Development of Forced Convection Heat Transfer Enhancement System by using Mesh Inserts in a Circular Tube

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ABSTRACT

In the present work, aluminium mesh type inserts flow has been developed. The aluminium meshes are arranged on spokes at the angle of 0^0, 45^0, 90^0 concerning horizontal are inserted in the test section to create turbulence. To carry out an experimental investigation using this mesh inserts, we have developed a forced convection system. In this system, we have wounded three 200 Volt heaters over a 500 mm test section of 25 mm diameter respectively. The input to the heater is controlled by a variable dimmer stat, and the mass flow rate is controlled by an orifice meter with a diameter of 25 mm across which the manometer is connected to measure flow rate. Experiments were carried out at Reynolds number greater than 4000. The experimental setup was validated first and readings with different inserts were taken. This led to the conclusion that the rate of heat transfer was improved by using mesh inserts inclined at an angle 0^0, 45^0, and 90^0. Among these, the inserts inclined at 45^0 angles showed maximum heat transfer rate i.e., 37.44%, 29.95%, and 38.40% for the manometric reading of 5 mm, 4 mm, and 3 mm respectively.

Keywords: Forced Convection, Aluminium, Circular, Mesh, Reynolds number

1 Introduction

The necessity to save energy while also reducing the size and cost of the device has prompted researchers to look at various heat transfer enhancement techniques. In the last few decades, heat transfer augmentation technology has been created and utilised to heat exchanger applications. To date, several attempts have been undertaken to minimise the heat exchanger's size and cost. The literature on improved heat transfer is growing at a quicker rate than the rest of the engineering literature. Literature related to heat transfer heat transfer augmentation strategies is one of the prominent part of heat transfer related literature. Sarada, et al. [1] investigated the use of mesh inserts to improve turbulent flow heat transfer in tubes by different methods. They developed sixteen different mesh inserts with screen diameters ranging from 10 mm to 22 mm. in the different porosity range. A continuous heat flux was uniformly applied to the horizontal tube. The Reynolds number fluctuated between 7000 and 14000. Shewale et al. [2] studied experimentally, a double-pipe heat exchanger to analyse the heat transfer characteristic of the twin pipe heat exchanger, and the amount of turbulence was increased by the revolving inner tube. The convective heat transfer coefficients for the counter-flow mode utilising water as the cold fluid in the tube side are calculated for both stationary and revolving inner tubes. A. P. Shahane et al. [3] conducted an experiment employing rectangular leaf type inserts that were inserted into a horizontal circular tube. These inserts were created out of aluminium material at various angles, such as 30°, 45°, 60°, and 90°. The working fluid was air, which was passed through the circular pipe. These louvered rectangular leaf type inserts inside a plain tube were

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used to examine heat transmission rate.

A. P. Shahane et al. [4] did experimental study of heat transfer coefficient in pipes of different shapes using a regression analysis. After computing all of the results for both pipes, they discovered that the elliptical pipe has a higher efficiency than the circular pipe, as well as a higher heat transfer coefficient, which resulted in increased heat transfer. When compared to Elliptical pipe, the heat transfer coefficient deviation is the greatest. S. M. Kale et al. [5] has done experimental analysis of flow-through pipe with copper mesh type inserts. S. S. Jadhav et al. [6] has studied horizontal circular pipe of copper and aluminium with different circular profiles for in-line arrangements under influence of forced convective air flow.

2 Experimental Work

2.1 Experimental Setup

Schematic representation of the experimental setup is shown in figure 1. The loop is made up of a blower unit and a horizontally oriented tube. The fan on the blower is set to run at a constant speed. MS pipe is connected to blower oulet. A U-tube manometer is used to measure the flow rate of the air flowing through the pipe. A 200W nichrome bend heater is used for heating the test section of the pipe. The heater is controlled using a dimmer switch. A dimmer stat is used to control the power input to the heater. This is done by varying the supply voltage through it and keeping the current below 2A. To measure air outlet temperature (T_{10}) and inlet air temperature (T_1), two thermocouples are used. One thermocouple is used at the inlet of pipe, before the thermally developing portion. The other thermocouple is located at the outlet of pipe, after the test section. T_2, T_3, and T_4 thermocouples are located on the thermally developing section. Similarly, T_5, T_6, T_7, T_8, and T_9 thermocouples are located on the test section. Insulation is provided on the outer portion of the test section. A control valve is used to control the air flow rate in test section.

