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Performance of Heat Transfer of A Plain Tube Fitted With V-Shaped Twisted Tape Inserts of Copper And Stainless Steel Material for Turbulent Flow

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ABSTRACT- This paper represents tube side pressure drop, friction factor, heat transfer co-efficient, heat transfer rate, enhancement of heat transfer efficiency and percentage of increase in those parameters for water using V-shaped twisted tape inserts of copper and stainless steel material into a plain tube. The test section is a circular tube made of copper having 26.6 mm inside diameter, 30 mm outside diameter and 939.8 mm in long, of which 900 mm is of effective length. V-cut twisted tape inserts are made of as 800 mm length, 1.5 mm thickness, twisted ratio 5 and width and depth of 8 mm are used in this experiment. The test section is perfectly insulated and electrically heated. Five k-type thermocouples are used for measuring wall temperature. Experimental Nusselt number is found ranging from 34.65 to 69.25 for smooth copper tube without insert whereas, 110.9 to 250.9 for V-cut twisted tape insert of stainless steel and 121.1 to 331.8 for V-cut twisted tape insert of copper. Heat flux is obtained ranging from 9163.8W/m^2 to 15828.3W/m^2 without insert, 18327.5 W/m^2 to 31656.6W/m^2 for stainless steel insert and 18327.5W/m^2 to 39570.8W/m^2 for copper insert. Increment of heat transfer of copper insert is as 2.52 times and of stainless steel insert as 2.5 times more than plain tube without insert. Convective heat transfer co-efficient is found as 3.2, 3.5 times more than plain smooth tube for stainless steel insert and copper insert. Heat transfer enhancement efficiency using stainless steel insert and copper insert is increased 3.2, 4.3 times more than plain tube without insert.

Keywords: *V-shaped insert, Friction factor, Heat transfer rate, Heat transfer performance, Heat transfer enhancement efficiency*

1. Introduction

Heat exchanger is one of the important devices, are used in various industrial purposes. Thermal performance of heat exchangers defines the efficiency and economic competitiveness for many industrial processes. Improving the thermal performance of the heat exchangers may cause in the reduction of its size as well as initial cost. A high-performance heat exchanger of a fixed size can provide an increased heat transfer rate along with that it might also cause a decrease in the temperature difference between the process fluids and, enabling efficient utilization of thermodynamic ability. To boost heat transfer and improve thermal performance, various heat transfer enhancement techniques are widely used from the last twentieth century. It is noted that heat transfer augmentation techniques are frequently used in areas specified as temperature effort transform, air conditioning and preservation systems, heat recovery processes, cooling of different electronics equipment's and chemical reactors. Hence, using high thermal performance heat exchanger is very much essential to save energy. Several techniques are incorporated to improve the thermal performance of heat transfer devices such as mechanically treated surfaces, rough surfaces as well as introductions of inserts (such as turbulators and swirl flow generators). From various passive techniques, insertion of swirl generator is one of the most promising methods. The swirl generator caused recirculation of an existing axial flow, which leads to an improvement of fluid mixing and thus obtained an efficient reduction of the thickness of boundary layer [1-2]. Many researchers have studied the topics from the very beginning of the 20th century to improve heat transfer characteristics inside a tube. Sarkar et al. [3] experimentally investigated the heat transfer enhancement and friction factor characteristics in turbulent flow through a tube fitted with wire-coil inserts. Agarwal and Raja Rao et al. [4] experimentally measured isothermal and non-isothermal friction factors and mean Nusselt numbers for uniform wall temperature during heating and cooling of servo-thermo oil in a circular tube with twisted tape inserts. Eiamsa-ard et al. [5] conducted experimental work to evaluate the heat transfer and fluid friction characteristics in a double pipe heat exchanger decorated with regularly spaced twisted tape inserts. Ahamed et al. [6] reported the prediction of heat transfer in turbulent flow through a tube with perforated twisted-tape inserts and also a new correlation was developed to predict the heat transfer characteristics. The study finalized that the perforated twisted-tape-inserts caused an increase of heat transfer rate at an expense of increased pumping power. Bhuiya et al. [7] assessed the influence of twisted wire brush inserts on the heat transfer enhancement and pressure drop characteristics of turbulent flow for four different twisted wire densities (100,150, 200, 250) and found to have a significant impact on the improvement of heat transfer as well as an increase in friction factor over the plain tube data.

