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Experimental Analysis of Heat Transfer for Turbulent Flow through Circular Pipe

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Abstract - High performance heat transfer system is of great importance in many industrial applications. The performance of conventional heat exchangers can be substantially improved by a number of heat transfer enhancement techniques. A variety of complex, highly viscous liquids are involved that undergoes heat exchange process while flowing through heat exchangers. Because of their viscous nature, they tend to have low flow rates and generally represent the dominant thermal resistance due to their viscous nature, adversely affecting size and cost of heat exchanger. The process industry is continuously working to incorporate enhancement in heat transfer. Enhancement techniques can be classified as active methods, which require external power or Passive methods, which require no direct application of external power. The enhanced surfaces are routinely used to improve thermal and hydraulic performance of heat exchangers. Experimental investigation of heat transfer of circular tube fitted with helical wire and twisted tape, have been studied under uniform heat flux conditions. Air is used as working fluid. The analysis is carried out for fully developed turbulent flow having Reynolds number range based on test tube inside diameter from 5,000 to 20,000. The experimental data obtained are compared with the smooth tube data available in the literature.

Keywords - Heat Transfer Enhancement, Augmentation, Turbulent Flow, Inserts, Passive Method

I. INTRODUCTION

High performance heat transfer system is of great importance in many industrial applications. The performance of conventional heat exchangers can be substantially improved by a number of heat transfer enhancement techniques. A variety of complex, highly viscous liquids are involved that undergoes heat exchange process while flowing through heat exchangers. Because of their viscous nature, they tend to have low flow rates and generally represent the dominant thermal resistance due to their viscous nature, adversely affecting size and cost of heat exchanger. The process industry is continuously working to incorporate enhancement in heat transfer. Enhancement techniques can be classified as active methods which require external power and passive methods, which require no direct application of external power. The enhanced surfaces are routinely used to improve thermal and hydraulic performance of heat exchangers. These heat exchangers are used in process industries, air-conditioning, refrigeration, power generation etc. Secondary flows are created by these techniques, causing the separation of the boundary layer results in better bulk fluid mixing which reduces the temperature gradients in the fluid flow.

It is expected that a heat transfer augmentation device should produce significant increase in heat transfer. There are many performance evaluation criteria available in the literature. In the present analysis, the performance evaluation criteria R_1 at constant flow rate (at same Reynolds number Re) is used to compare the performance of different cases.

The performance criterion, R_1 at equal pumping power is defined as:

$$R_1 = \frac{Nu}{Nu_o}$$

Nusslet number, Nu_o for turbulent flows are evaluated at the same Reynolds number for smooth tube given by following Dittus Boelter Correlation.

$$Nu_o = 0.023\,\mathrm{Re}^{0.8}\,\mathrm{Pr}^{0.4}$$

II. EXPERIMENTAL SET UP, DATA REDUCTION AND VALIDATION

The experimental set up used for measuring Nusselt number is described. The details of the experimental set up, data reduction and validation are presented. The experimental procedure followed to obtain the heat transfer is discussed. Heat transfer results for turbulent flow in the smooth tube are compared with the correlations of Dittus Boelter.

A) Experimental Set-up

An experimental test facility to measure heat transfer for smooth tube and other inserts, is constructed. Figure 3.1 shows the schematic arrangement of the experimental setup used. The test section is 1000 mm long stainless steel tube of wall thickness 5 mm and an outside diameter of d_o equal to 35.4 mm. In order to ensure the hydro-dynamically fully developed flow, a pipe of length 40 times the pipe diameter is provided upstream to the test section. Nine calibrated Chromel-Alumel K-type thermocouples 100 mm axially apart are placed over the tube. To provide uniform heat flux, an electrical resistance coil is wrapped around the circumference of entire test section form inlet to the outlet. The test section is thermally insulated using ceramic wool to minimise the heat loss.

