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EXPERIMENTAL ANALYSIS FOR ENHANCEMENT OF HEAT TRANSFER USING WIRE MATRIX AS A TUBE INSERT

Kailash Ashok Kale
Department of Mechanical
Engineering,
ADCET, Ashta, Maharashtra,
India

Saurabh Suryakant Jadhav
Department of Mechanical
Engineering,
ADCET, Ashta, Maharashtra,
India

Nandkishor Pralhad Sutar
Department of Mechanical
Engineering,
ADCET, Ashta, Maharashtra,
India

Shubham Jitendrasing Pardeshi
Department of Mechanical
Engineering,
ADCET, Ashta, Maharashtra,
India

Sourabh Bharat Howale
Department of Mechanical
Engineering,
ADCET, Ashta, Maharashtra,
India

Prashant S. Waydande
Department of Mechanical
Engineering,
ADCET, Ashta, Maharashtra,
India

Abstract— This paper presents experimental analysis for heat transfer using wire matrix as a tube insert. Experimentation is carried out by using wire matrix as a tube insert. Hot and cold water at various temperatures are used as testing fluid. Varieties of flow conditions are generated by changing the Reynolds number for achieving more accurate results under specific condition. Reynolds number is fluctuated from 1000 to 12000. Wire matrix having diameters 26 mm and 28 mm are used to conduct the experiment. Again in these diameters wire matrices having different densities namely low, medium and high density are used. In case of wire matrix, density refers to the number of turns per unit length. Nusselt number, Prandtl number and other performance parameters like pressure drop, friction factor is determined by using experimental correlations at the end and compared with the corresponding parameters obtained under plain tube condition. Result shows that Nusselt's number increases as the Reynolds number increases under the specific condition. Nusselt number obtained from tube fitted with wire matrix is larger than the Nusselt number obtained with plain tube condition. Heat transfer coefficient also increases with increase in Reynolds number. At the same time friction factor decreases with increase in Reynolds number. Increase in pressure drop along with increase in Reynolds number is observed.

Keywords— Heat transfer enhancement, tube insert, wire matrix, wire matrix density, performance evaluation criteria.

I. INTRODUCTION

Heat exchangers have very wide scope in various industries as well as in domestic applications. In food processing industries, dairies, process industries like petrochemical, thermal power plants and in domestic applications like refrigerator, heat exchangers are highly used.

Considering the optimization in case of heat exchangers, various researchers carried out the experiments so as to achieve maximum heat transfer rate for particular heat exchanger at minimum investment of cost and material. Later these experiments are renowned as Heat Transfer Augmentation techniques. [1] These techniques are as follows,

- A. Active Techniques** – These are the techniques in which electrical supply is needed for heat transfer augmentation. E.g. fluid vibration.
- B. Passive Techniques** – Passive techniques can work out without any electrical power supply for heat transfer augmentation. E.g. Surface modifications, Swirl generators, etc.

Nomenclature

A Area of heat transfer, m²



C_p	Specific heat at isobaric condition, $J\ kg^{-1}\ K^{-1}$
D_{out}	Outside diameter of outer pipe, m
D_{in}	Inside diameter of outer pipe, m
d_{out}	Outside diameter of inner pipe, m
d_{in}	Inside diameter of inner pipe, m
f	friction factor
h	heat transfer coefficient, $W\ m^{-2}\ K^{-1}$
k	thermal conductivity, $W\ m^{-1}\ K^{-1}$
L	Effective length of testing pipe, m
m_h	Mass flow rate of hot water, $kg\ s^{-1}$
m_c	Mass flow rate of cold water, $kg\ s^{-1}$

Nu	Nusselt number
P	Pressure of fluid flow, $N\ m^{-2}$
ΔP	Pressure drop across tube, $N\ m^{-2}$
ρ	Density of fluid, $Kg\ m^{-3}$
V_h	Velocity of hot water, $m\ s^{-1}$
q	Heat transfer rate by convection in hot fluid, $W\ m^{-2}$
μ	Dynamic Viscosity, $N\ m^{-1}\ s^{-1}$
Pr	Prandtl number
Re	Reynolds number
T	Temperature, $^{\circ}C$
T_b	Bulk mean temperature, $^{\circ}C$

C. Compound Techniques – In compound techniques, multiple techniques are implemented for single heat transfer application.

