EXPERIMENTAL INVESTIGATIONS ON HEAT TRANSFER AUGMENTATION USING ROTATING V-CUT TWISTED TAPE INSERTS IN A CIRCULAR TUBE

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ABSTRACT:
Experimental investigations are carried out using a rotating v-cut twisted tape insert in a circular tube to observe the effect on Nusselt number, pressure drop and heat transfer enhancement ratio. In this work, air is used as working fluid under constant heat flux condition. Twisted tape insert has twist ratio of 3.3. V-cut has 12 mm width and 6 mm depth. The speed with which twisted tape rotates varied from 0 to 300 RPM. The mass flow rate of fluid varied from 4 x 10^{-3} kg/s to 5.6 x 10^{-3} kg/s. Effect on Nusselt number and pressure drop are observed by varying both mass flow rate of air and rotational speed of tape and the obtained results are compared with those of plain tube and stationary insert. It is observed that, as mass flow rate increases, Nusselt number in the tube with rotating v-cut twisted tape insert was enhanced by 1.2 to 1.5 and 1.01 to 1.20 times respectively compared to the plain tube and stationary v-cut insert and pressure drop increased by 1.4 to 2.9 and 1.3 to 2.1 times respectively compared to that of plain tube and stationary v-cut insert. The heat transfer enhancement ratios were found to be in the range of 1.8 to 2.1. The obtained results show that both Nusselt number and pressure drop increase as mass flow rate and RPM of tape increases.

Keywords: Rotating Twisted tape inserts, RPM, heat transfer, pressure drop and enhancement.

1. INTRODUCTION:

Insert technology is the widely used technique in heat exchanger systems in order to enhance the heat transfer rate. After conducting so many experiments with different geometries and different profiles on twisted tape inserts, providing cuts on twisted tape inserts has become the recent interest of researchers to enhance the heat transfer rate. This is due to the fact that these cuts destruct the growth of boundary layer developed near the pipe boundary by creating the turbulence. It's a well-known fact that, twisted tape provides high turbulence by generating swirl flow (secondary flow). This swirl flow causes proper mixing of fluid particles inside the tube. In order to create more swirling and turbulence, twisted tape was rotated by connecting to the motor with some arrangements. It is really a novel concept on doing research with rotating twisted tape insert in a plain tube.

Researchers did enormous research by placing twisted tape insert in a plain tube in stationary condition. Al Amin et al. [1] observed the effect on heat transfer rate and heat enhancement efficiency by using a rotating twisted tape insert. They conducted the experiments by varying the volume flow rate from 8 to 16 liters per minute and the speed with which tape rotates varied from 0 to 600 RPM. They found that, higher heat transfer rate can be obtained at high RPM of twisted tape and flow rate of flowing water. Murgesan et al. [2] experimentally investigated the heat transfer, friction factor and thermal performance factor characteristics in a circular tube with v-cut twist tape insert (VTT). Their results proved that mean Nusselt number and mean friction factor increase with increasing depth ratio and decreasing twist ratio. For all the Reynolds numbers, heat transfer rate was much influenced by depth ratio than the width ratio of VTT. Naga Sarada et al. [3] experimentally investigated the heat transfer co-efficient and pressure drop in a horizontal tube by using the varying width twisted tape inserts (VWTT). They found that enhancement of heat transfer with twisted tape insert (TTI) as compared to plain tube varied from 36 to 48% for full width and 33 to 39% for reduced width inserts. The overall enhancement ratio of the tubes with full width TTI is 1.62 and 1.39 for reduced width TTI. C. Zhang et al. [4] presented a comparative review of self-rotating and stationary twisted tape inserts in a heat exchanger. They had covered all the topics from the development of self-rotating twisted tape and their effect on enhancement efficiency to all kinds of stationary twisted tapes with varying lengths, fins, winglets, slots, holes, cuts, helical and screw tapes and their effect on enhancement efficiency.