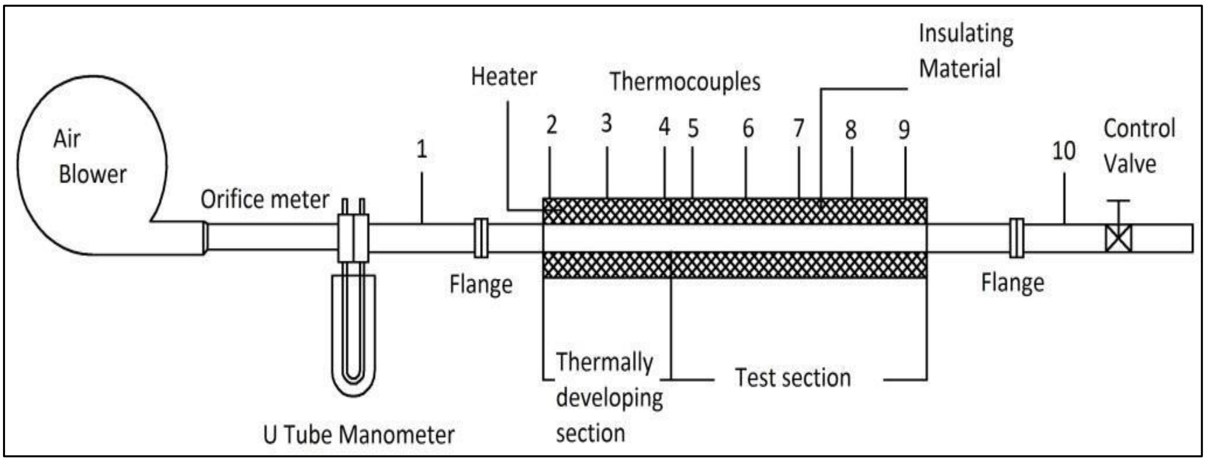

Figure 1: *Schematic illustration of experimental system*

2.2 Observations

1. Test section length, L=0.8m
2. I.D of test section, D=0.0250m
3. Orifice diameter 0, d= 0.022m
4. Coefficient of discharge of orifice meter, Cd=0.62
5. Cross sectional area of pipe, A= 4.90625 × 10-4 m^2
6. Area of orifice, Ao = 3.7994× 10-4 m^2
7. Surface area of test section, As =0.628 m^2

2.3 Observation Table

Table 1: *Plain Tube*

Sr. No.	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	hw, (mm)
1	33	48	48	48	48	49	46	49	49	38	5
2	33	52	52	52	52	52	50	53	52	40	4
3	34	54	54	55	55	56	53	56	56	42	3

2.4 Results for Plain Tube

Table 2: *Results for Plain Tube*

Sr. No.	hw, (mm)	T_s (°C)	T_a (°C)	Re	$NU_{(Ex)}$	$NU_{(Th)}$	$h_{(Ex)}$ (W/m^2K)	$h_{(Th)}$ (W/m^2K)	Q_t (W)
1	5	48.5	35.5	8193.024	19.55	28.24	20.56	29.71	20.50
2	4	51.8	36.5	7565.912	20.24	26.49	21.34	27.93	25.63
3	3	55.2	38	7580.897	17.69	26.53	18.74	28.10	25.31

2.5 Description of Mesh Insert

The current study focuses on experimental analysis of heat transfer in a horizontal circular tube with inserts, made of mesh, The working fluid used is air. Mesh inserts are made of aluminium. The 20mm diameter mesh is cut from a sheet of aluminium mesh. This mesh inserts are then fitted on aluminium rod in a group of 10. The distance between two meshes is 50mm. Three different rods are prepared which are fitted with mesh inserts at different angle i.e., at 0^0, 45^0 and 90^0 respectively. The three mesh inserts are shown in the fig. 2

