Experimental Investigation of Heat Transfer Performance of Matrix Coil Wire Inserts using CFD

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Abstract: The present work shows the results obtained from experimental investigations of the augmentation of turbulent flow heat transfer in a horizontal tube by means of Matrix coil wire inserts with air as the working fluid. Experiments were carried out for plain tube with/without Matrix coil wire insert at constant wall heat flux and different mass flow rates. The Matrix coil wire inserts are of same pitch but three different density of 8, 10, 12 no of turns per pitch and different material. The Reynolds number varied from 6000 to 13000. Both heat transfer coefficient and pressure drop are calculated and the results are compared with those of plain tube. It was found that the enhancement of heat transfer with Matrix coil wire inserts as compared to plain tube varied from 42% to 179 % for various inserts.

Keywords: Matrix coil wire insert, Heat transfer Enhancement, different density of insert with constant pitch

INTRODUCTION

Among many techniques (both passive and active) investigated for augmentation of heat transfer rates inside circular tubes, a wide range of inserts have been utilized, particularly when turbulent flow is considered. A lot of methods are applied to increase thermal performance of heat transfer devices such as treated surfaces, rough surfaces, swirling flow devices, coiled tubes, and surface tension devices Helical coil wire swirl tabulator is one of the commonly used passive types for heat transfer augmentation due to their advantages of steady performance, simple configurations and ease of installation . These type inserts generate swirling flow and cause improved fluid mixing between central region and the nearly wall region so, the heat transfer in tubes can be enhanced by fluid mixing. In this experimental study, differently from literature, the Matrix coil wire inserts are placed separately from the tube wall to augment heat transfer. So, the heat transfer is enhanced and also prevention of the contamination is supplied. The experiments are carried out with three different densities of 8, 10, 12 nos of matrix coil per pitch in the range of Reynolds number from 6000 to 13000.

EXPERIMENTAL SET-UP

The schematic diagram of experimental set-up is given in Fig. 1.

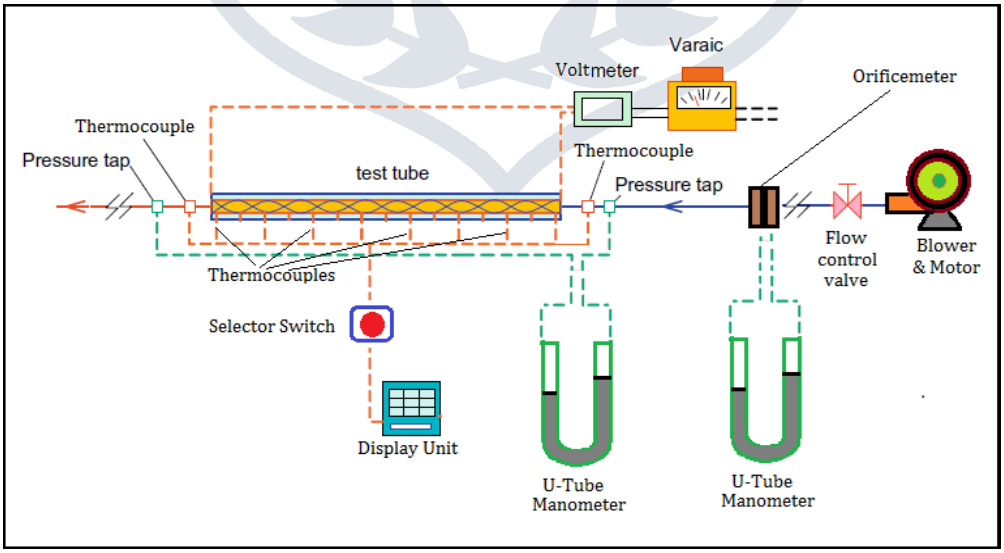

Fig.1 Experimental setup block diagram

The experimental facility includes a blower, an orifice meter to measure the volumetric flow rate, the heat transfer test tube (700 mm). The MS test tube 26 mm inner diameter (D_1), 30 mm outer diameter (D_2), and 2 mm thickness (t). The Matrix coil wire inserts are tested in this experiment, with three different density as 8,10& 12 no of coil per pitch but have same OD (=26mm). They are fabricated from Copper. The schematic figure of the Matrix coil wire insert is given in Fig.2.