Passive techniques consist of heat transfer enhancement either by surface modifications of heat exchanger such as providing fins or by using swirl generators like wire matrix, twisted tape. Liquid additives are also used. Various tube inserts such as wire matrix, twisted tapes, wire coils, helical screw acts as a swirl generator in a fluid flow inside the heat exchangers. They allow the fluid flow at inner periphery region of heat exchanger to flow towards core region and vice versa. They also act as a turbulence promoter by destroying the laminar fluid layer region inside fluid flow so as to improve the heat transfer rate.

Till now research work carried out by using wire matrix as a tube insert is very low as compared to other tube inserts such as twisted tapes, wire coil. Maradiya Chirag et al. (2018) [2]. Wire matrix can be widely used in process industries.

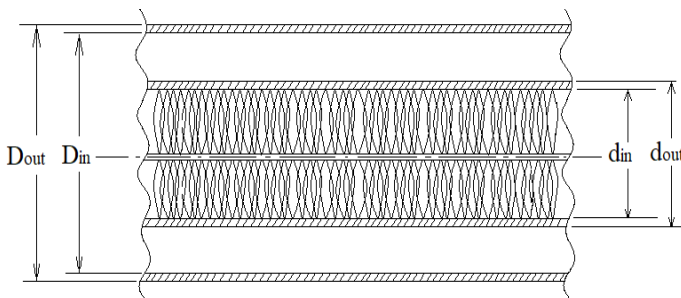


Fig. 1. Heat exchanger tube fitted with wire matrix

Till today researchers mostly used twisted tapes as a tube insert. Eiamsa-ard Smith et al. (2009) [3], [4] conducted the tests by using twisted tapes shorter than test tube with various lengths and twisted tape having length equal to test tube as an insert to

study heat transfer characteristics. Various flow conditions are generated by varying Reynolds number from 4000 to 20000. Results represent that tube fitted with full length twisted tape performs better heat transfer than tube with short length twisted tape. Also enhanced efficiency of full length twisted tape is found more than short length twisted tape. Eiamsa-ard and S. et al. (2010) [5] used twin co- twisted and twin counter twisted tapes as a tube insert for heat transfer enhancement. Determination of Nusselt number, friction factor and thermal enhancement index is done. Tests are conducted by varying the Reynolds number in between 3700 and 21000. It is observed that twin counter twisted tapes are more efficient than the twin co- twisted tapes. Heat transfer rate in a tube fitted with twin counter twisted tapes is 12.5- 44.5% higher than the tube fitted with co- twisted tape. Heat transfer enhancement is also done by using Nano fluids. Han D. et al. (2017) [6] used Al_2O_3 /water Nano fluid in double tube heat exchanger for heat transfer augmentation. Reynolds number is varied from 20000 to 60000. Results indicate that heat transfer increases with increase in temperature and volume concentration of Nano particles.

Gholamalizadeh Ehsan et al. (2019) [7] conducted the tests for heat transfer enhancement by using helically coiled heat exchanger with coiled wire with circular and rectangular cross section as a tube insert. Thermal performance parameters are compared with plain coiled heat exchanger. Results show that coiled wire tube inserts with circular cross section enhance the Nusselt number by 340.9%. Gracia Alberto et al. (2005) [8] used helical coiled wire as a tube insert. Water and water- propylene glycol mixtures are used as a test fluid. Thermo-hydraulic behavior is observed in laminar, transition and turbulent flow region. Results have shown that tube fitted with wire coil tube insert gives four times more heat transfer as compared to plain tube. At low Reynolds number wire coil does not give considerable results. Wire coil tube insert gives their best performance in transition fluid flow region as compared to other heat transfer augmentation techniques. Ritchie J. M. et al. (2007)

[9] carried out the experiment by using wire matrix as a tube insert so as to improve the heat transfer rate and to reduce the scaling problems inside the heat exchanger.

