Experimental Validation for Heat Transfer Enhancement by using Square Cut Circular Ring Insert

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Abstract— An experimental investigation is carried for heat transfer enhancement with the help of Square cut circular ring insert for heat exchanger application. Experimental investigation is for measuring tube side heat transfer coefficient, friction factor, thermal performance factor of air for turbulent flow in a circular tube fitted with square cut circular ring insert. An experimental setup consist of Blower, flow control valve to maintain measured quantity of flow, Orifice meter is used for flow measurement, Pressure drop is measure along test section and orifice meter with 2 U-tube manometer. A stainless steel tube of (SS304) material having 34mm of inner diameter & 38mm outer diameter & 1000mm test length is used. A mild steel of 0.5mm thickness square cut circular ring insert with 3 different cut area & 3 different pitch inserted into the smooth tube. The square cut circular ring have: (1). 8.5mm depth & 10mm width. (40% area remove) (2).6.5mm depth & 10mm width(30% area remove) (3).3.5mm depth & 10mm width (16% area remove) In each case (1), 6 insert with distance between insert is16cm. (2) 5 insert with distance between insert is 20cm. (3), 4 insert with distance between insert is 27cm. A uniform heat flux condition is created by Band type nichrome wire heater (9 heater 70w each at length of 100mm each) around the test section & asbestos insulation of 3mm thickness over the band type heater. Outer surface temperature of tube is measured at 8 different points of test section by K-type thermocouple. 2 Thermocouple is used for calculating heat loss to surrounding. Another 2 thermocouple is used for measuring the bulk temp (inlet & outlet temperature of air).

The Reynolds number is varied in the range of 4000 to 16000 with constant heat flux supplied by heater is 1.25 kw/m2 for smooth tube & tube with insert. Nusselt number obtained from smooth is compared with Dittus-Boelter correlation & errors are found to be in the range of ±7.0758%. Friction factor is compared with Blasius corotation. Experimental setup is validate with the help of Dittus-Boelter equation and Blasius co-relation. At comparable Reynolds number, Nusselt number in the tube with square cut circular ring insert is enhanced by 2.3 to 2.9 times at cost of increase of friction factor by compared to smooth tube & also at cost of increase of pressure drop as compared to that of smooth tube. Thermal performance factor are found to be higher than unity up to 14000 Reynolds number and also heat transfer enhancement is increases with increased of Reynolds number.

Key words: Heat Transfer Enhancement, Square Cut Circular Ring Insert, Nusselt Number, Pressure Drop, Thermal Performance Factor

I. INTRODUCTION

The aim of the project is to investigate the heat transfer enhancement by using square cut circular ring insert in circular tube for increasing the heat transfer rate & achieving higher efficiency in the application of heat exchanger, nuclear reactor, solar heaters, gas turbine, combustion chamber and many other practical heating devices. However present study permits the higher heat transfer rate but cause reasonable frictional penalty & axial pressure drop. It is proposed to make some modification or using different type of inserts to achieve heat transfer augmentation with minimum frictional losses & min. Axial pressure drop. The new type of insert is intended to have high heat transfer rate & minimum pressure drop from existing inserts. By increasing the thermal performance of heat exchanger we meant making the heat transfer operation more economical and efficient. In order to achieve that, we need to modify the construction of heat exchanger, using efficient metal surface for heat transfer to take place.

Several modification and new ideas to enhance the heat transfer led to many technical terms like heat transfer augmentation also tends to increase known as heat transfer intensification or enhancement. Application of augmentation technique the heat transfer coefficient but at the same time pressure drop also increases significantly. So, while applying any augmentation technique on heat exchanger analysis of both, heat transfer rate and pressure drop has to be done. Moreover long durability and economic feasibility are two other major issues that need to be addressed. To get high heat transfer rate keeping pressure drop under limit (keeping pumping cost under control), many techniques have been applied in recent years and are discussed in the following sections. Introduction of insertions in the flow path of inner tube side liquid has been quite effective in past studies. For experimental work, square cut circular ring insert is use. Effect of square cut circular ring insert is studied. Smith eiamsa – arda et al. [1] at 2010 studied heat exchanger tube with alternate clockwise and counter clockwise twisted tape insert. They have studied heat transfer characteristics, nusselt no. Characteristics and effect of twist ratio. They reported that 1. the c-cc twisted tape with twist ratio (y/w=3.0) cause higher turbulence & friction rate up to 90.5% over plain tube. 2. c-cc twisted tape provide higher nusselt no. & friction factor than typical twisted tape at about 12.8% - 41.9% and 12.5 - 41.5% respectively pongjet promvonge et al. [2] at 2012 studied heat transfer augmentation in helical ribbed tube with double twisted tape inserts. They have studied heat transfer characteristic, co-relation of nusselt no. & friction factor characteristics, effect of ribbed tube & twisted tape, effect of twist ratio on nusselt no. Sibelgunes, vyeseolozceyhan et al. [3] at 2012 studied the experimental investigation of heat transfer and pressure drop in a tube with coiled wire inserts placed separately from the tube wall. A.w.fan,j.j.deng et al. [4] at 2012 studied turbulent heat transfer and flow characteristics in a circular tube fitted with louvered strip inserts. Halit bas et al. [5] at 2012 studied heat transfer enhancement in a tube with twisted tape inserts place separately from the tube wall. Bodius salam, suman biswas et al. [6] at 2013 studied heat transfer enhancement in a tube using rectangular – cut
twisted tape insert. They have studied heat transfer coefficient, friction factor, heat transfer enhancement efficiency. They reported that nui is enhanced by 2.3 to 2.9 times, friction factor increase by 1.4 to 1.8 times as compare to smooth pipe m.m.k bhuinya et al. [7] at 2013 studied performance assessment in a heat exchanger tube fitted with double counter twisted tape inserts. They have studied ht.enhancement, fluid friction characteristics, different twist ratio(y= 1.92, 3.85, 5.92, 7.75).

