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Research Article

Heat Transfer Enhancement in Tube using Modified Twisted Tape Inserts

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Abstract: The aim of the present experimental investigations is to increase of turbulent flow heat transfer in a horizontal circular tube using six types of twisted tapes in which a total length relative to the diameter ratio is 24 and Reynolds number values runs from 4500 to 23500. Take twisted tapes amendment: (normal, regularly spaced, triangular-cut, rectangular-cut, semicircular-cut and drilled) twisted tape. In this study, the development of mutual relations between the Nusselt number, friction factor and enhance the efficiency of each type of inclusion twisted stripe have been taken into account. The results showed that the heat transfer process in tube with twisted ribbon provider drilled more efficient than other forms of twisted tape because the strong spiral flow along the tube length leads to more disturbance of the entire flow field.

Keywords: Heat transfer, tube, twisted tape

INTRODUCTION

Increase heat convey techniques suggest a different way new is used to augmet the heat transfer rate without greatly affect the overall performance of the system. The use of these techniques in heat exchangers, as well as,some applications of the heat exchanger is in the process industries, thermal power plant, air-conditioning equipment and refrigerators and radar for spacecraft, automotive and so on in the past decade and noted many of the studies on passive techniques to increase heat convey it requires an increase in the heat transfer of many engineering applications, Rising energy and materials cost led to increased efforts to produce devices heat exchangers more efficient. Some of the heat exchangers in require miniaturization specific applications, such as space applications by enhancing heat transfer. On the other hand, in the heat exchangers used in nautical applications and in industries chemical, the resistance to heat transfer increases as a heat exchanger becomes older due to fouling or scaling. in the case of low thermal conductivity of fluid passing through heat exchangers, there is a need to augmet the rate of heat transfer, it can improve this rate by introducing a disturbance in the flow of fluids since there are several techniques can be used as required to fulfill heat transfer rate in an existent heat exchanger at an economic pumping power, such as the twisted stripe inserts, wire coil inserts, brush inserts, mesh inserts, tape inserts... etc.

Lots of researchers studied the process of enhancing heat transfer inside tube provider with twisted ribbons under different forms, corridors, working liquids and the type of flow. Saha *et al*. (2001) used regularly spaced twisted tape element insert to study the heat transfer enhancement "HTE" and pressure drop characteristics in the tube. From the result, it is observed that "Pinching" of tape rather than in connecting the tape element with rods is better proposition from thermohydraulic. Eiamsa-ard *et al*. (2006) which presented the experience on the "HTE" and friction properties in a double tube heat exchanger provider with regularly twisted tape drawers and by comparing the result with a normal tube, it is clear that increasing the heat transfer coefficient with the increase in the pitch ratio. Chang *et al*. (2007) studied compound "HTE" in a tube provider with dentate twisted stripe DTS, through the results of the experiment appeared that friction factor and heat transfer rate is relatively high than peripheral twisted stripe PTS:

> Chang *et al*. (2008) *"examined the turbulent heat transfer in a swinging tube with a DTS insert under seagoing conditions. This swirl tube swings about two orthogonal axes under single and compound rolling and pitching oscillations. Synergistic effects of compound rolling and pitching oscillations with either harmonic or non- harmonic rhythms improve heat transfer performances."*