Results indicate that the thickness of fouling layer in tube with tube insert is much reduced and so reducing the adverse effects of fouling and sedimentation on the heat exchanger.

II. EXPERIMENTAL SETUP

Fig.2. shows schematic diagram of the experimental setup. It contained two metal tubes concentrically mounted. Inner tube was made up of copper material having inside diameter (d_{in}) 28mm and outside diameter (d_{out}) 30mm. And outer tube was made up of MS material having inside diameter (D_{in}) 52mm and outside diameter (D_{out}) 54.4mm. Both pipes were having effective heat transfer length 900mm. MS pipe was insulated by a thermal insulating material called Heatlon of 20mm thickness and thermal conductivity 0.025 W/mK to reduce heat losses.

Water has been used as a working fluid. The experimental setup consisted two storage tanks made up of PVC material. Tank consisted one electric heater of 2KW capacity along with stirrer. Two water pumps having capacity 0.5 HP were used to circulate water through concentric tubes in counter flow direction. Two rotameters having flow range of 0 to 10 LPM were used to measure flow rate through pipes. The flow rate was controlled by using two separate flow control valves after water

pressure drop between the fluids at inlet and outlet of the copper tube. Manometer having range 0 to 400mm of Hg was used.

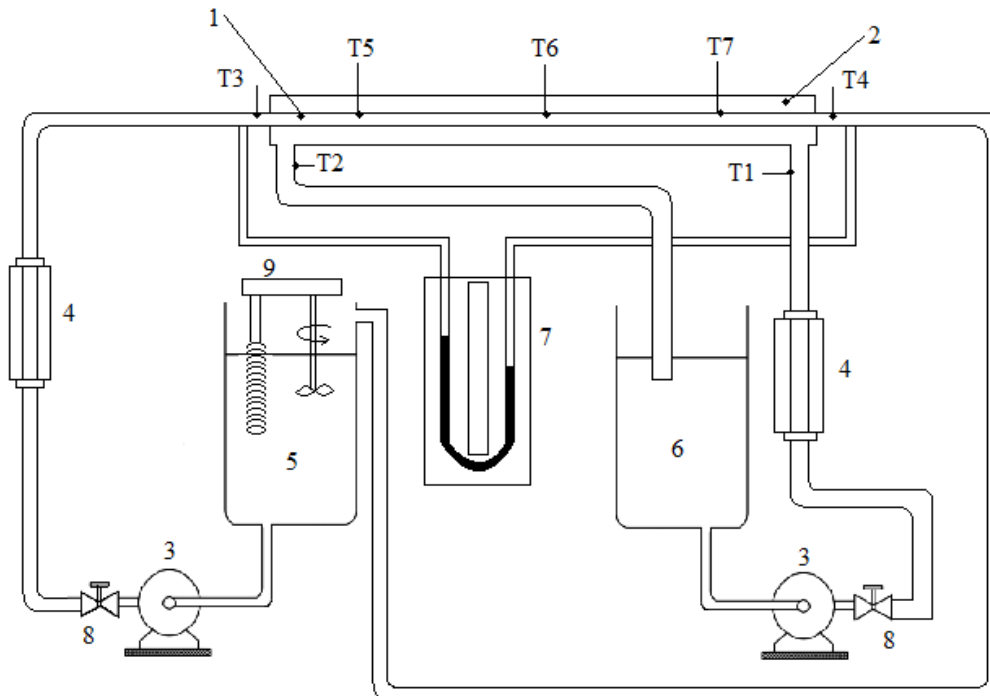
Inlet and outlet temperatures of cold and hot fluid named as T1, T2, T3 and T4 respectively were measured by PT100 type thermocouple. Since the heat was uniformly added along the effective tube length, the bulk temperature of fluid (T_b) was calculated by simple average method.

$$T_b = \frac{T5 + T6 + T7}{3} \quad \dots(1)$$

First trial was conducted on plain tube without using wire matrix. For evaluating better performance, wire matrices having two diameters i.e. 26mm and 28mm in three different densities i.e. low, medium and high were used to conduct another trial. Hot water which was maintained at 60°C in hot water tank circulated through inner copper tube and cold water which was stored in cold water tank circulated through outer MS tube. For this trial the flow rate for cold water kept constant at 8 LPM and flow rate for hot water varied from 1 LPM to 8LPM. And for these readings, all temperatures and pressure drop are recorded. The same procedure was followed to take further readings for other wire matrices.