II. EXPERIMENTAL SET-UP

The schematic diagram of experimental set up is shown in fig.2. The experimental setup consists of blower, flow control valve to maintain the measured quantity of flow through the test section, Orifice meter to measure the mass flow rate. Stainless steel tube of SS 304 material is used for test section having 34 mm inner diameter & 38mm of outer diameter and 1000mm of test length is used. Square cut circular ring insert is made by mild steel of 0.5mm thickness with 3 different cut area (40%, 30% & 16% area cut) and 3 different pitch inserted into smooth tube. A uniform heat flux condition is created by Band type nicrome wire heater.9 heater of 70w each at length 100mm each is mounted around the test section. Electric Power supply to heater is control by dimmerstat of 3kw capacity. The outer surface of the test tube is well insulated with asbestos insulation to reduce the convective heat loss to the surrounding. Outer surface temperature of the tube is measured at 8 different points of the test section by K-type thermocouple.2 thermocouple is used for calculating heat loss to surrounding. Another 2 K-type thermocouple is used for measuring the bulk temperature (inlet and outlet temperature of air).2 U- tube manometer is used to measure the pressure drop across the test section. Control panel consist of Voltmeter of (0-500v), ammeter of (0-5amp),temperature indicator of 12 channel.

A. Square Cut Circular Ring Insert:

The photographs of square cut circular ring insert are shown in figs.3 and 4. All inserts used in experiments are made up of mild steel sheet with 0.5mm of thickness. Square cut circular ring insert with 3 different cut area and 3 different pitch inserted into the plain tube. The square cut circular ring has: (1) 8.5mm depth and 10mm width that is 40% area remove (2) 6.5mm depth and 10mm width that is 30% area remove (3) 3.5mm depth and 10mm width that is 16% area remove. In each case (1) 6 insert with distance between insert is 16cm (2) 5 insert with distance between insert is20cm (3) 4 insert with distance between insert is 27cm respectively is used.

B. Working:

The experiments are conducted by varying the flow rate of air in terms of Reynolds number from 4000 to 18000 of the bulk air. Electrical power to heater is maintain constant. The test tube is heated from external surface during the experiment and the data of the temperature, mass flow rate, and pressure drop of the bulk air are recorded manually with time interval of 10 min. And data is recorded until steady state condition is achieved. Same process is repeated for 3 types of insert and 3 different pitch.

I) Data Reduction:

Heat transfer rate by the heater to air is calculated by measuring heat added to air. Heat added to air is calculated by,

\[ Q = m c_p (T_{out} - T_{in}) \]
Heat transfer coefficient is calculated from,
\[ h = \frac{Q}{A_x \times (T_2 - T_{in})} \]
Where, \( A_x = 2\pi r l \)

The bulk temperature is obtained from the average of air inlet and outlet temperature,
\[ T_{bulk} = \frac{T_{in} + T_{out}}{2} \]

Actual heat supplied to test section is calculated by,
\[ Q_{total} = Q_{actual} + Q_{loss} \]

\( Q_{actual} \) is the actual heat supplied by heater. \( Q_{loss} \) is heat loss to surrounding is calculated by,
\[ Q_{loss} = \frac{1}{2\pi kl} \times \ln \left( \frac{T_9}{T_{10}} \right) \]

\( T_9 \) is temperature recorded by thermocouple mounted at centre of test section below heater.
\( T_{10} \) is temperature recorded by thermocouple mounted at centre of test section above insulation.