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Bhuiya et al. [8] presented the experimental results on mean Nusselt number through a tube fitted with triple helical tape inserts and reported that the Nusselt number increased 2.75 to 4.5 times compared to that of the plain tube with the increase of helix angles (9^0 to 21^0). Eiamsa-ard et al. [9] considered the effects of twin counter/co-twisted tapes on heat transfer, friction factor and thermal enhancement indicators for four different twist ratios (2.5, 3.0, 3.5 and 4.0) in the turbulent flow region under constant heat flux conditions. Wazed et al. [10] showed the influence of perforated twisted tape inserts on the enhancement of heat transfer in turbulent flow through tube. Karwa et al. [11] reported the effect of relative roughness pitch and perforation of the spring roughness on heat transfer and friction factor for turbulent flow in an asymmetrically heated annular duct (radius ratio=0.39) with a heated tube having a spirally wound helical spring. An investigational research of heat transfer performance of porous twisted tape insert in a circular tube was carried out by Ahamed et al. [12]. A new idea was postulated by Hsieh and Huang et.al. [13] to foretell heat transfer and pressure drop of laminar flow in horizontal tubes with/without longitudinal inserts. Thorsen et al. [14] studied experimentally and analytically friction factor and heat transfer characteristics of turbulent air flowing through tubes with twisted strip swirl promoters. However, limited research works are identified related to heat transfer performance and friction factor characteristics through a tube with V-cut twisted tape inserts. In this research work, the effects of V-cut twisted tape inserts on heat transfer performance and friction factor characteristics for turbulent flow through a circular tube are evaluated.

2. Materials and Methodology

In this research work, V-cut twisted tape inserts of two different materials such as copper and stainless steel have been used. Inserts are made of as 800 mm length, 25 mm width and 1.5 mm thickness. V-cut twisted tape inserts of twisted ratio 5 and width and depth of 8 mm are used in this experiment.

Fig. 1: Twisted tape insert without any cut

Fig. 2: Twisted tape insert with V-cut

Fig. 3: V-shaped twisted tape insert of copper

Fig. 4: V-shaped twisted tape insert of stainless steel

In the experimental setup, test section is a smooth circular tube made of copper having 26.6 mm inside diameter, 30 mm outside diameter and 939.8 mm in long, of which length of 900 mm is used as the test section. Teflon tape is used for joining the tube and after that M- seal is used. Then the tube is wrapped with mica tape before wrapping with nichrome wire spirally wounded uniformly around the tube. Again mica glass fiber tape and heat insulating tape (Nittoflon tape) are used sequentially over the wrapped nichrome wire. The five K-type thermocouples are used for measuring outside surface temperature of tube in test section 15 cm apart from each other and started from 15 cm distance from entrance and finished before 15 cm from exit of heater length. Two thermometers are used at the inlet and outlet section of the tube for measuring the bulk temperatures. At the outlet section, the thermometer is placed in a mixing box. Pressure drop is measured at inlet and outlet of the test section by using manometer. Open loop system of water supply is used. The rate of flow is measured with the help of Rotameter in the travelling path of inlet water.