III. PARAMETERS CALCULATION

Firstly the Reynolds number was calculated for all wire



1. Copper Inner Pipe
2. MS Outer Pipe
3. Water Pump
4. Rotameter
5. Hot Water Tank
6. Cold Water Tank
7. U-Tube Manometer
8. Flow Control Valve
9. Heater with stirrer

- T1: Outer Pipe Inlet Temperature
 T2: Outer Pipe Outlet Temperature
 T3: Inner Pipe Inlet Temperature
 T4: Inner Pipe Outlet Temperature
 T5, T6, T7: Surface Temperatures

pumps. A U-tube manometer has been used to measure the

matrices to determine the type of fluid flow flowing through a



pipe. Pipe diameter (d_{in}) and density of fluid (ρ) remained constant for all readings. Hence the Reynolds number changed as velocity of hot fluid (V_h) and dynamic viscosity (μ) changed. Reynolds number was calculated by means of,

$$R_e = \frac{\rho \times V_h \times d_{in}}{\mu} \quad \dots(2)$$

As prandtl number is the ratio of kinematic viscosity (ν) to thermal diffusivity (α). It was calculated by means of,

$$P_r = \frac{\mu \times C_p}{k} \quad \dots(3)$$

The prandtl number calculated by equation (3) were depends upon dynamic viscosity (μ), thermal conductivity of pipe material (k) and the specific heat of hot fluid at isobaric condition (C_p).

Heat transfer coefficients (h) were calculated by means of,

$$h = \frac{q}{A \times (T_f - T_s)} \quad \dots(4)$$

Heat transfer Coefficient calculated by equation (4) were depends upon the rate of heat transfer by convection in hot fluid (q), the surface area and the difference between average hot fluid temperature (T_f) and average surface temperature (T_s). The term q which is rate of heat transfer by convection in hot fluid were calculated by simple heat transfer equation which was given by,

$$q = (m_h \times C_p)_{hot} \times (T_3 - T_4) \quad \dots(5)$$

The equation (5) depends upon mass flow rate (m_h), specific heat of hot fluid at isobaric condition (C_p) and temperature difference between hot fluids at inner and outer end of copper pipe.

Nusselt number depends on the heat transfer coefficient (h) and thermal conductivity of pipe material (k) and was given by,

$$N_u = \frac{h \times d_{in}}{k} \quad \dots(6)$$

Performance evaluation criteria (R_1) depends on heat transfer coefficient for tube with wire matrix insert (h_{insert}) and heat transfer coefficient for plain tube (h_{plain}). R_1 was calculated by means of,

$$R_1 = \frac{h_{insert}}{h_{plain}} \quad \dots(7)$$

Pressure drop (ΔP) was calculated to identify the decreased amount of pressure due to wire matrix insert. And friction factor (f) was calculated by means of,

$$f = \frac{\Delta P \times d_{in}}{2 \times L \times \rho \times V^2} \quad \dots(8)$$

Friction factor (f) depends upon pressure drop (ΔP) and velocity of the hot fluid flow (v) and it is given by,

$$V_h = \frac{m_h}{\rho \times A} \quad \dots(9)$$

IV. RESULTS AND DISCUSSION

The detailed study of variations in Nusselt number, pressure drop and performance evaluation criteria R_1 as per the changes in Reynolds number is carried out. These parameters are studied under both plain tube and tube with wire matrix insert conditions.