Promvonge (2008) pointed that the presence of the coil wire along with twisted straps inside the circular tube leads to a manifold increase in the heat transfer on the utilize of coil wire twisted ribbon alone, especially at smaller twist and the ratio of the coil pitch under the same conditions. Murugesan *et al*. (2009) investigated the heat transfer and friction characteristics of trapezoidal-cut twisted tape. It is revealed, that for this above tape there was a considerable augmentation in heat transfer coefficient and friction factor. Eiamsa-ard *et al*. (2009a, 2009b) have studied the process of heat transfer in a round tube with short- length of the tape twisted inserted and noted the result that the existence of a tube with short-length of the tape twisted inserted higher returns in the heat transfer rate and they also mathematically investigated the vortex flux in the tube caused by loose -suitable quirky bar insertion. Influence of the clearance ratio on 'Nu', "f &'g' are numerically investigated for twisted bar at two different evolution ratios. Eiamsa-ard *et al*. (2010a) have made a comparative investigation of enhanced heat transfer and pressure loss by insertion of solitary quirky bar, full-length double quirky bar and regularly-spaced double quirky bar as in the vortex generators. The result shows that all double quirky bar with a free spacing yield lower "HTE" compared with a full-length double quirky bar. Eiamsa-ard *et al*. (2010a) studied the effects of multiple quirky bar swirl generators on the heat transfer and friction properties of fluid in a rectangular channel. the experience shows that the channel with the 'X' and "S" provides highest rate of heat transfer and pressure loss of those who have a larger 'X' and free spacing ratio in a situation similar process. Eiamsa-ard *et al*. (2010c) studied the effects on "Nu", "f" and "g" of twin-counter/ co-twisted tape CT/CoT fitted in tube. The (CTv) are utilized as counter-vortex flow generators while (CoTv) are utilized as co -vortex flow generators. From the results also show that the CTv are more effective than the CoTv for "HTE" Eiamsa-ard *et al*. (2010b) offered study of turbulent heat transfer and flow friction characteristics in a circular tube provided with clockwise and counter-clockwise C-CC quirky bar. The results showed that the "HTE" of the C-CC quirkly bar increases with a low proportion of the twist and increasing of the twist angle values. Seemawute and Eiamsa-ard (2010) study the impact of peripheral cut- alternate axis twisted tape PT-A on the fluid flux and "HTE" characteristic. It is revealed that the PT-A offer the maximum thermal performance at constant pumping power. Eiamsa-ard *et al*. (2010c) investigated "HTE','f' and 'g' characteristics in a tube fitted with a delta airfoil quirky bar "DAB". Influences of the oblique O-DAB and straight S-DAB arrangements are also described. By comparing the thermic performance factor in the tube with each of the O-DAB and S-DAB, the results show that the performance of the first is higher than the second. Eiamsa-ard *et al*. (2010d) Investigated the effects of peripheral twisted stripe PTS inclusion on the "HTE", "f" and "g" characteristics in a round tube. From the result, it is revealed that "Nu", "f" and 'g' are found tobe increased with "DR" and "WR". Wang *et al*. (2011) anatomized the Computational Fluid Dynamics "(CFD)" modeling for the optimization of regularly spaced short -length quirky ribbon in a round tube. The configuration parameters were given by the 'S', 'X' and the angle of the evolution, from results show that the mean heat transfer and flux resistance increase with an increase in the angle of evolution. Guo *et al*. (2011) submitted numeral study on "HTE" and friction characteristics of laminar flow in a tube with stumpy - width and Center cleared quirky bar CCB, it was shown that CCB is good technique in laminar flow and the heat transfer can be enhanced with a change in central clearance ratio. Wongcharee and Eiamsa-ard (2011) experimentally investigated the promotion of heat transfer, "f" and "g" properties of the CUO/water nanofluid and modified "TA". Nanofluid use with alternative axis twisted tape "TA" provides considerably higher "Nu" and "g" than that of nanofluid with the PTS. Murugesan *et al*. (2011) studied the heat transfer characteristics of tube fitted with V-cut twisted tape VTT. The obtained results show that the mean Nusselt number and the mean "f" in the tube with "VTT" increases with in decrease 'X'.

And it displays the current work of new forms of twisted tape as follows: rectangular twisted ribbon cutting, semi-circular cut twisted stripe and drilled twisted tape, in addition to the normal twisted ribbon and regularly spaced twisted tape; to obtain turbulent flow data under carefully controlled conditions and from these data develop the first experimentally base correlation for predicting the associated heat transfer coefficients.

