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Research Article

Enhancement of Heat Transfer with Twisted Tape Inserts and Rectangular hole

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Abstract

Heat transfer augmentation techniques are used to increase rate of heat transfer without affecting much the overall performance of the system. These techniques are classified as active and passive techniques. The active technique required external power such as surface vibration and electric or acoustic fields, whereas the passive techniques required fluid additives, special surface geometries, or swirl/vortex flow devices, that is, twisted tape inserts. Heat transfer augmentation techniques are commonly used in areas such as heating and cooling in evaporators, air-conditioning equipment, thermal power plants, space vehicle, automobile etc. the passive techniques can play an important role in the heat transfer augmentation if a proper configuration of the insert is being selected depending on working conditions that have been reported in the literature .The experiments were carried out for twisted tape inserts at five different width ratios (W/D) of 0.35, 0.44, 0.53, 0.62 and 0.71 at constant twist ratio (H/D) of 2.5. The experimental results show that Nusselt number increases with increasing Reynolds number and increasing width ratio (W/D) of the swirl generators. Also the friction factor decreases with increasing Reynolds number and decreasing width ratio. The comparisons showed that, compared with the plain twisted tape, the twisted tape without rectangular hole has further improved convective heat transfer performance by about 1.40 and whereas lowered flow friction. The twisted tape with rectangular hole shows about 1.50 greater thermal performances than plain twisted tape.

Keywords: *Heat transfer enhancement, Twisted tape inserts width ratio, Twisted tape with rectangular hole.*

1. Introduction

The heat exchangers have an important role in the energy storage and recovery. A great deal of research effort has been devoted to developing apparatus and performing experiments to define the conditions under which an enhancement technique will improve heat transfer. In general, heat transfer enhancement in heat exchangers can be divided into two methods. One is the active method requiring extra external power sources such as fluid vibration, injection and suction of the fluid, jet impingement and electrostatic fields. The other is the passive method that requires no other power source. The devices in this category are surface coating, rough surfaces, turbulent/swirl flow devices, extended surfaces etc. And also in addition one method form Combination of the above two methods that is compound method such as rough surface with a twisted tape swirl flow device, rough surface with fluid vibration, rough surface with twisted tapes (N.C.Kanojiya *et al*, 2014).

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1.1 Passive method

The passive method used that not require any other power source. The devices in this category are surface coating, rough surfaces, turbulent/swirl flow devices, extended surfaces etc. Twisted tapes, as one of the passive heat transfer enhancement technology, have been extensively studied due to their advantages of steady performance, simple configuration and ease of installation (N.C.Kanojiya and V.M.Kriplani, 2014).

1.2 Twisted tape with turbulent flow

One of the ways to enhance heat transfer performance in passive method is to increase the effective surface area and residence time of the heat transfer fluid. Use of this technique causes the swirl in the bulk of the fluids and disturbs the actual boundary layer so as to increase surface area, given time and similarly heat transfer coefficient in existing system. Many researchers have contributed to the analysis of heat transfer and pressure drop for a laminar flow in circular tube with twisted tape as swirl generator. Twisted tape increases the heat transfer coefficient at a cost of rise in pressure drop. The important investigations of twisted tape for turbulent flow in a circular pipe are represented in following section. Twisted tape in turbulent flow is effective up to a certain Reynolds number range but a not over a wide Reynolds number range. Optimization in the Thermo hydraulic performance of tubes fitted with twisted tapes has gained increasing attention .For instance, experimentally studied the heat transfer and pressure drop characteristics of laminar flow in a circular tube fitted with regularly spaced twisted tape elements connected with rod. The results showed that the pressure drop of the tube fitted with the segmented twisted tape elements is 0.4 smaller than that of the tube fitted with a continuous twisted tape, and the former has a better thermo hydraulic performance (Nikhil s. Shirikhande, *et al*, 2014).