A. Friction Factor –

Fig.3. is the graph of friction factor (f) vs. Reynolds Number (Re) for plain tube, wire matrix with different density (Low, Medium and High) and different diameter 26 mm and 28 mm. As the density of wire mesh increases, more turbulence is generated inside fluid flow. This increases the pressure drop and ultimately increases the friction factor. In case of high density wire matrix with diameter 26 mm and 28 mm, more turbulence is created by the corresponding insert and so higher value of friction factor is seen.

For small Re , values of pressure drop were very small (0.1 to 0.8cm) and least count of manometer was 0.1cm. Hence those small pressure drops couldn't be measured with great accuracy.

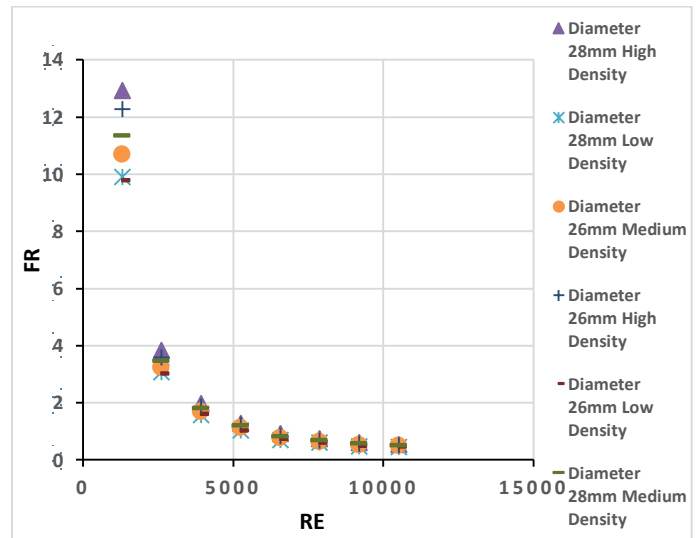


Fig.3. Friction factor Vs Reynolds number for all studied circumstances

B. Nusselt's Number –

The relationship between Nusselt's numbers and Reynolds numbers for with and without wire matrix inserts is shown in Fig.4. The value for Nusselt's number is increases as the Reynolds number is increased.

For plain tube the values of Nusselt's number are low, as compared to the values of Nusselt's number for tube with wire matrix inserts. At given Reynolds number, due to use of wire matrix inserts Nusselt's number increases as compared to that of the plain tube. The thickness of the thermal boundary increases as Reynold's number decreases, this tends to destruction of boundary layer. For the tubes with wire matrix, the Nusselt's numbers are enhanced between 23.8% and 68.2%, over that of the plain tube. The wire matrix induces the swirl into the flow which helps to proper fluid mixing and ultimately it increases the Nusselt's number.

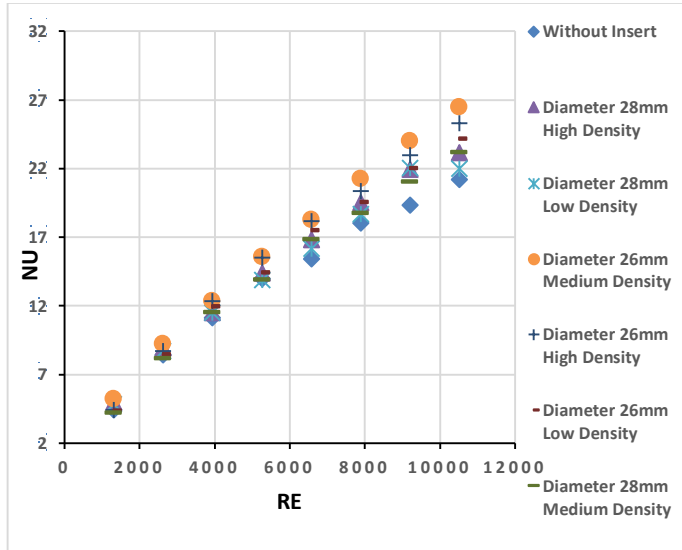


Fig.4. Effect of Reynold's Number over Nusselt's number

a. Effect of Density –

The effect of Reynolds number on Nusselt's number for 26 mm wire matrix diameter with varying density is shown in Fig.5. The difference in Nusselt's number with Reynold's number for low, medium and high density is shown. The Fig.5. shows that the Nusselt's number for low density wire matrix is less as compared to other. The Nusselt's number will be more as the density of the wire will increase.