Experimental apparatus: The experimental apparatus consists of test section, calming section and blower, as shown in Fig. 1. The calming section tube contains an orifice plate (British standard unit) and a manometer to gauge the flowing air through tube which is adjusted by using control valve. Nicele-chrome bend heater is coiled uniformly along 1200mm of the tube test section length to obtain the required heat flux. Seventeen thermocouples are fixed along the aluminum tube wall and two thermocouples are located in air stream, the firstly at inlet and the secondly at exit in test section to gauge the flowing air temperature. The heating tube at entrance and calming tube are connected by Teflon ring to reduce the thermal losses. The pressure difference is measured by manometer through the two taps placed at inlet and outlet of test section. The inside radius of the heating tube is (50 mm) with (2.5 mm) as thickness. Heat input can be regulated by changing the voltage and current of heater using transformor. Figure 2 shows clearly by sketching and dimensions six types (shapes) of twisted tape inserted inside test section tube used in the present study as follows: normal twisted tape, regularly spaced twisted tape, triangular-cut twisted tape, rectangular-cut twisted tape, semicircular-cut twisted tape and drilled twisted tape. All these twisted tapes are made up of aluminum strips of thickness 2 mm and width 50 mm:

"*The twist ratio (TR) is defined by ratio between one length of twist (or pitch length s) to inner diameter of tube (d)*".

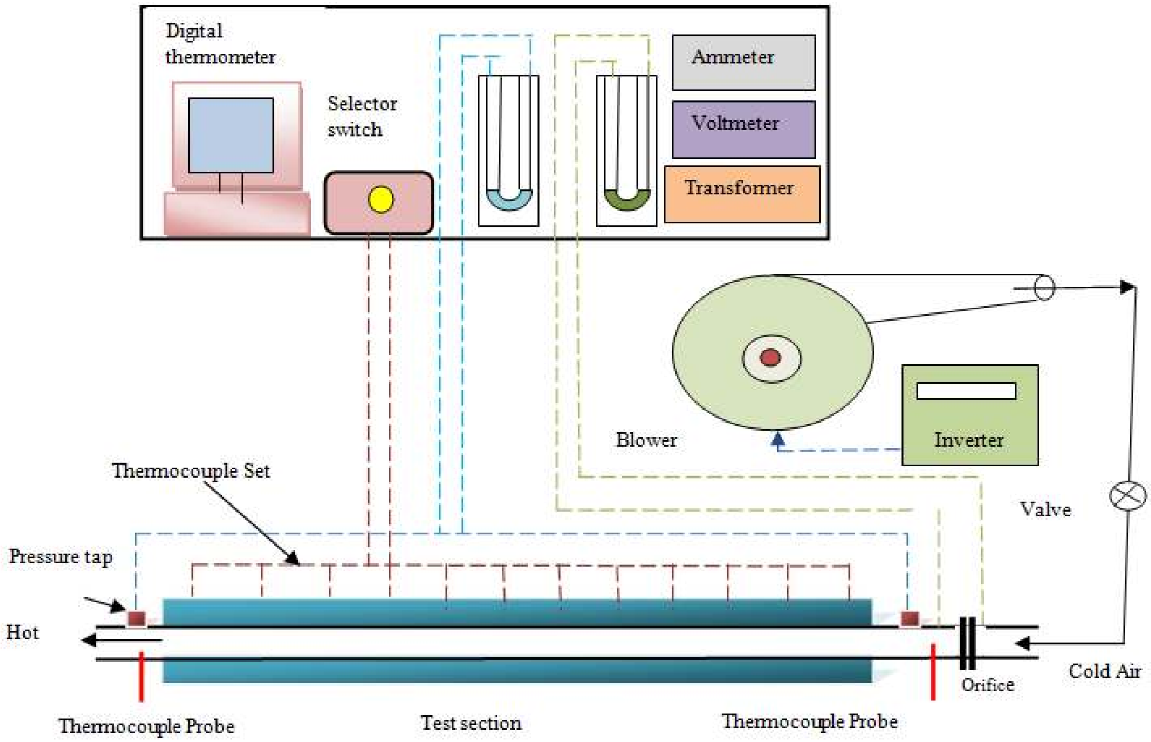
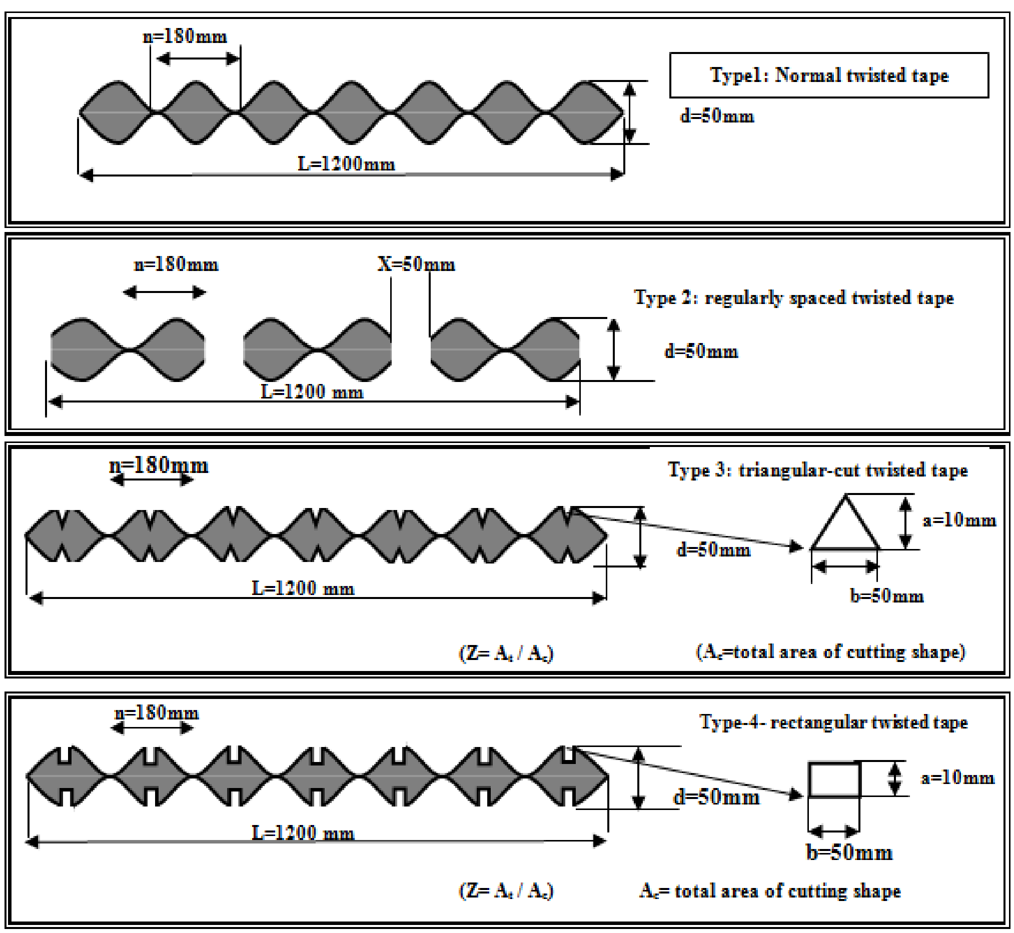