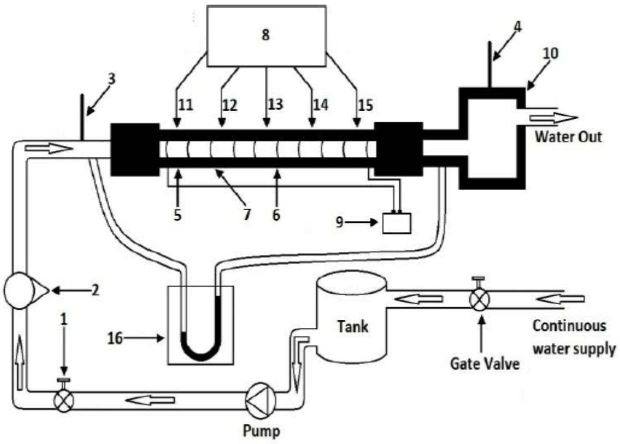

Fig. 5: Schematic diagram of experimental setup

1. Gate valve
2. Rotameter
3. Inlet thermometer
4. Outlet thermometer
5. Insulation
6. Test section (copper tube)
7. Nichrome-wire coil
8. Thermo-electric monitor
9. Voltage supply
10. Mixing box
11. Thermocouple 1
12. Thermocouple 2
13. Thermocouple 3
14. Thermocouple 4
15. Thermocouple 5
16. Manometer

Water was made to circulate throughout the system by a pump and different flow rate were maintained by regulating gate valve. Constant voltage was supplied to the heater by a voltage regulator and current was also supplied to the heater by a voltage regulator and current was also supplied to the thermocouple monitor. When the temperature in inlet and outlet thermometer and thermocouple monitor became steady, reading was taken for a given flow rate. Next reading was taken increasing flow rate in the same procedure. The flow rate was taken from 165 ml per sec and increased by 30 ml per sec up to 315 ml per sec for plain copper tube without insert and, with v-cut copper insert and, stainless steel twisted tape insert.

3. Mathematical Formulations

Heat transfer enhancement of water using twisted V-cut insert at circular tube is calculated by using the following equations,
Outer surface area is calculated from,

$$A_o = \pi d_o L \tag{1}$$

Where, d_o is outer surface diameter.
Inner surface area is calculated from,

$$A_s = \pi d_i L \tag{2}$$

Where, d_i is inner surface diameter.
Heat transfer rate is obtained from,

$$Q = m\, c_p (T_o - T_i) \tag{3}$$

Where, T_o is outlet temperature and T_i is inlet temperature.
Cross sectional area,

$$A_x = \frac{1}{4}\pi d_i^2 \tag{4}$$

Velocity,

$$V = \frac{m}{A_x} \tag{5}$$

Where, m is the flow rate in kg/sec and A_x is Cross sectional area.
Reynolds number,

$$Re_D = \frac{\rho V d_i}{\mu} \tag{6}$$

Nusselt number,

$$Nu = \frac{h d_i}{k} \tag{7}$$

Prandtl number,

$$P_r = \frac{\mu C_p}{k} \tag{8}$$

Where, μ and k at bulk temperature.

Bulk temperature,

$$T_b = \frac{T_O + T_i}{2} \tag{9}$$

Convective heat transfer coefficient is calculated from,

$$h = \frac{Q}{A(T_{w_i} - T_b)} \tag{10}$$

Where, T_{w_i} is tube inner surface temperature and T_b is bulk temperature.
Gnielinski equation,

$$Nu_D \frac{(f/8)(Re-1000)Pr}{1+12.7\left(\frac{f}{8}\right)^{\frac{1}{2}}(Pr^{2/3}-1)} \tag{11}$$

Where, $f = (0.790 \ln Re_D - 1.64)^{-2}$.
Flow area,

$$A_f = \frac{1}{4}\pi d_i 2 \tag{12}$$

Mean velocity,

$$u_{m} = \frac{Q}{\left(\frac{\pi}{4}\right) d_i^{\,2}} \tag{13}$$

The experimental friction coefficient,

$$f_{exp} = \frac{2\Delta P d_i^2}{\rho L {\mu_m}^2} \tag{14}$$

Convective heat transfer coefficient,

$$h = \frac{Nu * k}{d_i} \tag{15}$$

Heat flux,

$$q = \frac{Q}{A_s} \tag{16}$$

Where, $A_s = \pi d_i L$

Pressure difference,

$$\Delta p = \Delta h \rho g \times 13.6 \tag{17}$$

Outer surface temperature,

$$T_{WO} = \sum_{i=1}^{5} \frac{T_{wo,i}}{5} \tag{18}$$

Inner surface temperature,

$$T_{Wi} = T_{WO} - Q\,\frac{\ln(d0 - di)}{2\pi k_w L} \tag{19}$$

(19)

