International Journal of Technical Research and Applications e-ISSN: 2320-8163,
www.ijtra.com Volume 4, Issue 2 (March-April, 2016), PP. 236-239

EXPERIMENTAL ANALYSIS OF HELICAL COIL HEAT EXCHANGER WITH & WITHOUT FINS

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Abstract— **In the present days, Heat exchangers are the important engineering systems with wide variety of applications including power plants, nuclear reactors, refrigeration and air-conditioning systems, heat recovery systems, chemical processing and food industries. Helical coil configuration is very effective for heat exchangers and chemical reactors because they can accommodate a large heat transfer area in a small space, with high heat transfer coefficients. Helical coil heat exchangers are gaining wide importance now-a-days because it can give high heat transfer coefficient in small footprint of surface area. The shell and helical coil heat exchanger and its thermal evaluation with counter flow configuration are to be done. This paper focus on an increase in the effectiveness of a heat exchanger by brazing the fins on its external surface so as to increase the heat transfer rate by increasing its effective area. The thermal analysis is carried out considering the various parameters such as flow rate of cold water, flow rate of hot water, temperature, effectiveness and overall heat transfer coefficient.**

Index terms- **Helical coil heat exchanger, circular fins, Heat transfer, temperature drop, Pressure drop, overall effectiveness.**

NOMENCLATURES

A surface area of coiled tube, m2

Pr Prandtl number, = µCP/k

Dc coil Diameter, m

h averaged convective heat transfer

Coefficient, W/m2 K

k thermal conductivity, W/m2 K

L heat exchanger length, m

Q mass flow rate, kg/s

N number of turns

Nu Nusselt number

P pressure

Q Heat Transfer rate,

R Resistance

Re Reynolds number

t thickness of tube and shell, m

T temperature, oC

Greek letters

µ viscosity, N-s/m2

ρ density, kg/m3

Subscripts

i inside condition

o outside condition

h hot fluid

c cold fluid

avg average

max maximum

ov overall

I. INTRODUCTION

A heat exchanger is a device used to transfer heat between one or more fluids. The fluids may be separated by a solid wall to prevent mixing or they may be in direct contact.

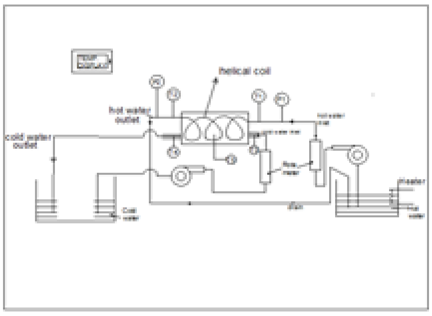
Heat Exchanger which consists of a shell, core, and tubes Although double pipe heat exchangers are the simplest to design, the better choice in the following cases would be the helical coil heat exchanger (HCHE): The main advantage of the HCHE, like that for the SHE, is its highly efficient use of space, especially when it's limited and not enough straight pipe can be laid. Under conditions of low flow rates, such that that the typical shell and tube exchangers have low heat transfer coefficients and becoming uneconomical. When there is low pressure in one of the fluids, usually from accumulated pressure drops in other process equipment. When one of the fluids has components in multiple phases (solids, liquids, and gases), which tends to create mechanical problems during operations, such as plugging of small diameter tubes. Cleaning of helical coils for these multiple phase fluids can prove to be more difficult than its shell and tube counterpart; However the helical coil unit would require cleaning less often. These have been used in the nuclear industry as a method for exchanging heat in a sodium system for large liquid metal fast breeder reactors since the early 1970s, using an HCHE device invented by Charles E. Boardman and John H. Germer. There are several simple methods for designing HCHE for all types of manufacturing industries, such as using the Ramachandra K. Patil method from India and the Scott S. Haraburda method from the United States.

