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Experimental Study of Condensation of Steam in Helically coiled Tubes

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Abstract: - *Helical coil is most widely used enhancement technique used in many industries because of its low cost, compact structure and long life. The condensation process of steam inside helical coil is investigated for different mass flux ranges from 68 kg/m^{2}s to 97 kg/m^{2}s and different saturation temperature range from 111 ºC to 120ºC. Heat transfer coefficient and overall heat transfer coefficient is plotted against mass flux which shows it increases with them*

Keywords: - *Helical coil; condensation; mass flux; Saturation temperature; heat transfer coefficient.*

I. Introduction

The development in the heat exchanger designs to fulfill growing industrial demands leads to evolution of helical coil heat exchanger as new design. Helical coil is widely used passive heat transfer enhancement techniques which used in many industrial applications like steam generators in nuclear power plant due to its higher compactness and superior heat transfer ability over straight tube

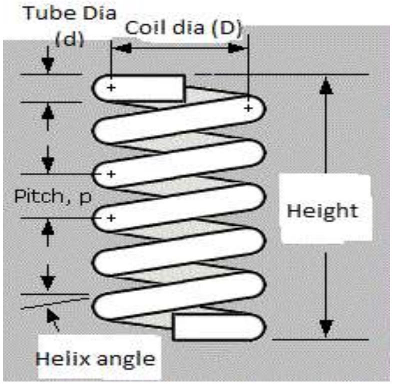

Fig.1 Geometry of helical coil

Tube diameter: d or 2r
Pitch: P: Distance between two adjacent arms.
Coil diameter: D or (2R) Measured between centers of the pipe.
Helix angle: α: The angle made by the projection of one turn of coil with the perpendicular to axis of coil when projection is taken on the plane passing parallel and through the axis of coil.

1.1 Hydrodynamics of flow through Helical Coil

It has been found that fluid flow through helical coil is more complex than straight tube. The curvature of coil governs the centrifugal force and effect of torsion is decided by pitch of the helix. Fluid passing through the core has more velocity that fluid flowing near the wall. Centrifugal force causes the new redial component of velocity to come into action. Thus fluid in core subjected to higher centrifugal force than the near wall fluid. This effect pushes the fluid at core to the outer wall and fluid at outer wall moves along the wall to inward direction due to pressure difference between outer and inner surfaces. This leads to the development of two counter rotating vortices as shown in figure sometimes called Dean Vortices and the circulatory flow of fluid normal to the main axial flow is termed as secondary flow also this exist over the entire length of coil.

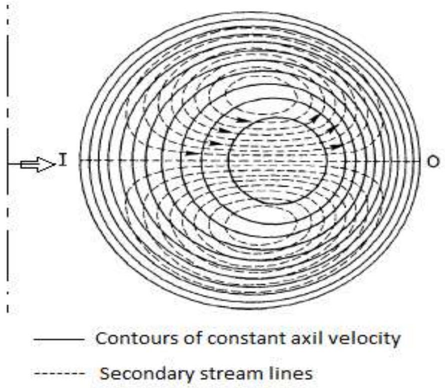

Fig.2 Flow path counters

The effect to curvature suppresses the turbulence fluctuations in fluid flow thus increase the value of Reynolds number require to attained fully develop turbulent flow pattern. At the same time torsion reduces the flow stability and increases the turbulence. The flow pattern in coil is depends on Dean Number of flow.

Dean No $De = Re\sqrt{\frac{d}{D}}$ (1)

Where $Re = Reynolds\ No. = \frac{\rho v d}{\mu}$ (2)

1.2 Project Objectives

- To investigate effect of coil diameter on heat transfer
- To study heat transfer by varying mass flux

II. Literature Review

Jayakumar et al [2] [3] investigated the heat transfer process in helical coil heat exchanger experimentally and by using computational tool. The effect of coil diameter, coil pitch, tube diameter and void fraction on heat transfer coefficient and pressure drop was investigated. CFD simulation was done for constant and variable properties of fluid. Observation states that heat transfer increases with increase in tube diameter and decrease in coil diameter [4]. Ebadian [5] investigated condensation heat transfer and pressure drop characteristics of R-134a at different mass flux, orientation and different saturation temperature flowing through helical tube and annular passage [6]. Results show that overall and refrigerant side heat transfer coefficient is highest at inclined position and lowest at vertical position. While comparing with the straight tube refrigerant heat transfer coefficient is found to be double in the annular channel [7]. Mozafarai [8] studied condensation process for different orientation and different vapour quality and performance index of helical coil is tested against straight pipe results which show helical coil gives higher heat transfer rates. They have reported the highest value of heat transfer coefficient at 30° inclination compared to horizontal and vertical position.

