HYDRODYNAMIC AND THERMAL PERFORMANCE OF TWISTED TAPE INSERT PROVIDED IN HEAT EXCHANGER TUBES: A REVIEW

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ABSTRACT

This work presents a review of the research recent results concerning the augmentation of hydrodynamic and thermal performance of various twisted tape inserts in heat exchanger tubes. The thermal and hydrodynamic correlations for various twisted tape elements have been summarized. A comparative study of thermal and hydrodynamic performance of numerous twisted elements has also been reported to understand the result of applications of twisted tape inserts in heat exchanger tubes. The literature review found that multiple twisted tapes heat exchanger tube shape enhanced hydrodynamic and thermal performance than other comparable twisted tape inserts heat exchanger tube shapes. The review of twisted tape inserts techniques existing in this paper will be helpful to the investigators working in this field.

Keywords: Heat transfer; heat exchangers; passive techniques; fluid flow.

1. INTRODUCTION

Energy is a primary need to live our daily life at expenses of some valuable things such as environment degradation by using fossil fuels. Heat exchangers play a heating/cooling role in various fields like electric power, metallurgy, chemical engineering, refrigeration, and air-conditioning etc by Sunil *et al.* (2019), Singh Suri *et al.* (2017) and Kumar & Kim (2016). Circular tubes are widely used in heat exchange equipment's because of the ease of production and its capability of withstanding a high pressure Kumar *et al.* (2017) and Singh *et al.* (2018). Insertion of twisted tapes into a tube provides a simple passive technique for enhancing the heat transfer by introducing vortex generator into the bulk flow by breaking laminar sub layer at the tube wall due to repeated changes in the surface geometry. While insert technology is employed for augmented heat transfer, pressure drop would be improved by inserting in twisted tape in a tube Kumar *et al.* (2017), Singh *et al.*(2018), Yashwant Singh *et al.* (2018) and Maithani *et al.* (2019).

Twisted tapes with various shapes were proposed and utilized by various researchers. Numerous investigations have carried out the investigators in twisted tape inserts and thus, there is need to review the past and current research so that the further research scopes can be identified and implemented. The present article is thus aimed with following objectives:

- To review the augmentation in heat transfer and pressure drop in heat exchanger tubes equipped with various twisted tape inserts.
- To arrange the heat transfer and pressure drop correlations of a variety of twisted tape inserts in heat exchanger tubes.
- To carry out comparative study of heat transfer and pressure drop of heat exchanger tubes equipped with twisted tape insert.

In order to achieve the desired objectives, the article is structured batch wise for each objective clearly addressed and explained in their respective context.

2. LITERATURE REVIEW ON TWISTED TAPE INSERT IN HEAT EXCHANGER TUBES

Efforts for improving the thermal and hydrodynamic performance of heat exchangers have directed the investigation in the direction of disturbing the viscous sub layer by proving twisted tape inserts. Many investigations have been carried out to analysis the flow field characteristics of thermal and hydrodynamic of twisted tape insert tubes. Singh *et al.* (2017) examined the efficiency factor of twisted tape round tube for stable heat flux. The Reynolds number covered in the range of 6300 to 22500 for co-twist arrangements in the turbulent flow of air in the round tube. Kongkaitpaiboon *et al.* (2010) experimentally investigated the augmentation of thermal hydrodynamic performance in circular tube equipped with perforated conical rings. It was concluded that the augmentation in thermal and hydraulic performance achieved was 3.67 and 2.89 times more than plain circular tube, respectively. Li and Guo (2009) carried out experimental and numerical investigation of turbulent heat transfer and stream resistance in an improved round tube equipped with twisted tape inserts.

Promvonge (2008) experimentally studied the thermal and hydrodynamic performance of circular HET fitted with wire coiled inserts. The maximum value of thermal and hydrodynamic performance has been found to be 2.13 within the range of the parameters examined. Zhang and Zhang and Liu (2013) carried out numerical analysis of 3D turbulence fluid flow to study heat transfer and fluid flow

characteristics for helical screw tape inserts without core rod inserts. Shabanian *et al.* (2011) performed an experimental and computational analysis to study the thermal performance in an air cooled round tube fitted with three different types of tape inserts. Krishna *et al.* (2009) investigate thermal performance enhancement technique and concluded that heat transfer and friction factor enhancement in helical and left–right twisted tape collectors was better than the plain circular tube collector and it was 3.78 and1.45 times more than that of plain tube collector. Eiamsa-ard *et al.* (2006) carried out a comparative experimental study on thermal performance in a round tube with regularly spaced tape inserts and plane tube. The results of the study reveal that thermal performance increases with decrease of space ratio.

Naphon *et al.* (2006) carried out an experimental study to the behaviour of heat transfer and flow friction in horizontal double circular tubes equipped with tape inserts having length and thickness 2.0 mm and 0.01 mm respectively. Maddah *et al.* (2014) conducted an experimental investigation on heat transfer augmentation of Alumina/water nanofluid in a flat double circular tube with customized tape inserts. Sharma *et al.* (2009) experimentally examined the thermal performance by establishing mathematical relationship among Nusselt number and friction factor. The working Alumina/water nanofluid was circulated through a circular round tube of with tape inserts. Eiamsa-ard *et al.* (2012) carried out an experimental investigation to study thermal performance using helically inserts by using three different y_{rs} and helical H_{rs} 2.0-3.0. It was found that by inserting helically tape inserts the value of hydrodynamic and thermal performance was significantly higher than conventional helical tape. Eiamsa-ard and Wongcharee (2013) examined the thermal performance in circular tube fitted with dual tape inserts in three different types of geometrical configurations. Jaisankar *et al.* (2009) experimentally investigated the efficiency factor of twisted inserts with various spacer length inserts in a thermosyphon solar water heating system.

Jaisankar *et al.* (2008) conducted an experimental investigation on heat efficiency factor of solar heater's hose tube with tape inserts of various twist ratios. Jaisankar *et al.* (2011) conducted an experimental investigation to study the characteristics of hydrodynamic and thermal performance of water heat exchanger equipped with helical and left-right tape inserts. Eiamsa-ard and Promvonge (2011) investigated thermal performance for turbulent flow rate through a round tube equipped with straight tape with double sided delta wings. Nananet *et al.* (2014) carried out an experimental investigation to study heat transfer enhancement by perforated helical tape inserts in circular tube. Eiamsa-ard *et al.* (2010) conducted an experimental investigation to study thermal performance in a circular tube fitted with triple twisted tape inserts along with alternate clockwise and counter clockwise twisted tape inserts.