Fig. 1: Schematic diagram of the experimental setup



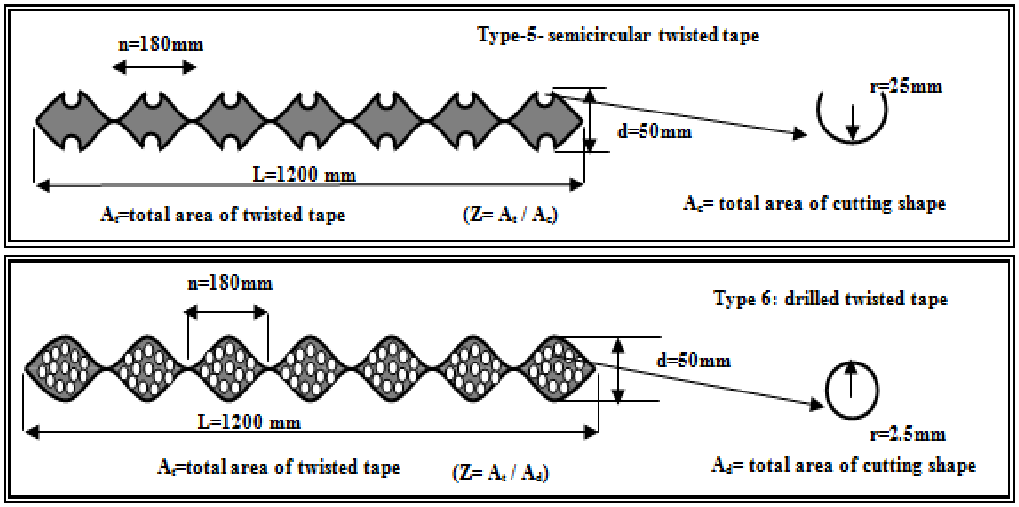


Fig. 2: Types of twisted tape used in the present work

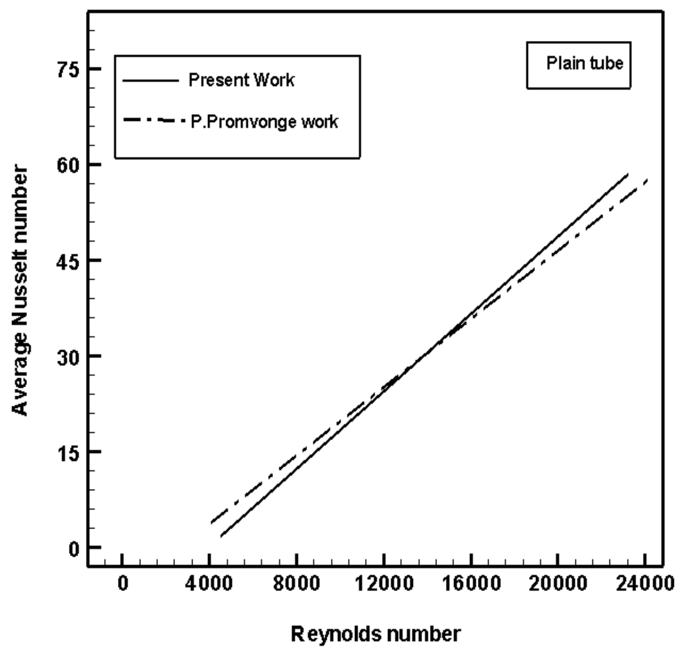


Fig. 3: Data verification of Nusselt number for plain tube

Triangular, rectangular and the semicircular-cut taken alternately on both the top and bottom of the tape to improve fluid mixing near the wall of the test section. Calculated fluid properties, on average, between the inlet and outlet bulk temperature.

Calculations of heat transfer: To calculate the average heat flux from the tube wall to the air is determined as follows:

$$Q = hA(T_w-T_b)+\sigma\varepsilon A(T_w^4-T_b^4) \quad (1)$$

$$Q = m_aC_p(T_{out}-T_{in}) \quad (2)$$

Hence,

$$H = [m_aC_p(T_{out}-T_{in})-\sigma\varepsilon A(T_w^4-T_b^4)]/A(T_w-T_b) \quad (3)$$

$$T_b = (T_{in}+T_{out})/2 \quad (4)$$

The time required to reach the steady state is approximately 3-4 h for each run.

The Nusselt number can be calculated using Eq. (3) as follows:

$$Nu = hd/K \quad (5)$$

The friction factor f is calculated from the following equation:

$$f = \Delta p / (4L/d)(\rho u^2/2) \quad (6)$$

Local values for Nu and Re were calculated on the basis of the air characteristics, according to the temperature of bulk fluid.

RESULTS AND DISCUSSION

Validation of the experimental setup: The experimental setup has been validated by comparison the present Nusselt number data in the circular plain tube with those predicted by Eiamsa-ard and Promvonge (2010) which was within $\pm 2\%$ Fig. 3. The empirical turbulent forced convection correlations for average Nusselt number and friction factor for plain tube have been deduced in the present work as follows:

$$Nu = 0.478\ Re^{0.012} \quad (7)$$

$$f = 18.67\ Re^{-0.687} \quad (8)$$

Tube wall temperature variation: The temperature distribution along the axial distance of plain tube and tube fitted with various types of twisted tape is shown in Fig. 4. As can be shown from this figure that the temperature distribution varies linearly with axial distance and it decreases as the type of twisted tape changes from type 1 to 6; respectively and the values of temperature are higher in the plain tube than that in the tube fitted with twisted tape inserts. The wall temperature is essentially used to evaluate the local and average Nusselt number.