Smith Eiamsa-ard, Pongjet Promvonge [5] did experiments using serrated twisted tape insert (STT) to find the effect on heat transfer and pressure loss in a constant heat flux tube. They observed that, the mean heat transfer rate of tube fitted with STT increases about 72.2% and 27% in comparison to plain tube and the twisted tape inserted tube respectively. In addition to that, mean Nusselt number increased with increase in serration depth ratio and decrease in serration width ratio. Salam B et al. [6] conducted experiments for measuring heat transfer coefficient and friction factor for turbulent flow in a circular tube with rectangular cut twisted tape insert (RTT). An average of 68% enhancement of heat flux was observed for tube with insert than that of smooth tube. Experimental friction factor value found to be 39% to 80% higher than smooth tube value. S. Eiamsa-ard et al. [7] experimentally investigated the heat transfer parameters in a tube fitted with delta – winglet twisted tape insert (DWT). They have observed that, oblique DWT is more effective turbulator than straight DWT. This is due to the fact that the thermal performance factor in a tube with O-DWT is more than S-DWT. Nusselt number, friction factor and thermal performance factor in a tube with the O-DWT are respectively 1.04-1.64, 1.09-1.95 and 1.05-1.13 times of those in the tube with twisted tape insert. P Seemawute, S Eiamsa-ard [8] experimentally found the effect of peripherally cut twisted tape insert with an alternate axis (PT-A) on fluid flow, heat transfer enhancement characteristics in a circular tube. Heat transfer rate in the tube fitted with the twisted tape, PT and PT-A are 57%, 102% and 184% respectively more than the plain tube. Combined action of PT-A is responsible for obtaining more heat transfer rate.

Pawan A et al. [9] experimentally determined the influence of the semi-circular cut twisted tape insert (STT) on pressure drop, Nusselt number and friction factor. They have observed that comparing with smooth tube and tube with plain twisted tape, Nusselt number and friction factor is more for STT but for increase in cut radius, friction factor reduces. Sami D. Salaman et al [10, 11] did CFD analysis of heat transfer and friction characteristics in a circular tube fitted with Quadrant cut and Elliptic cut twisted tape insert. They could achieve higher heat transfer rate and friction factor for Quadrant and Elliptic cut TTI compared to the plain tube and other twisted tapes. They also did CFD study on heat transfer enhancement of laminar Nano fluid flow in a circular tube fitted with Parabolic cut twisted tape. Chinaruk Thianpong et al [12] experimentally studied the heat transfer and friction factor characteristics in a test tube equipped with dual twisted tape element in tandem for several twist ratio (TR) and space ratios (SR). They found that, heat transfer rate for the dual tape is increased from 12% to 19% in comparison to single one and the increase in heat transfer rate over the plain tube is about 146%, 135% and 128% for TR 3, 4 and 5 respectively. The Nusselt number for the tube with dual TTI in tandem at SR 0, 0.75, 1.5 and 2.25 are about 146%, 140%, 137% and 132% over the plain tube respectively. The friction factor for dual twisted tape increased up to 23% over the single twisted tape.

Woei chang et al [13] did a comparative study of heat transfer and pressure drop in three tubes fitted with single, twin and triple twisted tape. The local Nusselt number in the tubes fitted with single, twin and triple twisted tape were respectively 1.5-2.3, 1.98-2.8 and 2.86-3.76 times of the Dittus - Boelter correlation for the plain tube. The Reynolds number and friction factor values increase when the number of twisted tapes placed in the tube increase. Tubes fitted with twin and triple twisted tape could offer the higher values of heat transfer augmentation with the similar levels of performance factor as those found in the tube fitted with single twisted tape.

