

# FLUID FLOW AND HEAT TRANSFER ENHANCEMENT IN WINGS WITH COMBINED SOLID RING TWISTED TAPE INSERTS CIRCULAR HEAT EXCHANGER TUBE

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Experimental examination is carried out to study the turbulent heat transfer and fluid flow characteristics in circular heat exchanger tube using combined wing with solid ring twisted tape inserts. A series of experiments has been performed with the range of Reynolds number ( $Re$ ) varied from 3000 to 21000, number of twisted taped inserts,  $N_{TT}$  varied from 1.0 to 4.0 with constant value of other twisted tape parameters such as rings pitch ratio,  $d_R/D_T = 1.0$ , wing pitch ratio,  $P_W/W_T = 3.0$  and wing depth ratio  $W_d/W_T = 1.67$ . Based on the examined, turbulent heat transfer and fluid flow in wing with combined solid ring twisted tape inserts results are compared with plain circular tube under same operating conditions. The experimental results show that the heat transfer is increased around 5.66 times than plane circular heat exchanger tube. The thermal and hydrodynamic performance parameter based on equal pumping power,  $\eta_p$  was found to be highest for  $N_{TT} = 3.0$ . The optimum value of thermal and hydrodynamic performance has been found to be 2.74 for  $Re$  of 3,000 within the range of the parameters investigated. Multiple wings with solid rings twisted tape inserts have been also shown to be thermally as well as hydraulically better in comparison to other similar twisted tape insert geometries.

**Keywords:** Heat transfer enhancement, multiple twisted tapes, twists ratio, wing pitch ratio, wing depth ratio and solid rings.

## 1. Introduction

The heat exchanger tubes are the core components enriched with various insert geometries to enhance heat transfer rate in most of the mechanical and thermal equipment's used in engineering devices to industrial and house hold appliances [1-3]. In the present scenario many studies have been carried out with the aim of energy saving by minimize the size, cost and power consumption of various heat exchanger techniques [4-6]. The compact and geometrically enriched heat exchanger with various inserts was found an efficient way to enhance the performance and efficiency of various equipment's [7-9]. The heat exchanger tube equipped with twisted tape inserts are widely employed techniques to enhance heat transfer rate and always perform better than plane tube [10-11]. To promote better fluid mixing, turbulence is generated near the wall giving rise to more velocities near the boundary layer and consequently enhances the heat transfer rate. The contribution of many researchers has been reported for the development of effective heat exchanger techniques to enhance passive heat transfer rate [12-13].

Akhavan-Behabadi et al. [14] experimentally studied seven diverse coiled wires inserts with  $H_{TT}$  ratios varies from 12.0mm to 69.0mm and diameters was taken 2.0mm and 3.50mm.

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Meng et al.[15] investigated the  $f_{TT}$  performances in DDIR tube was used to solve the field synergy equation numerically. The experimental results showed that the DDIR tube inserts has better comprehensive  $h_{TT}$  performance than the current  $h_{TT}$  enhancement tubes.

Gawandare et al.[16] experimentally investigated the  $h_{TT}$  and  $f_{TT}$  characteristics of circular tube fitted with full length copper square jagged TT inserts. They revealed that there is a noteworthy  $h_{TT}$  augmentation due to TT inserts. Al-Fahed et al. [17] carried out an experimental investigation to study and compare the results of  $h_{TT}$  coefficients and pressure drop for a plain tube, micro fins and TT inserts in laminar flow section. The maximum values of  $h_{TT}$  were obtained for TT inserts having  $y_{TT}$  3.60 and 5.40 than that of loose fit TT inserts. Suri et al.[18] reviewed the various circular tube equipped with a variety of twisted tape insert techniques on heat transfer enhancement. They showed that multiple twisted tape inserts better heat transfer enhancement as compared other single twisted tape insert heat exchanger tubes. Kongkaiptaiboon et al.[19] experimentally investigated the influences of the PCR on the turbulent convective  $Nu_{TT}$ , and  $\eta_\rho$ . Promvonge et al.[20] investigated the devices consisted of the TT inserts with constant or cyclically changing pitch ratio ( $H_{TT}$ ) of the wire coil inserts.

Zhang et al.[21] performed a numerical analysis of three dimensional turbulence stream to study  $Nu_{TT}$  and fluid flow characteristics for helical screw tape inserts without core rod inserts. Shabanian et al.[22] performed an experimental and computational analysis to study  $f_{rs}$ ,  $Nu_{rs}$  and  $\eta_{rs}$  characteristics of an air cooled HET fitted with three different types of tape inserts. These inserts included classic, butterfly and jagged TT. Krishna et al.[23] investigate various  $Nu_{TT}$  enhancement techniques. They investigated that the heat enhancement in helical and left-right TT collectors was better than the plain circular tube collector. Eiamsa-ard et al.[24] carried out a comparative experimental study of  $Nu_{TT}$ ,  $f_{TT}$  and  $\eta_\rho$  factor in a HET fitted with regularly spaced TT inserts. Jaisankar et al. [25] experimentally investigated the performance of  $Nu_{TT}$ ,  $f_{TT}$  and  $\eta_\rho$  characteristics of solar heater water tube equipped with TT inserts with different  $y_{TT}$ . Jaisankar et al. [26] performed experimental study to investigate the behaviour of  $Nu_{TT}$ ,  $f_{TT}$  and  $\eta_\rho$  for thermosyphon solar water heating system equipped with helical and left-right TT.