Wongwises et al [9] performs the experiments by taking R-134a as working fluid. He observes that Frictional pressure drop, and heat transfer coefficient increases with increase in vapour quality while decreases with increase in saturation temperature. New frictional pressure drop and HTC correlation was developed. Salimpur [10] studied thermal performance of R-404 for different coil radii by varying vapour quality he finds that decreasing coil radius enhances the heat transfer rate and proposed new correlation for heat transfer coefficient. In recent years Ravi kumar performs the experiment for shell and coil heat exchanger for smooth and dimpled helical coil tube and compares it with its straight tube counterpart. Result shows that dimpled tube helical coil gives higher heat transfer coefficients and frictional pressure drop than other heat exchangers. He presented new correlations for two phase heat transfer coefficient and frictional pressure drop. Ravi kumar [11] [12] also plotted his data against Taitel [13] flow regime maps for investigating the flow regime transition

Murai [14] studied the air water two phase flows in helical coil tube, the effect of centrifugal acceleration on flow pattern and temporal flow structure distribution were investigated. Results show that bubble to plug transition is significantly quickened as curvature radii decreases. A Sarmadian et al [15] studied the condensation of R-600a inside plane and helically dimpled horizontal tube. The condensation process is visualized to evaluate flow pattern transition. Observations show that enhancement in surface delays the transition from annular to intermittent flow and hence increases rate of heat transfer. The stratified wavy flow observed in smooth tube was not seen in dimpled tube.

III. Experimental Setup

The test rig is developed to evaluate the performance of helical coil for condensation process. The test section was condenser with 3 different helical coils with different coil diameter remaining the pitch and tube diameter constant.

Steam is produced by portable boiler. Orifice meter is used to find the mass flow rate of the steam (working fluid) along with Differential manometer. Mass flow rate is controlled by ball valve in-line with orifice meter.

17 number of T-type thermocouple (copper-constantan) was used to measure the outer wall temperature of the test condenser. They are placed at 120 degree apart from each other on the outer periphery of the coil and are securely placed by using mechanical clamp with rubber shoe to insulate it from the surrounding water. Inlet & outlet temperature of the cooling water to the shell side and that of steam for coil is taken by RTD sensors. Temperature is displayed on 8-channel digital temperature indicator having least count of 0.1°C. Thermocouples were calibrated against Thermometer having 1°C of resolution.

Cooling water from the city main is supplied to the tank of test section which has arrangement to accommodate different coil diameters. Shell is manufactured by 3 mm MS sheet. Diameter of tank is 295 mm and height 450 mm with approximate capacity of 30Liters. Cooling water flow rate is measured using acrylic rotameter .range is 0-20 lpm with 0.5 lpm calibration.

Burdon make pressure gauge is installed upstream of the coil to find inlet pressure of steam. Complete piping system is thermally insulated by ***Superlon*** pipe insulator having thickness of 19mm.

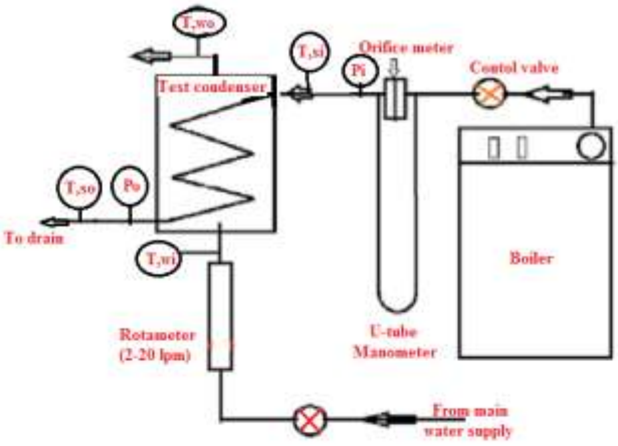

Fig.3 Schematic diagram of experimental set up

Initially a little superheated Steam is supplied to the condenser where steam releases its heat to the cooling water flowing through the shell. Wet steam is then supplied to the post condenser to cool down it further and then delivered to the drain tank. Cooling water flow rate is kept at particular value by controlling the regulating valve attached to the main line. Some experimental operating conditions are repeated to ensure the repeatability of the boiler and instruments. Readings are taken at interval of every 15 minute. Steady state is considered when 2-3 successive readings are constant or remain same. The three different mass flux and three different steam saturation temperature is used to perform the experiment

IV. Data Reduction

Analysis of data generated during experiments is essential to find the values of mass flux, coefficient of heat transfer and average vapour quality during each test run at steady state. Steady state is confirmed when 2-3 successive reading are constant. Thermo-physical properties of steam are taken from online source as given in reference [17]. Table show the range experimental test conditions.