2.1 EXPRIMENTAL SET UP:

Blower is fitted to the circular pipe consisting of the test section having 27.5 mm diameter and 3.2 mm thickness as shown in figure 1. The piping system contains control valve and orifice meter (diameter = 14 mm, coefficient of discharge = 0.64). The former one is used to control the air flow rate and the latter is used to find the volume flow rate of air flowing through the pipe. The difference in water level in the two limbs of water manometer is used to find the volume flow rate of air (m^3/s) flow in the tube. Nicrome bend heater is placed in the test section up to a length of 40 cm. The input to heater is given by rotating dimmer start and supply power is controlled by voltmeter (0 – 220 Volts) and ammeter (0 - 10 Amps). To measure the temperatures, six number of J type thermocouples with an accuracy of ±2% are used in the equipment. Out of six, two are placed at the entrance (T_1) and exit (T_6) of the test section in order to measure the temperature of air entering and leaving the test section respectively. Remaining four thermocouples (T_2, T_3, T_4, T_5) are located in the heating zone by maintaining 10 cm distance between the thermocouples. Temperature indicators are used to show the temperatures sensed by the thermocouples. Two pressure gauges(P_1, P_2) are provided to measure the pressure drop across the test section. Figure.2 shows the v- cut twisted tape insert which is made up of aluminum. Short length cylindrical rod and bearing arrangement is attached to the both ends of the tape in order to support and facilitate the free rotation of tape in the tube. This cylindrical rod is fixed into the chuck provided to the motor shaft.