The variation in Nusselt's number will be more at higher Reynold's number. The density of wire will help to create more turbulence hence the Reynold's number value will be higher. This turbulence will help for proper mixing of the fluid so that heat transfer rate will increase.

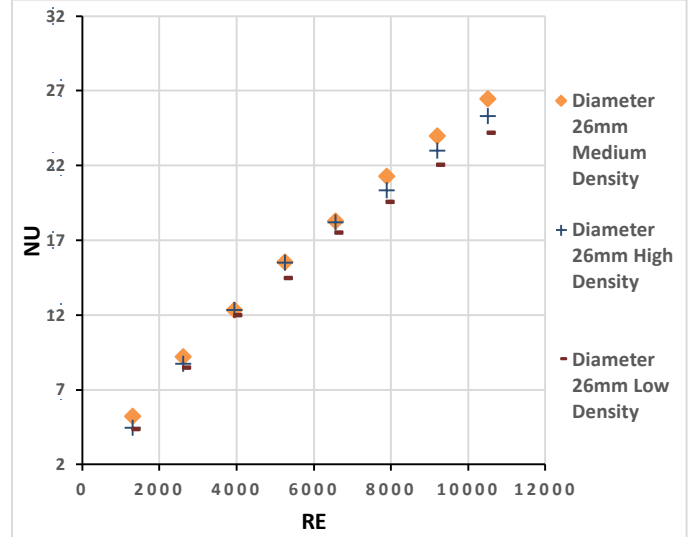


Fig.5. Effect of Reynold's number over Nusselt's number for 26 mm diameter matrix

Fig.6. indicates the effect on Nusselt's number with respect to the Reynold's number for wire matrix having diameter 28 mm. The Fig.6. follows the same nature as like Fig.5. Here the Nusselt's number for high density wire matrix is more and lower value of Nusselt's number is obtained for low density wire matrix insert. As the density of wire matrix is increases the Reynold's number also gets increase. The increased Reynold's number will help to create more vortexes into the fluid. It interrupts the fluid film nearer to the tube surface and contributes in the higher heat transfer.

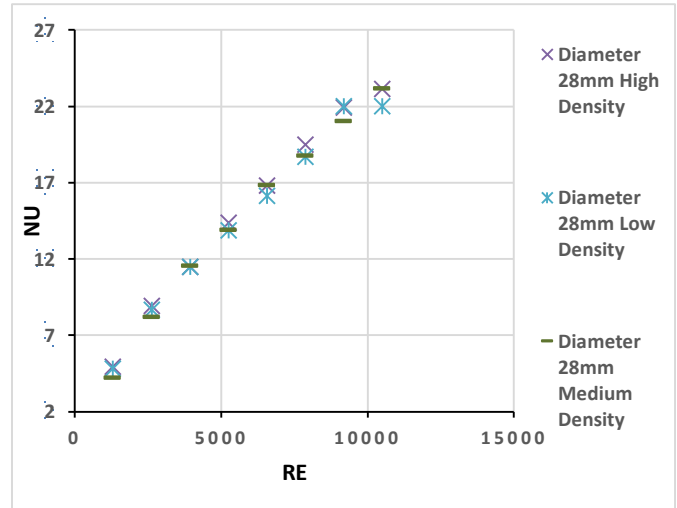


Fig.6. Effect of Reynold's number over Nusselt's number for 28 mm diameter matrix



C. Performance evaluation criteria (R₁) –

Fig.7. shows the graph of Performance evaluation criteria, R₁ vs. Reynolds number. Maximum R₁ is observed for 26 mm diameter wire matrix with medium density & then decreases with respect to density and diameter. From this we can infer that 26 mm diameter wire matrix with medium density is the loud design and is giving better performance than other wire matrix insert.