Sarada *et al.* (2010) studied the Nu_{rs} increase in a round tube with changing breadth of tape inserts. Their outcome demonstrates that the utmost augmentation in thermal and hydraulic performance is observed to be 2.16 and 2.66 times of that of the plain round tube, respectively. Eiamsa-ard and Promvonge (2010) experimentally studied the thermal behaviour of plane circular pipe equipped with multi tape inserts along with various clock wise and counter clockwise tape inserts. Eiamsa-ard *et al.* (2006) experimentally studied the behaviour of flow friction and heat transfer in two-fold round tube fitted with tape inserts. A significant improvement were noticed in both flow friction and heat transfer. Eiamsa-ard *et al.* (2010) examined thermal performance in a round tube fitted with pooled devices among the tape inserts and steady or at regular intervals varying wire coil insert. Eiamsa-ard *et al.* (2010) experimentally investigated the efficiency factor in a circular pipe fitted with delta-winglet tape inserts. Sharma *et al.* (2003) explored a new method to enhance heat transfer in a round pipe equipped with twisted tape inserts. Sharma *et al.* (2005) discovered new mathematical generalized correlations for heat transfer and fluid flow for a round pipe fitted with twisted tape inserts. Yilmaz *et al.* (2003) carried out an experimental investigation to study the effects of special geometry of various components on efficiency factor. Chang *et al.* (2007) conducted

an experimental investigation on twisted tape with cut and explored enhancement in performance of twisted tape with cut in comparison to smooth round tube. Chang *et al.* (2007) carried out an experimental investigation to study thermal performance in a round tube fitted with jagged tape inserts.

Seemawute and Eiasma-ard (2010) experimentally investigated the thermal performance through a round pipe having peripherally-cut twisted tape inserts. The thermal performance in round tube with peripherally-cut tape inserts with alternate axis, peripherally-cut tape inserts and multi tape inserts was found 23%, 45% and 62%, respectively than that of plain round tube. Eiamsa-ard *et al.* (2010) experimentally examined the behaviour of thermal performance for a round tube fitted with sole tape inserts, complete length dual tape inserts and on a regular basis spaced dual tape inserts below identical wall heat flux circumstances. Bhuiya *et al.* (2013) experimentally examined the thermal performance for a turbulent flow through a round tube fitted with perforated tape inserts. The experimental consequences revealed a significant augmentation in thermal performance than the consequences of plain round tube. Karami *et al.* (2012) experimentally analysed the thermal performance in an air cooled round tube heat exchanger equipped with typical tape inserts. Murugesan *et al.* (2011) experimentally examined the efficiency factor for plain round pipe fitted with V-cut tape insert.

Murugesan *et al.* (2010) experimentally investigated the thermal performance of a double round tube fitted with simple plane tape inserts and tape having wire nails. Murugesan *et al.* (2010b) experimentally investigated the efficiency factor for a double circular tube having square-cut tape inserts and plain tape inserts. Their results revealed that the thermal performance for round tube equipped with square-cut tape inserts were significantly more than plain tape inserts. Promvonge and Eiasma-ard (2007) experimentally studied the augmentation in thermal hydrodynamic performance of round tube attached with narrow conical ring. Nagarajan *et al.* (2010) experimentally examined the augmentation of thermal hydrodynamic performance of round tube attached with left-right tape inserts. New empirical correlations based on experimental data were introduced for thermal performance.

Thianpong *et al.* (2009) carried out an investigation to examine the thermal performance in a dimpled shape circular tube fitted with different tape inserts. Sivashanmugam and Suresh (2006) analysed the circular pipe fitted with helical twisted tape inserts experimentally. Sivashanmugam and Suresh (2007) experimentally determined the efficiency factor for circular pipe incorporated with various helical ST inserts having spacer distance end to end 100 mm, 200 mm, 300 mm and 400 mm. Chang *et al.* (2009) experimentally examined the thermal performance in a round tube equipped with various tape inserts. Eiamsa-ard *et al.* (2009) experimentally examined the thermal performance in turbulent section for round tube fitted through small length tape inserts. Promvonge (2008) experimentally examined the thermal performance in turbulent flow within a round pipe fitted with wire coils shape inserts and tape inserts.

Bharadwaj *et al.* (2009) analysed the augmentation of thermal hydrodynamic performance of round tube attached with grooved twisted tapes. Mazumder and Saha [2008] experimentally investigated the thermal performance in heat exchanger fixed with tape inserts for turbulent flow. Murugesan *et al* .(2012) carried out an experimental investigation of thermal performance through circular tube incorporated with various twisted tape inserts. The range of Reynolds number (Re_{rs}) was varied from 2000 to 12000 and water was taken as base fluid in the experiment. Wongcharee and Eiamsa-ard (2011) experimentally determined the thermal performance of round tube attached with customized tape inserts with alternating alignment. Zhang *et al.* (2012) experimentally examined the thermal performance in a round pipe with three and four tape inserts. Their analysis shows a significant improvement of thermal performance for three and four tape inserts. Ray and Date (2001) investigated thermal performance in heat exchanger fitted with tape inserts. The outcome of the analysis yields a significant improvement in thermal performance for twisted tape inserts

as compared plain heat exchanger. Salam *et al.* (2013) conducted an experimental analysis to study the behaviour of flow friction and heat transfer in turbulent flow in a heat exchanger with rectangular slash tape inserts. Pal and Saha (2014) experimentally investigated the efficiency factor in a tube fitted with coiled corrugation roughness along with oblique teeth tape inserts. The working fluid in the experiment was taken viscous oil with laminar flow. Klaczak (2000) investigated the efficiency factor in round tube with erect copper pipe tape inserts. Experiments were carried out with air as working fluid and four tape inserts of twist ratio ranging from 1.63 to 5.28 and the range of Reynolds number varied from 110 to 1500. Rout and Saha (2013) examined the behaviour of heat transfer and pressure for laminar flow inside a round pipe with tape inserts constituted from wire coil helical screw.

Agarwal and Rao (1996) experimentally studied the augmentation of thermal hydrodynamic performance of double pipe with wire coiled inserts. The experiments examined double pipe in succession by keeping wall temperature constant. Sivashanmugam and Suresh (2006) experimentally examined the behaviour of heat transfer and pressure drop in laminar stream in circular pipe with twisted tape as inserts for twist ratio values of 1.94, 2.92, 3.92, and 4.88. Wongcharee and Eiamsa-ard (2011) experimentally examined the thermal performance in round tube along with alternating anti-clockwise and clockwise tape inserts. It was found that the performance of round tube alternating anti-clockwise and clockwise tape inserts significantly enhances the thermal performance as compared to tube with tape inserts. Sujoy et al. (2012) experimentally examined efficiency factor for laminar flow in round tube made up of circular passage with centre-cleared.