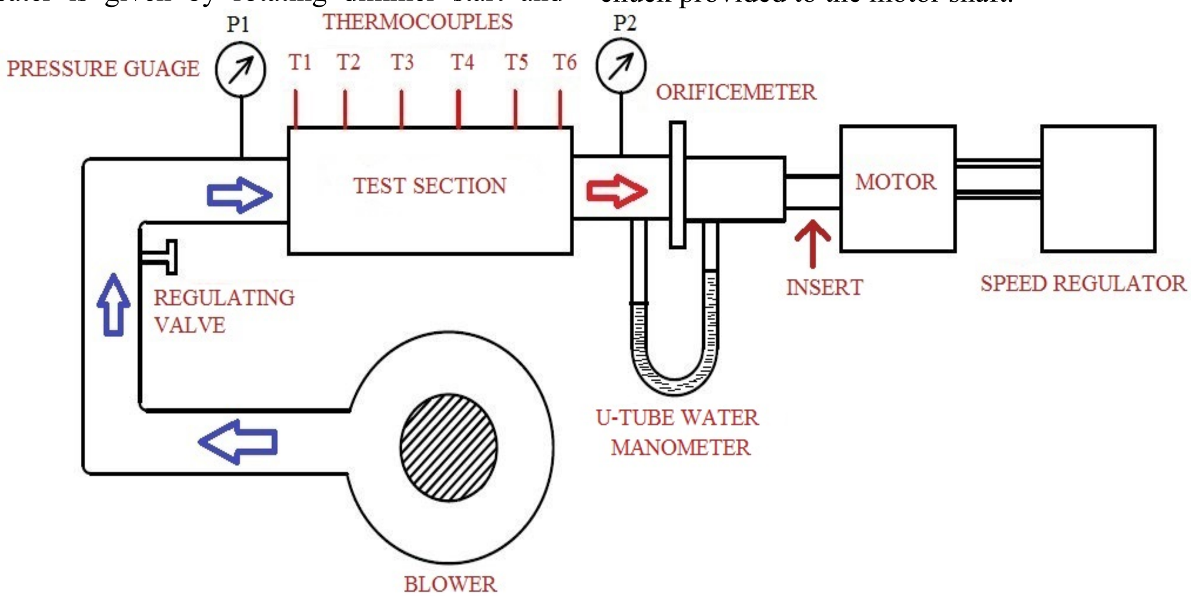

Fig.1. Schematic diagram of experimental setup

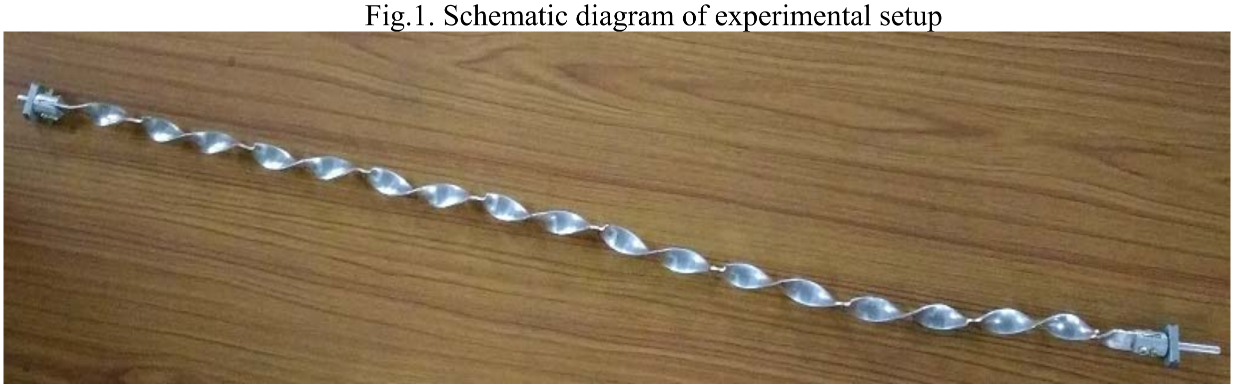

Fig.2. Photograph of v-cut twisted tape inserts

2.2 EXPERIMENTAL UNCERTAINTY:

Before conducting the experiment by placing insert in the tube heat transfer characteristics are calculated for plain tube for different flow rates of air. Figure.3 shows the deviation between Nusselt number obtained from experimental condition and Nusselt number obtained from theoretical condition (using Dittus – Boelter correlation). The experimental Nusselt number is always less than theoretical Nusselt number. This is may be due to that fact that all kinds of heat transfer losses (conduction, convection, radiation) take place in experimental condition. It is observed that, 11.5 to 13% of uncertainty is found to be present in Nu. Figure.4 shows the variation of pressure drop with mass flow rate of air for the plain tube. The graph shows that the pressure drops keep on increasing as the mass flow rate of air increases.

