\, A\, (\Delta T_m)$

Then find effectiveness (ε)

$$NTU = \frac{AU}{Cmin}$$

$$MhCh = Cmin$$

Then find C_{min}/C_{max} value, using this value calculate effectiveness (from HMT Data Book Pg. No 163.)

V. RESULTS AND DISCUSSIONS

Experimental observations of inlet temperature of hot water, effectiveness, and overall heat transferred coefficient for helical coil heat exchanger was given in below table.

Flow	Inlet Temp (^{o}c)	Effective ness (ε)	Overall heat transfer coefficient (U) (W/mk)
Parallel flow	60	0.505	2226.89
	70	0.471	1995.45
Counter flow	56	0.92	2077.61
	60	0.84	1876.67

For straight tube heat exchanger,

Flow	Inlet Temp (^{o}c)	Effective ness (ε)	Overall heat transfer coefficient (U) (W/mk)
Parallel flow	60	0.43	977.49
	70	0.41	837.75
Counter flow	56	0.78	876.43
	60	0.65	764.35

Temperature contour for parallel flow,

Total length of coil 760mm.the coil was divided into three equal parts and analysed in ANSYS 16.0 (CFD). The inlet temperature is 60°C and final outlet temperature of coil is 34^{0}C. The inlet cold fluid temperature 29^{0}C and outlet is 33^{0}C.

i. Hot fluid inlet 60°C and outlet is 48 °C
Cold fluid inlet 29 °C and outlet is 30 °C

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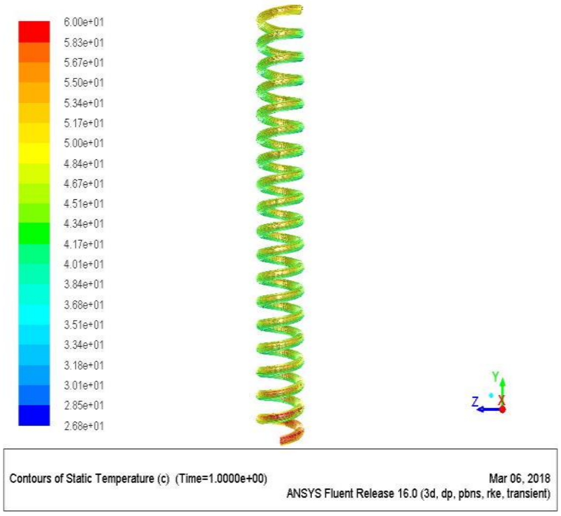
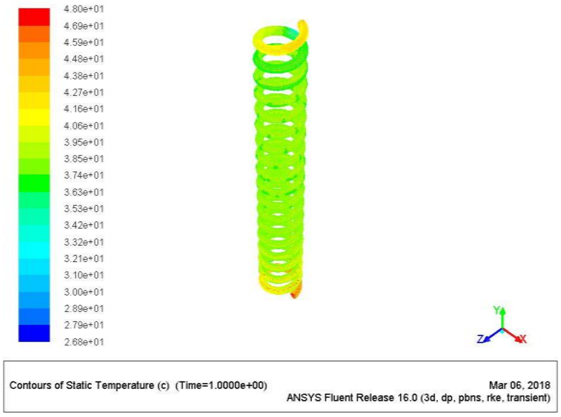
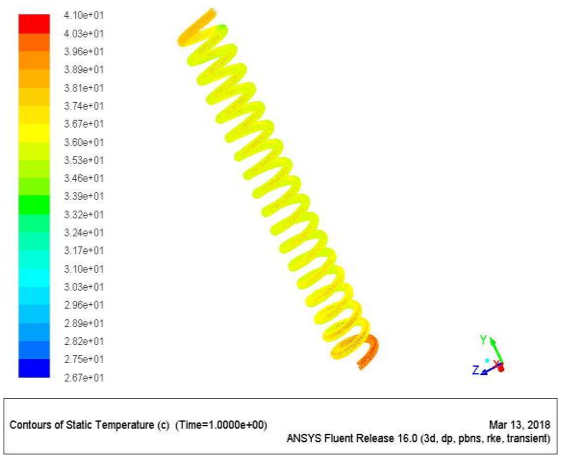


ii. Hot fluid inlet 48°C and outlet is 41 °C
Cold fluid inlet 30 °C and outlet is 31.5 °C



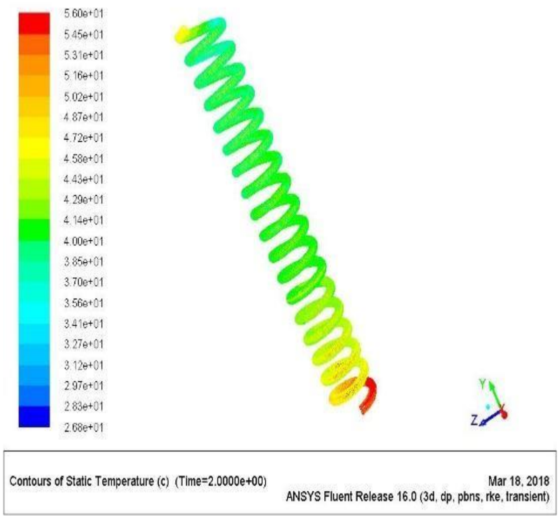
iii. Hot fluid inlet 41°C and outlet is 34 °C
Cold fluid inlet 31.5 °C and outlet is 33 °C