Nusselt no. Is calculated by,
\[ Nu = \frac{h \delta}{k} \]

Friction factor, \( f \) is calculated from
\[ f = \frac{\Delta p}{(\frac{1}{2})(\rho u_{avg}^2)} \]
\( \Delta p \) is the pressure drop across tapping. All fluid properties are evaluated at bulk temperature.

C. Results and Discussion

1) Validation of experiment for Plain Tube
In the beginning, results of the present plain tube are validated with those obtained from the standard empirical correlation of Dittus-Boelter and that of Blasius for friction factor as given below;
2) Nusselt number correlation
Empirical correlation of Dittus-Boelter;
\[ Nu = 0.023Re^{0.8}Pr^{0.4} \]
Empirical correlation of Blasius;
\[ f = 0.316Re^{-0.25} \]

The present friction factors are within ±9.9955% as compared to those achieved from Blasius correlation shown in fig.6.

Fig. 6: Verification of friction factor for plain tube

3) Effect of square cut circular ring insert
The variation of Nusselt number with Reynolds number for 6, 5 and 4 insert for 40% area cut is shown in fig.7

Fig. 7: Variation of Nusselt number with Reynolds number for 4, 5 & 6 insert for 40% of area cut (Maximum cut)

Fig. 8: Variation of Nusselt number with Reynolds number for 4, 5 & 6 insert for 30% of area cut (Medium cut)
The variation of Nusselt number with Reynolds number for 4, 5 and 6 insert for 40% area remove is shown in fig.7. Nusselt number from the plain tube is also plotted for comparison. Nusselt number increases with the increase of Reynolds number. In this case Nusselt no. For 6 insert is increased by 35-45% as compare to plain tube. For 5 insert is increased by 11-40% and for 4 insert Nusselt number is increased by 8-27% as compare to plain tube.

Fig. 9: Variation of Nusselt number with Reynolds number for 4, 5 & 6 insert for 16% of area cut (Minimum cut)

Fig. 8 shows variation of Nusselt number with Reynolds number for 4, 5 and 6 insert for 30% area remove. In this case Nusselt no. For 6 insert is increased by 33-44% as compare to plain tube. For 5 insert is increased by 29-40% as compare to plain tube and for 4 insert is increased by 22-33% as compare to plain tube.

Fig. 9 shows variation of Nusselt number with Reynolds number for 4, 5 and 6 insert for 16% area remove. Where Nusselt number from plain tube is also plotted for comparison. In this case, Nusselt number for 6 insert is increased by 38-47% as compare to plain tube. For 5 insert is increase by 32-39% as compare to plain tube. For 4 Insert is increased by 35-41% as compare to plain tube.

Fig. 10: Variation of Nusselt number with Reynolds number for 4, 5 & 6 insert for 40%, 30% & 16% of area cut (Maximum, medium & minimum cut)

Fig. 11: shows variation of Nusselt number with Reynolds number for 4, 5 and 6 insert for 40%, 30% and 16% area remove.
In this case, for 4 insert and 40% area remove \( \frac{N_{tu}}{N_{tu_{ref}}} \) is in between 1.09-1.38. For 5 insert 40% area remove \( \frac{N_{tu}}{N_{tu_{ref}}} \) is in between 1.12-1.67. For 6 insert and 40% area remove \( \frac{N_{tu}}{N_{tu_{ref}}} \) is in between 1.56-1.83. For 4 insert and 30% area remove \( \frac{N_{tu}}{N_{tu_{ref}}} \) is in between 1.29-1.50. For 5 insert 30% area remove \( \frac{N_{tu}}{N_{tu_{ref}}} \) is in between 1.40-1.68. For 6 insert and 30% area remove \( \frac{N_{tu}}{N_{tu_{ref}}} \) is in between 1.50-1.79. For 4 insert and 16% area remove \( \frac{N_{tu}}{N_{tu_{ref}}} \) is in between 1.54-1.72. For 5 insert 16% area remove \( \frac{N_{tu}}{N_{tu_{ref}}} \) is in between 1.48-1.64. For 6 insert and 16% area remove \( \frac{N_{tu}}{N_{tu_{ref}}} \) is in between 1.63-1.79.

4) Thermal Enhancement factor

### Table 1: Observation Table

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<tr>
<th>S.N</th>
<th>Reynolds Number</th>
<th>( V_m ) m/s</th>
<th>( m_a ) kg/s</th>
<th>( h_m ) [m]</th>
<th>( h_a ) [mm]</th>
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<td>62</td>
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</table>

Table 1: Observation table for Reynolds number, velocity of air, mass flow rate of air, height of air column and height of water column. This height of water column is set in manometer to achieve particular Reynolds number. Sample calculation for calculating mass flow rate is given below.