Peak Value of R₁ is obtained for highest Reynold's Number and then decreases with decreasing Reynold's Number. This happens because the higher degree of turbulence is generated as the Reynolds number increases in the smooth tube itself as the Reynolds number exponent in R₁ increases from 1.09 to 1.24 when fluid flow varies from laminar, then transition to turbulent flow. Hence when we use any heat transfer augmentation technique, its net effect is to increase in turbulence inside the fluid flow. So we can confer that wire matrix inserts improves the heat transfer rate at higher Reynolds number significantly as that of lower Reynolds number.

The results indicate that the wire matrix with medium density increases and gives higher value of performance evaluation criteria (R₁). The wire matrix with 26 mm diameter gives more value as compared to 28 mm diameter wire matrix. This is because of some amount of fluid can flow near to the pipe wall without getting disturbed by wire matrix. The lowest performance evaluation criteria (R₁) are obtained for lowest Reynolds number of 2600.

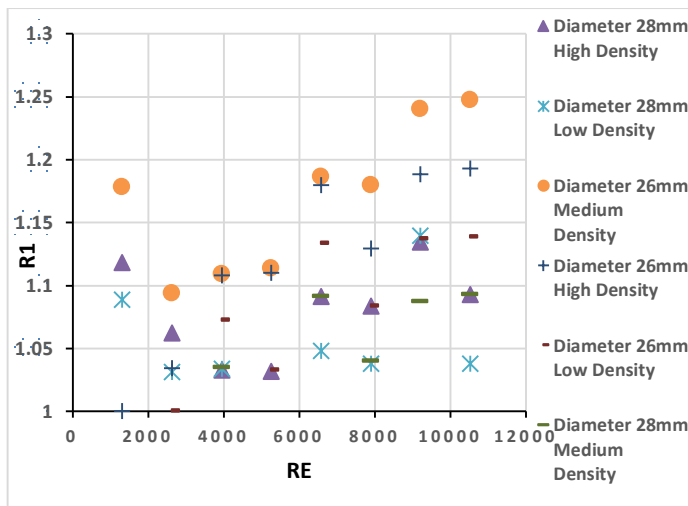


Fig.7. Performance Evaluation Criteria (R₁) Vs. Reynolds number (Re) for all circumstances

D. Pressure Drop –

Fig.8. shows the pressure drop effects for different wire matrix inserts arrangements with Reynolds number. The wire

matrix insert used into the study will create resistance to the fluid flow, which ultimately results into increase in pressure drop into the flowing fluid. This decrease in pressure into the flowing fluid and hence will require high capacity pumping device. The best design will be considered that will create less pressure drop, but because of use of wire matrix insert it create the resistance and pressure drop occurs. The Fig.8. shows the variations in pressure drop as the Reynolds number changes. At higher Reynolds number more swirls are created inside fluid flow and as a result pressure drop get increased with Reynolds number.

In Fig.8 we have shown that plain tube have minimum pressure drop. The maximum resistance is offered by high density wire matrix hence more pressure drop is observed in this study. The lowest pressure drop is observed in case of low density wire matrix with 26 mm diameter. The more amount of fluid can pass through low density wire matrix therefore minimum resistance is offered by this type of arrangement. Minimum pressure drop can be obtained as the density of the wire matrix decreases.

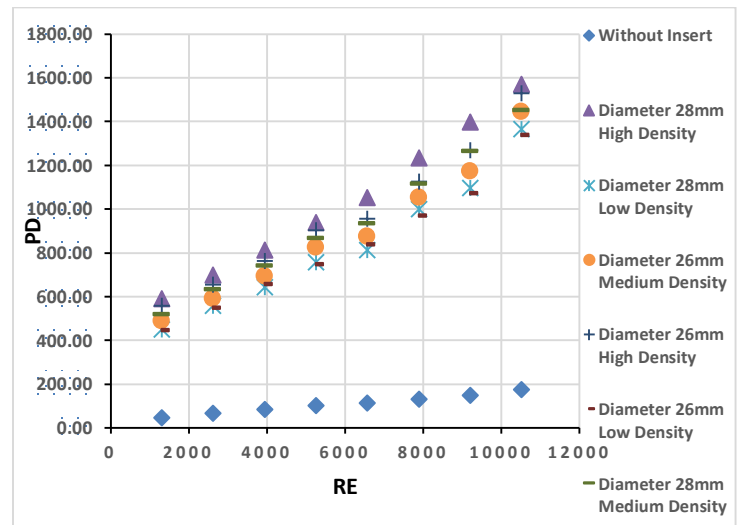


Fig.8. Effect of Pressure Drop over the Reynold's Number for different arrangement