Eiamsa-ard and Promvonge.[27] investigated  $Nu_{TT}$  and  $f_{TT}$  characteristics for turbulent flow rate through a HET equipped with straight tape with double sided delta wings inserts and T-W with alternate axis. Seemawute and Eiasma-ard.[28] carried out an experimental investigation to study the behaviour of  $h_{TT}$  characteristics for turbulent flow through a circular tube with peripherally-cut TT inserts with an alternate axis. Eiamsa-ard et al.[29] carried out comparative experimental study on  $Nu_{TT}$  enhancement for a round tube equipped with single TT inserts, full length dual and regularly spaced dual TT inserts under uniform wall heat flux conditions. Murugesan et al.[30] carried out an experimental analysis to study the behaviour of  $h_{TT}$ ,  $\eta_\rho$  factor and  $f_{TT}$  characteristics in a plain circular tube and circular tube with V-cut TT inserts.

It has been seen that no study is available in which effect of wing with combined solid ring twisted tape inserts circular heat exchanger tube has been investigated. In the present investigation, it has been planned to experimentally study the effect of variation in  $N_{TT}$  of circular heat exchanger tube. With the focus on circular heat exchanger tube, the  $Re_{TT}$  ranging from 3000-21000 is selected. The effect of number of twisted tap inserts on thermal and hydrodynamic performance is experimentally studied. The optimum value of number of twisted tape inserts circular heat exchanger parameters have been determined and discussed.

## 2. Twisted tape geometry and parameters range

Wings with combination of solid ring twisted tape inserts heat exchanger tube are tested and number of twisted tape inserts are compared in the experimental work. The geometrical dimensions of twisted tape inserts heat exchanger tube are listed Table.1 and Figs 1-2. The geometrical parameters for the heat exchanger tube with wings with combination solid ring twisted tape inserts are diameter of tube ( $D_T$ ), width of tape ( $W_T$ ), pitch between wings ( $P_W$ ), and wing depth ( $W_d$ ). Dimensionless parameters expressed as rings pitch ratios ( $d_R/D_T$ ), wing pitch ratios ( $P_W/W_T$ ) and wing depth ratios ( $W_d/W_T$ ).

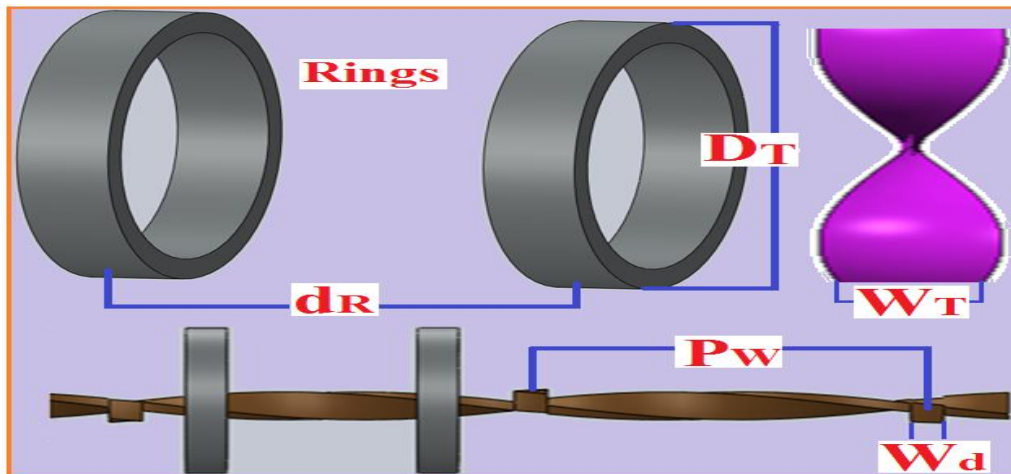


Fig. 1 Discuss square wings with combined solid rings twisted inserts heat exchanger tube parameters.