Figure 2: *Photograph of inserts inclined at 0^0, 45^0 and 90^0*

2.6 Experimental Procedure for Inserts

Experimental procedure used in this study is as mentioned below:

I. The flange is removed from the test section. The insert is placed into the tube.

II. The test section is heated to a pre-set value. The amount of heating is controlled by using a dimmer stat, and the experiment is carried out under similar settings as the experiment with plain tube without inserts.

III. Temperatures are recorded from the temperature indicator every 5 minutes after reaching steady state.

IV. The operation is repeated for varying air mass flow rates.

V. Temperatures, flow rates, and air velocity were recorded for each test run.

VI. The average temperature between the intake and output temperatures was used to calculate the fluid characteristics.

VII. The experiment was run with a constant heat input and different air flow rate.

VIII. The above mentioned procedure is repeated for each insert.

3 Result and Discussion for Inserts at 0^0, 45^0, 90^0

In this study analysis is done for investigating heat transfer characteristics of a horizontal tube which with different types of inserts. The thermal performance of tube fitted with inserts is observed to be greater than that of plain tube. Temperature values and Nusselt number values in the horizontal tube with mesh inserts is noted. The readings are taken for Reynolds numbers range of 5000 to 10000. Nusselt number increases as Reynolds number rises. The result tables for mesh inserts inclined at various angles are given below.

Table 3: *Results for mesh inserts inclined at 0^0*

hw, (mm)	T_s (°C)	T_a (°C)	Re	$NU_{(Ex)}$	$Nu_{(Th)}$	$h_{(Ex)}$ (W/m^2K)	$h_{(Th)}$ (W/m^2K)	Q_t (W)
5	56.2	37.5	6878.893	23.69	24.55	25.05	25.96	36.78
4	58.4	38	6969.534	21.53	24.80	22.80	26.27	36.53
3	60.4	38.5	7062.28	19.07	25.06	20.22	26.58	34.77

Table 4: *Results for mesh inserts inclined at 45^0*

hw, (mm)	T_s (°C)	T_a (°C)	Re	$Nu_{(Ex)}$	$Nu_{(Th)}$	$h_{(Ex)}$ (W/m^2K)	$h_{(Th)}$ (W/m^2K)	Q_t (W)
5	53.4	36	6476.74	22.79	23.39	23.99	24.63	32.77
4	56.4	37	6663.91	22.75	23.93	24.02	25.27	36.59
3	59	38.5	6818.75	24.07	24.37	25.53	25.85	41.09

Table 5: *Results for mesh inserts inclined at 90^0*

hw, (mm)	T_s (°C)	T_a (°C)	Re	$Nu_{(Ex)}$	$Nu_{(Th)}$	$h_{(Ex)}$ (W/m^2K)	$h_{(Th)}$ (W/m^2K)	Q_t (W)
5	52.2	34	6345.56	21.98	23.02	23.01	24.11	32.88
4	57.2	36	6476.74	20.91	23.4	22.01	24.63	36.64
3	58	36.5	6697.70	19.6	24.03	20.67	25.34	34.88

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Fig. 3 to 4 shows the trend of wall temperatures for the inserts inclined at 0^0, 45^0 and 90^0 respectively. Figures shows that wall temperatures at different point increases with increase in Reynolds number. The wall temperatures of horizontal tubes at various points are denoted by the letters T_5, T_6, T_7, T_8, and T_9. They are found to increase when the Reynolds number rises.

