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AN EXPERIMENTAL PERFORMANCE INVESTIGATION OF COUNTER FLOW HELICAL COILED HEAT EXCHANGER

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Abstract: The purpose of this study is to determine the relative advantage of using a helically coiled heat exchanger against a straight tube heat exchanger. It is found that the heat transfer in helical circular tubes is higher as compared to Straight tube due to their shape. Helical coils offer advantageous over straight tubes due to their compactness and increased heat transfer coefficient. The increased heat transfer coefficients are a consequence of the curvature of the coil, which induces centrifugal forces to act on the moving fluid, resulting in the development of secondary flow. The curvature of the coil governs the centrifugal force while the pitch (or helix angle) influences the torsion to which the fluid is subjected to. The centrifugal force results in the development of secondary flow. Due to the curvature effect, the fluid streams in the outer side of the pipe moves faster than the fluid streams in the inner side of the pipe. The difference in velocity sets-in secondary flows, whose pattern changes with the Dean number of the flow. In current work the fluid to fluid heat exchange is taken into consideration, Most of the investigations on heat transfer coefficients are for constant wall temperature or constant heat flux. The effectiveness, overall heat transfer coefficient, effect on effectiveness of heat exchanger, when mass flow rate of hot water is kept constant with vary mass flow rate of cold water are studied and compared for parallel flow, counter flow arrangement of Helical coil and Straight tube heat exchangers. The inner heat transfer coefficient calculated from Wilson plot method and variations of various dimensionless numbers i.e. Reynolds Number, Nusselt's Number and Dean's number are studied. Then Nusselt number and correlation obtained on the basis of inner heat transfer coefficient. All readings were taken at steady state condition of heat exchanger. Copper was chosen as the as metal for the construction of the helical tube. The fluid flowing through the tube was taken as water. The result shows that the heat transfer coefficient is affected by the geometry of the heat exchanger. Helical coil heat exchanger are superior in all aspect studied here. In present paper analysis of counter flow heat exchanger is done.

Keywords: Helical coil heat exchanger, Straight tube heat exchange, Overall heat transfer coefficient, Effectiveness, Wilson Plot, Reynold's number, Nusselt.s number, Dean number etc;

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INTRODUCTION

A heat exchanger is a device that is used to transfer thermal energy (enthalpy) between two or more fluids, between a solid surface and a fluid, or between solid particulates and a fluid, at different temperatures and in thermal contact. In heat exchangers, there are usually no external heat and work interactions. Typical applications involve heating or cooling of a fluid stream of concern and evaporation or condensation of single- or multi component fluid streams. In other applications, the objective may be to recover or reject heat, or sterilize, pasteurize, fractionate, distil, concentrate, crystallize, or control a process fluid.

Heat exchangers are one of the mostly used equipment in the process industries. Heat exchangers are used to transfer heat between two process streams. One can realize their usage that any process which involve cooling, heating, condensation, boiling or evaporation will require a heat exchanger for these purpose. Process fluids, usually are heated or cooled before the process or undergo a phase change. Different heat exchangers are named according to their application. For example, heat exchangers being used to condense are known as condensers, similarly heat exchanger for boiling purposes are called boilers.

Performance and efficiency of heat exchangers are measured through the amount of heat transfer using least area of heat transfer and pressure drop. A better presentation of its efficiency is done by calculating over all heat transfer coefficient. Pressure drop and area required for a certain amount of heat transfer, provides an insight about the capital cost and power requirements (Running cost) of a heat exchanger. Usually, there is lots of literature and theories to design a heat exchanger according to the requirements.

LITERATURE REVIEW

Extensive work has been completed on the flow and heat transfer characteristics in helical coils. The purpose of this literature review is to go through the main topics of interest. The chapter begins with the fundamental parameters used in single-phase flow that are essential for the calculations of heat transfer and pressure drop were described. Secondly, a review of experimental work of heat transfer in helical coils is presented. The following research papers are studied in detail and the abstract of the work is presented here.