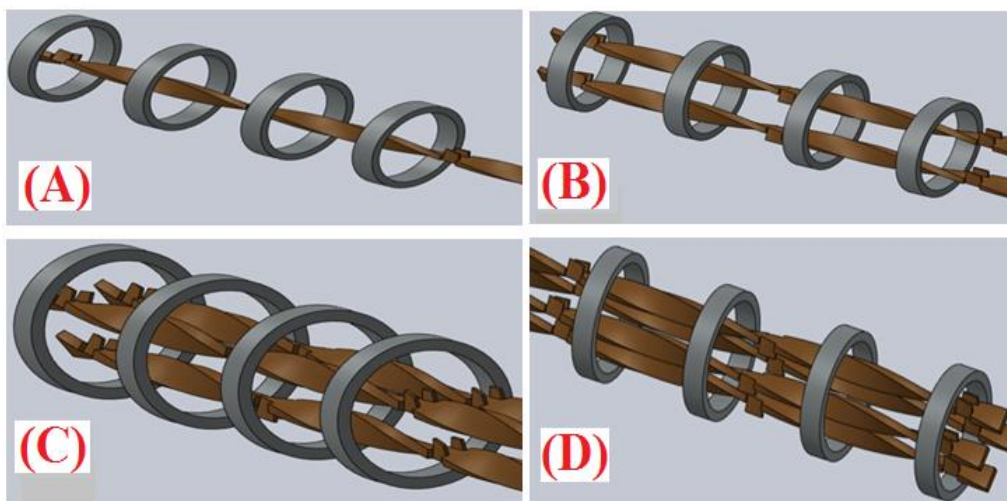


Fig. 2 Schematic of twisted tape with square wings with combined solid rings circular tube (A) single twisted tapes (B) Double twisted tape (C) Triple twisted tape (D) Multiple (Four) twisted tape.

Table.1 Geometrical parameter with range.

S.N.	Name of parameters	Range
1.	$N_{TT}$	1.0-4.0
2.	$d_R/D_T$	1.0
3.	$P_W/W_T$	3.0
4.	$W_d/W_T$	1.67
5.	Re	3000-21000

### 3. Experimental details

An experimental investigation is carried out by fabricating the setup as per the ASHARE standards. A GI Pipe of 68 mm outer and 65 mm inner diameter is used to fabricate the setup. The dimensions of different setup sections viz. entry, test and exit section are 2.5 m, 1.4 m and 1.5 m, respectively. A 3 HP, centrifugal blower is attached to the exit section for suction of air through the test section. The test section is provided by uniform heat flux of  $1000 \text{ W/m}^2$  with a heating element and Variac transformer. The experimental setup is equipped with sixteen thermocouples arranged in series, twelve for monitoring the temperature of tube wall and three for monitoring the variation of fluid temperature of test section at inlet and outlet. A U-tube manometer is employed for monitoring the fluid flow rate at the test section. Digital micro manometer with least count of 0.1 Pascal was used for measuring the pressure drop across the test section. The solid rings and twisted tapes with square wing perforation are made up from 0.50 mm thickness aluminium sheet. The schematic of the experimental setup and photographic view of multiple wings with combined solid ring twisted tape inserts is shown in Fig. 3.

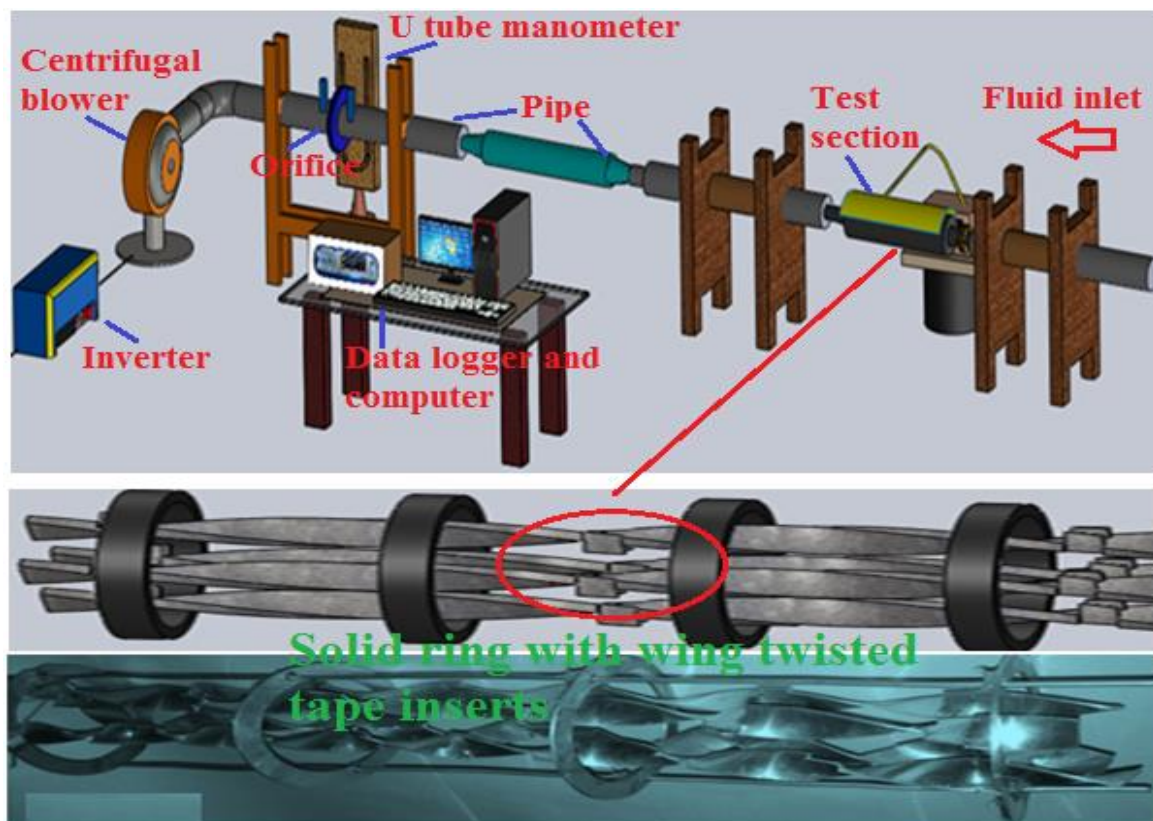


Fig. 3 Schematic of experimental setup and photo graphic view of multiple wings with combined solid ring twisted tape inserts.

