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Experimental Study on Helical Coil Heat Exchanger

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***Abstract* -** The recovery of waste heat has been a topic of concern for large-scale industrial companies for several decades. This recovery not only makes an operation more environment friendly, but it also helps to cut costs. In addition to this, it can reduce the amount of resources needed to power a facility. Many industries have implemented different methods of waste heat recovery. One popular choice is using a heat exchanger. This paper presents the study of two types of heat exchangers: straight and helical coil tube. The helical coil heat exchanger has been experimented and analyzed on the basic of log-mean temperature difference (LMTD), heat transfer coefficient and Reynolds number. Based on the results, it is found that helical coil heat exchangers are efficient and its overall heat transfer coefficient increases with mass flow rate.

***Index Terms* -** helical coil heat exchanger, fouling, heat transfer coefficient, LMTD and Reynolds number

I. Introduction

The heat is a form of energy that transfers from the hot object to the cold object, and it transferred through the conduction, the convection and the radiation**.** The heat energy has many usages in the industry as making metals, chemicals, refining oil and processing the food. The shortage of heat energy leads to conserve or to make best use of it. In several industrial processes there is waste of energy or a heat stream that being exhausted in atmosphere. The heat exchangers plays important role to recover this heat and place it to use by heating a different stream within the process. This practice saves a lot of money in industry, as the heat supplied to other streams from the heat exchangers would otherwise come from an external source that is more expensive and more harmful to the environment. The purpose of constructing a heat exchanger is to get an efficient technique of heat transfer from one fluid to another, by direct contact or by indirect contact. In a heat exchanger the heat transfer through radiation is negligible in comparison to conduction and convection. But convection plays the major role in the performance of a heat exchanger. There are numerous applications of heat exchangers such as heat recovery systems, refrigeration, waste water treatment plants, pharmaceuticals, oil and gas industries, HVAC, food & beverage processing industries. In addition to these applications heat exchangers are also used in large scale chemical and process industries for transferring the heat between two fluids which are at a single or two states [1].

In general, the heat transfer techniques can be divided into two groups: active and passive. The active techniques need external forces like fluid vibration, electric field and surface vibration where as passive techniques requires special surface geometries like varied tube inserts. The straight tube heat exchanger has been the oldest type of heat exchanger that has been in use.

The research work has been performed by various investigators on enhancing the performance of straight tube heat exchanger by changing geometric such as baffle arrangement [2], types of tube arrangement, length of the pipe etc. The main challenge in heat exchanger design is to make it compact and to get maximum heat transfer in minimum space. However, it was found that straight tube heat exchangers have restriction in terms of sizing and space which are significant parameters while designing industrial heat exchangers. In 1970 Charles Boardman and John Germer introduced helical coil tube heat exchanger as one of the best passive heat transfer enhancement techniques. The various experimental research work have indicated that helical coil tube heat exchangers are the most useful because of its spiral coil configuration which provides more heat transfer area and better flow in minimum space [3]. This configuration leads higher heat transfer coefficient as compared to straight tube heat exchanger under the same experimental conditions.

II. Straight Tube Heat Exchangers

Straight tube is the type of shell and tube heat exchangers and this is one of the most popular types of heat exchanger due to its flexibility and can be used in systems with higher operating temperatures and pressures. The shell and tube heat exchanger consists of front header, rear header, tube bundle and shell. The fluid enters the tube side of the exchanger via front header and leaves the exchanger through rear header. The tube bundle comprises of the straight tubes, *tube sheets, baffles* and tie rods etc. to hold the bundle together. The bundle of parallel heat exchanger tubes held in place with tube sheets and placed into a shell. Figure 1 illustrate the straight tube heat exchanger where two fluids will exchange heat, one fluid flows over the surface of the tubes whereas the second fluid flows through the tubes. The fluids can be single or two phase and can flow in a parallel or a cross/counter flow arrangement. However experimental studies proven that the straight tube heat exchangers have many disadvantages such as less heat transfer efficiency and require more space [4]. The cleaning of straight tubes is difficult and fouling is often a problem when overall heat transfer coefficient is addressed. This needs periodic cleaning of the shell as well as the tubes.