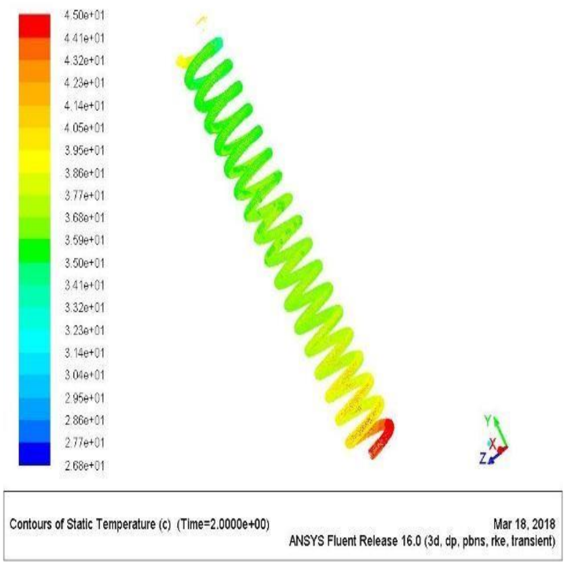
Temperature contour for counter flow,

Total length of coil 760mm.the coil was divided into three equal parts and analysed in ANSYS 16.0 (CFD). The inlet temperature is 56ºC and final outlet temperature of coil is 33^0C. The inlet cold fluid temperature 29^0C and outlet is 32^0C.

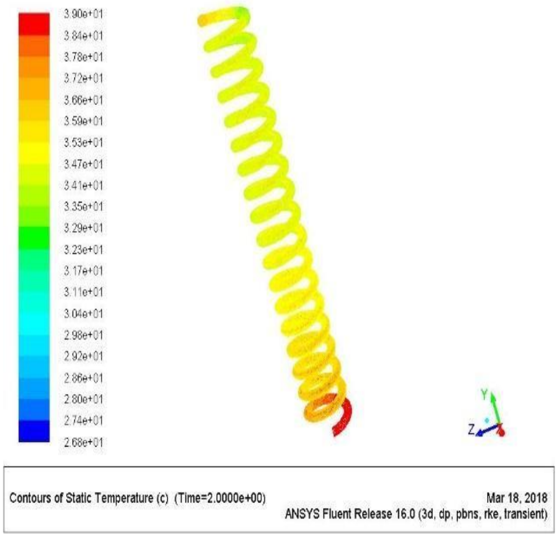
i. Hot fluid inlet 56ºC and outlet is 47 ºC Cold fluid inlet 29 ºC and outlet is 29.5 ºC



ii. Hot fluid inlet 47ºC and outlet is 39 ºC Cold fluid inlet 29.5ºC and outlet is 31 ºC



iii. Hot fluid inlet 39ºC and outlet is 34.5 ºC Cold fluid inlet 31 ºC and outlet is 33 ºC



VI. ADVANTAGES

1) Helical coils give better heat transfer characteristics, since they have lower wall resistance & higher process side coefficient.

2) 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.
3) A helical coil offers a larger surface area in a relatively smaller reactor volume and a lesser floor area.
4) The spring-like coil of the helical coil heat exchanger eliminates thermal expansion and thermal shock problems, which helps in high pressure operations.
5) Fouling is comparatively less in helical coil type than shell and tube type because of greater turbulence created inside the curved pipes.

VII. APPLICATIONS

In the present days heat exchangers are the important engineering systems with wide variety of applications including

- ✓ Power plants
- ✓ Nuclear reactors
- ✓ Refrigeration
- ✓ Air-conditioning systems
- ✓ Heat recovery systems
- ✓ Chemical processing and food industries.

VIII. LIMITATIONS

1) For highly reactive fluids or highly corrosive fluid coils cannot be used, instead jackets are used.
2) Cleaning of vessels with coils is more difficult than the cleaning of shells and jackets.
3) The design of the helical tube in tube type heat exchanger is also a bit complex and challenging.

IX. CONCLUSION

1) The helical tube allows the fluid to be in contact for greater period of time so that there is an enhanced heat transfer compared to that of straight tube.

2) Comparative study is carried out between helical coil heat exchanger and straight tube heat exchanger. The effectiveness and overall heat transfer coefficient of heat exchanger greatly affected by the hot water mass flow rate and cold water flow rate. When cold water mass flow rate is constant and hot water mass flow rate is increased both the effectiveness as well as the overall heat transfer coefficient increases.

3) Results indicated that helical coil heat exchanger showed increase in the heat transfer rate, effectiveness and overall heat transfer coefficient over the straight tube heat exchanger on all mass flow rates and operating conditions.

4) The centrifugal force due to the curvature of the tube results in the secondary flow development which enhances the heat transfer rate.

5) Comparative study shows that helical coil heat exchanger is having better performance that straight tube heat exchanger

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