[1] Thermal performance and pressure drop of a shell and helically coiled tube heat exchanger with and without helical crimped fins have been investigated by Naphon. Naphon and Wongwiset provided a literature review on heat transfer and flow characteristics of single-phase and two-phase flow in curved tubes including helically coiled tubes and spirally coiled

tubes. The majority of the studies related to helically coiled tubes and heat-exchangers have dealt with two major boundary conditions, i.e. constant heat flux and constant wall temperature. However, these boundary conditions are not encountered in most single-phase heat exchangers.

Helical coils are used for various processes such as heat exchangers because they can accommodate a large heat transfer area in a small space, with high heat transfer coefficient. In the coiled tube, the flow modification is due to centrifugal forces. The centrifugal forces are acting on the moving fluid due to the curvature of the tube results in the development of secondary flow which enhances the heat transfer rate. This phenomenon can be beneficial especially in laminar flow. Helical coiled tubes are used in a variety of applications including food processing nuclear reactors, compact heat exchangers, heat recovery systems, chemical processing and medical equipment.

[2] Prabhanjan, G. S. V. Ragbavan and T. J. Kennic Have done experimental study to determine the relative advantage of using a helically coiled heat exchanger versus a straight tube heat exchanger for heating liquids. The particular difference in this study compared to other similar studies was the boundary conditions for the helical coil. Most studies focus on constant wall temperature or constant heat flux, whereas in this study it was a fluid-to-fluid heat exchanger. All tests were performed in the transitional and turbulent regimes.

[3] McConalogue and Srivastava (1968) performed numerical studies to determine the characteristics of the secondary flow for fully developed laminar flow. Their results showed that as the axial velocity was increased, the maximum value of the axial velocity moved towards the outer wall and the secondary vortices also migrated closer to the outer wall. In the coiled tube, the flow modification is due to centrifugal forces. The centrifugal forces are acting on the moving fluid due to the curvature of the tube results in the development of secondary flow which enhances the heat transfer rate but pressure drop also increases. Vimal Kumar et al. experimentally and numerically studied the tube in tube heat exchanger. Another research done on coiled inverter flow. The different types of baffles used to increase the turbulence. Experimentally observed the tube side pressure drop and heat transfer. They present the variation of pressure drop versus tube side mass flow rate on different modules. The pressure drop increases with increase number of bends. The new empirical correlation developed for friction factor and heat transfer.

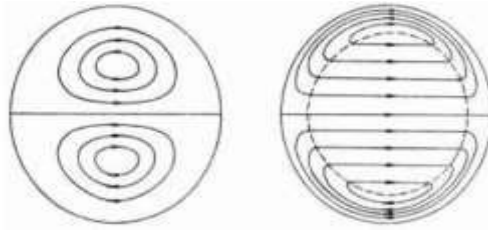


Figure : Secondary flow pattern in helical coiled tube

[4] Nasser Ghorbani, Hessam Taherian, Mofid Gorji, Hessam Mirgolbabaie, Have done an experimental investigation of the mixed convection heat transfer in a coil-in-shell heat exchanger is reported for various Reynolds and Rayleigh numbers, various tube-to-coil diameter ratios and dimensionless coil pitch. The purpose of this article is to check the influence of the tube diameter, coil pitch, shell-side and tube-side mass flow rate over the performance coefficient and modified effectiveness of vertical helical coiled tube heat exchangers. The calculations have been performed for the steady-state and the experiments were conducted for both laminar and turbulent flow inside coil. It was found that the mass flow rate of tube-side to shell-side ratio was effective on the axial temperature profiles of heat exchanger.

[5] Syam sunder and Sharma experimentally investigated by inserting a twisted tap in the flow path of circular tube with Al₂O₃ water nano-fluid. They formulated the correlation for heat transfer coefficient and friction factor at 0.5% volume concentration of Al₂O₃ / water nano-fluid.

EXPERIMENTAL SETUP

❖ Helical Coil Heat Exchanger

The helical coil heat exchanger is fabricated in heat transfer lab. The schematic of the experimental set-up used for the present investigation is shown figure. The set-up consisted of the following components;

1. Hot water storage
2. Pump
3. Coil inlet rotameter
4. Shell
5. Helical coil

6. Shell outlet tank
7. Thermocouple
8. Electric Heater
9. Coil outlet tank
10. Shell inlet rotameter
11. Cold water storage

The schematic diagram of the experimental set up is as shown in Fig. 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 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. The shell is well insulated so as to avoid the heat loss to the surrounding. 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. Thermo couple are used to note down temperature at entry and exit of hot and cold water flows respectively. Following fig. shows the experimental setup.