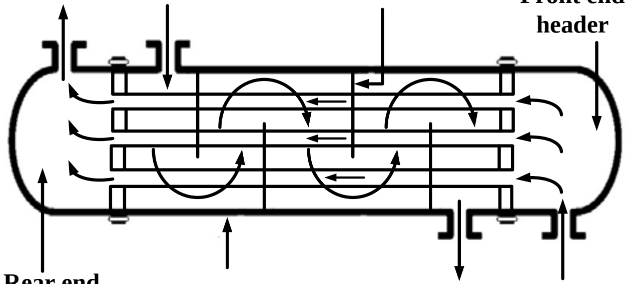

Figure 1: Straight tube heat exchanger

III. Helical coil heat exchangers

The helical coil heat exchangers are a compact shell and tube design consisting of several layers of coiled tubes within a closed shell. The basic construction of the type used for this experimental work with the appropriate nomenclature is illustrated in Figure 1. The helical coil has:

H – Height of pitch,
2r – Diameter of tube,
2Rc – Diameter of helical coil,
i – Curvature ratio (i.e. ratio of tube and coil diameter),
2α – The helix angle (angle between its projection on a surface and measuring angle between the coils).

The flowing fluid experiences centrifugal force because of curved shape of the tube. The local axial velocity of the fluid particle and the radius of curvature of the coil decide the magnitude of centrifugal force experienced. The velocity of fluid particles flowing at the core of the tube is higher than those flowing near to the tube wall. Thus, less centrifugal force will be experienced by the fluid particles flowing close to the tube wall than in the tube core. This pushes the fluid from the core region towards the outer wall (away from the coil axis). This stream bifurcates at the wall and drives the fluid towards the inner wall on the tube bound, inflicting generation of counter-rotating vortices referred to as secondary flows [5]. This leads to produce extra transport of the fluid over the cross section of the tube. This extra convective transport will increase the heat transfer and therefore the pressure drop when compared to straight tube. It's been found that the impact of coil curvature is to suppress turbulent fluctuations arising within the flowing fluid and smoothing the emergence of turbulence. Thus it will increase the value of the Reynolds number (Re) needed to attain a fully turbulent flow, as compared to it of a straight pipe. The impact of turbulent fluctuations suppression enhances as the curvature ratio of coil increases.

- *Fouling in Heat Exchangers*

The deposition of any unwanted material on heat transfer surfaces is named as fouling. This could considerably impact on the thermal and mechanical performance of heat exchangers. Fouling could be a dynamic development that changes with time and that will increase thermal resistance and lowers the heat transfer coefficient of heat exchangers. In addition to this, it also impedes fluid flow, accelerates corrosion and will increase pressure drop across heat exchangers. Helical coil heat exchangers have shown significance enhancements in fouling behavior of heat exchangers operation [6]. The quadrant shaped shells side baffles plates are arranged at an angle to the tube axis creating helical flow pattern on the shell sides. Because of this flow pattern, it provides low fouling characteristics which increases the schedule cleaning period of tube bundle. In this paper, experimental investigation will be carry out for a counter flow tube helical coil heat exchanger where hot and cold water flows through the tube and shell respectively.

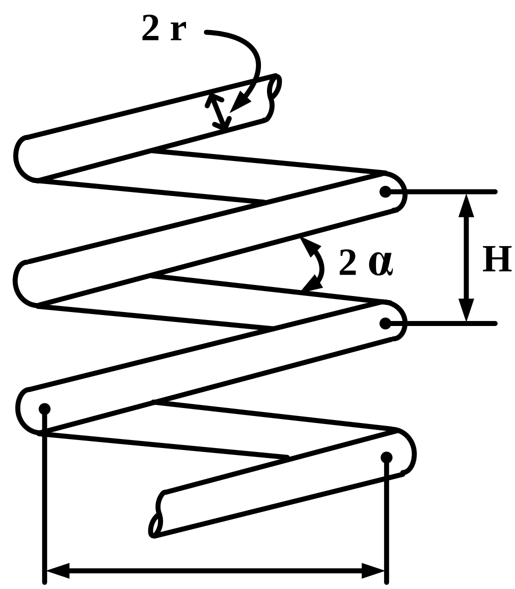

Figure 2: Helical Coil tube

III. Experimental setup

The schematic of the experimental set-up used for the present investigation is shown in Figure 1. The main components in the set up include helical coil tube, shell, thermocouples, centrifugal pumps, heating element, cold water storage tank, flow controlling and measuring devices. The helical coil copper tube is placed in the shell and hot water is made to flow through tube with the help of a centrifugal pump. The shell is well insulated so as to avoid the heat loss to the surrounding. To ensure maximum heat transfer the copper helical coil is fully immersed in the cold water flowing through the shell. The arrangement is made so that, flow direction of hot and cold water is perfectly counter by 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 flow rate of shell side cold water flow.