Average nusselt number: Figure 5 shows the variation of average Nusselt number with Reynolds number for plain tube and tube fitted with modified twisted tape inserts as follows:

- Full length twisted tape
- Regularly-spaced twisted tape
- Triangular-cut twisted tape
- Rectangular-cut twisted tape
- Half-circular-cut twisted tape
- Drilled twisted tape

As can be seen from this figure, the heat transfer process in the tube improves as the type of twisted tape changes from 1to 6, respectively. Generally, the heat convey coefficient at tube fitted with twisted stripe inserts is superior than in the plain tube and the Nusselt number increases as Reynolds number increases. It is evident that the twisted bar inserts create vortex flow and pressure gradient in the radial direction. The thickness of boundary layer along the tube wall increases with the augmet of radial vortex and pressure leads to more heat flow through the air. In fact, vortex caused the flow to be turbulent, which led to even preferable convection heat transfer which increases as the type of variables twisted tape from type 1-6, respectively. Throughout the experimental results, let us discuss the results step by step as follows:

- The regular spaced twisted tape gives the higher values of heat transfer rate than the full length twisted tape because of more violently swirl with the regular space resulted from high values of Reynolds number (Re ranges from 4500 to 23500). This result is in contrast with results worked by Eiamsa-ard *et al.* (2006) in which the Reynolds number ranged from (2300 to 7500).