The rate of heat transfer by conduction is calculated,

$$Q = \frac{2\pi K L (T_{WO} - T_{Wi})}{\ln(r_o - r_i)} \tag{20}$$

$$\%\text{ of error} = \{(Nu_{exp} - Nu_{th})/Nu_{th}\} \times 100 \tag{21}$$

4. Results and Discussion

For smooth copper tube, experimental Nusselt number ranging from 34.65 to 69.25 and theoretical Nusselt numbers ranging from 37.9 to 64.7 are calculated using (Eq. 4.7 & 4.11), to compare the values and using (Eq. 4.21) errors are found within -8.57% to 7.03%. Reynolds numbers are calculated by using (Eq. 4.6) and it ranges from 5044.8 to 8713.8. Heat transfer rate, Q is obtained within 689.2 W to 1190.4 W using (Eq. 4.3). Heat flux, q is found ranging from 9163.8W/m^2 to 15828.3W/m^2 using (Eq. 4.16). Heat transfer co-efficient, h is calculated ranging from 807.7W/m^{2o}C to 1614W/m^{2o}C using (Eq. 4.10). Theoretical friction factor f_{th} is obtained within 0.039 to 0.033 using (Eq. 4.11) and experimental friction factor, f_{exp} 0.09 to 0.057 using (Eq. 4.14). Heat transfer enhancement efficiency is varied in the range of 0.7 to 0.89. For smooth copper tube inserted with V-cut twisted tape of stainless steel, results are found as experimental Nusselt number ranging from 110.9 to 250.9 and theoretical Nusselt number ranging from 37.9 to 64.7. Reynolds numbers are ranged from 5044.8 to 8713.8. Heat transfer rate, Q is obtained within 1378.4W to 2980.9W. Heat flux, q is found ranging from 18327.5 W/m^2 to 31656.6W/m^2. Heat transfer co-efficient, h is calculated from 2584.2W/m^{2o}C to 5847.6W/m^{2o}C. Theoretical friction factor f_{th} is obtained within 0.039 to 0.033 and experimental friction factor, f_{exp} 0.107 to 0.066. Heat transfer enhancement efficiency is varied in the range of 2.09 to 3.078. For smooth copper tube inserted with Copper V-cut twisted tape, results are found as experimental Nusselt number ranging from 121.1 to 331.8 and theoretical Nusselt numbers ranging from 37.9 to 64.7. Reynolds numbers are ranged from 5044.8 to 8713.8. Heat transfer rate, Q is obtained within 1378.4W to 2976.1W. Heat flux, q is found ranging from 18327.5W/m^2 to 39570.8W/m^2. Heat transfer co-efficient, h is calculated from 2823.1W/m^{2o}C to 7733.2W/m^{2o}C. Theoretical friction factor f_{th} is obtained within 0.039 to 0.033 and experimental friction factor, f_{exp} 0.116 to 0.069. Heat transfer enhancement efficiency is varied in the range of 2.22 to 4.01. Fig. 6 shows comparison of experimental and theoretical Nusselt number of plain tube with Reynolds number for data validation. Variation of data between experimental and theoretical Nusselt number is less than 20%. So, obtained data is valid for this experiment.