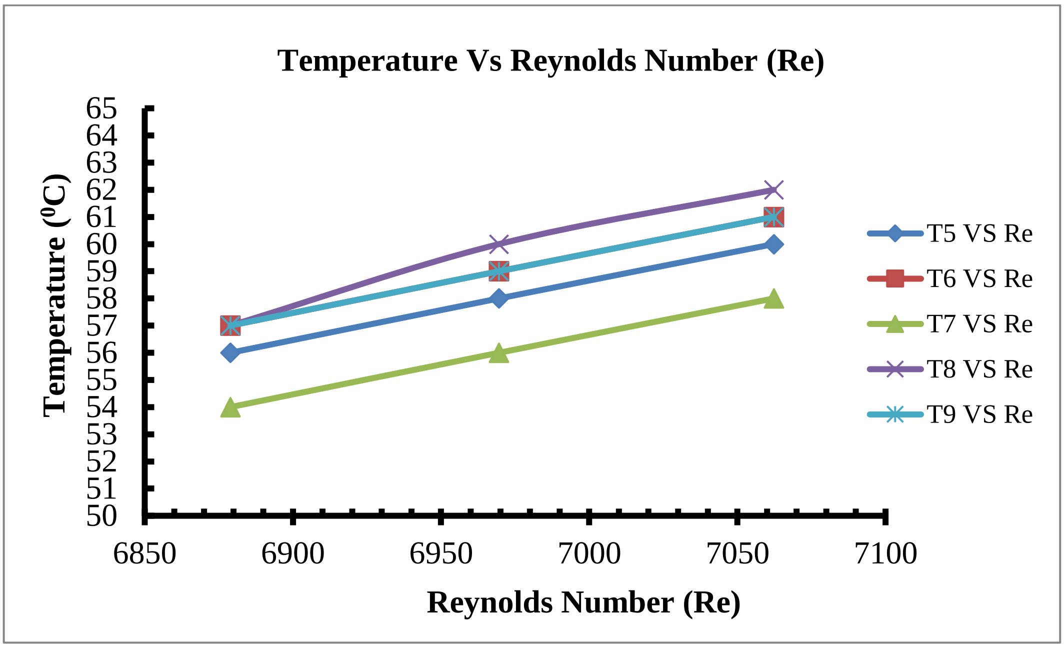

Figure 3: *Temperature variation as function of Reynolds Number (Re) for inserts inclined at 0^0*

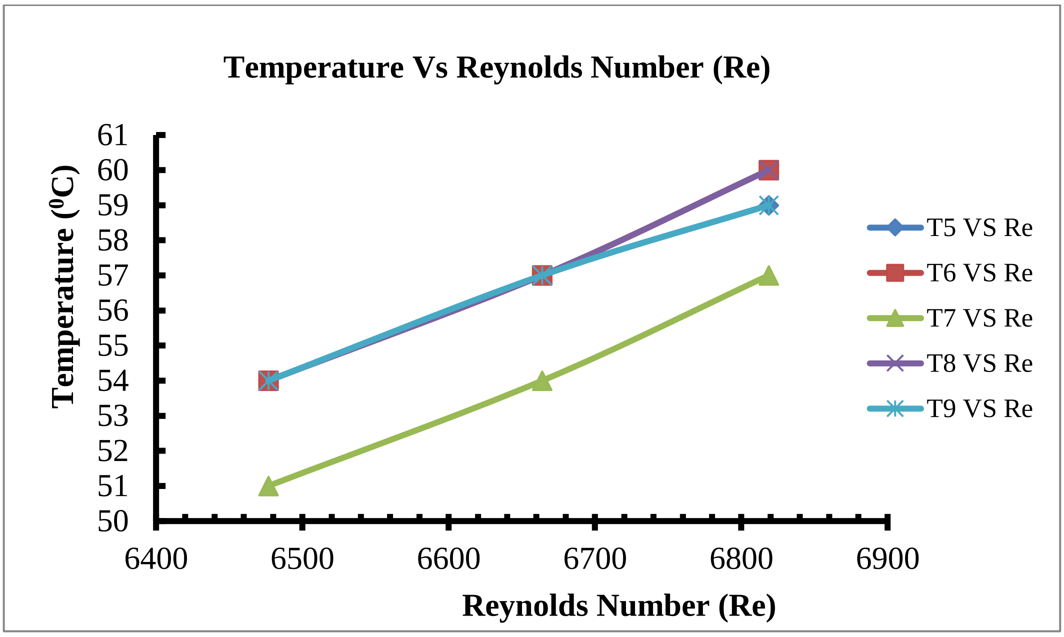

Figure 4: *Temperature variation as function of Reynolds Number (Re) for inserts inclined at 45^0*