The geometrical parameters under investigation are rings pitch ratios ( $d_R/D_T$ ) mm, wing pitch ratios ( $P_W/W_T$ ) mm, wing depth ratios ( $W_d/W_T$ ) mm, number of twisted tapes ( $N_{TT}$ ), and ratio of inner diameter to tube diameter ( $d_{iR}/D_T$ ) mm. The details of the investigated geometrical and flow parameters are depicted in the table 2.

### 4. Data reduction

The experimental data for heat exchanger was recorded under steady state conditions for given heat flux and mass flow rate of air. The heat transfer rate to air flowing in

the tube was computed. Under the steady state conditions of the experiment for given air mass flow rate ( $\dot{m}$ ) the heat transfer rate  $Q_u$ , heat transfer coefficient ( $h_{TT}$ ), Nusselt number ( $Nu_{TT}$ ) and friction factor ( $f_{TT}$ ) have been calculated using the following equations:

The net local wall temperature  $T_{TT}$  inside the tube is the average temperature of all thermocouples embedded in the test section of experimental setup.

$$T_{TT} = \frac{1}{12} \sum_{i=1}^{12} T_{C_i} \quad (1)$$

Where  $T_{b_{TT}} = \frac{T_i + T_o}{2}$  is bulk mean temperature of fluid and it is calculated by equation.

The flow rate of mass of fluid is estimated by using the following equation [24, 29, 33]:

$$\dot{m} = C_d A_o \left[ \frac{2 \cdot \rho_{TT} \cdot (\Delta P)_o}{1 - \beta^4} \right]^{0.5} \quad (2)$$

Where  $(\Delta P)_o = 9.81 \cdot (\Delta h_{TT})_o \cdot \rho_{TT} \cdot \sin \theta$  and  $\beta$  is the ratio is the throat diameter to orifice-plate to tube diameter and value is 0.5.

The heat transfer coefficient of air mass fluid flow in the test section is calculated using the following equation:

$$Q_u = \dot{m} C_p [T_o - T_i] \quad (3)$$

$$h_{TT} = Q_u / A_o (T_{TT} - T_{b_{TT}}) \quad (4)$$

Where  $T_{b_{TT}}$  is an arithmetic mean of the inlet and the exit temperature of air flowing through the test section. Nusselt number of air mass flow in the test section is calculated from the equation:

$$Nu_{TT} = h_{TT} D_{TT} / K_{TT} \quad (5)$$

The velocity of air mass flow in heat exchanger tube is calculated from the given equation:

$$V_{TT} = \dot{m} / W_T \cdot H_{TT} \cdot \rho_{TT} \quad (6)$$

The Reynolds number of air mass flow in the heat exchanger tube is calculated from equation:

$$Re_{TT} = V_{TT} \cdot D_{TT} \cdot \rho_{TT} / \mu_{TT} \quad (7)$$

The friction factor of air mass flow in test section of heat exchanger tube is calculated from pressure drop equation as:

$$f_{TT} = 2 \cdot (\Delta P)_d \cdot D_{TT} / 4 \cdot \rho_{TT} \cdot L \cdot V_{TT}^2 \quad (8)$$

Where  $(\Delta P)_d = 9.81 \times (\Delta h_{TT})_d \cdot \rho_{TT}$

The thermal and the hydraulic performance of air mass flow in a multiple square wing twisted tape inserts is compared with plain tube by using the equation:

$$\eta_p = \left( \frac{Nu_{TT}}{Nu_{SS}} \right) / \left( \frac{f_{TT}}{f_{SS}} \right)^{\frac{1}{3}} \quad (9)$$

## 5. Uncertainties analysis

An uncertainty analysis for estimation of errors involved in experimental data measurement has been carried out. The uncertainty is estimated based on errors associated with measuring instruments [31]. The uncertainty results are presented in Table.2.

Table.2. Range of uncertainty in the measurement of essential parameters.

S.N.	Parameters	Error range (%)
1	Mass flow rate	1.45-3.15
2	Heat gain	0.93-2.94

3	Heat transfer coefficient	1.56-3.54
4	Reynolds Number	0.78-1.56
5	Nusselt number	1.09-3.32
6	Friction Factor	0.78-1.67

## 6. Validation of experimental results

Empirical correlations of Dittus-Boelter and Gnielinski equation for  $Nu_{TT}$  and Blasius equation with Petukhov correlation for  $f_{TT}$  were validated with experimental data for plain tube heat exchanger.