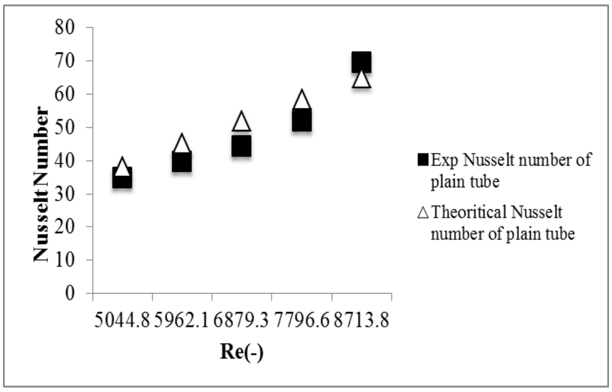

Fig. 6: Comparison of experimental and theoretical Nusselt number of plain tube with Reynolds number for data validation.

From fig. 7, it is noticed that Nusselt number is increased with Reynolds number. It is also noticeable that increase of Nusselt number with respect to Reynolds number in case of stainless steel insert is more than plain tube without insert. But in case of copper insert, the increment rate is higher than both plain tube and plain tube with stainless steel insert. Increment of Nusselt number of copper insert is averaged as 3.5 times and of stainless steel insert as 3.2 times more than plain tube without insert.

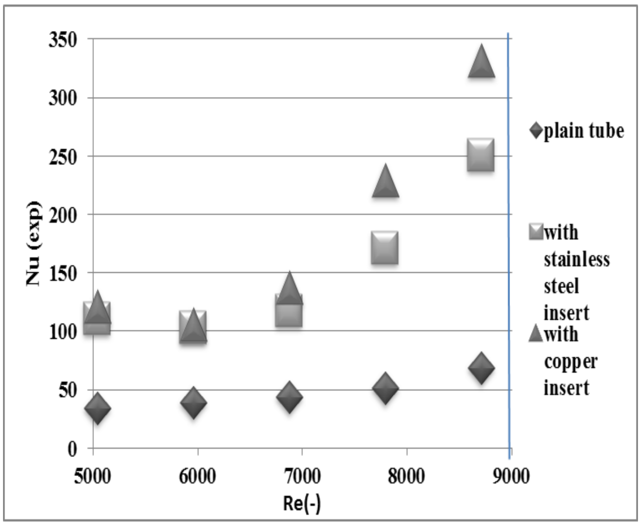

Fig. 7: Variation of Nusselt Number with Reynolds Number.

Fig. 8 shows that ratio of experimental Nusselt number inserted with stainless steel and experimental Nusselt of plain tube without insert is varied from about 3.2 to 3.8 and, 3.7 to 4.98 for plain tube inserted with copper and of plain tube without insert.

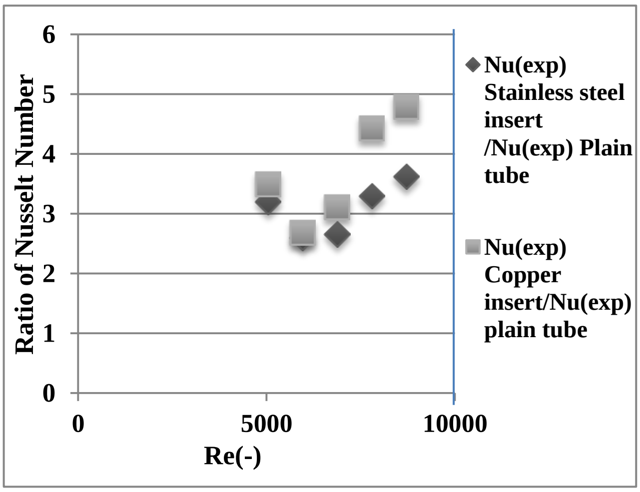

Fig. 8: Variation of ratio of exp. Nusselt number of two inserts and plain tube with Reynolds number.

From fig. 9, it is shown that friction factor is decreased with increase of Reynolds number. Friction factor decreases more in case of copper insert and stainless steel insert than plain tube without insert. Variation of convective heat transfer co-efficient with Reynolds number of plain tube inserted with V-shaped twisted tape made of stainless steel and copper material is shown in fig. 10. Convective heat transfer co-efficient is found as 3.2, 3.5 times more than plain smooth tube for stainless steel insert and copper insert.