However, these are based upon assumptions of estimating inside heat transfer coefficient, predicting flow around the outside of the coil, and upon constant heat flux. During studies published in 2015, several researchers found that the boundary conditions of the outer wall of exchangers were essentially constant heat flux conditions in power plant boilers, condensers and evaporators; While convective heat transfer conditions were more appropriate in food, automobile and process industries.

These heat exchanger 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.

EXPERIMENTAL SETUP

The schematic diagram of the experimental set up is as shown in Figure. The experimental set up consists of a shell in which the helical coil copper tube is placed through which hot water is made to flow with the help of a centrifugal pump.



To ensure maximum heat transfer the copper helical coil is fully immersed in the cold water flowing through the shell, the inlet and outlet are so placed as shown in Fig. 1.The shell is well insulated so as to avoid the heat loss to the surrounding. The main components in the set up include centrifugal pump, heating element, cold water storage tank and hot water storage tank. The heat exchanger which includes the helical copper tube and insulated shell is perfectly sealed so as to avoid the leakage of hot water flowing through tube and cold water flowing through shell in a counter flow manner.

The water in the storage tank is heated using a heating element, as the water reaches to a prescribed temperature. The centrifugal pump circulates the hot water through the helical coil. The ball valves are used to control the flow rate of hot and cold water. A calibrated rotameter was used to measure the shell side cold water flow rate while for the tube side hot water flow rate a calibrated vane type flow meter is used and data was recorded using a data logger system. The inlet and outlet temperatures of hot and cold water were recorded using calibrated LM 35 temperature sensor through the data logger system. Pressure gauges were used to measure the pressure loss in the helical coil tube. The tube and shell side thermo-physical properties of water were assessed at their mean temperatures.

COMPONENT SPECIFICATION

Thermometer : (K-TYPE Thermocouple) (material:- chrome aluminium) for temperature measurement of inlet and outlet of shell and coil we used thermosensor of range -10 to 110 degree.

Rotameter**:** For flow measurement of inlet of helical coil (hot water) and inlet of shell (cold water) we used rotameter of range 0 to 10 LPM.

Electrical heater
Wattage-3000 watts
Voltage-230 V AC/50 Hz
Pump:
Power – 0.5HP
Head - 15 meters
Speed - 2880 rpm
Discharge - 900 LPH
Volt – 240

Table 1: copper tube specification

TYPE	COLOUR	USE	STANDARD
ACR	BLUE	A/C & R	ASTM B280

SELECTED SIZE IS (5/16):-
Outer diameter of tube (do) = 7.96mm
Inner diameter of tube (di) = 6.33mm
Thickness of tube (t) = 0.81mm
Coil Diameter (D) = 0.21m
Tank size: - 50 Lit Capacity.
Length of coil needed (L) = 3.14 X Dc X N.
Dc = 0.21 m (coil diameter)
N = 7 (no. of turns)
On Substituting (L) = 4.615 m. Pitch = 0.03m
Shell dimension**:-**

Table 2: Shell properties and Dimensions**.**

Material	Length	Width	Height

Galvanized Steel	500 mm	350 mm	250 mm

FINS:
Table 3: Fin Type & Dimension

Area Calculation:
Table 7: Effective Area of coil with Fins.

	Area of fins 1				Area of fins 2			
	(O.D=16mm I.D.=8mm)				(O.D=24mm I.D.=8mm)			
Area of coil	Area of fins	Total area	Net effective area	%increase	Area of fins	Total area	Net effective area	%increase
0.099m^2	0.0844m^2	0.1834m^2	0.1816m^2	46%	0.386m^2	0.485m^2	0.482m^2	80%

Observation Table:
Table 8: Temperature difference (hot water) for various coil with different Flow rates.