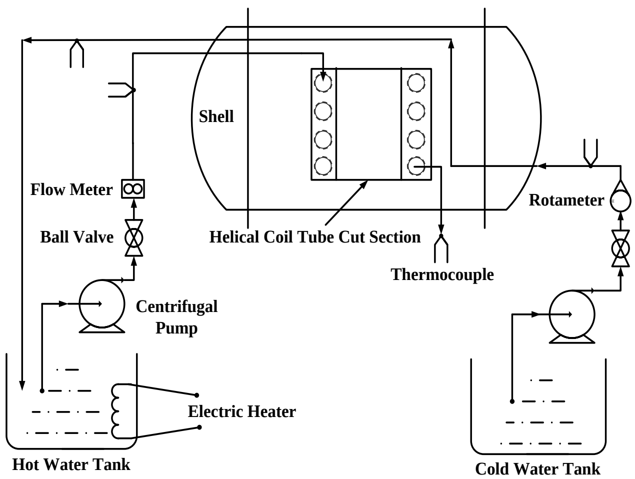

Figure 3: Experimental set-up

The tube side hot water flow rate was measured using calibrated vane type flow meter. The inlet and outlet temperatures of hot and cold water were recorded using RTD thermocouples with accuracy of 0.1°C. The tube and shell side thermo-physical properties of water were assessed at their mean temperatures. Table-I shows the specification of helical coil and Table-II shows the operating range of heat exchanger.

Table I : Characteristics dimension of helical coil tube

Parameters	Dimension
Turns of helical coil	06 turns
Inner diameter of coil	10 mm
Outer diameter of coil	12 mm
Wall thickness	1 mm
Stretched length of coil	3334 mm
Helical diameter of the coil	178 mm
Fluid used	Water

Table II : Range of operating parameters

Parameters	Range
Tube side water flow rate	0.003 – 0.024 Kg/sec
Shell side water flow rate	0.004 – 0.0251 Kg/sec
Tube inlet temperature	55 – 59°C
Tube outlet temperature	42 – 50°C
Shell inlet temperature	35 – 37°C
Shell outlet temperature	44 – 49°C

The formulas used to calculate overall heat transfer coefficient (Uo), LMTD, Reynolds number (Re) and effectiveness (ϵ) are listed below:

$$Q_{hot} = m_h * C_{ph} * \Delta T_h$$

$$Q_{cold} = m_c * C_{pc} * \Delta T_c$$

where, $\Delta T_h = T_{hi} - T_{ho}$ and $\Delta T_c = T_{ci} - T_{co}$

$$U_o = \frac{Q_{avg}}{(Ao * LMTD)} \quad (1)$$

where, $Q_{avg} = \frac{(Q_{hot} + Q_{cold})}{2}$

$$LMTD = \frac{(\Delta T_1 - \Delta T_2)}{\ln(\Delta T_1 / \Delta T_2)} \quad (2)$$

where, $\Delta T_1 = T_{hi} - T_{co}$ and $\Delta T_2 = T_{ho} - T_{ci}$

$$Re = \frac{(\rho * \nu * D_i)}{\mu} \quad (3)$$

$$\epsilon = \frac{C_h * (T_{hi} - T_{ho})}{C_{min} * (T_{hi} - T_{ci})} = \frac{C_c * (T_{co} - T_{ci})}{C_{min} * (T_{hi} - T_{ci})} \quad (4)$$

where, $C_h = m_h * C_{ph}$ and $C_c = m_c * C_{pc}$

V. Results

Figure 4 shows the graph of mass flow rate of hot water Vs effectiveness. It is observed that effectiveness of helical coil heat exchanger initially decreases from 0.62 to 0.52 and it gradually increases as mass flow rate of hot water increases. The effectiveness initially dropdown as hot water capacity rate is less than cold water capacity rate ($C_h < C_c$). When mass flow rate is increased above 72 LPH it is observed that, effectiveness starts to increase as hot water capacity increases. Figure 5 shows the graph of mass flow rate of hot water Vs overall heat transfer coefficient.