Sujoy (2012) experimentally examined laminar flow in a heat exchanger fitted with centre-cleared twisted tape insert. Ibrahim (2011) experimental examination to determine the efficiency factor in round tube was carried out with flat double round tube with full length helical screw tape inserts. Patil (1999) experimentally examined the performance of heat transfer in laminar flow in heat exchanger equipped with circular pipe and varying width tape inserts. Saha (2010) experimentally examined the behaviour of heat exchanger equipped with twist tape of square cut as well as rectangular segment with slanting ribs. Saha and Mallick (2004) experimentally examined the changes in behaviour of Nusselt number and flow friction of laminar stream through specially designed heat exchanger made up of duct shaving square cut and rectangular segment twisted tape with or without slanting teeth.

Pramanik and Saha (2006) experimentally examined the thermal performance in laminar stream flowing in round tube fitted with flat rectangular and square passage fitted tape inserts. Their investigation showed that the performance of twisted tape having regularly spaced geometry was improved than that full-length twisted tape inserts. Bilen *et al.* (2001) examined the heat transfer rate of heat exchanger tube equipped with rectangular blocks by using Taguchi method, considering angular displacement of the block with span and stream wise disposition. Kurtbas *et al.* (2009) experimentally examined the performances of heat transfer and friction loss in a round tube by constructing a novel conical twisted tape inserts. Al-Fahed *et al.* (1998) experimentally examined the behaviour of heat transfer and flow friction factor using oil as a functional fluid and then compared these results for a plain round tube, micro fins and tape inserts. Promvonge (2007b) carried out an experimental investigation to study the augmentation of thermal hydrodynamic performance of round tube fitted with numerous twisted tape shapes. In the experiment range of Reynolds number was varied from 3000 to 18000 laterally with three different pitch ratios ranging from 4.0 - 6.0. Chompookham *et al.* (2010) experimentally examine the behaviour of wedge obstacle and winglet vortex generators. It was discovered that the combined ribs and the WVG show the considerable enhancement in efficiency factor over the smooth passage. Bartwal *et al.* (2018) experimentally investigated passive heat transfer enhancement technique. Air was used as a working fluid with the range of Reynolds number varied from 5000 to 40,000.

The maximum TEF of 2.84 is retrieved for the $PR = 3$, and $G = 9$. Akhavan-Behabadi *et al.* (2010) experimentally studied the augmentation of thermal hydrodynamic performance of round tube attached with various coiled wires inserts. Meng *et al.* (2005) examined the thermal hydrodynamic performance of round tube attached with vortex generator. Their analysis showed that the DDIR tube inserts has better thermal performance than the other tubes.

Sarac and Bali (2007) experimentally studied the augmentation of thermal hydrodynamic performance of round tube attached with vortex generator. Their analysis showed that the decaying of the efficiency factor decreased steadily from the axial. Yang *et al.* (2011) investigated that the convergence of the tube can raise the stream rate which can decrease the turbulence generated in the stream and consequently there is decline in the heat transfer. Datt *et al.* (2018) presents the heat transfer and friction characteristics of turbulent circular tube flow through a square wing with combined solid ring twisted tape inserts have been analyzed experimentally. The finest value of thermal and hydrodynamic performance has been found to be 2.74 for of 3,000 within the range of the parameters investigated.

Hong *et al.* (2019) investigated turbulent thermal and fluid flow characteristics of multiple twisted tapes (MTTs) inserted sinusoidal rib tube (SRT) heat exchangers. The results ravelled that by inserting SRT there is increase in heat transfer enhancement of about 27.4%–39.5% and increased friction loss of around 49.4%–74.7% higher than that in the baseline of spirally corrugated tube (SCT), also the overall thermal performance was enhanced up to 1.59 for the alone use of SRT. Piriyarungrod *et al.* (2018) presents the thermo-hydraulic characteristics in the heat exchanger tube inserted with multiple-twisted tapes (M-TT). The experimental results found that the use of multiple-twisted tapes (M-TT) with N = 3, 4, 5 and 6 leads to the considerable increases in heat transfer enhancement and friction factor as compared to those of single twisted tape.

Farnam *et al.* (2018) explored that the heat transfer coefficient and pressure drop of the straight-tube and twisted-tube fitted with twisted-tapes are higher than those of the straight-tube and twisted-tube alone, and evidently, both the parameters increase with the decrease in the twist ratio. Eiamsa-ard, and Wongcharee (2018) developed Micro-fin tubes into which non-uniform twisted tapes were inserted in a counter-current arrangement gave higher heat transfer enhancement than the ones in a co-current arrangement. Karami *et al.* (2012) developed imperialist competitive algorithm is used to obtain optimize heat transfer rate in an air cooled heat exchanger fitted with the classic twisted tape inserts. According to the results, in order to obtain greatest heat transfer rate, the twist ratio must be at the lowest level.

Sarviya and Fuskele (2018) investigated heat transfer augmentation using a novel kind of twisted tape inserts with continuous cut edges. From obtained results it is evident that higher heat transfer rates can be achieved by employing twisted tape inserts with continuous cut edges at the cost of a reasonable pressure drop. Sarviya and Fuskele (2018) experimentally examined the thermal hydraulic performance of a heat exchanger tube equipped with various twisted tape widths and twist ratios. It can be seen that the combining effects of both the geometric and structural modifications, an improved design with optimum comprehensive performance was suggested.

Ayub *et al.* (2018) developed unique shell and tube heat exchanger with interstitial twisted tapes was tested with propylene glycol/water solution. From results it is clear new design heat exchanger showed better thermal enhancement index for the whole range of fluid concentrations. Lei *et al.* (2017) carried out numerical simulations to investigate the thermo-hydraulic performance of the two reformed shell-and-tube heat exchangers equipped with louver baffles. The numerical results revealed that the heat transfer coefficient per pressure drop of both the shell-and-tube heat exchangers with louver baffles are higher than that of the shell-and-tube heat exchanger with segmental baffles. Han *et al.* (2019) carried out multi-objective optimization of corrugated tube with loose-fit twisted tape to achieve the optimal performance, using response surface methodology and Non-dominated

sorting genetic algorithm . The optimal design variables against *Re* are also obtained, which carried out practical significances for designing perfect heat exchanger.