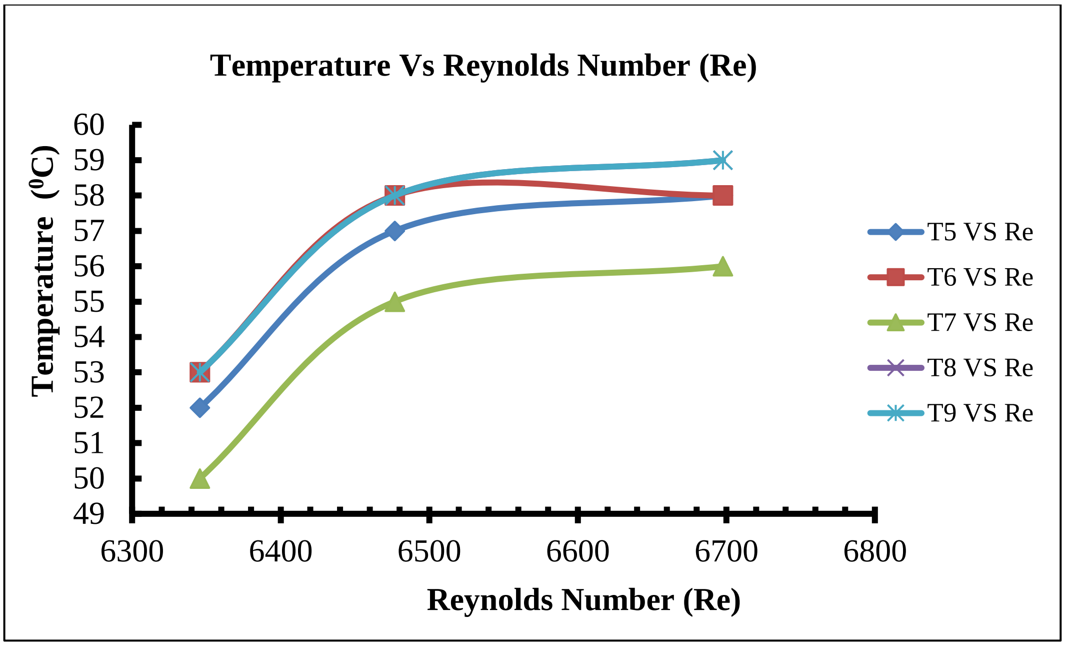

Figure 5: *Temperature variation as function of Reynolds Number (Re) for inserts inclined at 90^0*

The Nusselt number value is observed to be maximum in case of inserts oriented at 45^0. This could be due to the higher resistance to the airflow, which results in producing more turbulence. It is noticed that as the Reynolds number is increased, the Nusselt number also increases. Due to this, more heat is carried away by air, causing the Nusselt number to rise. In the presence of inserts inclined at 45^0 at a manometric head of 3mm, the Nusselt number increased by up to 36% as compared to plain tube.

Figures 6 to 8 represent the variations in Nu with Re for mesh inserts inclined at 0, 45, and 90 degrees, respectively.