		Normal coil			Coil with Fins1			Coil with Fins 2		
					(O.D=16mm I.D=8mm)			(O.D=24mm I.D=8mm)		
Sr.no.	Flowrate (lpm)	Inlet temp	Outlet temp.	ΔT	Inlet temp.	Outlet temp	ΔT	Inlet temp.	Outlet temp	ΔT
1	2	52.1	42.3	9.8	52.1	41.1	11	52.1	38.3	13.8
2	2.5	52.7	43.6	9.1	52.7	41.8	10.9	52.7	39.5	13.2
3	3	53.6	44.7	8.9	53.6	43	10.6	53.6	40.5	13.1
4	3.5	53.9	45.1	8.8	53.9	43.6	10.3	53.9	40.9	13
5	4	54.7	46.2	8.5	54.7	44.5	10.2	54.7	41.8	12.9

Calculation for Overall heat transfer co-efficient & Heat Transfer Rate:
1. for Normal Coil:
STEP 1:
Heat carried by Hot water:
$Q_h = m_h \times Cp_h \times \Delta T_h$
=3.33/60 x 4179.2 x (52.1-42.3)
= 2273.06 W
STEP 2:
Heat carried by Cold water:
$Q_c = m_c \times Cp_c \times \Delta T_c$
=2.22/60 x 4178x (28.6-26.4)
= 340.08 W
STEP 3:
The average of two readings Qavg,
Qavg = (Qh + Qc)/2
= (2273.06+340.08)/2
= 1306.57 W
STEP 4:
Log mean temperature difference (LMTD)
LMTD=19.45ºC
STEP 5:
Overall heat transfer coefficient (Uo),
The outer surface area of heat exchanger
Ao = π*do* L
= π x 0.00796 x 3.959
= 0.099 m^2
U_o=QavgA x LMTD
=1306.570.099 x 19.45
=678.54W/m^2K
STEP 5:
Heat Transfer Rate,
Q= U x A x ΔT
=678.54 x 0.099 x (52.1-42.3)
= 658.31W
2.Coil With Fins 1:
STEP 1:

Type	Material	D_o	D_i	Width
Circular Fins	Copper	24mm	7.96mm	2mm

Heat carried by Hot water:
$Q_h = m_h \times Cp_h \times \Delta T_h$
=3.33/60 x 4179.2 x (52.1-41.1)
= 2551.40 W
STEP 2:
Heat carried by Cold water:
$Q_c = m_c \times Cp_c \times \Delta T_c$
=2.22/60 x 4178x (28.6-26.4)
= 340.08 W
STEP 3:
The average of two readings Qavg,
Qavg = (Qh + Qc)/2 = (2551.40+340.08)/2
= 1530 W
STEP 4:
Log mean temperature difference (LMTD)
LMTD=18.75ºC
STEP 5:
Overall heat transfer coefficient (Uo),
The outer surface area of heat exchanger
Ao = π*do* L + Fin effective Area
= π x 0.00796 x 3.959 +0.08265
= 0.18165 m^2
U_o=QavgA x LMTD
=1530.040.18165 x 18.75
=449.21W/m^2K
STEP 5:
Heat Transfer Rate,
Q= U x A x ΔT
=449.21 x 0.18165 x (52.1-41.1)
= 897.58W
1. for Coil with Fins 2:
STEP 1:
Heat carried by Hot water:
$Q_h = m_h \times Cp_h \times \Delta T_h$
=3.33/60 x 4179.2 x (52.1-38.3)
= 3200.84 W
STEP 2:
Heat carried by Cold water:
$Q_c = m_c \times Cp_c \times \Delta T_c$
=2.22/60 x 4178x (28.6-26.4)
= 340.08 W
STEP 3:
The average of two readings Qavg,
Qavg = (Qh + Qc)/2
= (3200.84+340.08)/2
= 1770.46W
STEP 4:
Log mean temperature difference (LMTD)
LMTD=17.04ºC

STEP 5:
Overall heat transfer coefficient (Uo),
The outer surface area of heat exchanger
Ao = π*do* L +Effective area of fins
= π x 0.00796 x 3.959 +0.383
= 0.4820 m^2
U_o=QavgA x LMTD
=1770.460.4820 x 17.04
=269.171W/m^2K
STEP 5:
Heat Transfer Rate,
Q= U x A x ΔT
=269.171 x 0.4820 x (52.1-38.3)
= 1790.41W

Table 9 : Overall heat transfer co-efficient & heat transfer rates.