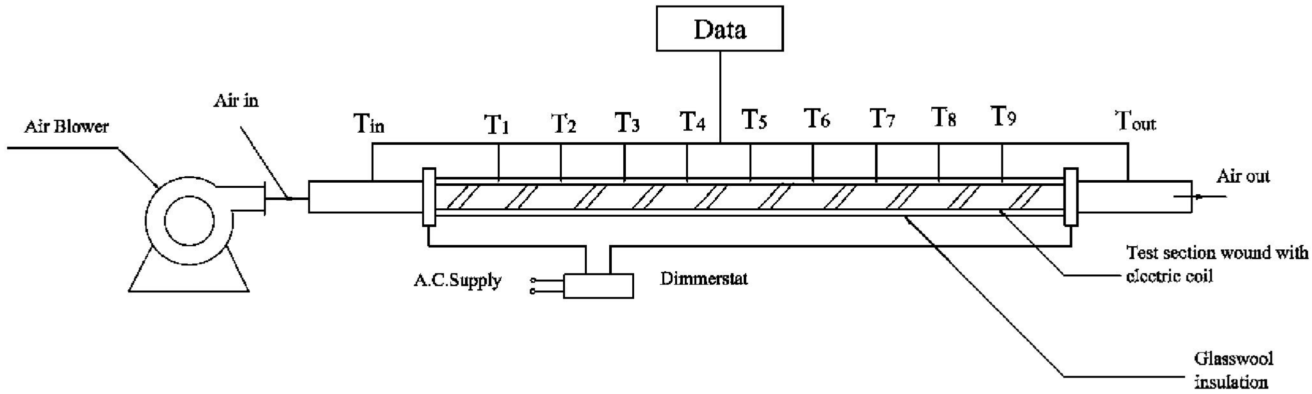

Fig 1. Schematic of Experimental Set up

Air as working fluid is forced into test section using an air blower. The flow rate of air in test section is regulated using an inlet valve and a by-pass valve. The mass flow rate is calculated by anemometer. The Reynolds number, *Re* based on the tube inner diameter is varied from 4000 to 10000. A thermocouple is placed at entry and exit of the test section respectively to measure the bulk mean air temperature.

B) Experimental Procedure

Test fluid, air is allowed to flow through the test section. The mass flow rate of air is adjusted by the valve so that it will give the required Reynolds number at the test section. The entire periphery of the test section is provided with constant uniform heat flux through variable transformer. The input power to the test section is adjusted such that the temperature difference between the mean wall temperature and mean bulk is around 15°C. The system is allowed to reach steady state for each reading of Reynolds number. The approximate time duration for the system to reach steady state is found to be 1.5 to 2.0 hours. At steady state, the temperature readings of wall, inlet and outlet are recorded. The value of Nusselt number is calculated for each wall thermocouple temperature readings. The wall temperature is taken at the thermocouple which is placed at L/d ratio more than 10. Nusselt number thus calculated is the mean of the Nusselt number obtained at various axial locations of the wall.

C) Data Reduction

The mass flow rate is calculated based on the velocity measurement using an anemometer.
The total input power supplied to the test section is calculated from measurement of current and voltage supplied to it.

$$Q_{in} = V \times I$$

Heat carried by air from test section is

$$Q_{out} = \dot{m} C_P (T_{bo} - T_{bi})$$

Outlet and inlet temperature of air T_{bo}, T_{bi} is measured using three thermocouples located at each end of the test section.

The unaccounted heat shall not exceed 10% of the total heat supplied. Therefore, the energy balance is checked by following equation

$$\frac{(Q_{in} - Q_{out})}{Q_{in}} \leq 10\%$$

As the flow of air is single phase, it is assumed that the bulk temperature is linearly varying across the test section from inlet to outlet. The intermediate values are obtained by interpolation between inlet and outlet bulk temperatures. The value of Nusselt number for fully developed flow is determined as:

$$Nu_{avg} = \frac{Q_{out} \times d}{A(T_w x - T_b x)k}$$

The Nusselt number for smooth tube is obtained by using Dittus-Boelter Equation.

$$Nu_S = 0.023 \times \mathrm{Re}^{0.8} \times \mathrm{Pr}^{0.4}$$

D) Validation of the Experimental Test Set Up

The experimental test facility is validated for heat transfer smooth tube flow. The data for smooth tube flow is available in the literature. Experimental data of Nusselt number for smooth tube flow at different Reynolds number, are validated using correlation of Dittus-Boelter. Figure 2. shows Nusselt number as a function of Reynolds number. There is a fairly good agreement between the values predicted by Dittus-Boelter with the experimentally obtained values of Nusselt number. Figure 3. shows that the present analysis has a variation of less than 8 % in the measurement of Nusselt number with values specified by Dittus Boelter Correlation.