The standard equations to find the value of  $Nu_{TT}$  and  $f_{TT}$  for plain tube are given by Dittus-Boelter equation:

$$Nu_{TT} = 0.023Re^{0.8}Pr^{0.4} \quad \text{for } Re \geq 21,000 \quad (10)$$

Blasius equation:

$$f_{TT} = 0.085Re^{-0.25} \quad (11)$$

The standard equations to find the value of  $Nu_{TT}$  and  $f_{TT}$  for plain tube are given by Gnielinski equation:

$$Nu_{TT} = \frac{\left(\frac{f}{8}\right) (Re - 1000) Pr}{1 + 12.7 \left(\frac{f_{TT}}{8}\right)^{\frac{1}{2}} \left(Pr_{TT}^{\frac{2}{3}} - 1\right)} \quad \text{for } 3,000 \leq Re \leq 21,000 \quad (12)$$

Petukhov equation:

$$f_{TT} = (0.079 \ln Re - 1.64)^{-2} \quad (13)$$

The standard values of  $Nu_{TT}$  and  $f_{TT}$  with respect to  $Re$  for plane heat exchanger tube are compared with the values obtained from experimental investigation and it is noticed that there is a logically good conformity between the three sets of values confirm the precision of the data collected from this experimental investigation as shown in the Fig.4 (A-B).

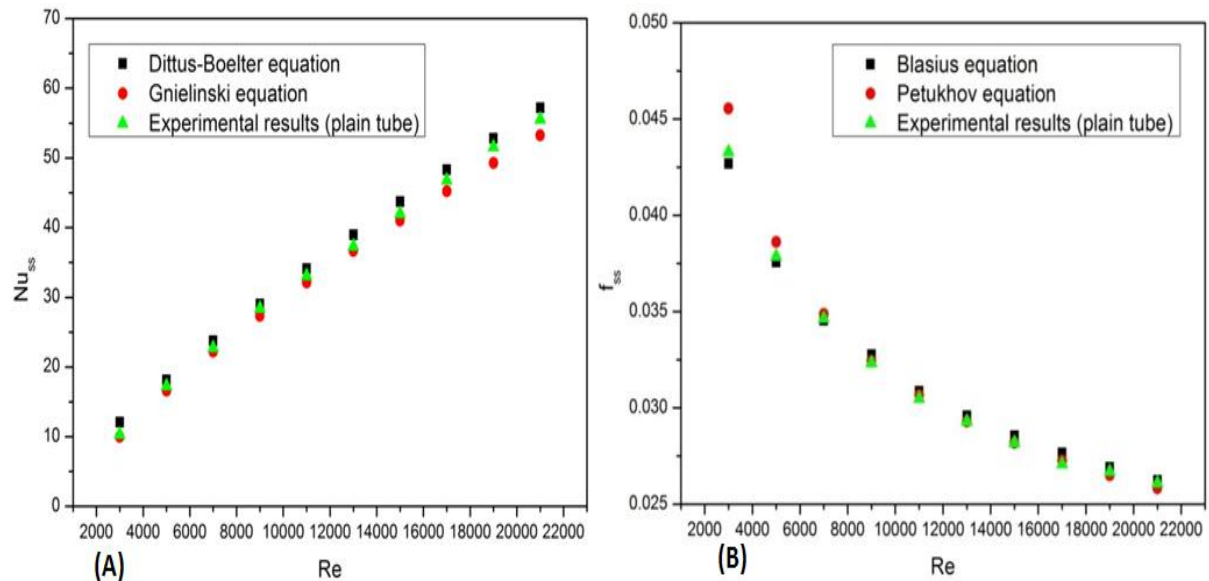


Fig.4. Comparison of present experimental results with previous correlations for (A)  $Nu_{TT}$  and (B)  $f_{TT}$



## 7. Results and discussion

In the present work the effects of heat exchanger tube with wings with combination of solid ring twisted tape inserts with number of twisted tape inserts and operating parameters on thermal and hydraulic performance are discussed.

### 7.1 Heat and fluid flow

The variation of  $Nu_{TT}$  with varied ranges of  $Re$  for plane tube and multiple wings with solid rings twisted tape inserts is presented in Fig.5 (A). The other geometrical parameters are fixed such as  $W_d/W_T = 0.167$ ,  $P_W/W_T = 3.0$  and  $d_R/D_T = 1.0$ . It is shown that there is a considerable enhancement of  $Nu_{TT}$  with the increase of  $Re$  for multiple wings with solid rings twisted tape inserts as compare to plane tube. Inside the heat exchanger tube without any inserts, the radial velocity components of the flow generate boundary layer separation. The boundary layer effect can be minimized by introducing multiple wings with solid rings twisted tape inserts in heat exchanger tube. The multiple wings with solid rings twisted tape inserts induces swirl flow inside the tube which further enhances flow turbulence intensity and consequently generates high convection heat transfer than the plain tube. Thus, the value of  $Nu_{TT}$  is greater for higher swirling flow and found maximum for  $N_{TT} = 3.0$ .