Li *et al*. (2019) a numerical investigation is conducted to investigate air side heat transfer and pressure drop performance of twisted oval tube bundles with in line layout in cross flow. The results revealed that the twisted oval tube bundles perform excellent heat transfer performance compared with other tube bundles in cross flow. Li *et al*. (2019) the ratio of outer major axis to outer minor axis, twist pitch length, transverse tube pitch, longitudinal tube pitch and number of longitudinal tube rows on the air side heat transfer tube and pressure drop performance are examined, which reveals that the twisted oval tube is an aerodynamic tube that is free of the angle of attack. Tan *et al*. (2012) concluded that the emergence of twist in the twisted oval tube results in secondary flow and it is this secondary flow that enhances the total velocity and temperature distributions of the twisted oval tube. Saravanan and Jaisankar (2019) examined that the helix with V cut twisted tape insert has given better thermal performance than helix with square cut twisted tape insert for an identical twist ratio. Aroonrat and Wongwises (2019) determine the influence of dimpled depth on the condensation heat transfer coefficient and pressure drop of R-134a flowing inside circular dimpled tubes. Wang *et al*. (2019) investigated the heat transfer performance in laminar flow of a round tube equipped with a longitudinal vortex generator. Results reveal that multiple pairs of additional longitudinal vortexes are developed, and the fluid can rub the tube wall due to the concave shape surface of the insert.

Ponnada *et al*. (2019) the effect of perforated twisted tapes with alternate axis, perforated twisted tapes and regular twisted tapes with different twist ratios are compared by experimental investigation in a circular tube under constant heat flux condition. At constant pumping power, the maximum thermal performance factor obtained is 1.433, 1.396 and 1.24 respectively for perforated twisted tapes with alternate axis, perforated twisted tapes and regular twisted tapes. Abolarin *et al*. (2019) experimentally investigate the heat transfer and pressure drop characteristics in a smooth circular tube with alternating clockwise and counter clockwise twisted tape inserts. An increase in heat flux significantly enhanced the heat transfer in the laminar flow regime and delayed transition.

Geometries/parameters of various twisted tape inserts and correlations developed between the parameters by various investigators for heat transfer, pressure drop and thermal-hydraulic performance for different twisted tape inserts used in heat exchanger tubes are given in Table1.

3. COMPARATIVE STUDY OF VARIOUS TWISTED TAPE INSERT HEAT EXCHANGER TUBES

From the investigation of heat transfer and pressure drop it is concluded that heat transfer in the twisted tape inserts in round tube is improved with a significant rise in the pressure drop. Thus, it is important to choose twisted tape geometry that should not only outperformed in heat transfer but also retain the pressure drop at a minimum possible level. In order to achieve this goal of simultaneous consideration of thermal as well as hydraulic performance a parameter that is taken in consideration is known as efficiency parameter. The optimum data selected for various parameters of the tape inserts are like, twist length, twist ratio, pitch ratio, twist angle, etc. Thermal hydraulic performance parameter of various twisted tapes has been determined using their corresponding correlations of heat transfer rate; friction factor and thermal hydraulic performance as listed in Table 1.

Figure 1 represents the multiple twisted tape inserts shape that provides the utmost value of thermal hydraulic performance with air as test fluid among all the twisted tape shapes examined. Figure 2 represents the multiple spiky twisted tape inserts shape that provides the utmost value of thermal hydraulic performance with water as test fluid among all the twisted tape shapes examined. Figure 3 represents the circular with center cleared twisted tape inserts shape provides the utmost value of thermal hydraulic performance with oil as test fluid among all the twisted tape shapes examined. In a dynamic air field