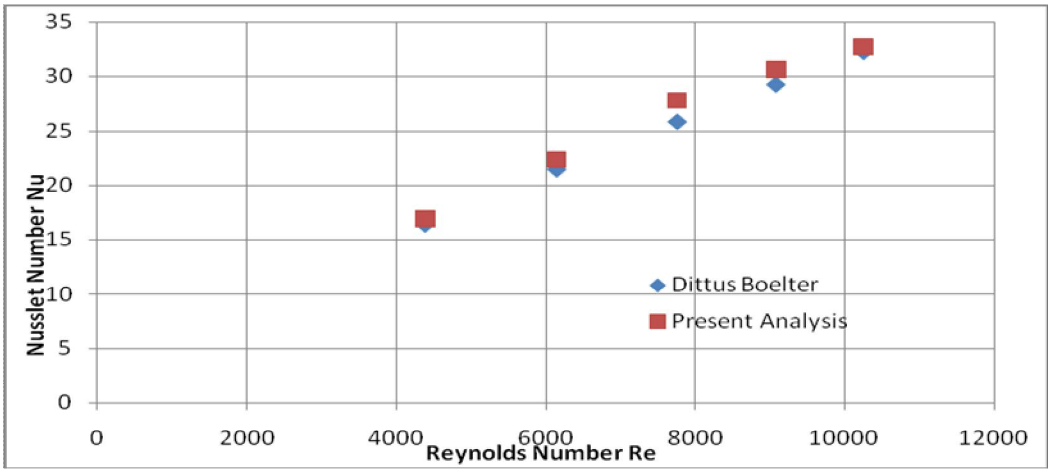

Fig 2. Variation of Nusselt number, *Nu* with Reynolds number, *Re* for smooth tube flow

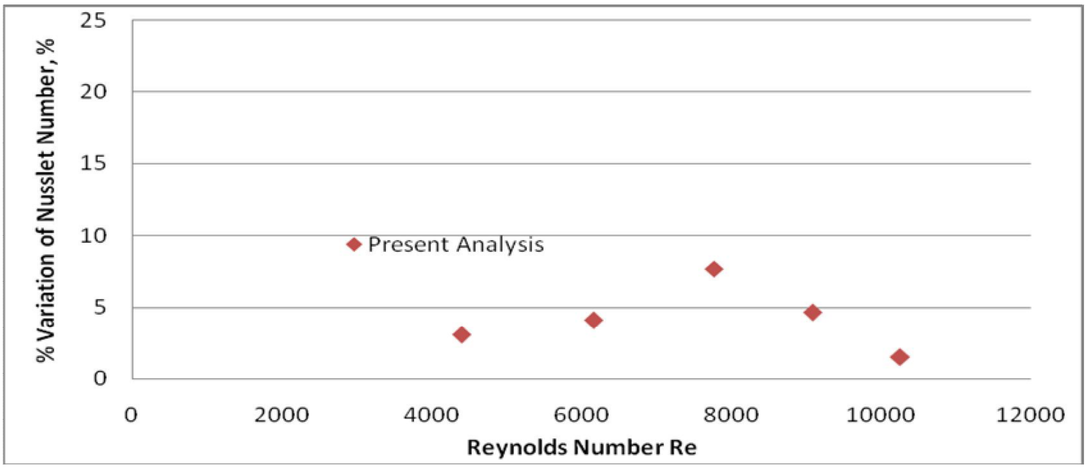

Fig 3. % Variation of Nusselt number, *Nu* with Reynolds number, *Re* for smooth tube flow

III. Results and Discussion

The experimental data for heat transfer characteristics for modified tube, helical wire coil is obtained. In this chapter, comparison of performance characteristics of different configuration of the tube is carried out. The parameters like percentage of blockage of the tube and Reynolds number *Re*, are systematically varied. The effects of these parameters on heat transfer are presented in this chapter. The results are expressed in terms of % of enhancement over the corresponding smooth tube heat transfer.