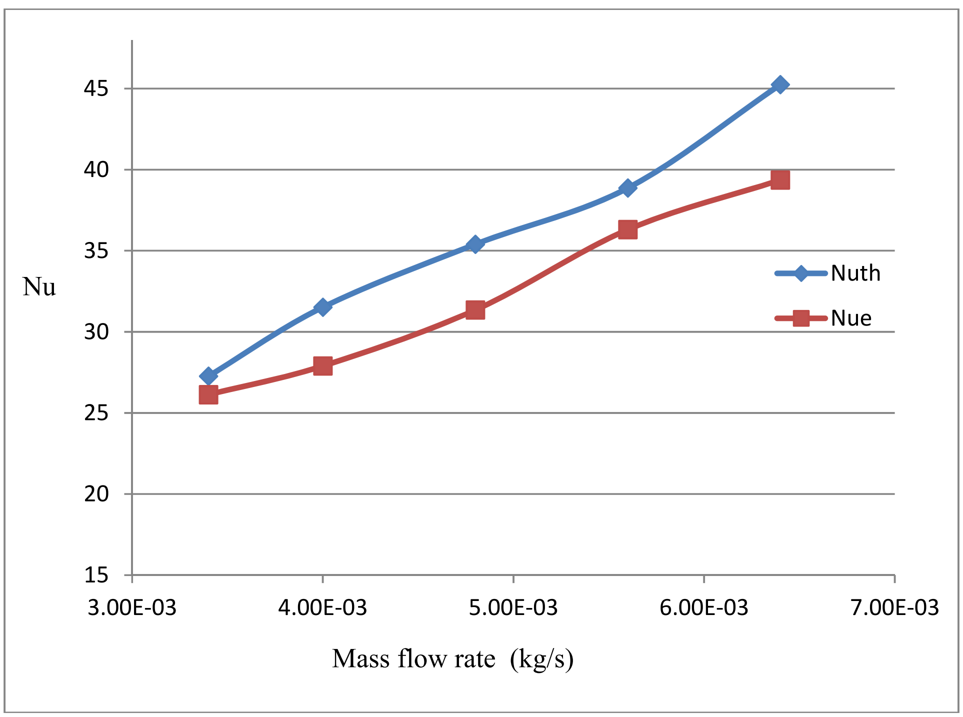

Fig.3. Validation of Nusselt number for plain tube

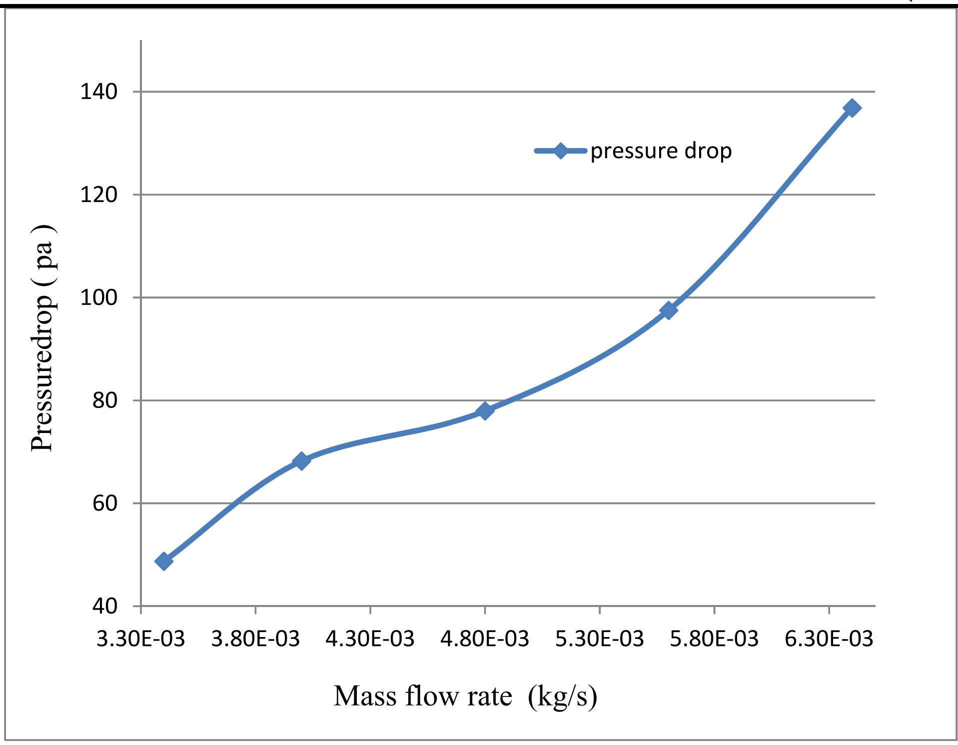

Fig.4. Pressure drop vs Mass flow rate for plain tube

3. HEAT TRANSFER AND PRESSURE DROP CALCULATIONS:

Dittus – Boelter correlation for plain tube

$$Nu_{th} = 0.023 \text{ x } \mathrm{Re}^{0.8} \text{ x } Pr^{0.4} = {(h_{th}\, D)}/{K} \quad (1)$$

(While calculating Nu for tape inserts, D_h is used instead of D)

$$\Delta P = \rho_{H_2o}\, g\, y_m = {(\rho_a f_{exp} L\, u^2\,)}/{2\,D} \quad (2)$$

$$\eta = ({Nu}/{Nu_p}) \;/\; ({f}/{f_p})^{\frac{1}{3}} = ({h}/{h_p})_{\;pp} \quad (3)$$

4. RESULTS AND DISCUSSION:

The variation of Nusselt number (Nu) with mass flow rate is shown in figure 5. It's observed that Nusselt number values for stationary v–cut twisted tape insert are higher than the plain tube. This may be due to the swirl flow generated by twisted tape insert. Nusselt number values for rotating insert are more than stationary insert because the rotation of tape exaggerates the turbulence and swirl flow in the tube. It's is also observed that Nusselt number values keep on increasing as RPM of tape increases. As mass flow rate increases, Nusselt number for plain tube varied from 27.9 to 36.3 and for stationary insert varied from 38.2 to 45.3 and for rotating insert Nusselt number varied from 39 to 52.5. From all the observations, it's proved that as mass flow rate increases, Nusselt number increases and the maximum value of Nusselt number 52.52 obtained for the insert which is rotating at 300 RPM at a mass flow rate of 5.6 x 10^{-3} kg/s.