stream, the roughness creates turbulence and improves the heat transfer/exchange by convection. The literature reveals that single twisted tape inserts in a tube of heat exchanger thermo-hydrodynamically performs best as compared to delta and helical twisted tape inserts, as the twist ratio induces multiple vortex stream cells which helps to enhancement of local heat transfer rate. Various investigators concluded that multi type twisted tape inserts in heated tube surface of a heat exchanger tube boost up the rate of heat transfer. Further it was concluded that the utilization of multiple twisted tape increases the number of vortex flow as compared to single twisted tape inserts, which helps to increase the heat transfer rate, as shown in Figure 4.
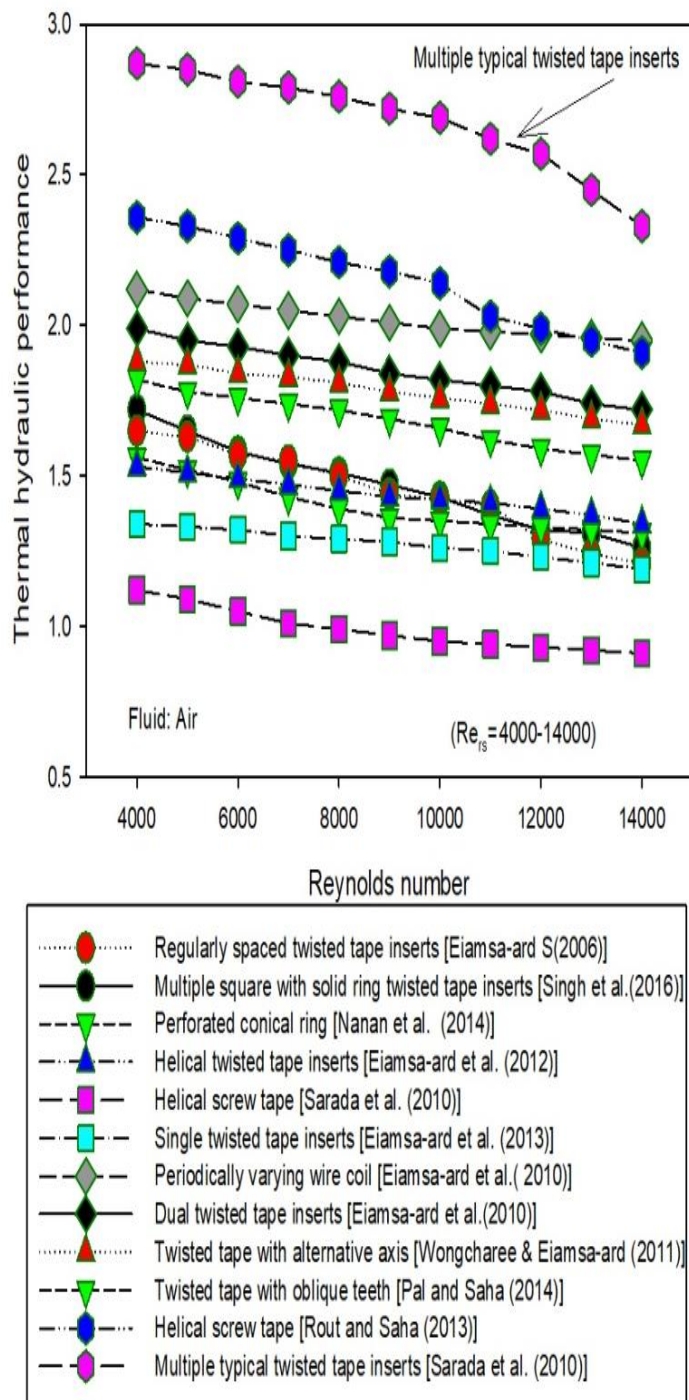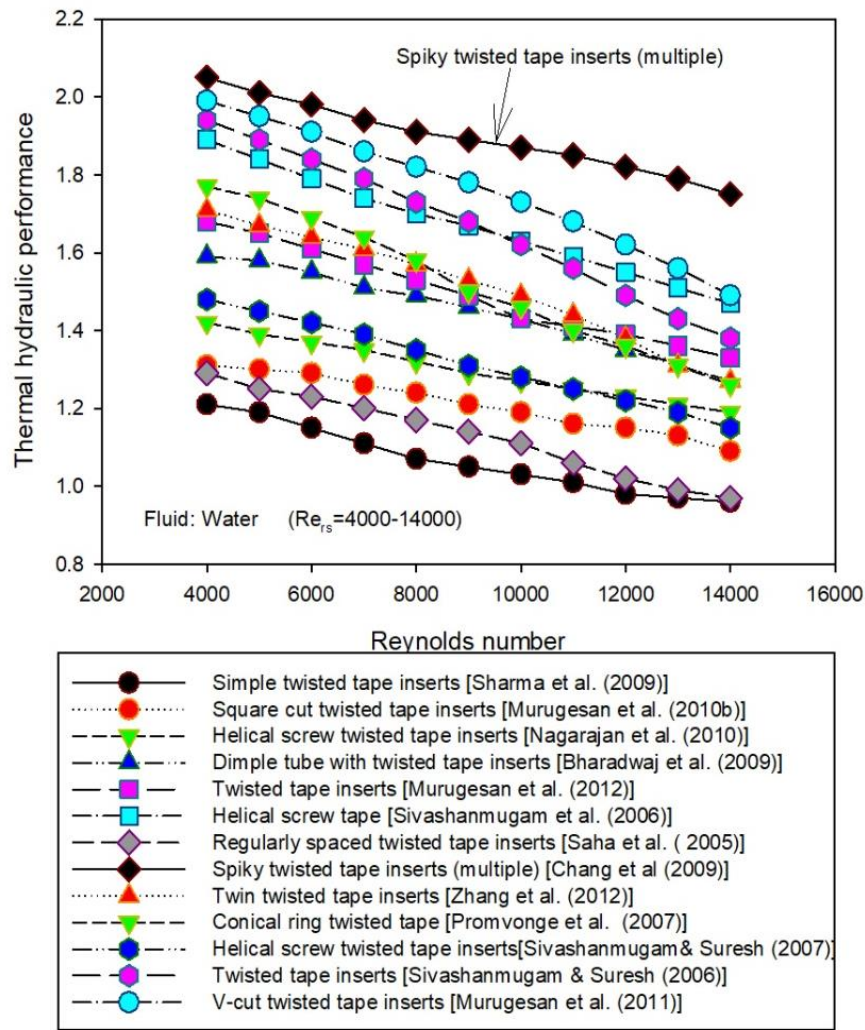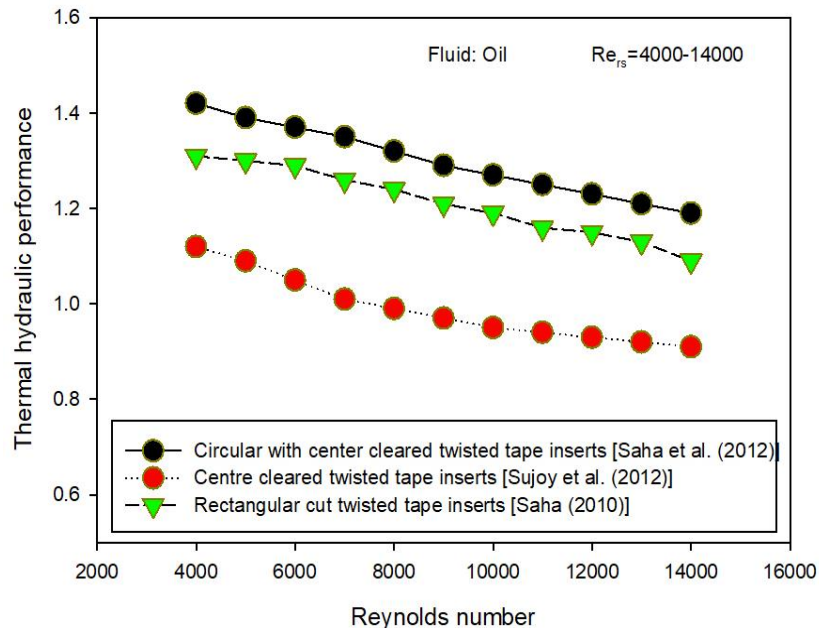