Table III : Results for various mass flow rate of hot water

Sr. No.	ΔT_1 (in °C)	ΔT_2 (in °C)	LMTD	ϵ	U_o	Re
1	19.7	11.3	15.72	0.62	462	2089
2	17.2	16.9	19.84	0.47	552	4795
3	15.8	21.8	21.56	0.51	635	6949
4	13.8	24.5	21.91	0.58	716	7943
5	21.1	25.6	27.08	0.62	779	9986

It is observed that as mass flow rate of hot water increases the overall heat transfer coefficient of heat exchanger increases. Figure 6 shows the graph of mass flow rate of hot water Vs Reynolds number. According to (3) the Reynolds number is directly proportional to flow velocity. As mass flow rate of hot water increases the Reynolds number increases, this is because flow velocity increases.

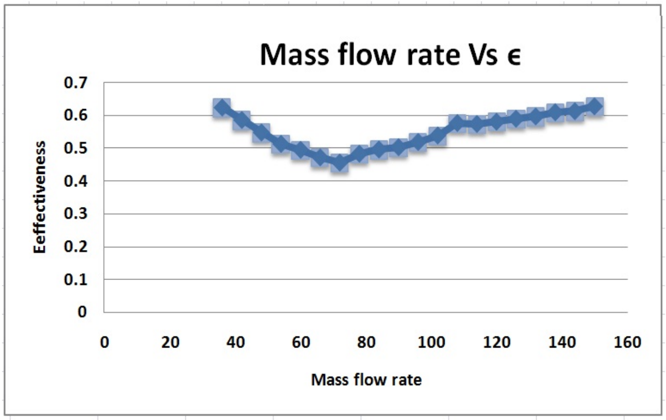

Figure 4: Plot for mass flow rate of hot water with effectiveness

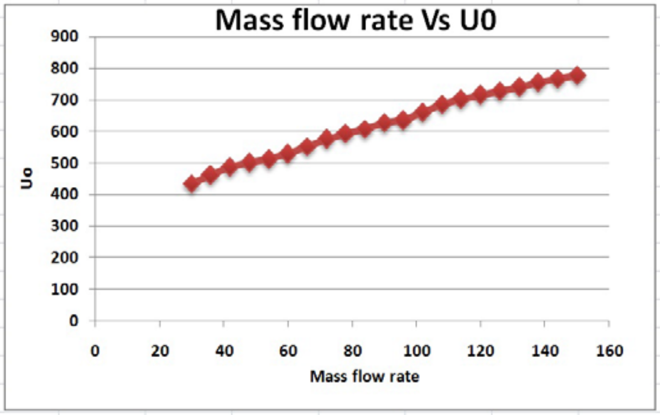

Figure 5: Plot for mass flow rate of hot water with overall heat transfer coefficient

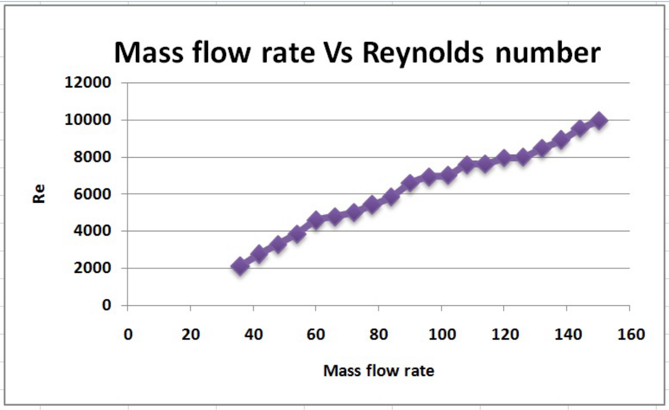

Figure 6: Plot for mass flow rate of hot water with Reynolds number

VI. Conclusion

An experimental investigation was carried out to review the overall heat transfer coefficients and effectiveness of shell and helically coiled tube heat exchangers. It is observed that, once cold water mass flow rate is constant and hot water mass flow rate is increased the overall heat transfer constant will increase. The helical tube permits the water to be in contact for larger period of time in order that there is an enhanced heat transfer compared to that of straight tube. It is also observed that hot water mass flow rate greatly affects effectiveness of heat exchanger. The effectiveness of helical coil heat exchanger gradually increases as flow rate of hot water increases. The overall heat transfer of heat exchangers depends on its LMTD.

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