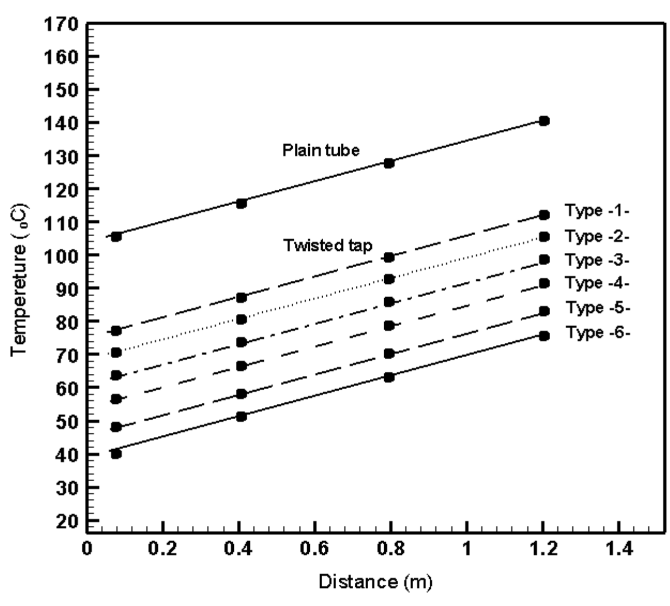


Fig. 4: Temperature distribution along the axial distance of tube

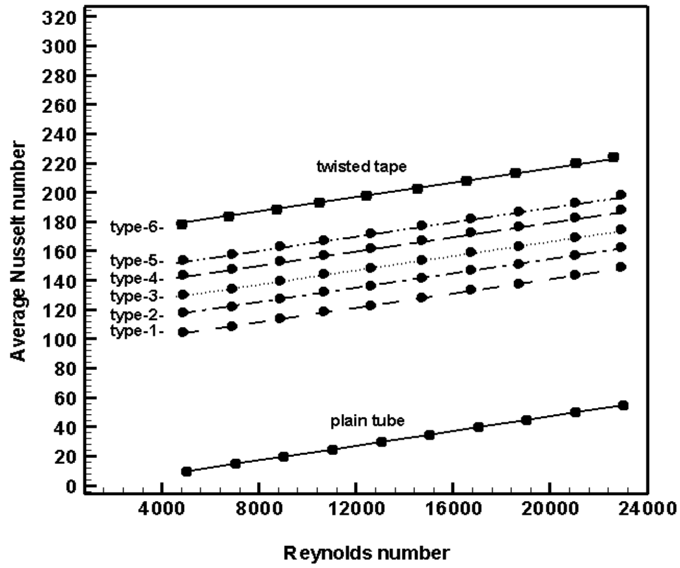


Fig. 5: Variation of average Nusselt number with Reynolds number

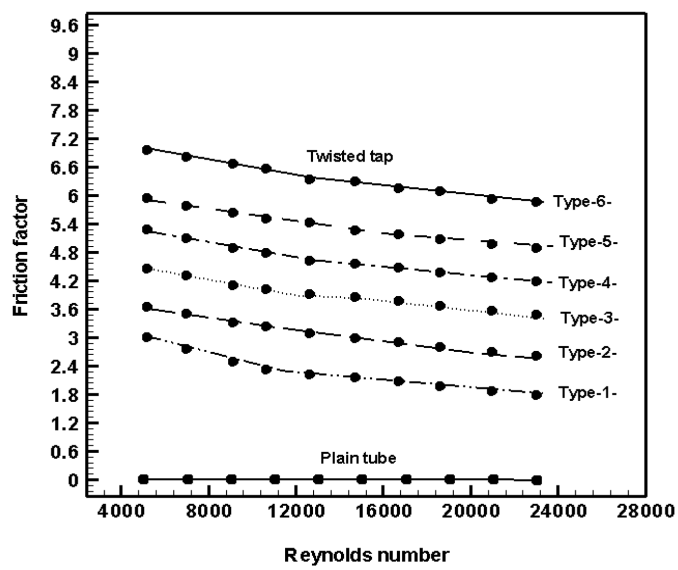


Fig. 6: Friction factor versus Reynolds number for six types of twisted tape compared with plain tube

- The heat convey process at tube fitted with drilled twisted stripe insert is superior than those in other modified twisted tape because the strong spiral flow over tube length and disturb the entire flow field.
- The increasing of cutting area in the twisted tape leads to increasing of heat transfer process. So, the Nusselt number values increase as z increases for twisted stripe with engineering shape sections like triangular-cut, rectangular-cut and semicircular-cut, respectively.

The heat transfer data for tube fitted with modified twisted tapes are correlated as follows:

$$Nu=1.960\ Re^{0.211}\ \text{(type 1)} \tag{9}$$

$$Nu= 2.184\ Re^{0.421}\ X^{-0.165}\ \text{(type 2)} \tag{10}$$

$$Nu= 2.274\ Re^{0.543}\ Z^{-0.133}\ \text{(types 3, 4 and 5)} \tag{11}$$

$$Nu=3.577\ Re^{0.685}\ Z^{-0.121}\ \text{(type 6)} \tag{12}$$