Fig.5 (B) shows the values of  $Nu_{TT}$  as function of  $N_{TT}$  for the selected  $Re$  values where a maximum in the values corresponding to a  $N_{TT} = 3.0$  for all  $Re$ . It can be observed that  $Nu_{TT}$  enhance significantly with the increase of number of multiple wings with solid rings twisted tape inserts from  $N_{TT} = 1$  to  $N_{TT} = 3$  and then it starts decreasing with the increase of  $N_{TT}$ . When circular tube is fitted with multiple wings with solid rings twisted tape inserts then it decreases the hydraulic diameter of the tube and increases the fluid flow with generation of addition swirl flow. Hence, the swirl flow creates disturbance in between the particles of fluid and boundary layers, hence the heat exchange between the core layer and tube wall continues for a longer period. The heat exchanger tube multiple wings with solid rings twisted tape inserts, generates additional flow jets to the main flow streams through the wings and consequently accelerates the main flow streams. The value of  $Nu_{TT}$  attain maxima in a plot for  $N_{TT} = 3$  with respect to the prescribed range of  $Re_{TT}$ . In general, the multiple twisted tapes yield higher heat transfer rate than the single one around 10% to 15%. This improvement in  $Nu_{TT}$  for constant value of  $W_d/W_T = 0.167$ ,  $P_W/W_T = 3.0$  and  $d_R/D_T = 1.0$  is around 10% to 15% for  $N_{TT} = 1$ , 15% to 20% for  $N_{TT} = 2$ , and around 18% to 25% for  $N_{TT} = 3$  is higher than that of plane tube.

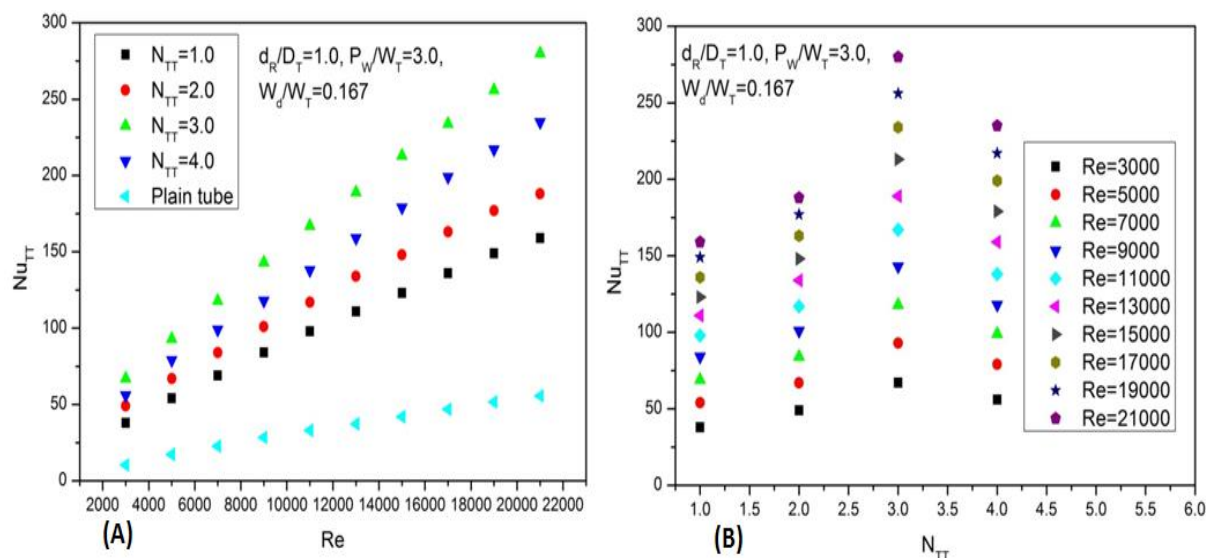


Fig. 5 (A) Variation of  $Nu_{TT}$  with  $Re_{TT}$  for different values of  $N_{TT}$  (B) Variation of  $Nu_{TT}$  with  $N_{TT}$  for different values of  $Re_{TT}$ .

The variation of  $f_{TT}$  with  $Re_{TT}$  for fixed range of  $W_d/W_T = 0.167$ ,  $P_W/W_T = 3.0$  and  $d_R/D_T = 1.0$  with various  $N_{TT}$  is shown in the Fig.6 (A). The twisted tape inserts generate swirl flow which further increase the wetted surface area and dissipation of fluid pressure near the tube wall. Owing to this effect the fluid flow has high pressure loss in the heat exchanger tube equipped with multiple wings with solid rings twisted tape inserts. Fig.6 (A) shows that the value of friction factor  $f_{TT}$  decreases with increasing value of Reynolds number. When the intensity of fluid flow increases gradually then it would increase the heat flow for all wings twisted tape inserts and it higher for  $N_{TT} = 4.0$ . Fig.6 (B) shows the values of  $f_{TT}$  as function of  $N_{TT}$  for the selected Re values where a maxima in the values corresponding to a  $N_{TT} = 4.0$  for all Re.