A) Technical Details of the tube

The central core portion of the tube is blocked by a rod of three different diameters viz, 8 mm, 10 mm and 12 mm. Figure 4 shows the schematic of the tube. The rod is placed inside the tube in such a way that it remain exactly at the centre position of the test section

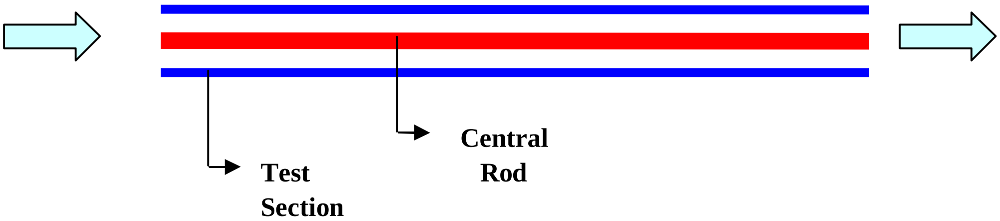

Fig. 4. Vortex generator in round tube

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B) Results and Discussion

The experimental results are expressed in terms of Nusselt number ratios as a function of % of blockage and Reynolds Number Re. The ratio of Nusselt number for augmented case to the Nusselt number for smooth tube, at equal Reynolds numbers are presented as the performance ratio $R_{1,.}$ i.e. Nu/Nu_o. at equal Reynolds number specified as Nu/Nu_c.

1) Heat transfer results of Tests section with 8 mm diameter Rod

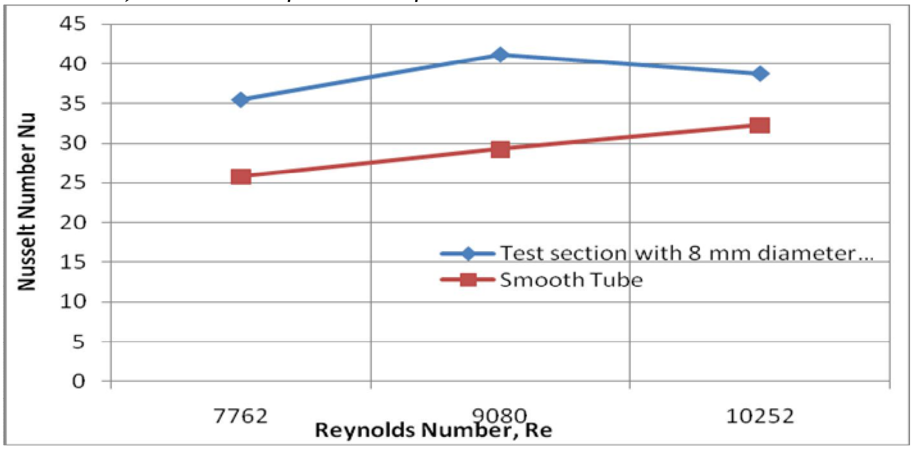

Fig 5. Variation of Nusselt number, *Nu* with Reynolds number, *Re* for Test section with 8 mm central Rod.