Fig. 1 Comparison of thermal hydraulic performance as function of Reynolds number for different type of twisted tape inserts with air as working fluid.
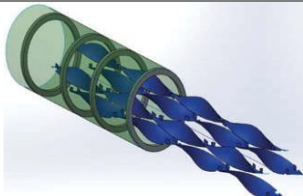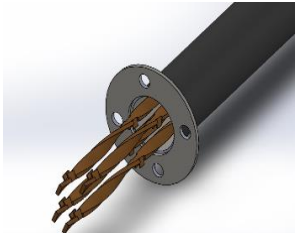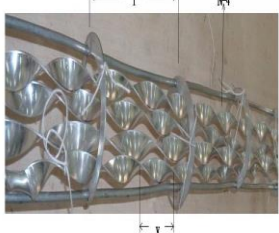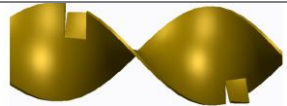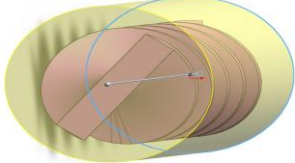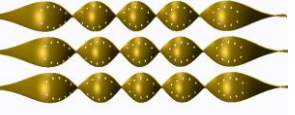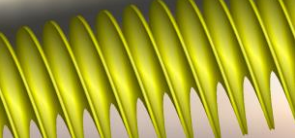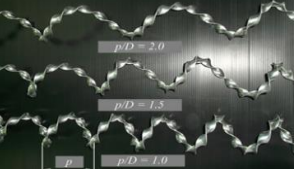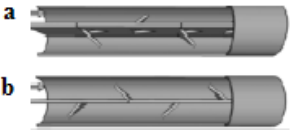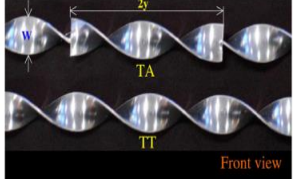
Fig. 2 Comparison of thermal hydraulic performance as function of Reynolds number for different type of twisted tape inserts with water as test fluid.
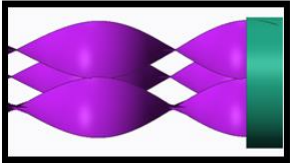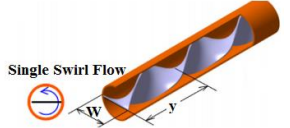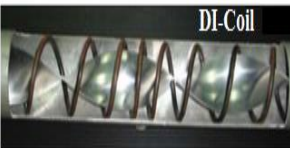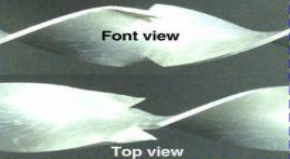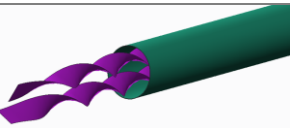