Fig.2 Schematic of Matrix coil wire Inserted

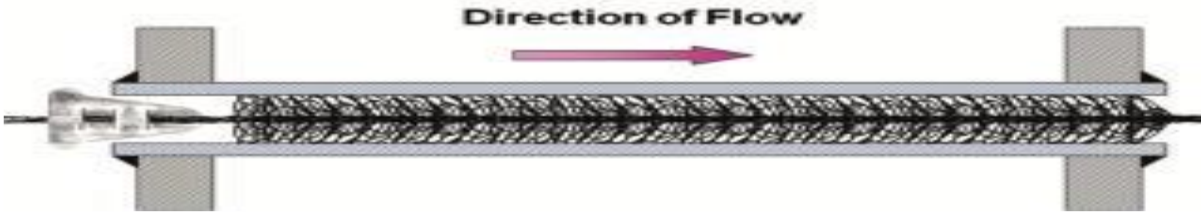

Fig.3 Actual view of Matrix coil wire Insert

Actual photographs of stainless steel matrix coil wire inserts

Fig 4 Matrix coil wire insert of high density 12 no of turns per pitch

A 0.5HP blower is used to force air through the test tube. Uniform heat flux is applied to external surface of the test tube by means of heating with electrical winding, whose output power is controlled by a variac transformer to supply constant heat flux along the entire section of the test tube. The outer surface of the test tube is well insulated with glass wool to reduce the convective heat loss to the surroundings. The external surface temperatures of the test tube wall are measured by 6 K-type thermocouples, which are placed on the outer wall of the test tube. Also the inlet and outlet temperatures of the bulk air are measured by two K-type thermocouples at given points. An inclined manometer is used to measure pressure drop across the test tube. After air passes the test tube, it enters to the orifice meter for determining volumetric flow rate readings. For this purpose a separate U-tube manometer is placed across orifice meter. The volumetric flow rate of air supplied from the blower is controlled by varying control valve position. The experiments are conducted by varying the flow rate in terms of Reynolds numbers from 4181 to 9466 of the bulk air. The test tube is heated from the external surface during the experiments, and the data of temperatures, volumetric flow rate, pressure drop of the bulk air and electrical output are recorded after the system is approached to the steady state condition. The Nusselt number, Reynolds number, friction factor, heat transfer enhancement are calculated based on the average outer wall temperatures and the inlet and outlet air temperatures.

3. Data collection and analysis

The data reduction of the obtained results is summarized in the following procedures:

Heat Transfer Calculations

$T_s = (T_2+T_3+T_4+T_5+T_6+T_7)/6$ (1)

$T_b = (T_1+T_8)/2$ (2)

Equivalent height of air column, $h_{air} = (\rho_w * h_w)/\rho_a$ (3)

Discharge of air, $Q_a = Cd * Ao \sqrt{2 * g * h_{air}}$ (4)

Velocity of air flow, $V = Q_a / A$ (5)

Reynolds number, $Re = V D/\nu$ (6)

$Q = \dot{m} * C_p * (T_8 - T_1)$ (7)

$h = \frac{Q}{A (T_s - T_b)}$ (8)

$Nu = \frac{h D}{k}$ (9)

$$f = \frac{\Delta P}{\frac{L}{D} * \frac{\rho_a V^2}{2}} \quad (10)$$

$$\eta = \frac{(Nu_i/Nu)}{(f_i/f)^{0.333}} \quad (11)$$

Validation experiments of plain tube

In this study, experimental results of Nusselt number and friction factor for the plain tube are obtained and validated with equations of Dittus Boelter and Petukhov as given below;

$Nu_{th} = 0.023\ Re^{0.8}\ Pr^{0.4}$ (12)

$f_{th} = (1.82 * \log_{10} Re - 1.64)^{-2}$ (13)

The comparisons of Nusselt number and friction factor for the present plain tube with existing correlations are shown in Figs. 4 and 5, respectively. These figures shows that validation experiments of heat transfer in terms of Nusselt number and friction factor for the plain tube are in good agreement with the results obtained from Dittus-Boelter and Petukhov equations. The results of present plain tube and previous equations are nearly the same. Thus, this accuracy provides reliable results for heat transfer and friction factor in a tube with Matrix coil wire inserts in this present study.