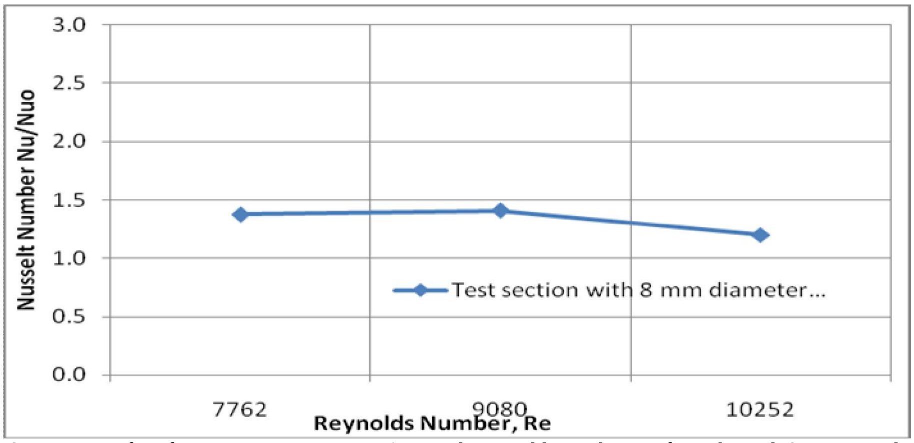

Fig 6. Variation of Performance Ratio R_1 i.e. Nu/Nu_o with Reynolds number, *Re* for Tube with 8 mm central rod.

Figure 5. show the variation of Nusselt number with Reynolds number for test section with 8 mm diameter central rod and for the smooth tube. It is observed that there is significantly rise in heat transfer enhancement of heat transfer. Figure 6. shows that the performance ratio R1 i.e. Nu/Nuo is found to be in the range of 1.2 to 1.4. i.e. % of enhancement is found to be 20% to 50% more in comparison with the smooth tube.

2) Heat transfer results of Tests section with 10 mm diameter Rod

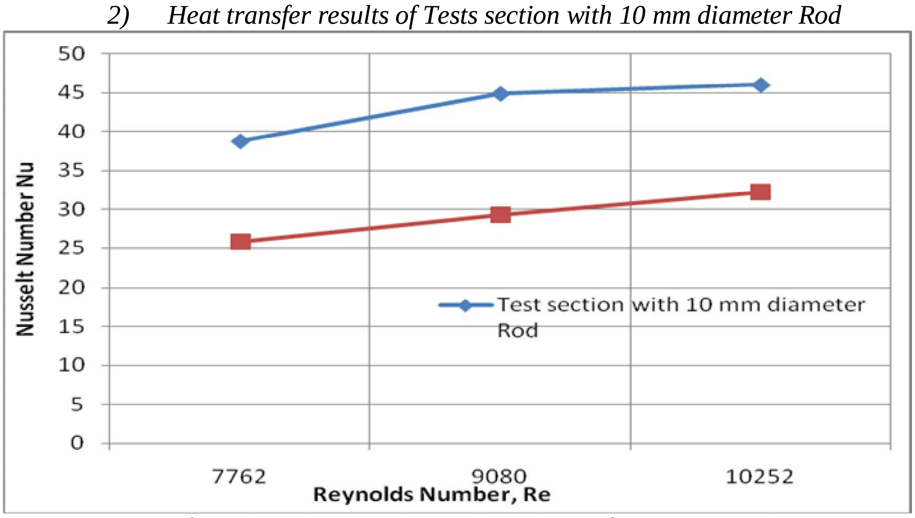

Fig 8. Variation of Nusselt number, *Nu* with Reynolds number, *Re* for Test section with 10 mm central Rod.

Figure 7. show the variation of Nusselt number with Reynolds number for test section with 10 mm diameter central rod and for the smooth tube. It is observed that there is significantly rise in heat transfer enhancement of heat transfer. Figure 8. shows that the performance ratio R1 i.e. Nu/Nuo is found to be in the range of 1.4 to 1.6. i.e. % of enhancement is found to be 40% to 60% more in comparison with the smooth tube.