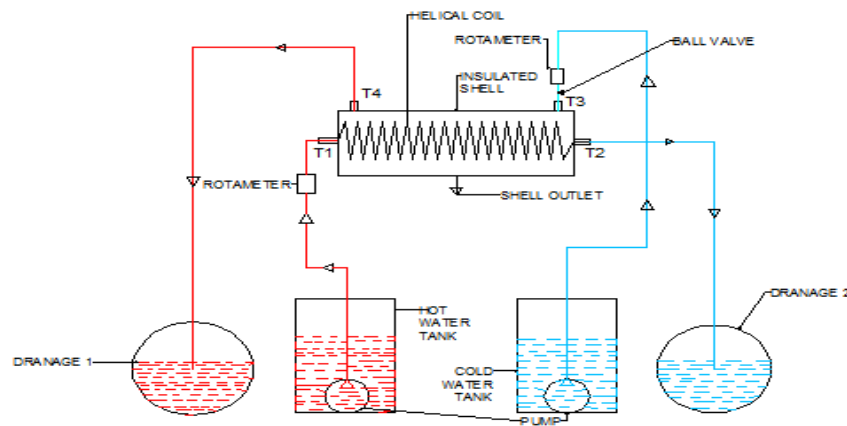


Figure: Flow diagram of experimental setup

So spring benders are used on larger tubing primarily to accomplish slight bends or curves. Although the spring bender is designed for use on the *outside* of tubing, a smaller spring is sometimes inserted into the tubing to make a bend at the tubing end.

List of Specifications of parts

1. Thermocouple

A thermocouple is a type of temperature sensor, which is made by joining two dissimilar metals at one end. Thermocouple inserted for temperature measurement is K-Type. The Type K thermocouple has a **Chromel** positive leg and an **Alumel (Nickel- 5% Aluminum and Silicon)** negative leg. The temperature range for Type K is -201 to 1260°C and its wire colour code is yellow and red.

2. Rotameter

For flow measurement of inlet of helical coil (hot water) and inlet of shell (cold water) we used acrylic water rotameter of range 10 to 100 LPH.

3. Helical Coil

Material	Copper
Length	10.5m
Inner Diameter	0.65cm
Thickness	1mm
Pitch	1.4cm
Number of Turns	37
Pitch Diameter	10cm

4. Shell

Length	50cm
Inner Diameter	13cm

Outer Diameter 15.5cm

5. Manufacturing of Shell

Component	Material
helical coil	Copper(k=386 W/mK)
Shell	Cast Iron(k=55 W/mK)
Insulation	Foam(k=0.045 W/mK)

6. Properties of Water

Properties	Unit	Cold Water	Hot Water
Specific Heat, Cp	KJ/Kg°C	4.183	4.216
Thermal Conductivity, k	W/m°K	0.58	
Viscosity, μ	N-s/m ²	0.00082942	0.00028157
Density, ρ	Kg/m ³	997.5	961

❖ Experimental Arrangement

Experimental arrangement of heat exchanger as shown in figure 16. Heat exchanger is divided into two parts: one is measuring board and other is working components. Different components of the heat exchanger are;



Experimental Methodology

Experiments were performed for various inlet temperatures and flow rates of hot water entering the test section. The hot water flows through the test coil with constant flow rate and cold water flows through the shell. The inlet hot water temperatures were adjusted at desired level by using electric heaters. The system was allowed to reach steady state before any data was recorded. The flow rates were controlled by adjusting the ball valve and measured by the rotameter having range 10 to 100 LPH. Experimental procedure is as follows:

First fill the water in both tanks and switch on the electric supply to the heater of hot water tank. After reaching the desired temperature of hot water, start the pump of hot water side and circulate the hot water through the test coil. The mass flow rate of hot water is controlled by ball valve and measured by the rotameter. At the same time circulate the cold water through the shell by starting the pump. The flow rate of cold water is controlled by ball valve kept in cold water line and measured by the rotameter. The test was conducted for counter flow configuration. Water inlet and outlet temperatures of coil side and shell side are measured