E. Heat Transfer Coefficient –

Fig.9. shows the heat transfer results for wire matrix with low, medium and high density for 26 mm and 28 mm diameter along with the Reynold's number. As the diameter of wire matrix decreases, more turbulence is generated inside fluid flow and as a result increment in heat transfer coefficient takes place as the density of wire matrix increases. In case of 26 mm diameter medium density, higher intensity of turbulence is created which destructs the whole thermal boundary layer and as



a result much higher value of heat transfer coefficient is obtained. For higher values of Reynolds number, heat transfer by natural convection is negligible as compared to forced convection but it plays an important role at smaller Reynolds number. For $Re > 5000$, variations in the values of Heat transfer coefficient were found to be well within $\pm 8\%$ for most of the readings. So it can be concluded that heat transfer results in case of plain tube are reasonably correct.

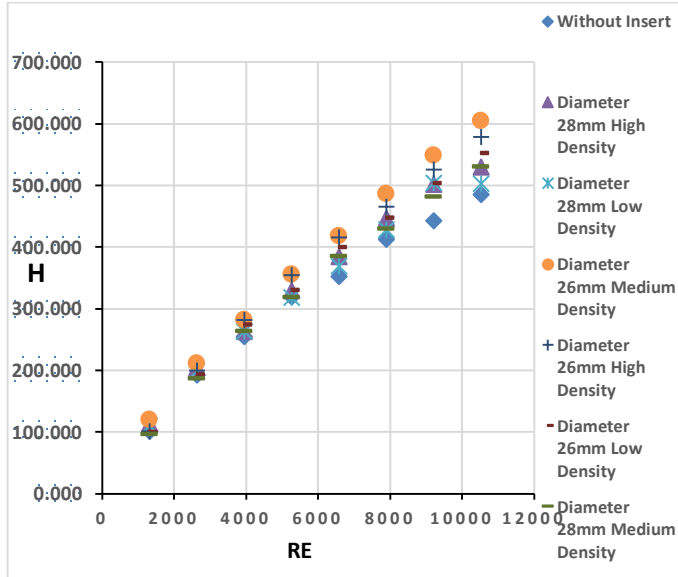


Fig.9. Heat Transfer Coefficient Vs Reynold's Number

V. CONCLUSIONS

A. Experimental tests has been carried out in more comprehensive manner with six wire matrix tube inserts and by varying the Reynold's number in between 1000 to 12000. So that profound concluding remarks can be obtained regarding various thermo-hydraulic properties like heat transfer coefficient, Nusselt number and friction factor.

B. Friction factor goes on decreasing with increase in Reynolds number. Maximum friction factor of 4 is observed for wire matrix of diameter 28mm with high density.

C. With increase in Reynold's number, Nusselt number also increases. In every flow condition, Nusselt number for tube fitted with wire matrix has been always enhanced than the plain tube. Lowest Nusselt number has been found in laminar regime. Also fewer variations in Nusselt number were found when the fluid flow was in laminar regime.

D. Pressure drop increases as the Reynold's number increases along with increase in density of wire matrix. This is due to swirl generated by the wire matrix. However there was

very least pressure drop in plain tube. Wire matrix with 28mm diameter and high density has given the highest pressure drop.

E. There were considerable variations in performance evaluation criteria as per the flow conditions and swirl generated by wire matrix. Lowest performance evaluation criteria has been observed when fluid flow was in transient regime, while the highest performance evaluation criteria of 1.25 has been observed for wire matrix of 26mm diameter with medium density and at Reynold's number approximately 10500.

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