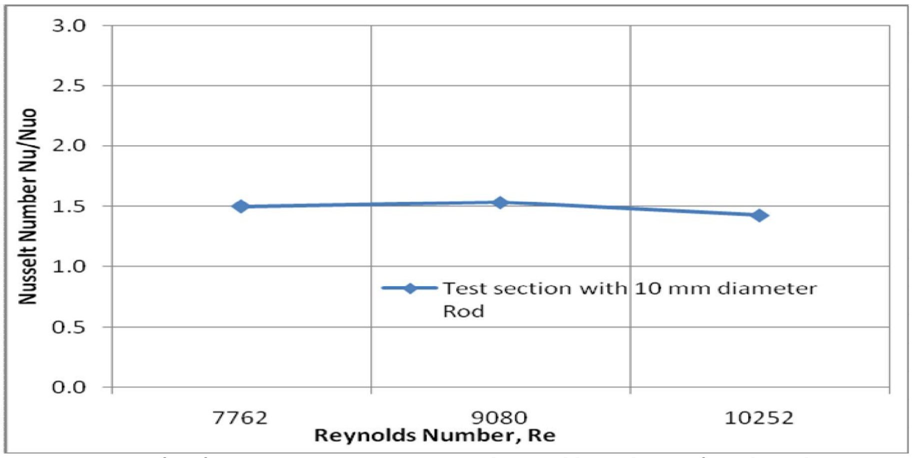

Fig 8. Variation of Performance Ratio R_1 i.e. Nu/Nu_o with Reynolds number, *Re* for Tube with 10 mm central rod.

3) Heat transfer results of Tests section with 12 mm diameter Rod

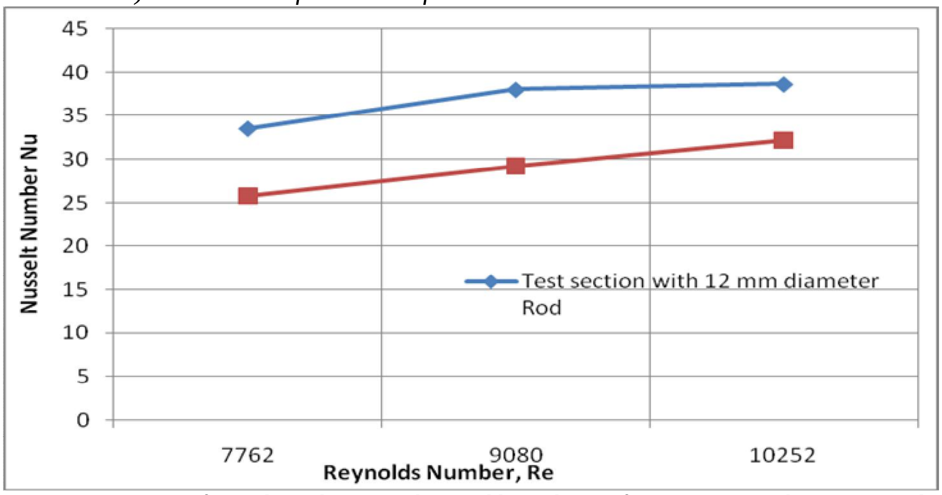

Fig 9. Variation of Nusselt number, *Nu* with Reynolds number, *Re* for Test section with 12 mm central Rod.

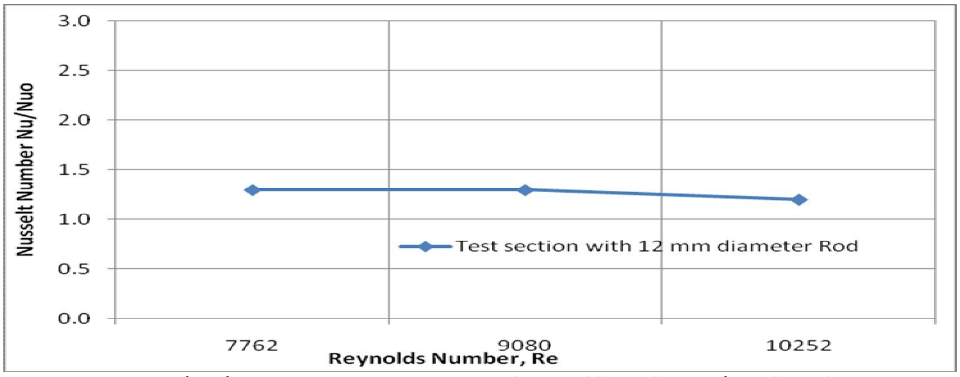

Fig 10. Variation of Performance Ratio R_1 i.e. Nu/Nu_o with Reynolds number, *Re* for Tube with 12 mm central rod.

Figure 9. show the variation of Nusselt number with Reynolds number for test section with 12 mm diameter central rod and for the smooth tube. It is observed that there is significantly rise in heat transfer enhancement of heat transfer. Figure 10 shows that the performance ratio R1 i.e. Nu/Nuo is found to be in the range of 1.2 to 1.3. i.e. % of enhancement is found to be 20% to 30% more in comparison with the smooth tube.