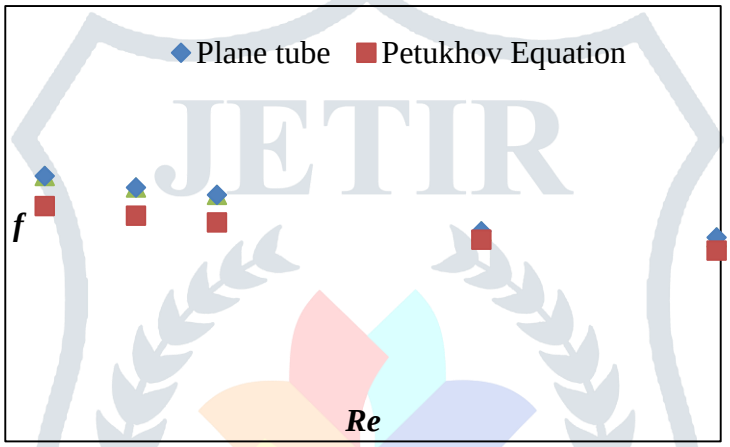

Fig.5 Validation results for friction factor

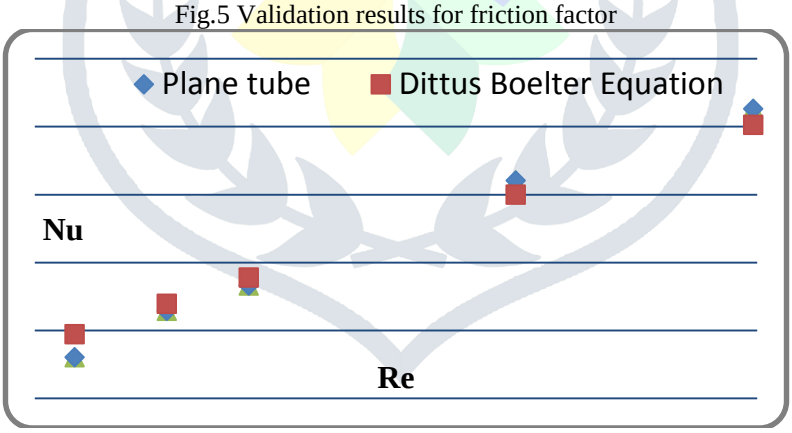

Fig.6 Validation results for Nusselt number

4. Graphs for Nusselt No. & Friction factor without insert and with Copper and stainless steel inserts at different Reynolds No.