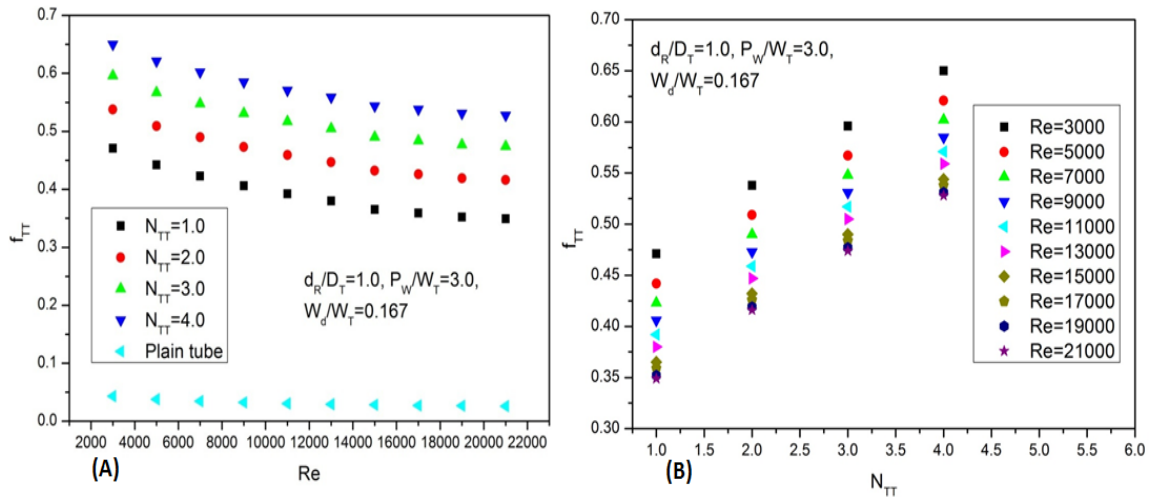


Fig. 6 (A) Variation of  $f_{TT}$  with  $Re_{TT}$  for different values of  $N_{TT}$  (B) Variation of  $f_{TT}$  with  $N_{TT}$  for different values of  $Re_{TT}$ .

## 7.2 Thermal hydraulic performance

The heat transfer in multiple wings with solid rings twisted tape inserts is better than the plain tube. The effectiveness of twisted tape inserts is measured by using thermal hydraulic parameter  $\eta_p$  [32-35] in terms of  $Nu_{TT}$  and  $f_{TT}$ . In this investigation the value of these parameters for multiple wings with solid rings twisted tape inserts is investigated and plotted in Fig.7. It is investigated that the multiple wings with solid rings twisted tape inserts generate extra tangential flow which further increases the contact are and hydraulic length of flowing fluid.

The heat exchanger tube equipped with multiple wings with solid rings twisted tape inserts extract maximum amount of heat from the circular tube wall and transfer it to the flowing fluid. Fig. 7 shows the thermal hydraulic performance of heat exchanger tube equipped with multiple wings with solid rings twisted tape inserts for fixed range of  $W_d/W_T = 0.167$ ,  $P_W/W_T = 3.0$  and  $d_R/D_T = 1.0$  for all prescribed range of Reynolds number, it can be seen from the graph that the maximum value of thermal hydraulic performance parameter  $\eta_p = 2.75$  with respect to  $Re_{TT} = 2000$  is observed for heat exchanger tube equipped with  $N_{TT} = 3.0$  and it is also observed that the value of  $\eta_p$  decreases with the increase of  $Re_{TT}$  from 2000 to 21,000. Table.3 shows the values of thermal hydraulic performance determined for this geometry multiple wings with solid rings twisted tape inserts have been compared with other similar twisted tape inserts. It can be seen that the multiple wings with solid rings twisted tape inserts results is best thermal hydraulic performance.



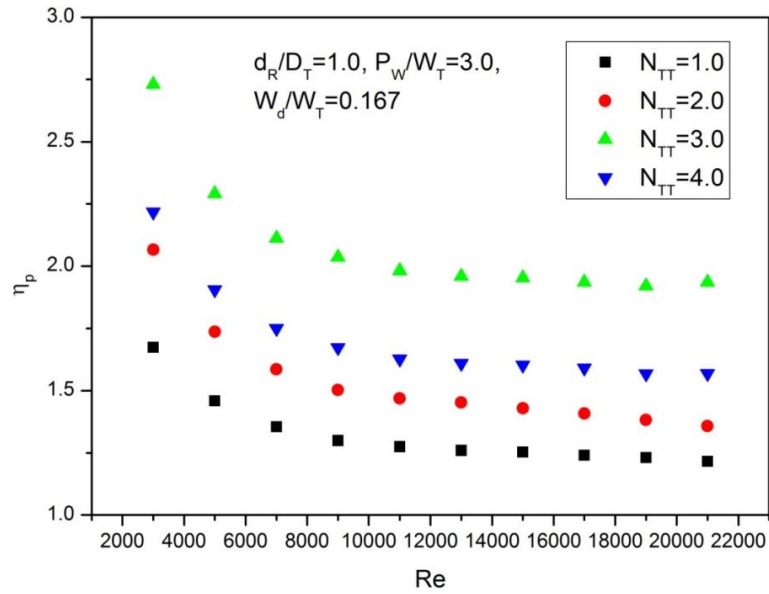


Fig.7 Variation of  $\eta_p$  with  $Re_{TT}$  for different values of  $N_{TT}$ .