Results of friction factor: Behavior of friction factor is in reverse with behavior of heat transfer process. The values of friction factor decrease as Reynolds number increases as shown in Fig. 6. The values of friction factor in plain tube are much lower than that in tube fitted with modified twisted tape inserts in which the friction factor increases as the type of twisted tape

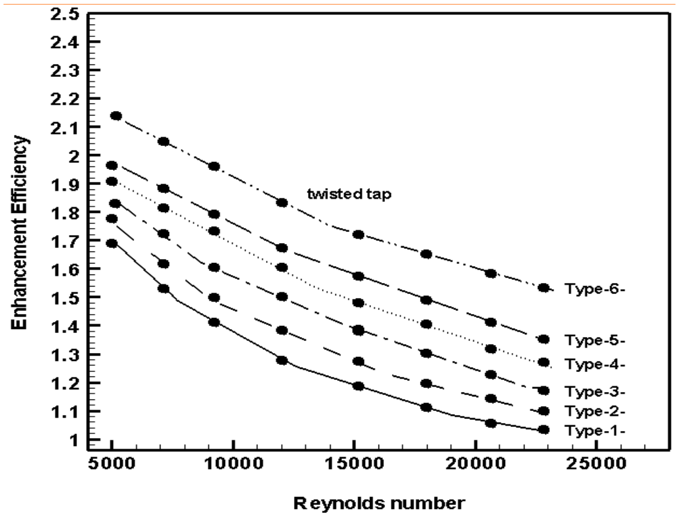


Fig. 7: Enhancement efficiency versus Reynolds number for six types of twisted tape

variables from (1-6), respectively, because of higher tangential touch between subaltern flow and wall tube surface. Empirical equations of friction factor are deduced for all types of twisted tape used in the present work as follows:

$$f = 19.56\ Re^{-0.632}\ \text{(Type 1)} \quad (13)$$

$$f = 20.34\ Re^{-0.593}\ X^{-0.101}\ \text{(Type 2)} \quad (14)$$

$$f = 21.89\ Re^{-0.582}\ Z^{-0.099}\ \text{(Types 3, 4 and 5)} \quad (15)$$

$$f = 24.56 Re^{-0.543}\ Z^{-0.012}\ \text{(Type 6)} \quad (16)$$

Performance evaluation analysis: The concept of enhancement quality is derived from the performance ratio. Performance ratio defined as the:

"*ratio of Nusselt number to friction ratio at the same pressure drop which is derived from Dittus-Boelter equation and Blasius equation of turbulent flow*" (Hasim *et al*., 2003) as follows:

$$\zeta = \frac{Nu}{Nu_p} \Bigg/ \left(\frac{f}{f_p}\right)^{1/3} \quad (17)$$

Figure 7 Shows the enhancement efficiency value increases as Reynolds number decreases and as the type of modified twisted stripe modifies from (1-6), sequentially. The empirical equations of enhancement efficiency are derived in the following forms:

$$\zeta = 10.542\ Re^{-0.987}\ \text{(Type 1)} \quad (18)$$

$$\zeta = 11.64\ Re^{-0.100}\ X^{-0.0125}\ \text{(Type 2)} \quad (19)$$

$$\zeta = 13.243\ Re^{-0.122}\ Z^{-0.0132}\ \text{(Types 3, 4 and 5)} \quad (20)$$

$$\zeta = 14.213\ Re^{-0.142}\ Z^{-0.0221}\ \text{(Type 6)} \quad (21)$$

CONCLUSION

- From the previous studies, using twisted tape and modified twisted ribbon inserts mixes the bulk flux well and therefore performance in the laminar flow is the best, because in laminar flux the thermic resistant is not finite to a superfine region. In addition to the quirky bar insert is more efficient in laminar flow and pressure drop penalty is created during turbulent flow.
- The temperature distribution varies linearly along the longitudinal axis of horizontal tube for turbulent forced convection with Reynolds number ranges from 4500 to 23500.
- To enhanced heat transfer process in the tube using a twisted ribbon inclusion. As well the type of twisted bar indicates the increasing amount of enhancement efficiency
- In case of modified twisted tape, more turbulence is created during the swirl of fluid and gives higher heat transfer rate compared to plain twisted tape.
- The performance of heat exchanger increases respectively with the utilize of (full length, regular space, triangular-cut, rectangular-cut, half-circular-cut and drilled) twisted tape.
- Performance ratio decreases as Reynolds number increases, but stays more than one, so the enhancement is competent in the point of energy savings.
- The friction factor increases under effect of the swirl flow with high Reynolds number.
- Predictive correlations for Nusselt number, friction factor and enhancement efficiency have been developed.
- Experimental data are compared with fundamental equation. Errors are within ±6% and ±7% for Nusselt number and friction factor, respectively.

NOMENCLATURE

- A : Surface area of tub, ($0.188m^2$)
- A_c : Total area of triangular, rectangular, or semicircular -cut shape of twisted tape (0.0035, 0.007, 0.0054 m^2) respectively
- A_d : Total area of drills in the twisted tape, (0.0078 m^2)
- A_t : Total area of twisted tape, (0.067 m^2)
- d : Inner diameter of tube, m
- C_p : Specific heat, J/kg.km
- G : Thermal performance factor
- L : Length of tube, m
- f : Friction factor
- Δp : Pressure drop, N/m^2
- Pr : Prandtle number (μ C_p/k)
- Nu : Nusselt number (h d/k)
- Re : Reynolds number (u d ρ/μ)
- Q : Heat gained by air, watt
- u : Velocity of air, m/s
- m_a : Mass flow rate of air, kg/secm
- x : Regularly spaced between twisted tape, m
- n : Twisted length, m
- X : Twisted ratio
- S : Spacing between two twisted tapes
- Z : Area ratio,
- T : Air temperature,°C

Subscripts:

- In : Inlet
- Out : Outlet
- B : Bulk
- W : Wall surface
- P : Plain tube

Greek symbols:

- ε : Emissivity of copper
- σ : Stefan-Boltzmann constant = $5.67\times10^{-8}W/m^2K^{-4}$
- ζ : Performance efficiency
- ρ : Density of air Kg/sec
- μ : Viscosity of air $N.s/m^2$
- k : Thermal conductivity of air W/m.K

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