1.3 Twisted tape with inserts widths

Recently, some new types of twisted tapes were developed by some investigators. Eiamsaard and Promvonge developed a twisted tape with serrated edges. Their experiment demonstrated that the heat transfer rate and thermal performance factor in the tube with this type of twisted tape insert were about 1.04-1.27 and 1.02-1.12 times those in the tube with smooth twisted tape insert, respectively. Later, Rahimia et studied the heat transfer and friction factor characteristics of the tube fitted with perforated, notched and jagged twisted tapes. The results revealed that only the jagged insert was better than the conventional twisted tape in the heat transfer coefficient and thermal performance factor. More recently, Chang et invented a broken twisted tape insert which can induce a better fluid mixing. They reported that, as compared with those of the tube fitted with smooth twisted tape, the heat transfer coefficient, mean Fanning friction factor and thermal performance factor of the tube fitted with broken twisted tape were augmented up to 1.28-2.4, 2.0-4.7 and 0.99-1.8 times, respectively, in a Re range of 1000-40000 (Prashant Tikhe and A.M.Andhare, 2015).

It done a numerical study on heat transfer and friction factor characteristics of laminar flow in a circular tube fitted with centre cleared twisted tape. The computation results demonstrated that the flow resistance can be reduced by both methods; however, the thermal behaviours are very different from each other. For tubes with short width twisted tapes, the heat transfer and thermohydraulic performance are weakened by cutting off the tape edge. Contrarily, for tubes with centre-cleared twisted tapes, the heat transfer can be even enhanced in the cases with a suitable central clearance ratio. The thermal performance factor of the tube with center-cleared twisted tape can be enhanced by 1.2 by 1 as compared with the tube with conventional twisted tape.

The use twisted tape inserts has been shown to be an effective heat transfer enhancement technique. Most studies report high heat transfer enhancement and fluid friction for low twist ratios for both modified and typical twisted tape inserts. The present investigation is aimed at studying the frictional and heat transfer characteristics in turbulent region using reduced width twisted tape inserts under constant wall heat flux. The objective of using reduced (varying) width twisted tapes is to reduce the pressure drops associated with full width twisted tapes without seriously impairing the heat transfer augmentation rates and to achieve material savings (S. Suresh, ***et al***, 2012) (Ganesh R. Ghodake, ***et al***, 2010).

2. Experimental Details

The apparatus consists of a centrifugal blower unit fitted with a circular tube, which is connected to the Snail entrance (Volute casing) which is connected to test tube located in horizontal orientation. Flexi glass heater encloses the test section to a whole length of 1000mm. Input to heater is given through rheostat. Four thermo couples T1, T2, T3 and T4 at a equal distance of 15 cm from the origin of the heating zone are embedded on the walls of the tube and one thermocouple is placed in the air stream at the exit (T5) of the test section to measure the temperature of flowing air. The digital device multimeter is used to display the temperature measured by thermocouple at various position. The temperature measured by instrument is in 0C. The test tube of 3mm thickness is used for experimentation. A U tube manometer measures the pressure drop across the test section filled with water. The pipe system consists of a valve, which controls the airflow rate through it and an orifice meter to find the volume flow rate of air through the system. The diameter of the orifice is .0125m and coefficient of discharge is 0.61. The two pressure tapings of the orifice meter are connected to a water U-tube manometer to indicate the pressure difference between them. Display unit is a digital multimeter used to indicate Temperature.

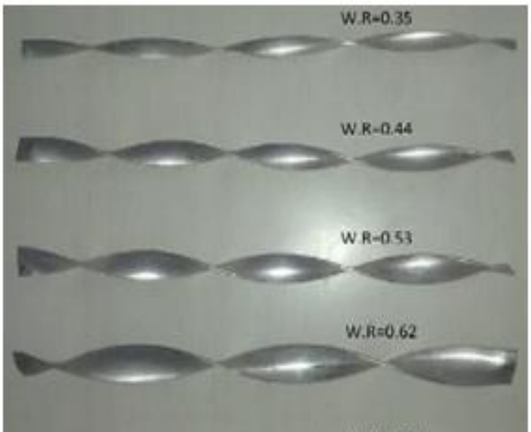

Fig.1 Twisted tape inserts with width ratio

For the width ratio enhancement the experiments were carried out in an open-loop experimental facility as shown in Fig. 4. The loop consisted of 0.5 hp high pressure blower, orifice meter to measure the flow rate, and the heat transfer test section. The aluminium test tube has a length of L = 500 mm, with 56 mm inner diameter (ID), 60 mm outer diameter(OD), and 2 mm thickness (t).