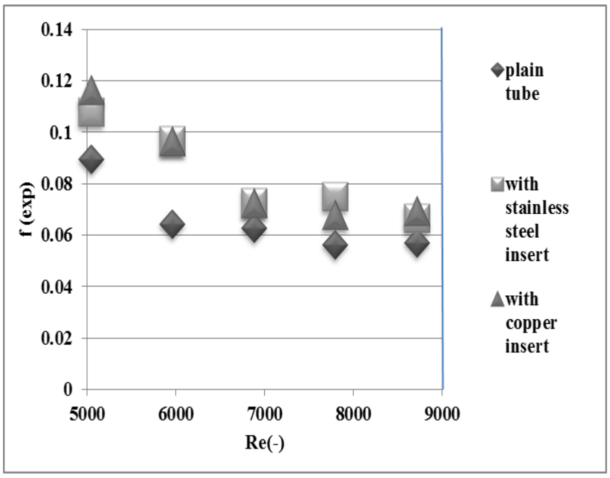

Fig. 9: Variation of experimental friction factor with Reynolds Number.

Rate of heat transfer with Reynolds number of plain tube inserted with V-shaped twisted tape made of stainless steel and copper material is shown in fig. 11. It is found that heat transfer rate is increased with Reynolds number. It is known to all that more disturbances in fluid flow causes more heat transfer. Increment of heat transfer of copper insert is as 2.52 times and of stainless steel insert as 2.5 times as plain tube without insert.

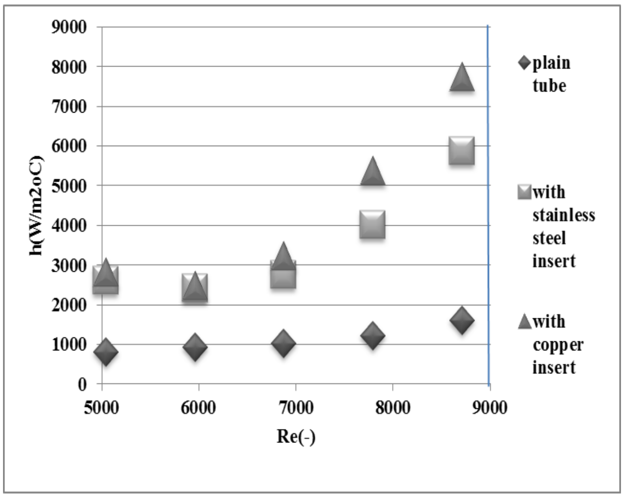

Fig. 10: Variation of convective heat transfer co-efficient with Reynolds Number.

From fig. 12, it can be easily reached into decision that heat transfer enhancement efficiency is increased more than plain tube in case of stainless steel insert and copper insert. Heat transfer enhancement efficiency ratio with Reynolds Number is shown in fig. 13. Heat transfer enhancement efficiency ratio of plain tube with stainless steel insert and plain tube without insert is varied from 3.1 to 3.5. Heat transfer enhancement efficiency ratio of plain tube with copper insert and plain tube without insert is varied from 3.3 to 4.5.

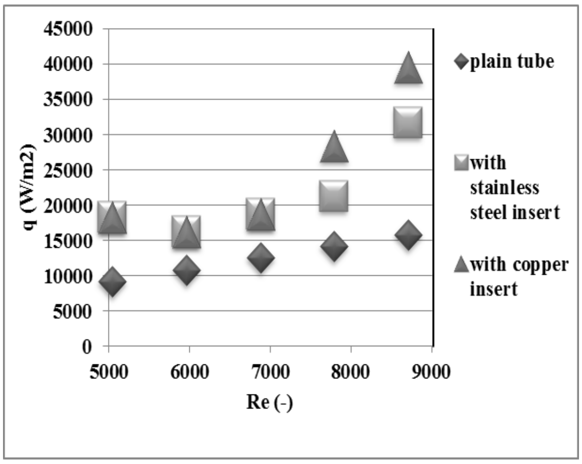

Fig. 11: Variation of heat flux with Reynolds Number.