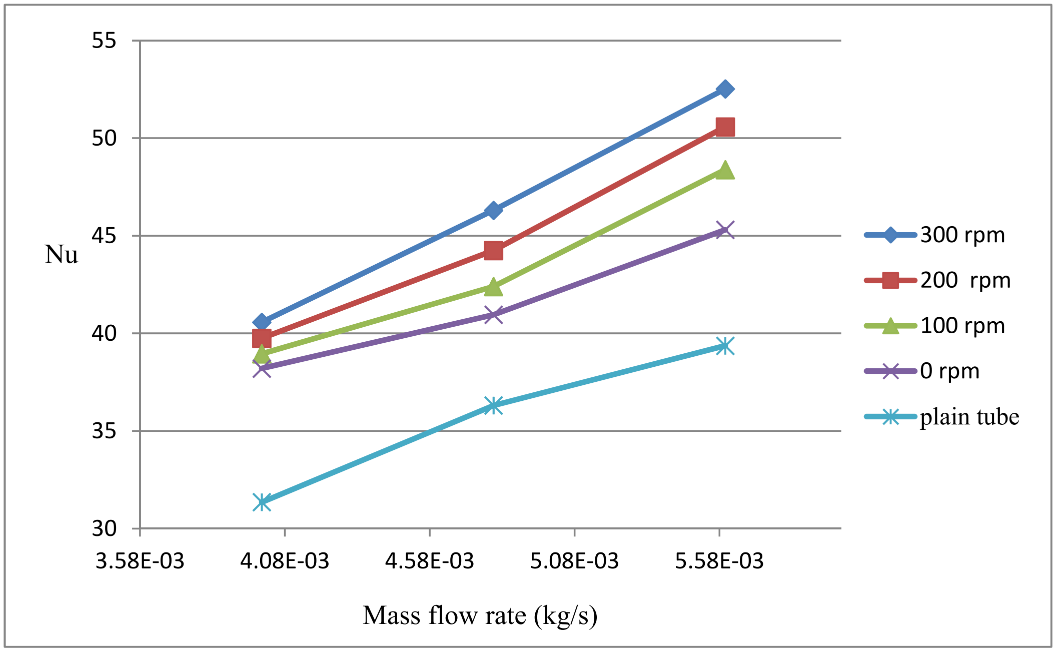

Fig. 5 Nu vs Mass flow rate

The variation of pressure drop with mass flow rate is shown in figure 6. The variation of pressure drop is the same as that of Nu. Insert provides restriction to the free flow of air by reducing the effective diameter and by creating turbulence. Due to this, pressure drop values for stationary v-cut twisted tape (varied from 78 pa to 136 pa) are more than the plain tube values (varied from 68 pa to 97 pa). Due to higher induced turbulences, the pressure drop values for rotating insert (varied from 97 pa to 283 pa) are more than the stationary insert. From all the observations it is noted that, as mass flow rate increases, pressure drop increases and the max value of 283 pa pressure drop is obtained for the insert which is rotating at 300 RPM at a mass flow rate of 5.6 x 10^{-3} kg/s.