3. Photograph of Experimental Setup

Fig.2 Photograph of experimental setup

During experiments, inlet bulk air, was drawn through the clam section to achieve a fully developed flow prior to being heated by an adjustable electrical heater wrapping along the test section, Air flow rate was varied corresponding to Reynolds number (Re) between 7500 and 13000. Pressure drop across the test section was measured using an inclined U-tube manometer filled by the monomeric fluid having low specific gravity (SG.) of 0.816 to ensure reasonably accurate measurement of the low pressure drop encountered at low Reynolds numbers. In the present test, all data were taken at steady state.

Fig.3 Twisted Tape without Rectangular Hole

Fig.4 Twisted Tape without Rectangular Hole

4. Data Reduction

In the present work, the air used as the test fluid is flowed through a uniform heat-flux and insulated tube. The steady state of the heat transfer rate is assumed to be equal to the heat loss in the test section which can be expressed as

$Qair = Qconv$,

In which

$$Qair = \dot{m} * Cp,air * (To - Ti) = V * I \quad (1)$$

The heat supplied by electrical winding in the test tube is found to be 3 to 8 higher than the heat absorbed by the fluid for thermal equilibrium test. Thus, only the heat transfer absorbed by the fluid is taken for internal convective heat transfer coefficient calculation.

The convection heat transfer from the test section can be written by,

$$Qconv = h * A * (Ts - Tb) \quad (2)$$

Where

$Tb = (To + Ti)/2$

And

$Ts = (T1 + T2 + T3 + T4 + T5)/5$

4.1 Heat Transfer Evaluation

Friction Factor Evaluation
Where,
Friction factor, f can be written as,

$(V \times \Delta P)0 = (V \, \Delta p)$

Where
U is an average velocity calculated by dividing the measured volumetric air flow rate by the inlet cross-section area (A). The Reynolds number based on an inner diameter of the test tube diameter can be expressed as

$$Re = U\,D / v \quad (3)$$

All of the thermo-physical properties (k, , , Cp) used for the calculations of the dimensionless numbers (Nu, Pr) are all evaluated at the bulk fluid temperature (*Tb*).

4.2 Thermal Performance Factor Evaluation

In the present study, the concept of equal pumping power is applied for evaluating thermal performance. The constant pumping power criteria can be expressed as For a constant pumping power,

$\tilde{v} \times \Delta Pp = \tilde{V} \times \Delta Pt$

$(fRe3)0 = (fRe3)$

$Re0 = Re(f/f0)1/3$

The thermal Performance factor is defined as (TPF) in which U is mean air velocity in tube. All thermo physical properties are determined at Overall bulk air Temp.

$\eta = (Nut/Nup)/(ft/fp)(1/3)$ (4)

A thermal performance factor with a value above unity indicates that the use of the enhancement device results in overall energy saving as compared to the operation without the device.

5. Review of Work Carried Out

They did the review on heat Transfer Characteristics using inserts in Tubes. The overall conclusions which they found during the study the twisted type insets heat transfer rate increase in turbulence of the flow and also the pressure drop increases. For conical ring inserts, the heat transfer rate more than that of the plain surface tube simultaneously increases the frication factor. The friction factor increases in the fully laminar region and increased the heat transfer. In mesh insert, pressure drop increases by increasing the ratio of porous material and enhancement of heat transfer rate when compared with the plain tube. Similarly In a baffle insert, the rate of pressure drop increases with varying the Reynolds number for transient flow conditions.

Studied experimental investigation on heat transfer and pressure drop characteristics of turbulent flow in a heating tube equipped with perforated twisted tapes with parallel wings for Reynolds number range from 5500 to 20500. They did the design of perforated twisted tape with the following concepts: - The wings induced an extra turbulence near tube wall which caused to disrupt the thermal boundary layer efficiently. - The existing holes along a core tube reduce the pressure losses of the tube. The various parameters investigated by them i.e. the hole diameter ratio and wing depth ratio. And also typical twisted tape was also tested for the assessment. They compare the results with the plain tube, the result shows that the tubes with perforated twisted tape heat transfer rate increases up to 208 and also with the twisted tape the heat transfer enhance up to 190. They evaluate the overall performance during experimentation under the same pumping power with that of perforated twisted tape with ratio of d/W and w/W which are equal to 0.11and 0.33 respectively, gives the maximum thermal performance factor of 1.32, in the Reynolds number range of 5500.