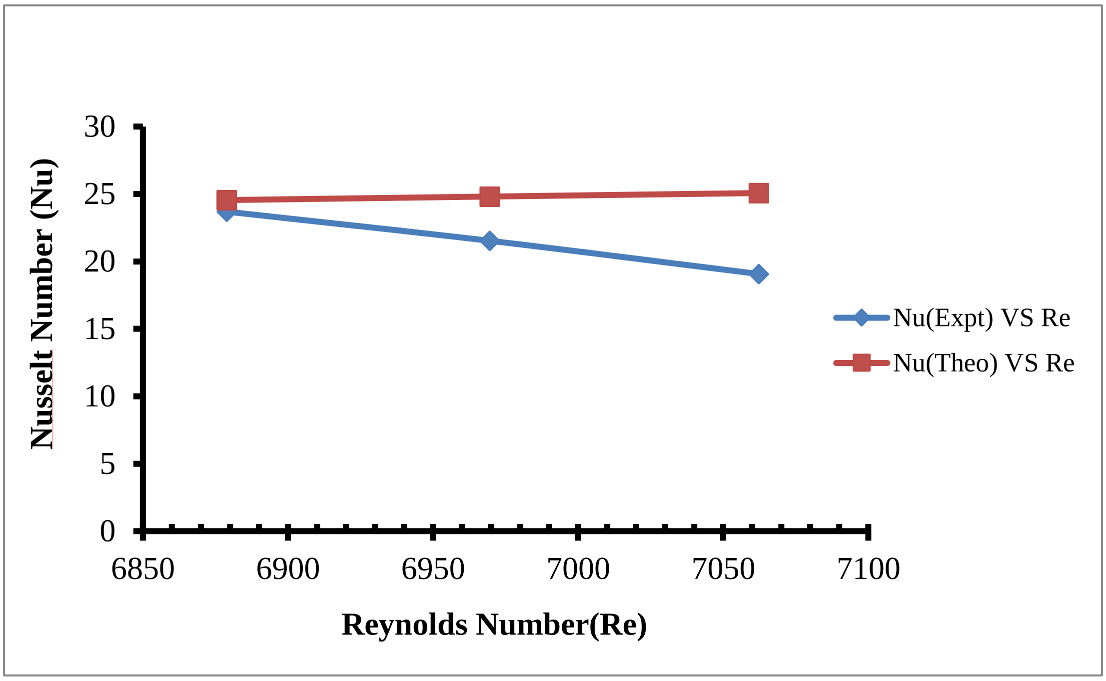

Figure 6: *Nusselt Number (Nu) and Reynolds Number (Re) variations for inserts inclined at 0^0*

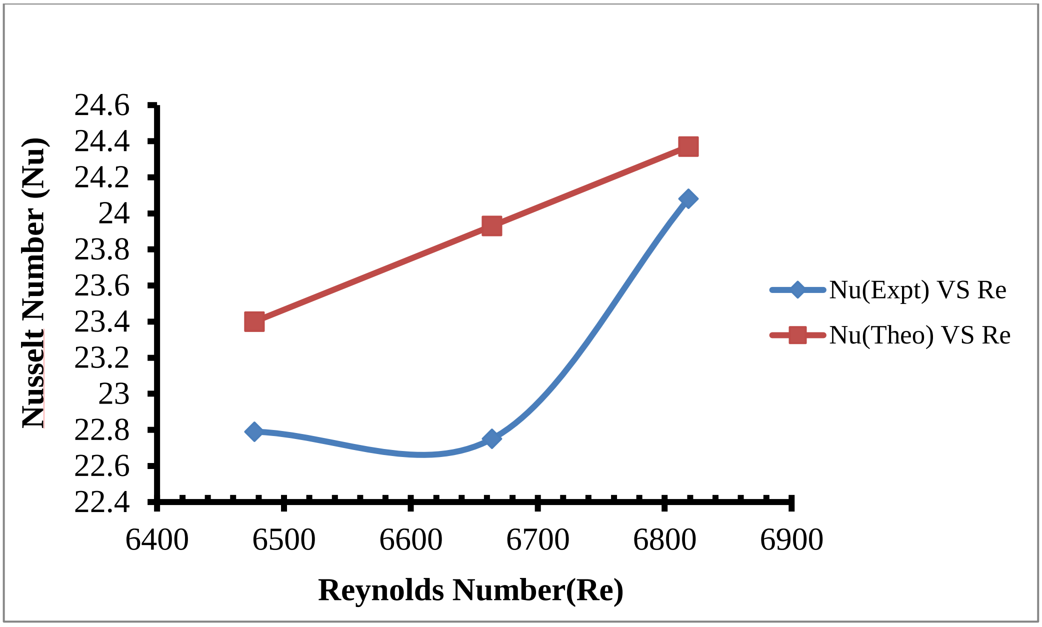

Figure 7: *Nusselt Number (Nu) and Reynolds Number (Re) variations for inserts inclined at 45^0*