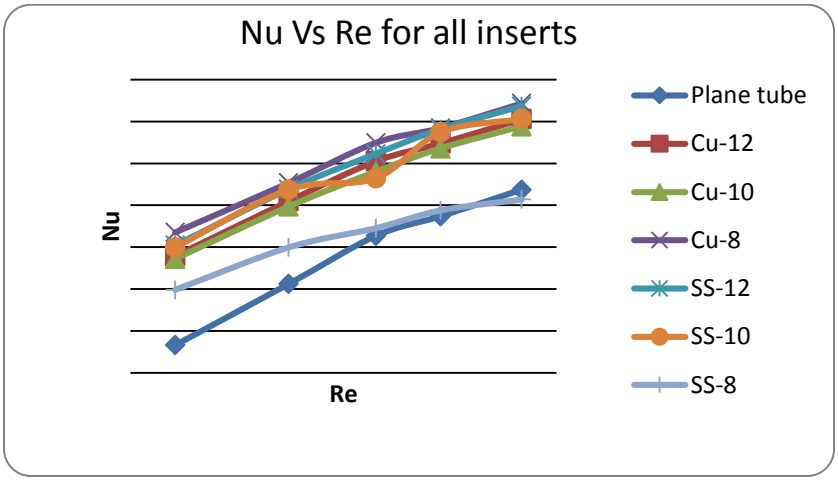

Fig7 Variation of Nusselt number for different insert configurations

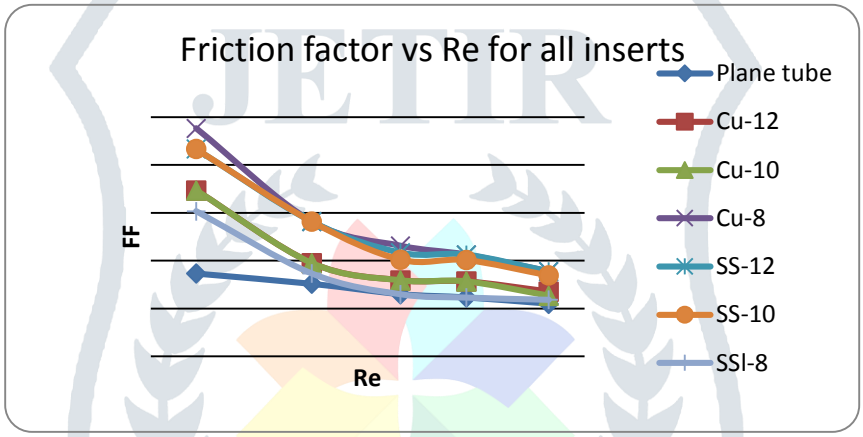

Fig.8 Variation of friction factor for different insert configurations

5. Graphs for Enhancement with Copper and stainless steel inserts at different Reynolds No.

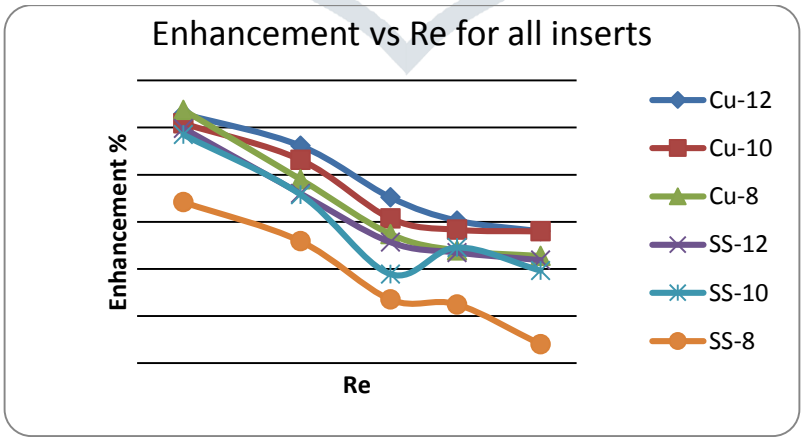

Fig.9 Variation of Enhancement for different insert configurations

6. CFD Graphical Results:-

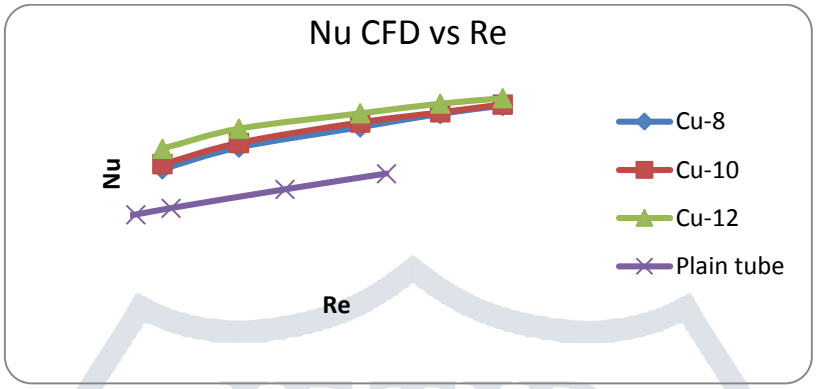

Fig.10 Variation Nu CFD with Re for Cu inserts

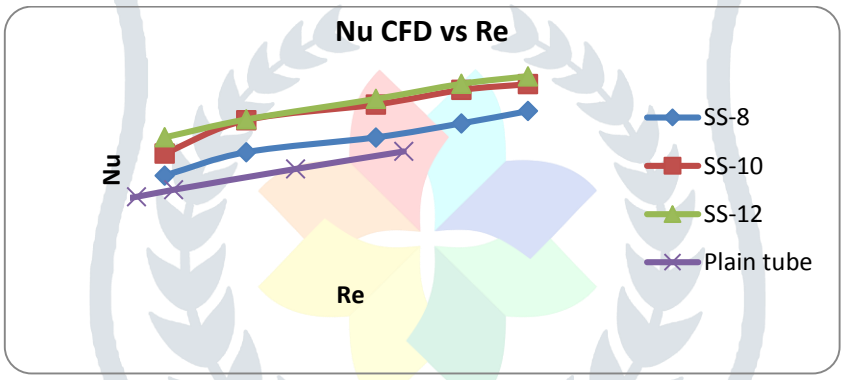

Fig.10 Variation Nu CFD with Re for SS inserts

7. Final Results and Discussion

Heat Transfer and Overall Enhancement Characteristics

- The variation of Nusselt number with Reynolds number for various Matrix coil wire inserts is shown in Figure 7. Highest Nusselt number was obtained for Copper Matrix coil wire insert with highest density.
- The variations of friction factor with Reynolds number for Matrix coil wire inserts are presented in Figure 8. It is observed that the friction factor gradually reduced with rise in Reynolds number. It is observed to be maximum for insert having Highest density 12 turns per pitch.
- It is evident from Figures 7 that when a Matrix coil wire insert is inserted into a plain tube there is a significant improvement in Nusselt number because of secondary flow, with greater enhancement being realized at lower Reynolds numbers and for lower density for same pitch. This enhancement is mainly due to the centrifugal forces resulting from the spiral motion of the fluid and partly. It is observed that the increase in density causes increment in Nusselt numbers as well as rise in pressure drop.
- The overall enhancement ratio is useful to evaluate the quality of heat transfer enhancement obtained over plain tube at constant pumping power. It is found to be more than unity for all the Matrix coil wire inserts used. Variations of overall enhancement ratio η against Reynolds number for various inserts are shown in figure 9. It observed that overall enhancement tended to decrease gradually with the rise of Reynolds number. The maximum value of overall enhancement is 2.4 for Cu Matrix coil wire insert having Density of 12 nos of turns per pitch. It is seen in Figure 9 that, for Matrix coil wire inserts having density 8, 10 and 12 nos of turns per pitch curves are of decreasing order for a given pitch in the range of Reynolds number from 6000 to 13000.