Table1 Operating parameters

Parameters	Range
Saturation temperature of steam (°C)	111.2±0.3 to 120 ±0.3
Mass flux (kg/m^{2}s)	68 - 98
Cooling water flow rate (LPM)	2 - 9

Average coefficient of heat transfer can be calculated by following equation

$$h_{steam} = \frac{Q_w}{\pi\, d_i\, L\left(T_s - T_{i,wall}\right)} \quad \left(\frac{W}{m^2}\,°C\right) \tag{3}$$

Where T_s is saturation temperature of steam $T_{i,wall}$ is inner wall temperature and Q_w is amount of heat taken away by cooling water.

Inner wall temperature is calculated by finding out average outer wall temperature $T_{o,wall}$ which is arithmetic mean of temperature measured at 17 location along the coil.

$$T_{o,wall} = \frac{1}{N}\sum_{i=1}^{N} T_{o,wall_i} \tag{4}$$

$$T_{i,wall} = T_{o,wall} + \frac{Q_w\ ln\left(\frac{d_o}{d_i}\right)}{2\ \pi L\ k} \tag{5}$$

The heat transfer rate Q_w is determined by rise in cooling water temperature and mass flow of the same by using following equation.

$$Q_w = \dot{m}_w \times C_p \times \left(T_{wi} - T_{wo}\right) \tag{6}$$

V. Results and Discussions

Helical coils with different coil diameter and other geometric parameters such as tube diameter, pitch and number of turn keeping same were tested for different mass flux, saturation temperature and different average vapour quality. Total 48 tests were performed.

4.1 Effect of mass flux

The steam side heat transfer coefficient is plotted against mass flux. It shows that heat transfer coefficient increases with the increase in mass flux. This is because increase in mass flux leads to increase in flow velocity of vapour and liquid film which in turns increases the flow turbulence. The effect of coil diameter is also studied which shows that as coil diameter decreases heat transfer coefficient increases. The decrease in coil diameter enhances the effect of centrifugal forces on the flow characteristics.

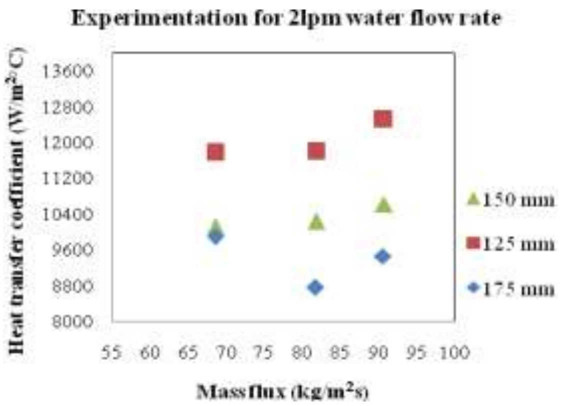

Figure 4 Effect of Mass flux on Coefficient of heat transfer **(h_0)** for 2LPM

The effect of mass flux on coefficient of heat transfer of steam when water flow rate of steam is maintained 2 lpm throughout all experimentations is shown in figure4. It shows that coefficient of heat transfer increases with mass flux.

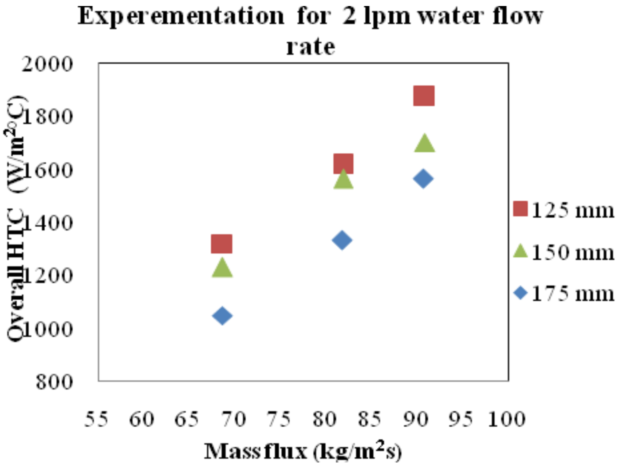

Figure 5 Effect of Mass flux on Overall Coefficient of heat transfer ***(U_0)*** for 2LPM

With increase in mass flux of steam overall heat transfer coefficient also increases in same fashion. The helical coil with smallest coil diameter shows higher values than other two coils with larger coil diameter. The effect of mass flux on overall coefficient of heat transfer for 2lpm water flow rate is shown in figure 5. It has seen than overall CHT increases with increase in mass flux.

VI. Conclusions

From the experimental observations and analysis of results we can drawn some conclusion as follows The steam side average heat transfer coefficient has direct relation with the mass velocities of the steam. Coil diameter has significant effect on heat transfer coefficient. Average coefficient of heat transfer increases with increment in average vapour quality. Overall heat transfer coefficient increases with increase in both mass flux and average vapour quality of steam.

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