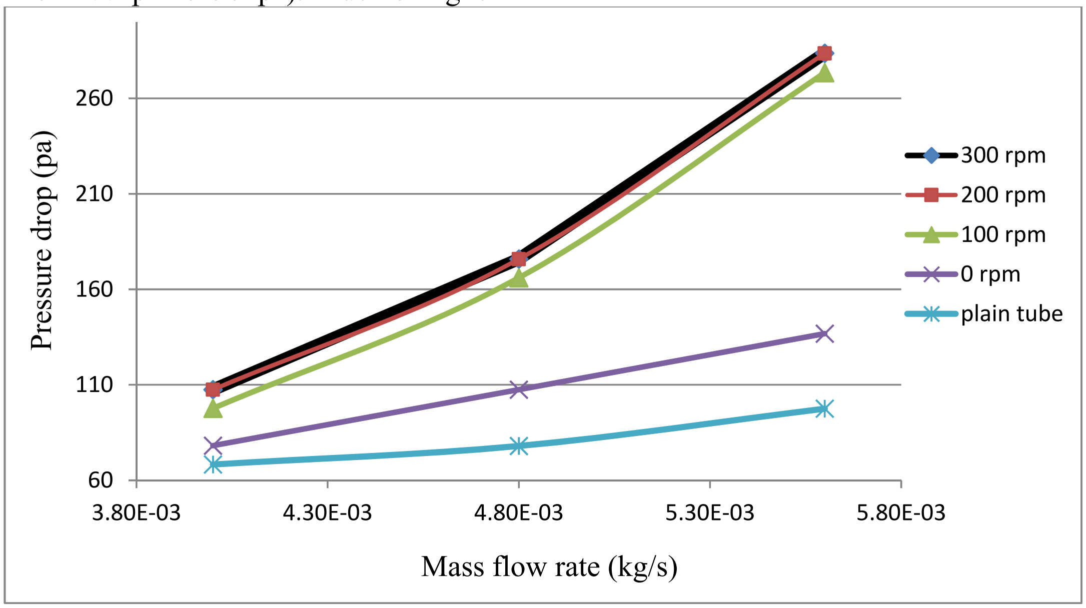

Fig. 6 Pressure drop vs Mass flow rate

HEAT TRANSFER ENHANCEMENT RATIO:

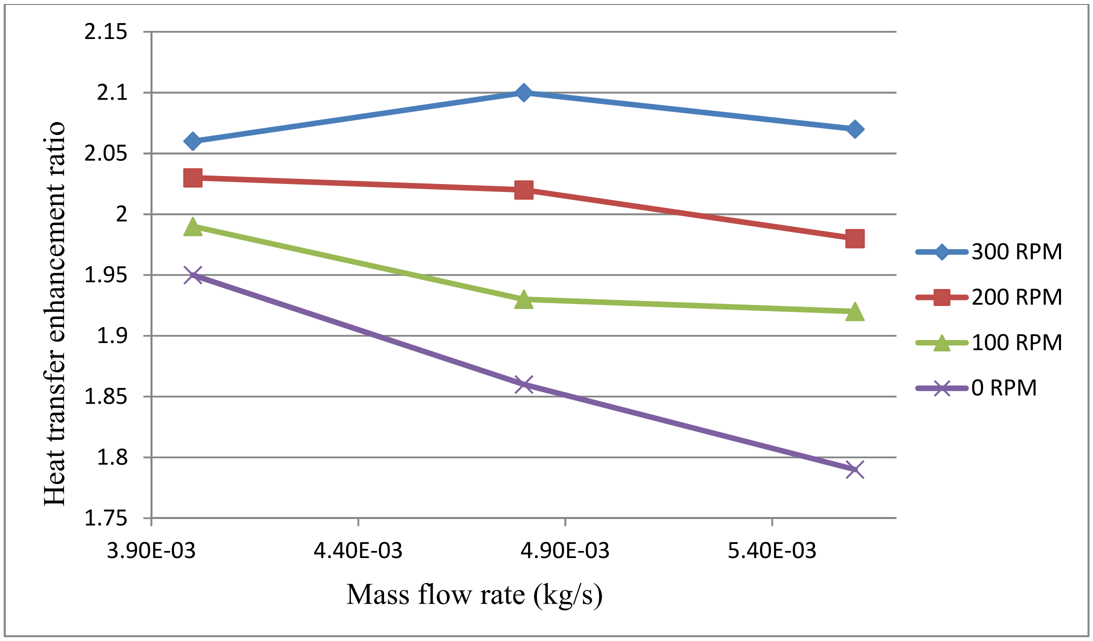

Fig. 7 Heat transfer enhancement ratio vs Mass flow rate

Variation of heat transfer enhancement ratio (η) with mass flow rate at various speeds of v-cut twisted tape insert is shown in figure 7. Heat transfer enhancement ratio is a ratio between heat transfer coefficient obtained with insert and without insert. Heat transfer enhancement ratio values obtained for all the situations are above 1.7. It is also proved that heat transfer enhancement ratio values obtained for rotating insert are higher than stationary insert and the entire values lie between 1.79 and 2.1. The minimum value of heat transfer enhancement ratio is 1.79 and it is obtained at a mass flow rate of 5.6 x 10^{-3} kg/s at 300 RPM. The maximum value of heat transfer enhancement ratio is 2.1 and it is obtained at a mass flow rate of 4.8 x 10^{-3} kg/s at 300 RPM. At a particular mass flow rate of air, heat transfer enhancement ratio values keep on increasing as the speed of v-cut twisted tape increases. For a particular speed of tape, heat transfer enhancement ratio decreases slightly as mass flow rate of air increases.

5. CONCLUSION:

In this paper, experimental investigations are carried out to study the heat transfer characteristics such as Nusselt number, pressure drop and heat transfer enhancement ratio using v-cut twisted tape insert under stationary and rotating conditions by varying the mass flow rate and rotational speed of insert.

The conclusions can be drawn as follows:

1. For the plain tube, both Nusselt number and pressure drop increase as the mass flow rate increases.

2. In the range of mass flow rates investigated, Nusselt number values for stationary and rotating twisted tape inserts are higher than those of the plain tube values. Nusselt number in the tube with rotating v-cut twisted tape insert were enhanced by 1.2 to 1.5 and 1.01 to 1.20 times compared to the plain tube and stationary v-cut insert respectively. The maximum value of Nusselt number 52.52 was obtained for the insert which is rotating at 300 RPM at a mass flow rate of 5.6 x 10^{-3} kg/s.
3. With the increase in mass flow rate of air, pressure drop also increased for both rotating and stationary inserts due to turbulence intensities. Tube with rotating v-cut twisted tape insert, pressure drop increased by 1.4 to 2.9 and 1.3 to 2.1 times compared to that of plain tube and stationary v-cut insert respectively. The max value of 283 pa pressure drop obtained for the insert which is rotating at 300 RPM at a mass flow rate of 5.6 x 10^{-3} kg/s.
4. Heat transfer enhancement ratio values obtained for rotating insert are higher than stationary insert and all the values lie between 1.79 and 2.1. The maximum value

of heat transfer enhancement ratio is 2.1 and it is obtained at a mass flow rate of 4.8 x 10^{-3} kg/s at 300 RPM.

6. NOMENCLATURE

Full forms:

RPM revolutions per minute
TTI Twisted tape insert
PTT Plain twisted tape insert
VWTT Varying width twisted tape insert
VTT V- cut twisted tape insert
S-TT Semi-circular cut twisted tape insert
O-DWT Oblique delta-winglet twisted tape insert
S-DWT Straight delta-winglet twisted tape insert
STT Serrated twisted tape insert
RTT Rectangular cut twisted tape insert
PT-A Peripherally-cut twisted tape with alternate axis insert
PT Peripherally-cut twisted tape insert
Nu Nusselt number
Nu_{th} theoretical Nusselt number
Nu_e experimental Nusselt number
Nu_p Nusselt number for the plain tube
Pr Prandtl number
Re Reynolds number

Symbols:

ΔP Pressure drop (pa)
η heat transfer enhancement ratio
h heat transfer co-efficient(W / m^2 K)
h_{th} theoretical heat transfer co-efficient (W / m^2 K)
h_p heat transfer co-efficient for the plain tube (W / m^2 K)
y_m manometer reading (m)
f friction factor
f_p friction factor for the plain tube
D diameter of the inner pipe (m)
D_h hydraulic diameter (m)
k Thermal conductivity(W / m K)
pp constant pumping power

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