D. Sample Calculation for Mass Flow Rate:

Decide maximum Reynolds Number for Study, assume 18000 Reynolds Number:

\[
Re = \frac{\rho v D}{\mu}
\]

\[
18000 = \frac{1.20 \times 0.34 \times 10^{-3}}{1.81 \times 10^{-5}}
\]

\[
v = 7.17 \text{ m/s}
\]

Mass flow rate of Air is given by,

\[
m_a = \frac{\rho A u}{\mu}
\]

\[
m_a = 1.20 \times 0.0009 \times 7.17
\]

\[
m_a = 8.62 \times 10^{-3} \text{ kg/s}
\]

To find out Height of Air column,

\[
m_a = c_d \times \frac{\pi}{4} \times (d_a)^2 \times \rho_a \times \frac{\sqrt{2 g h_a}}{\sqrt{1 - \beta^4}}
\]

\[
8.62 \times 10^{-3} = 0.65 \times (2.01 \times 10^{-4}) \times 1.2 \times \frac{\sqrt{2 \times 9.81 \times h_a}}{\sqrt{1 - 0.5^4}}
\]

To find height of Water column,

\[
h_a = \frac{h_m \times \rho_a}{\rho_w}
\]

\[
P_1 = 51.646 \text{ m}
\]

\[
h_w = 62 \text{ m}
\]

This height of water column is set in the manometer and then actual testing is start.

E. Sample Calculation for Nusselt No

Total heat supplied to the test pipe is,

\[
Q_{total} = Q_{actual} + Q_{loss}
\]

Heat loss to the surrounding is given by,

\[
Q_{loss} = \frac{\Delta T}{R_{tm}}
\]

\[
Q_{loss} = \frac{1}{2 \pi h_{ref} \ln \left( \frac{D}{d} \right)}
\]

\[
Q_{total} = 42.3488 \text{ w}
\]

\[
Q_{actual} = Q_{total} - Q_{loss}
\]

\[
Q_{actual} = 107.6510 \text{ w}
\]

Heat transfer coefficient is calculated by,

\[
q_{avg} = h_{avg} \times A \times (T_e - T_m)
\]

\[
h_{avg} = 36.8308 \text{ w/m}^2 \text{k}
\]

Now Nusselt number is calculated as,

\[
Nu = \frac{h_{avg}}{k_{air}}
\]

\[
\times Nu = 45.3712
\]

This sample calculation for Plain Tube and 18000 Reynolds number.

III. CONCLUSIONS

An experimental investigation is carried for measuring tube side heat transfer coefficient, friction factor, thermal enhancement factor of air for turbulent flow in a circular tube fitted with square cut circular ring insert. From the experimental results, the conclusions can be summarized as follows:

In the presence of Square cut circular ring insert, the heat transfer augmentation is taken place by two mechanisms, as the insert is act as swirl flow generator produces helical flow at periphery, due to which centrifugal
forces are induced when rotating helical flows are super imposed with axially directed central core flow.

As the density of most liquid decreases with temperature resulting centrifugal force move the heated fluid from boundary layer towards the core of flow passage and hence heat transfer augmentation is achieved.

In other heat transfer enhancement is achieved as this insert is used for increasing the heat transfer surface area also this insert is act as turbulence promoter which increases the flow turbulence level.

The Nusselt number obtain from experiment for smooth tube is within ±0.7058 % as obtain from well known Dittus-boelter equation.

The friction factor obtain from experiment for smooth tube is within ±9.9955% as obtain from Empirical correlation of Blasius .

The Nusselt number increased with increase of Reynolds number. The experimental Nusselt number value for 4, 5 & 6 insert for 40% area remove is 8-27%,11-40 % &35-45 % as compare to plain tube.

The experimental Nusselt number value for 4, 5 & 6 insert for 30 % area remove is 22-33%, 29- 40% &33- 44% as compare to plain tube.

The experimental Nusselt number value for 4, 5 & 6 insert for 16 % area remove is 35-41%, 32-39%, &38-47% as compare to plain tube.

Thermal enhancement factor decreases with increase in Reynolds number. For all inserts, Thermal enhancement factor are higher than 1(unity) for the Reynolds number up to 14000 for 4, 5 & 6 insert for 40% of area remove.

Fig. 12 shows the variation of the thermal enhancement factor with Reynolds number for the pipe equipped with square cut circular ring insert. Figure shows the variation of thermal enhancement factor for 4, 5 & 6 insert for 40% area remove. From figure it is shown that thermal enhancement factor decreases with increase in Reynolds number. For all inserts, Thermal enhancement factor are higher than 1(unity) for the Reynolds number up to 14000.

REFERENCES