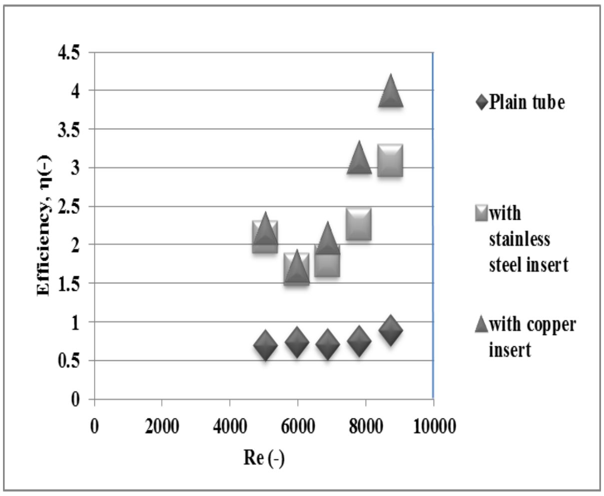

Fig. 12: Variation of heat transfer enhancement efficiency with Reynolds Number.

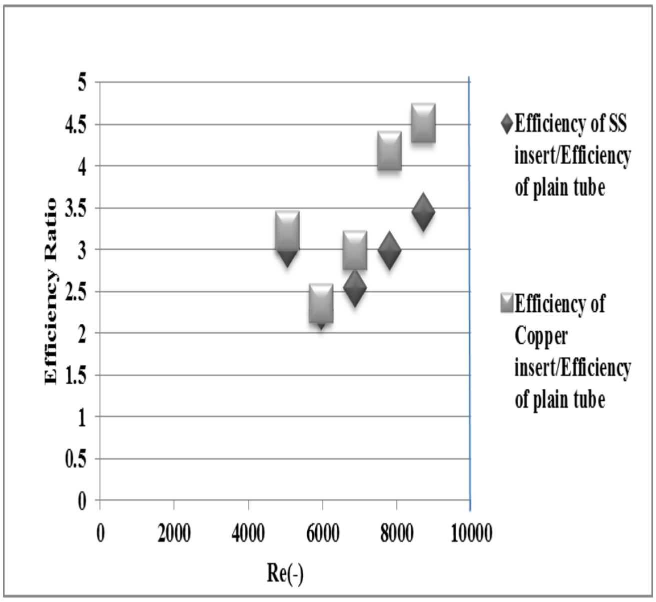

Fig. 13: Variation of efficiency ratio vs. Reynolds number.

5. Conclusions

Experimental investigation of friction factor, convective heat transfer co-efficient, heat transfer and, heat transfer enhancement efficiency of a circular plain tube fitted with V-shaped twisted tape inserts of copper and stainless steel material have been presented in this paper. Nusselt number and Reynolds number of the tube fitted with V-shaped twisted tape inserts are nakedly higher than the value of smooth plain tube. Increment of Nusselt number of copper insert is as 3.5 times and of stainless steel insert as 3.2 times as plain tube without insert. Along with that, convective heat transfer co-efficient is found as 3.2 times more than plain smooth tube for stainless steel insert and, 3.5 times more for copper insert As a result, heat transfer rate of tube fitted with inserts is more than that of tube without inserts. Results show that using V-shaped tape inserts of copper and stainless steel, heat transfer rate is increased about 2.5 times than plain tube without insert. Overall heat transfer enhancement efficiency is increased using V-shaped inserts. Heat transfer enhancement efficiency of a tube fitted with V-shaped twisted tape inserts of stainless steel and copper material is increased about 3.2 to 4.0 times than smooth tube. This type of heat transfer enhancements techniques can be used in various applications such as refrigeration, automotive, process industry, chemical industry, nuclear reactors, and solar water heaters etc. The author's next research step is to investigate heat transfer enhancement in a smooth plain tube fitted with V-shaped twisted tape insert for different spacing in turbulent flow.

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