8 Conclusions:-

The study presents an experimental investigation of the potential of Matrix coil wire insert to enhance the rate of heat transfer in a horizontal circular tube with inside diameter 26 mm with air as working fluid. The Reynolds number varied from 6000 to 13000. The effects of parameters such as modified density, Reynolds number on the heat transfer and overall enhancement ratio are studied.

The following conclusions can be drawn:

 The enhancement of heat transfer with Matrix coil wire inserts as compared to plain tube varied from 72 to 218% for Cu inserts and 42 to 179 % for SS inserts. This enhancement is mainly due to the centrifugal forces resulting from the spiral motion of the fluid.

 When theoretical and experimental values are compared of Nusselt number then the copper insert with density 12 nos of turns per pitch gives 179% rise in Nusselt number and Nu decreases with density of material.

 When theoretical and experimental values of friction factor are compared then copper insert with density 12 nos of turns per pitch gives 2.89 times rise as compared plane tube. But Nu is also increasing hence proving the insert to be better in terms of heat transfer enhancement and also at lesser pumping power

 The increase in pressure drop by increasing density is not as significant as the increase in Nusselt number. The optimum value obtained for minimum pressure drop is copper with density 12 nos of turns per pitch.

 Error in CFD Nu no. to Experimental Nu is maximum up to 5.12% for SS inserts and is maximum up to 2.89% for Cu insert. It also indicates validation of our experimental setup

Thus the enhanced performance can be achieved using Matrix coil wire insert as compared to plane tube.

Thus, from the considerations of enhanced heat transfer and savings in pumping power Matrix coil wire insert are seen to be attractive for enhancing turbulent flow heat transfer in a horizontal circular tube.

9. Future work may be extended to:

• Change the pitch distance of Matrix coil wire insert to get optimum value.

• Compound enhancement techniques maybe applied i.e., the tape inserts can be coupled with coil wire inserts for better enhancement

•We can try some modifications in the geometry of Matrix coil wire with the help of CFD analysis.

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