4) Comparison of Heat transfer results of Tests section with Different central Rods

The comparison of the performance characteristics of all the three configuration of the tests section is shown in fig. 11. and 12. It is observed that the test section with 10 mm diameter rod gives maximum heat transfer in comparison with the test section having central rod of 8 mm and 12 mm. This is true for all the three values of Reynolds number

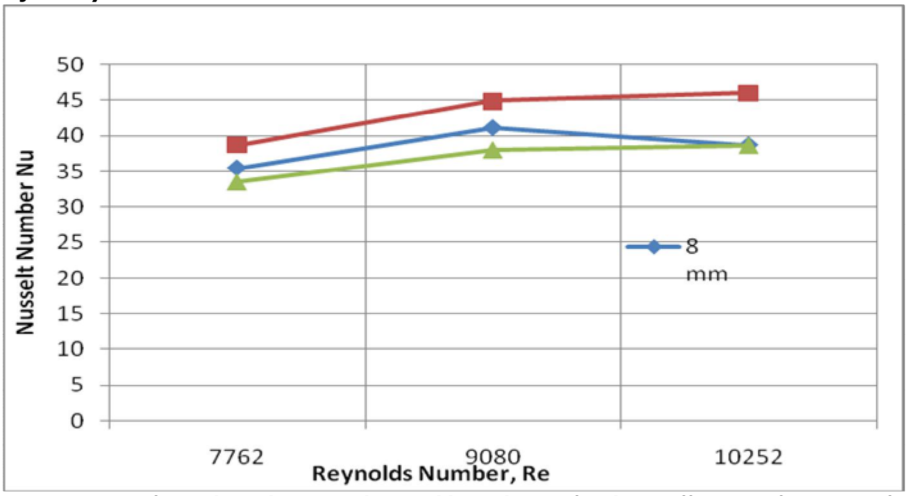

Fig 11. Variation of Nusselt number, *Nu* with Reynolds number, *Re* for Three Different Configurations of Test section

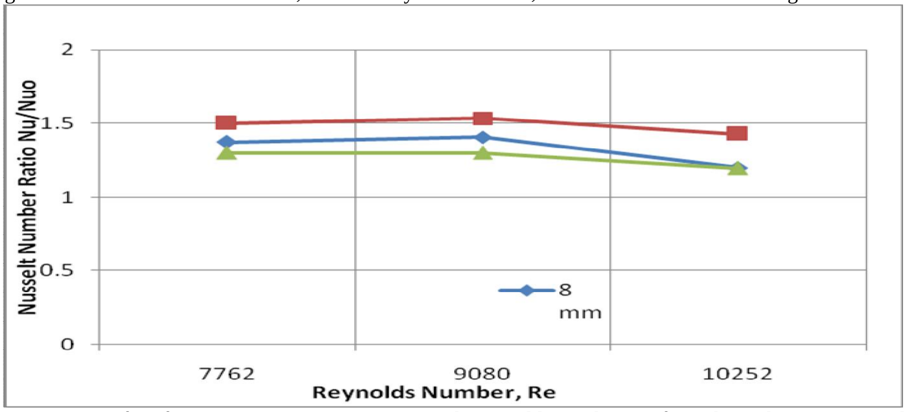

Fig 12. Variation of Performance Ratio R_1 i.e. Nu/Nu_o with Reynolds number, *Re* for Tube with 12 mm central rod.

IV. CONCLUSIONS

The measurements of heat transfer in round tube are carried out to understand heat transfer performance of the test section having different percentage of blockages at its centre. Following are the conclusions that may be drawn from the experimental data obtained.

- Experimental investigation of heat transfer of circular tube fitted with different percentages blockages, have been studied under uniform heat flux conditions with air as the working fluid.
- All the three configurations show the Nusselt number augmentation (Nu/Nu_o) of 1.2 to 1.5 for all the three Reynolds number studied.
- This enhancement in heat transfer is due to division / breaking or separation of boundary layers. This causes reduction in temperature and velocity gradients in the flow, results in enhancement of heat transfer.

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