Fig. 3 Comparison of thermal hydraulic performance as function of Reynolds number for different type of twisted tape inserts with oil as test fluid.
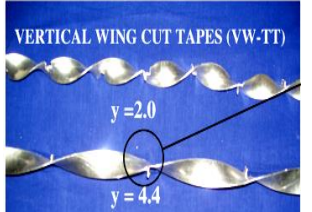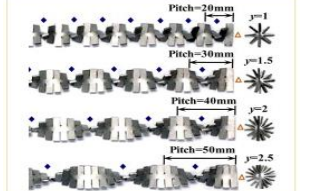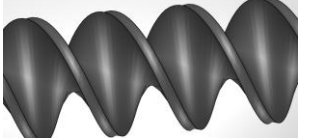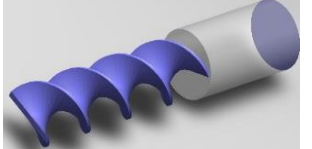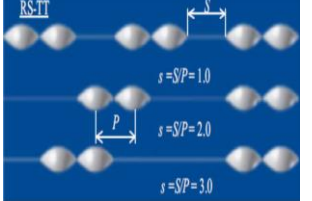
Table 1 Correlations developed for heat transfer; pressure drop and thermal hydraulic performance in twisted tape insert heat exchanger tubes.
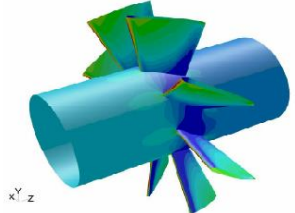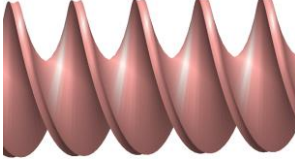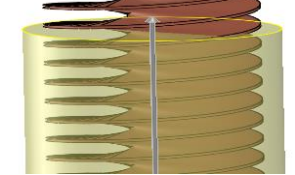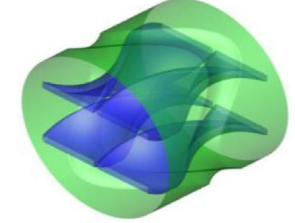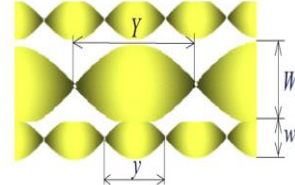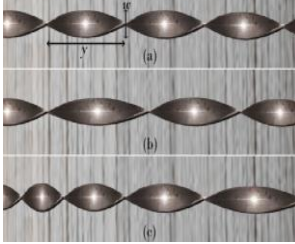
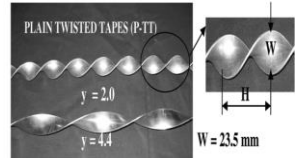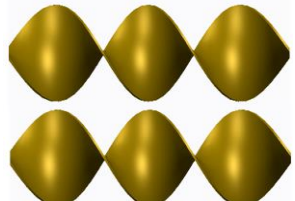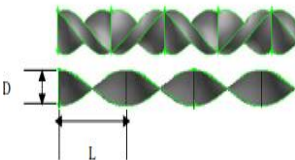| Twisted tape geometry Working fluid: Air	Parameters/optimum ranges	Correlations
Tube with solid rings and square wings TT inserts. Datt et al. (2018).	Fluid: Air Parameters: $3000 \leq Re_{rs} \leq 21000$ $NTT = 1.0{-}4.0$, $dR=DT = 0.5{-}2.0$, $PW=WT = 2.0{-}3.5$, $Wd=WT = 0.083 \quad\quad -0.333$, $Nu_{rs} = 283$, $f_{rs} = 0.62$ $\eta_\rho = 1.29$ and 2.74	$Nu_{TT} = 0.0007Re^{0.74}(d_R/D_T)^{0.17}B_o\ (d_R/D_T)^{0.17}$ $exp[-0.18\ ln(d_R/D_T)^2]\ (P_W/W_T)^{2.53}$ $\qquad exp[-1.26(ln(P_W/W_T))^2] \times (W_d/W_T)^{-0.78}$ $\times \qquad exp\left(-0.19(ln(W_d/W_T))\right)^2$ $\times (d_{iR}/d_{oR})^{7.57}exp\left(-2.3(ln(d_{iR}/d_{oR}))\right)^2 \times (N_{TT})^{0.69}exp\left(-0.25(ln(N_{TT}))\right)^2$ and $f_{TT} = 0.47Re^{-0.128}(d_R/D_T)^{1.97}$ $exp(-0.047(ln(d_R/D_T)))^2(P_W/W_T)^{-0.022}$
Multiple squares perforated twisted tapes inserts. Singh et al. (2017).	Fluid: Air Parameters: $5000 \leq Re_{rs} \leq 24000$ a/W_T of 0.250 and T_L/W_T of 2.5 Minimum and maximum values of results: $Nu_{rs} = 2.12 - 5.69$ $f_{rs} = 0.15-\quad\quad 0.32$, $\eta_\rho = 2.2 - 3.8.$	$Nu_{rs} = Re_n^{0.9204} \times (a/W_T)^{-1.062}Exp\left(-0.329(ln(a/W_T))\right)^2 \times (T_L/W_T)^{1.8701}\ Exp(-1.136ln(T_L/W_T)^2)$ $f_{rs} = 2.68Re_n^{-0.4077}(a/W_T)^{-0.9735}Exp(-0.2978\ ln(a/W_T))^2$ $\times (a/W_T)^{1.841}$ $\times Exp(-1.2398ln(T_L/W_T)^2)$ $\eta_p = 1.64 \times 10^{-2}Re_n^{0.3389} \times (a/W_T)^{-0.5337}Exp\left(-0.1625(ln(a/W_T))^2\right) \qquad \times (T_L/W_T)^{3.7071}\ Exp(-2.1598ln(T_L/W_T)^2)$
Solid ring with multiple twisted tapes inserts. Singh et al. (2016).	Fluid: Air Parameters: $6300 \leq Re_{rs} \leq 22500$ Twist ratios 2, 3, and 4. Minimum and maximum values of results: $Nu_{rs} = 20 - 120$ $f_{rs} = 0.010 - 0.027$, $\eta_\rho = 1.6 - 2.0.$	$Nu_{rs} = 0.09653(Re_{rs}^{0.7834})\ N^{0.0551}exp(0.0256lnN^2)TR^{0.2127}$ $exp(-0.1696lnTR^2)$ $f_{rs} = 1.073(Re_{rs}^{-0.0786})\ N^{0.0352}exp(0.1094lnN^2)TR^{0.4696}$ $exp(-0.3760lnTR^2)$ $\eta_{rs} = 3.033(Re_{rs}^{-0.0786})\ N^{0.0188}exp(0.1063lnN^2)TR^{0.1304}$ $exp(-0.0968lnTR^2)$ $Nu_{rs} = 0.0832(Re_{rs}^{0.7899})\ N^{0.0383}exp(0.0355lnN^2)TR^{0.23757}$ $exp(-0.2488lnTR^2)$ $f_{rs} = 1.042(Re_{rs}^{-0.0539})\ N^{0.0873}exp(0.0772lnN^2)TR^{0.4780}$ $exp(-0.3660lnTR^2)$ $\eta_{rs} = 2.94(Re_{rs}^{-0.0771})\ N^{0.0072}exp(0.0237lnN^2)TR^{0.1097}$ $exp(-0.0814lnTR^2)$
T wisted tape inserts with and without oblique teeth. Pal and Saha (2014).	Fluid:Air, Parameters: $y_{rs} = 2.20$ and $5.0.$ Minimum and maximum values of results: $Nu_{rs} = 5 - 57$ $f_{rs} = 0.2 - 1.2$, $\eta_\rho = 1.3 - 1.82.$	$Nu_{rs} = 5.172Gz^{0.3699}\left(\frac{Re_{rs}}{\sqrt{F}}\right)^{0.1414}[Pr_{rs}^{0.2048}Gr^{-1434}$ $(sin\theta)^{0.33710}]$ $f_{rs} = 17.355(Re_{rs}/\sqrt{V})^{0.043491}$ $(sin\alpha)^{-0.100061}h_c^{-0.8215}t_{hl}^{-0.07074}(sin\theta)^{-0.375767}$
Perforated conical ring twisted-tapes. Nanan et al. (2014).	Fluid: Air Parameters: $6000 \leq Re_{rs} \leq 20000$, Pitch ratios = 4.0, 6.0, 12.0. Holes perforation N = 4, 6 and 8. Minimum and maximum values of results: $Nu_{rs} = 24 - 94$ $f_{rs} = 0.03 - .042$, $\eta_\rho = 1.28.$	$Nu_{rs} = 0.035Re_{rs}^{0.795}Pr_{rs}^{0.4}(d/w)^{-0.068}(s/w)^{0.066}$, $f_{rs} = 1.915Re_{rs}^{-0.299}(d/w)^{-0.068}(s/w)^{0.994}$ and $\eta_{rs} = 4.058Re_{rs}^{-0.145}(d/w)^{-0.045}(s/w)^{0.045}$