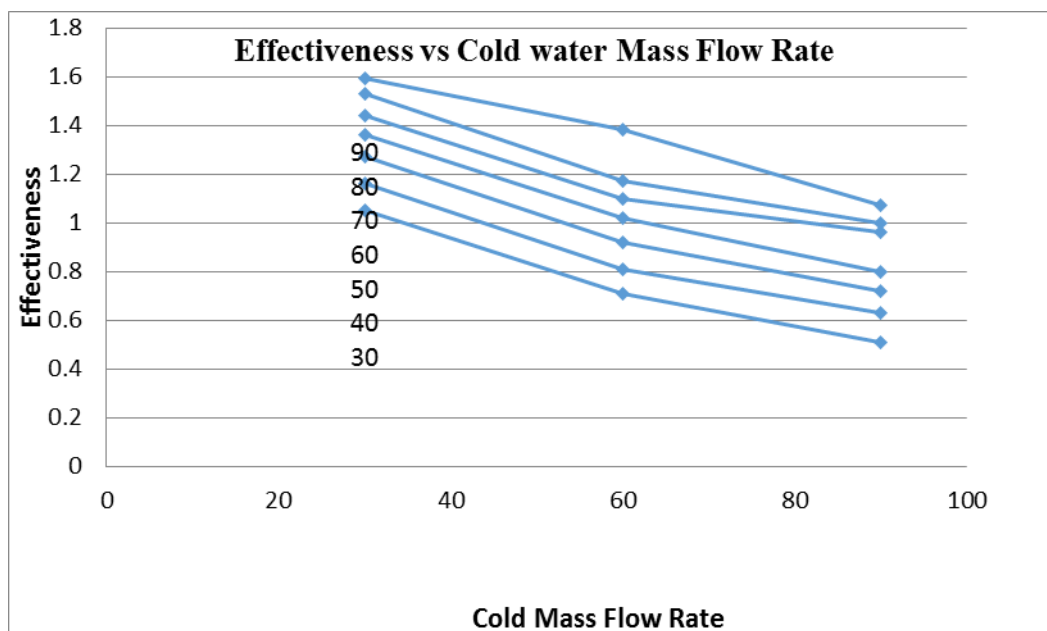
by the temperature indicator. Record the temperature readings for mass flow rate of hot water kept constant and varying the mass flow rate of cold water. Repeat the procedure.

RESULT AND DISCUSSIONS

The experiment was conducted for single-phase water to water heat transfer application. This project presents a comparative analysis of different correlations given by the different researchers for helical coil heat exchanger. The various equations use different parameters for the analysis. It was found that the centrifugal force due to the curvature of the tube results in the secondary flow development which enhances the heat transfer rate. This phenomenon can be beneficial especially in laminar flow regime. The results obtained from the experimental investigation of heat exchanger operated at various operating conditions are studied in detail and presented.

Effectiveness Vs Cold water mass flow rate

The graph of Effectiveness Vs Cold mass flow rate shows as the flow rate of cold water increases the slope of line decreases. It implies that as we go on increasing the cold water flow rate the effectiveness (ϵ) goes on decreasing