	Normal coil		Coil with Fin 1		Coil with Fin 2	
Sr.no	U(W/m^2K)	Heat Transfer(W)	U(W/m^2K)	Heat Transfer(W)	U(W/m^2K)	Heat Transfer(W)
1	678.54	658.31	449.21	897.58	269.17	1790.41
2	678.54	611.29	449.21	889.42	269.17	1712.57
3	678.54	597.86	449.21	864.94	269.17	1699.6
4	678.54	591.14	449.21	840.46864.94	269.17	1686.6
5	678.54	570.99	449.21	832.30840.46	269.17	1673.35

Reynolds number calculation:
Table 7: Reynolds Number for various lpm.

Discharge	density	Diameter	Area	velocity	Reynolds No.
m^3/s	ρ	d	m^2	m/s	ρvd/μ
3.33E-05	1000	0.008	4.98E-05	0.671	5341.16
4.16E-05	1000	0.008	4.98E-05	0.84	6686.4
5.00E-05	1000	0.008	4.98E-05	1.012	8039.6
5.83E-05	1000	0.008	4.98E-05	1.175	9353
6.67E-05	1000	0.008	4.98E-05	1.342	10682.3

Re = [ρ v D/μ]
=1000*0.671*0.008/0.001
=5341.16

Dean number calculation:
Table 7: Dean Number for various lpm.

Diameter	Coil diameter	Radius	d/R	d/R^0.5	Dean No.
d(m)	Dc(m)	R(m)			De
0.00796	0.18	0.09	0.0884	0.2974	1588.46
0.00796	0.18	0.09	0.0884	0.2974	1988.53
0.00796	0.18	0.09	0.0884	0.2974	2390.97
0.00796	0.18	0.09	0.0884	0.2974	2781.58
0.00796	0.18	0.09	0.0884	0.2974	3176.91

De = Re$[d/R]^{0.5}$
= 5341.16*$[0.008/0.09]^{0.5}$
= 1588.46

Results and Discussion

When temperature increases there is a gradual rise in the Effectiveness. But in case of Straight pipe configuration one can
notice a gradual drop in the effectiveness with the rise in the temperature. By increasing mass flow rate of hot water the effectiveness increases at constant cold water mass flow rate. When mass flow rate of cold water is maintained at lower value the effectiveness is maximum but, when mass flow rates of cold water increases effectiveness decreases correspondingly.
The overall heat transfer coefficient and Heat transfer rate increases with increase mass flow rate of hot water. The overall heat transfer coefficient and Heat transfer rate increases with increase in the effective area of the coil with brazing fins and further increases with increasing number of fins or increasing the outer diameter of the fins. With increase in the flow rates of hot water, Reynolds number and Dean number increases**.**

Conclusion

Helical Coil Heat Exchanger is most effective for low flow rates, as flow rate increases heat transfer rate decreases. Heat transfer characteristics of the heat exchanger with helical coil are also studied Fluid particles are found to undergo oscillatory motion inside the pipe and this causes fluctuations in heat transfer rates. Its observed that the variation in tube diameter has greater influence on temperature drop and pressure drop. As the tube diameter goes on reducing the temperature drop increased along with loss of pressure also takes place i.e. pressure drop occur due to which pumping power increases. Temperature drop is maximum for lower flow rate and goes on reducing as the flow rate increases. Whereas pressure drop is directly proportional to flow rate. It indicates that helical coils are efficient in low *Re*.. Hence, it is desirable to have small coil diameter (*D*) and large tube diameter (*d*) in helical coil heat exchanger, for large intensities of secondaries in tube.

It implies that for the same surrounding area the helical pipe absorbed is more than that of straight copper tube. With increase in Flow rate , the turbulence increases n heat transfer rate decreases. The influencing parameters on effectiveness and overall heat transfer coefficient in the decreasing order are: Flow rate, Hot water inlet temperature.

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