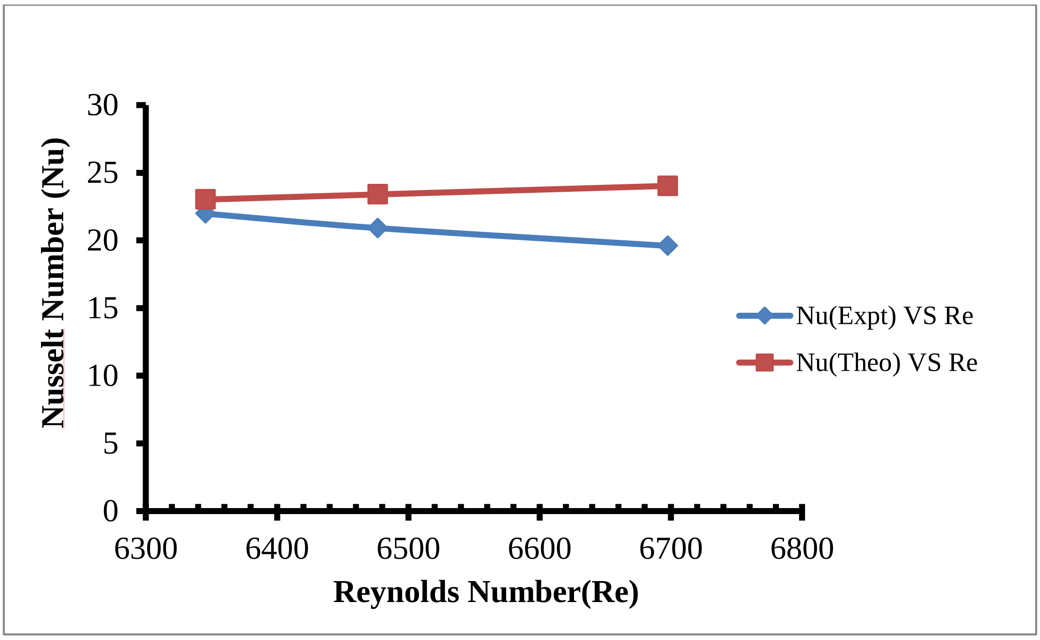

Figure 8: *Nusselt Number (Nu) and Reynolds Number (Re) variations for inserts inclined at 90^0*

4 Conclusions

4.1 Concerning Plain Tube

The heat transfer characteristics of externally heated tube are experimentally investigated in an externally heated horizontal tube.

I. The experimental data is found to be in good agreement with the correlation values.
II. The experimental data in present is reasonably consistent with Dittus-Boelter correlation for Nusselt number and the friction factor.
III. With increase in mass flow rate, the turbulence increases, resulting in better mixing. This in turn results in more heat being carried away by air, causing Nusselt number to increase.

4.2 Concerning Mesh Inserts

The following are the results of our experimental investigation:

I. When a horizontal tube with mesh inserts inclined at 0^0, the heat transfer rate enhanced by 44.26%, 29.84%, and 27.21% for manometric readings of 5mm, 4mm, and 3mm, respectively.

II. When compared to plain tube, the heat transfer rate for horizontal tube with mesh inserts inclined at 45^0 increased by 37.44%, 29.95%, and 38.40% for manometric readings of 5mm, 4mm, and 3mm, respectively.

III. When a horizontal tube with mesh inserts inclined at 90^0 was compared to a plain tube, the heat transfer rate rose by 37.65%, 30.04%, and 27.44% for monomeric readings of 5mm, 4mm, and 3mm, respectively.

IV. Mesh inserts inclined at 45^0 were reported to have the highest heat transfer rate.

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