Table.3 Comparative study of previous investigations.

S.N.	Investigator (s)	Twisted tape shapes	Maximum value of $\eta_p$
1.	Suri et al.[18]	Solid ring with multiple TT	2.03
2.	Kongkaitpaiboon et al.[ 19]	Perforated conical- ring	1.65
3.	Promvonge.[20]	Non-uniform wire coil combined with twisted tape	1.29
4.	Zhang et al.[21]	Helical screw tape	1.75
5.	Shabanian.[22]	Classic, Jagged and Butterfly with inclined angle of $90^\circ$ twisted tapes	1.54
6.	Krishna et al.[23]	Jagged twisted tape	1.12
7.	Eiamsa-ard et al.[24]	Regularly spaced TT	1.18
8.	Jaisankar et al.[25]	Left-Right inserts of twist with various spacer length.	1.51
9.	Jaisankar et al.[26]	Twisted tape geometry with twist ratio 3.0 (helical, Left- Right).	1.49
10.	Eiasma-ard et al.[27]	Helical screw-tape inserts.	1.43
11.	Seemawute and Eiamsa-ard.[28]	Peripherally-cut twisted tape with an alternate axis.	1.31
12.	Eiamsa-ard et al.[29]	Dual twisted tape	1.88
13.	Murugesan et al. [30]	V-cut twisted tape insert	1.71
14.	Present study	Multiple square wings with solid rings	2.75

## 8. Conclusions

In this article, experimental investigation is carried out to study the turbulent heat transfer and fluid flow characteristics in circular heat exchanger tube using wings with combination of solid ring twisted tape inserts. A series of experiments has been performed with the range of Reynolds numbers ( $Re_{TT}$ ) varied from 3000 to 21000, number of twisted taped inserts,  $N_{TT}$  varied from 1.0 to 4.0 with constant value of other twisted tape parameters such as rings pitch ratio,  $d_R/D_T = 1.0$ , wing pitch ratio,  $P_W/W_T = 3.0$  and wing depth ratio  $W_d/W_T = 1.67$ .

Based on the examined, turbulent heat transfer and fluid flow in wing with combined solid ring twisted tape inserts results are compared with plain circular tube under same operating conditions. The main findings of this paper are as follows:

1. The turbulent heat transfer and friction factor of the circular heat exchanger tube are strong function of number of twisted tape inserts,  $N_{TT}$ . The maximum enhancement in the turbulent heat transfer has been found to be 5.66 times over the plain tube corresponds to  $N_{TT} = 3.0$ .
2. A significant enhancement in the value of the thermal hydrodynamic performance has been found. The value of the thermal and hydrodynamic performance varies between 1.29 and 2.74 for the range of operating parameters investigated.
3. The thermal and hydrodynamic performance parameter based on equal pumping power,  $\eta_p$  was found to be highest for  $N_{TT} = 3.0$ . The optimum value of thermal and hydrodynamic performance has been found to be 2.74 for Re of 3,000 within the range of the parameters investigated.
4. Multiple wings with solid rings twisted tape inserts has also been shown to be thermal as well as hydraulic better in comparison to other similar twisted tape insert geometries.

### Nomenclature

A	Convection heat transfer area of channel, $m^2$
$C_p$	Specific heat capacity of air, J/kgK
$D_T$	Diameter of tube, m
$f_{TT}$	Friction factor
$h_{TT}$	Heat transfer rate coefficient $W/m^2K$
HET	Heat exchanger tube
k	Thermal conductivity of air, W/mK
L	Length of tube, m
$\dot{m}$	Mass flow rate of air, kg/s
$N_{TT}$	Number of twisted tape
$Nu_{TT}$	Nusselt number
$P_{TT}/H_{TT}$	Rib pitch ratio
$P_W$	Pitch between wings, m
$Pr_{TT}$	Prandtl number
$\Delta P$	Pressure drop, Pa
$q_{TT}$	Heat flux, W
Re	Reynolds number
$T_i$	Inlet temperature, K
$T_m$	Mean temperature, K
$T_o$	Outlet temperature, K
$T_L$	Twist length, m
$T_L/W_T$	Twist ratio
TT	Twisted tape
TTT	Typical twisted tape
$P_W/W_T$	Wing pitch ratios
$W_T$	Width of tape, m
$W_d$	Wings depth, m
$W_d/W_T$	Wing depth Ratios
$d_R/D_T$	Rings pitch ratios

### Greek Symbols

$\beta$	Ratio of orifice diameter to pipe diameter
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$\mu_{TT}$	Dynamic viscosity, Ns/m
$\rho_{TT}$	Density, Kg/m <sup>3</sup>
$\eta_p$	Performance evaluation factor

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