Investigations on heat transfer rate and friction factor on conical rings which are used as turbulators, which are mounted over the test tube. The Conical rings with three different diameter ratios of the ring to tube diameter (i.e. d/D = 0.5, 0.6, 0.7) was introduced for the tests. For each ratio, the rings placed with three different arrangements i.e. converging conical ring, referred to as CR array, diverging conical ring, DR array and converging diverging conical ring And the DR array founds the better heat transfer than the others. The heat transfer enhancement efficiency increases with decreasing the Reynolds number and ratios of diameter for the test. It was concluded that the effects of using the conical ring cause a substantial increase in friction factor.

6. Result and Discussion

6.1. Heat Transfer

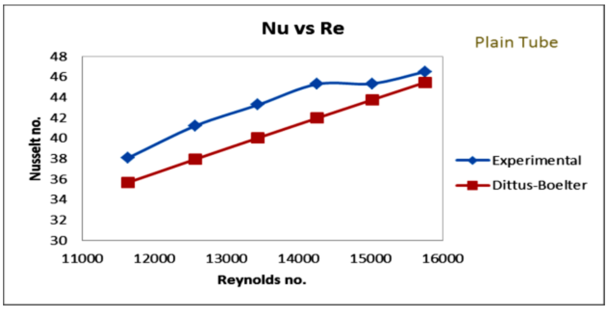

Fig.5 Comparison of the experimental results and the theoretical data of then Nusselt number (Nu)

The heat transfer characteristics for the airflow in the tube with twisted tape without hole and tube with twisted tape have rectangular hole have been measured respectively within the Reynolds number range of 25,000 to 95,000 Graph shows that, for the studied Reynolds number range from 25,000 to 95,000, the experimental results of the average Nusselt numbers of the plain tube agree reasonably well with the empirical Dittus Boelters correlation for the circular duct flow. As is expected, within the studied Reynolds number range the Nusselt numbers of the twisted tape without rectangular hole tube increase with the Reynolds number. For the tube with twisted tape with rectangular hole Nusselt number is about 40 to 50 higher than the plain tube within the Reynolds number range of 25,000 to 95,000 The heat transfer enhancement should be that the rectangular holes on the twisted tape increase the turbulent mixing in the flow near the wall by producing multiple vortex pairs, which enhance the turbulent flow heat transfer from the wall. Enhancement efficiency of the twisted with rectangular hole is goes on decreasing with the increasing Re no.

6.2 Friction Factor

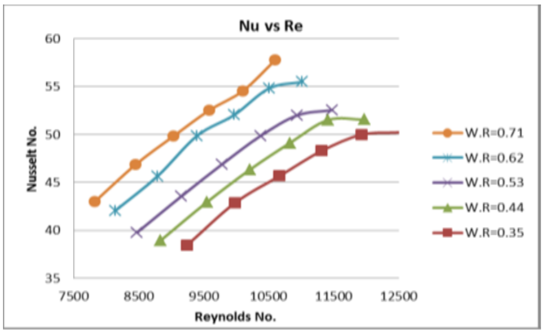

Fig.6 Variation of the Nusselt number (Nu) versus the Reynolds number for width ratio (w) of twisted tape

Based on the experimental system, the pressure loss characteristics for the airflow in the tube with twisted tape and with twisted tape with rectangular hole have been measured respectively within the Reynolds number range of 2500095000. The friction factors of Plain tube, tube with twisted tape without rectangular hole, tube with twisted tape with hole are presented in graph. Graph shows that, for the studied Reynolds number range from 2500095000, the experimental results of the friction factors of the plain tube agree reasonably well with the empirical Blasius correlation. Fig. plots the comparison of the experimental values of the friction factors of the tube with twisted tape without rectangular hole and tube with twisted tape with hole with plain tube over the Reynolds number range of 2500095000. It can be seen that in the Reynolds number range of 2500095000, depending on the rectangular hole arrangement tube show different flow friction characteristics.