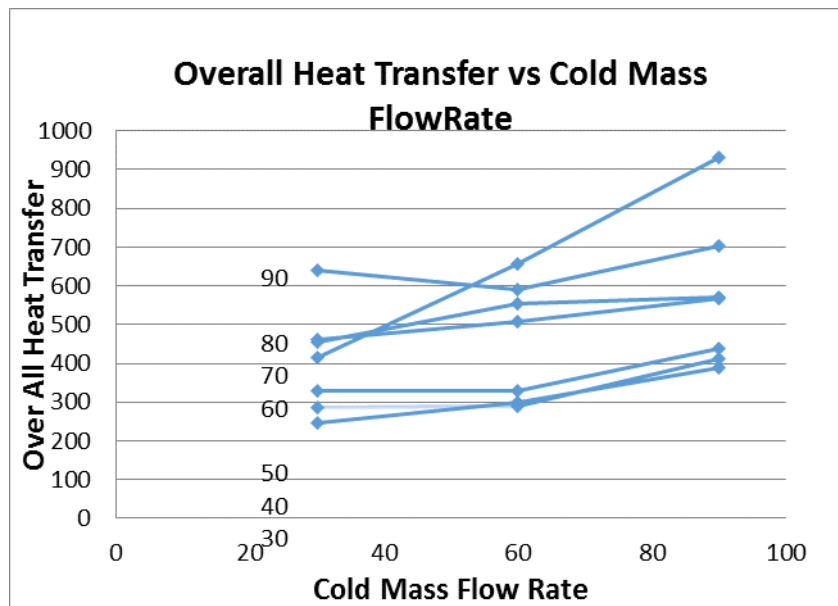
Effectiveness Vs Cold mass flow rate

Heat transfer rate (Average) Vs Cold water mass flow rate

The Graph of Average heat transfer rate Vs cold water mass flow rate shows that the line on graph goes on increasing. It implies that as we go on increasing cold water mass flow rate the Heat transfer rate (Q) in the heat exchanger continuously goes on increasing.

Overall Heat transfer rate Vs Cold water mass flow rate

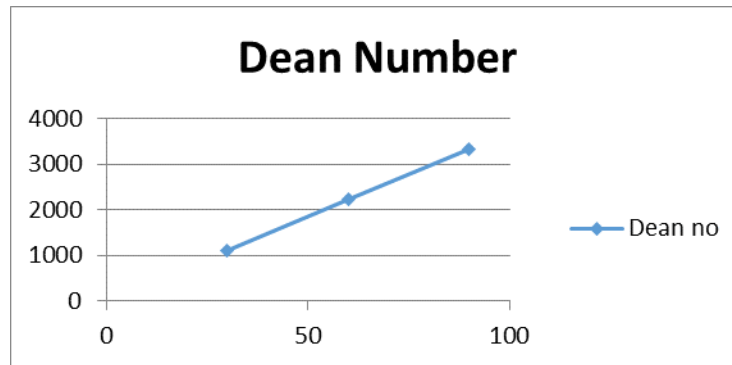
The Graph of Overall heat transfer rate vs. cold water mass flow rate shows that the line on graph goes on increasing. It implies that as we go on increasing cold water mass flow rate the Overall heat transfer coefficient in the heat exchanger continuously goes on increasing



Heat transfer coefficient Vs cold mass flow rate

Dean no. Vs Cold water mass flow rate

Dean number is the property of fluid flowing in curved tubes and shells which signifies the extent of turbulence due to secondary flow. Greater will be the turbulence higher will be the heat exchange. The Graph of Dean Number Vs. cold water mass flow rate shows that the line on graph goes on increasing. It implies that as we go on increasing cold water mass flow rate the Dean Number continuously goes on increasing



Dean Number Vs cold mass flow rate

CONCLUSION

Experimental study of a single-phase water to water helical coiled heat exchanger was performed considering hot water in the coil at constant flow rate conditions and with cooling water in the shell. The mass flow rates in the coil tube are kept constant and in the shell were varied and the counter-current flow configurations were tested. The various equations use different parameters for the analysis. It was found that the centrifugal force due to the curvature of the tube results in the secondary flow development which enhances the heat transfer rate.

It was concluded that increasing cold water mass flow rate the Heat transfer rate (Q) in the heat exchanger continuously goes on increasing. The experimentally obtained overall heat transfer coefficient (U_o) for different values of flow rate in the coiled tube and in the shell region were reported. It was observed that the overall heat transfer coefficient increases with increase in the mass flow rate of cold water, for the constant mass flow rate of hot water.

The effectiveness of heat exchanger is affected by hot water mass flow rate and cold water mass flow rate. When hot water mass flow rate is constant and cold water mass flow rate increased the effectiveness decreases. Dean number is the property of fluid flowing in curved tubes and shells which signifies the extent of turbulence due to secondary flow. In this experiment observed that increasing cold water mass flow rate the Dean Number continuously goes on increasing.

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