6.3. Effects of the tape width ratio

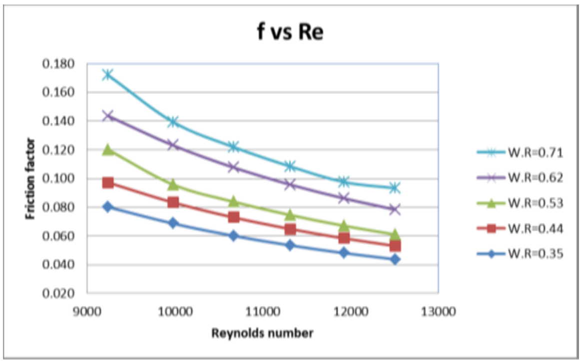

Fig.7 Variation of the friction factor (*f*) versus the Reynolds number for width ratio (w) of twisted tape

The experimental data of the Nusselt number and friction factor and their variation with a Reynolds number of twisted tape inserts with width ratios (w = 0.35, 0.44, 0.53, 0.62 and 0.71) are shown in Figures 6 and 7. Figure 6 indicates that the Nusselt number increases with Reynolds number increasing and the heat transfer rate is higher for the twist tape set than for the plain tube because of strong swirl flow in the presence of the twist tape. It is found that the heat transfer rate with the width ratio (w = 0.71) is higher than those with other ratios (w = 0.35, 0.44, 0.53 and 0.62); this means that the turbulent intensity obtained from the higher width ratio is higher than those from lower width ratios (w). Moreover, it is also noted that Nu decreases more rapidly when w is relatively large and then the decrease of Nu slows down with further reduction of w. Figure 7 shows the variation of friction factor with a Reynolds number for different width ratios (w = 0.35, 0.44, 0.53, 0.62 and 0.71). The friction factor obtained from the tube with twisted tape insert is significantly higher than the plain tube. Moreover, the use of higher width ratio leads to higher tangential contact between the swirling flow and the tube surface. Therefore, the twisted tape with width ratio (w = 0.71) has a maximum friction factor.

6.4. Correlations for prediction of heat transfer

The correlations were developed for the turbulent flow region in the range of Reynolds number 7500 to 13000. The correlation developed for Nusselt number obtained from the present experimental results of the tube fitted with the reduced width twisted inserts could be written in terms of width ratio (w =W/D), Reynolds number (Re), and Prandtl number (Pr) in below Eqs., respectively. Nu = 0.01193 Re 0.9404 w 0.3687 Pr0.33 (Eq.) The Nusselt number values predicted from the above correlation above Eq. were compared with the experimental values respectively. It could be noted that the Nusselt number values obtained from the predicted correlation. All investigated Agreed well with the experimental values for all the investigated cases of the proposed correlations.

Normalized von-misses stress at the end of load application for two different materials with thickness value of 0.75 mm. Also Fig.6 shows normalized displacement contour and normalized von-misses stress at the end of load application for two different materials with thickness value of 0.85 mm.

Conclusions

From this review, various ways of enhance the heat transfer rate by generating the swirl flow by passive method can be observed by using various types of inserts. In perforated twisted tape inserts, heat transfer rate increases hence, heat transfer coefficient increases with decreases in pressure drop.

The key findings based on experimental results of present study are summarized as follows:

1) The heat transfer enhancement offered by twisted tapes of different width ratio is significant compared to plain tube.
2) The Nusselt number increases with increasing Reynolds no. and width ratio of twisted tape.
3) The enhancement in heat transfer is higher for twisted tape having width ratio=0.71 and lower for width ratio=0.35.
4) Nu no increases about 28 to 30 hole, and by 47 to 60 in experimental values are because of manufacturing and measuring errors.
5) Enhancement efficiency obtains by twisted tape with hole experimentally about 2 to 4
6) The size and shape of the rectangular hole is the key behind the flow not experiencing a large separation. The lack of a large flow reversal and the flow impingement along the downstream edge of the rectangular hole contribute to the greater enhancement in the heat transfer on the tube surface.

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