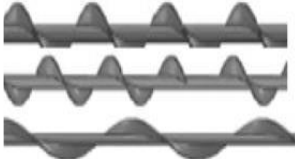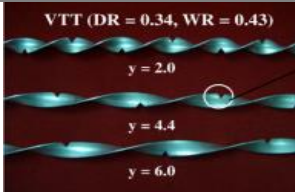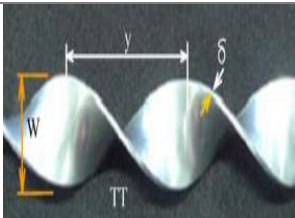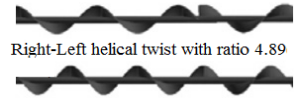|		
Micro–fins tubes. Eiamsa-ard et al. (2013).	Fluid: Air, Parameters: $5660 \leq Re_{rs} \leq 17000$. Minimum and maximum values of results: $Nu_{rs} = 39 - 410$ $f_{rs} = 0.5 - 0.46$, $\eta_{\rho} = 1.1 - 1.94$.	$Nu_{rs} = 0.185 Re_{rs}{}^{0.49} Pr_{rs}{}^{0.4} (y_{rs}/D_s)^{-0.21}$ $f_{rs} = 4.14 Re_{rs}{}^{-0.25} (y_{rs}/D_s)^{-0.21}$, $Nu_{rs} = 2.29 Re_{rs}{}^{0.48} Pr_{rs}{}^{0.4} (y_{rs}/D_s)^{-0.21}$ (TT taken in reverse directions for offset swirl) $f_{rs} = 5.29 Re_{rs} e^{-0.26} (y_{rs}/D_s)^{-0.33}$
Perforated twisted tape insert. Bhuiya et al. (2013).	Fluid: Air Parameters: $72000 \leq Re_{rs} \leq 50,200$ Minimum and maximum values of results: $Nu_{rs} = 80 - 290$ $f_{rs} = 0.032\ 0.14$, $\eta_{\rho} = 1.3 - 1.6$.	$Nu_{rs} = 0.0002 Rp^3 - 0.0046 Rp^2 + 0.0034 Rp + 0.6569 Re_{rs}\ [0.00005 Rp^3 - 0.0013 Rp^2 + 0.0073 Rp + 0.5501] Pr^{0.33}$ $f_{rs} = -0.0027 Rp^3 - 0.0583 Rp^2 + 0.0455 Rp + 25.436\ Re_{rs}\ [0.0009 Rp^3 - 0.0022 Rp^2 + 0.012 Rp - 0.6001]$.
Helical screw-tape. Kumar et al. (2013).	Fluid: Air Parameters: $10 \leq Re_{rs} \leq 1000$ Wire diameter 0.0769, 0.1026) Helix angle 30º ,60º) Minimum and maximum values of results: $Nu_{rs} = 5 - 132$, $f_{rs} = 0.02 - 1.2$, $\eta_{\rho} = 1.45 - 1.71$.	$Nu_{rs} = 5.172 \left\{ \left[(1 + 0.08932 Gz^{0.9125})^{2.5} + 802273 \times 10^{-6} (Sw.Pr_{rs}{}^{0.565})^{2.655} \right]^{2.0} + 1.5638 \times 10^{-15} (Re_{rs} Ra)^{2.18} \right\}^{0.1} (\mu_b/\mu_w)^{0.14} \times [1 + exp(0.08858 p)]$ $+ [1 + \exp(0.08135.\sin\theta) / (d/D_{rs})^{-0.6683}]$ ('θ' = coil helix angle). $f_{rs} = 17.355 \left(\frac{\pi + 2 - 2\delta/D_{rs}}{\pi - 4\delta/D_{rs}} \right)^2 (1 + 10^{-6} Sw^{2.67})^{1/7} \times [1 + \exp(0.05538.\sin\theta) / (d/D_{rs})^{-0.6938}] [1 + exp(0.0785 p)]$
Classic twisted tape inserts. Karami et al. (2012).	Fluid: Air Parameters: $4021 \leq Re_{rs} \leq 16116$ $y_{rs} = 1.75, 2.3, 2.9$ and 3.5 Minimum and maximum values of results: $Nu_{rs} = 49.07 - 116.19$	$Nu_{rs} = 90.2 + 14.7 Re_{rs} - 3.72 R - 0.276 Re_{rs}{}^2 - 0.539 Re_{rs} \times R$
Helical twisted tape. Eiamsa-ard et al. (2012).	Fluid: Air Parameters: $2000 \leq Re_{rs} \leq 6000$ 2, $y_{rs} = 2.0, 2.50, 3.10$. Pitch ratios 1.5 & 3.0. Minimum and maximum values of results: $Nu_{rs} = 35 - 120$ $f_{rs} = 0.03 - 0.042$, $\eta_{\rho} = 1.29$.	$Nu_{rs} = 0.96 Pt^{0.4} \left(\frac{p}{D} \right)^{-0.18}$ $Nu_{rs} = 0.053 Re_{rs}{}^{0.796}\ Pt^{0.4} \left(\frac{Y_{rs}}{W} \right)^{-0.127} \left(\frac{p}{D} \right)^{-0.188}$ and $f_{rs} = 12053 Re_{rs} - 0.2959 \left(\frac{Y_{rs}}{W} \right) - 0.652 \left(\frac{p}{D} \right)^{-1.513}$
(a)TT with back wing. (b)TT with forward wing. Eiamsa-ard et al. (2011).	Fluid: Air Parameters: $4000 \leq Re_{rs} \leq 20000$ Wing width ratios of 0.5, 0.67 and 0.83. $y_{rs} = 0.75$, 1.0 and 1.25. Minimum and maximum values of results: $Nu_{rs} = 35 - 147$ $f_{rs} = 0.25 - 0.50$, $\eta_{\rho} = 1.19$.	$Nu_{rs} = 0.101 Re_{rs}{}^{1.73} Pr_{rs}{}^{0.4} (e_p)^{-0.265} (e_w)^{-0.287}$ and $f_{rs} = 0.898 Re_{rs}{}^{0.994} Pr_{rs}{}^{0.4} (e_p)^{-0.516} (e_w)^{0.656}$ (T-W towards the back wing set up) $Nu_{rs} = 0.11 Re_{rs}{}^{0.731} Pr_{rs}{}^{0.4} (e_p)^{-0.283} (e_w)^{-0.316}$ and $f_{rs} = 0.55 Re_{rs}{}^{-0138} (e_p)^{-0.635} (e_w)^{0.759}$ (T-W towards the back wing set up)
Twisted tape with alternate axis. Wongcharee and Eiamsa-ard (2011).	Fluid: Air Parameters: $830 \leq Re_{rs} \leq 1990$ $y_{rs} = 3.0$, Density of nanofluid varied from 0.30% to 0.70%. Minimum and maximum values of results: $Nu_{rs} = 12 - 67$ $f_{rs} = 0.32 - 0.67$, $\eta_{\rho} = 1.5 - 5.4$.	$Nu_{rs} = 0.026 Re_{rs}{}^{0.927} (Pr_{rs})^{0.4} (\phi_{rs} + 1)^{0.128}$ (Tube with TT with alternative axis) $Nu_{rs} = 0.0050 Re_{rs}{}^{1.0620} (Pr_{rs})^{0.40} (\phi_{rs} + 1)^{0.112}$ (Tube with TTT) $f_{rs} = 4.487 Re_{rs}{}^{-0.297} (\phi_{rs} + 1)^{0.1001}$ $f_{rs} = 3.234 Re_{rs}{}^{-0.308} (\phi_{rs} + 1)^{0.082} ($ $\eta_{rs} = 0.027 Re_{rs}{}^{0.693} (\phi_{rs} + 1)^{0.094}$ $\eta_{rs} = 0.0060 Re_{rs}{}^{0.8320} (\phi_{rs} + 1)^{0.0850}$

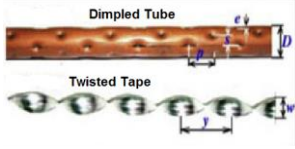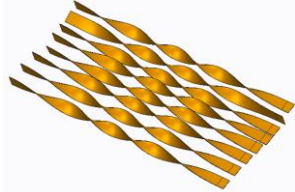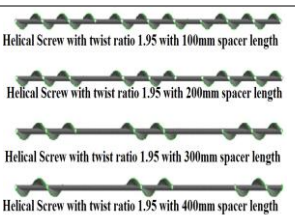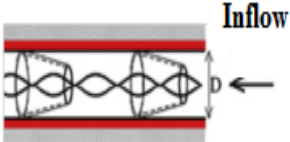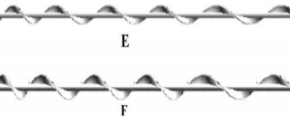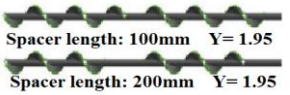|	Fluid: Air	
Multiple typical twisted tapes. Sarada *et al.* (2010).	Fluid: Air Parameters: $6000 \leq Re_{rs} \leq 13500$ Widths of the TT 10.0mm to 22.0 mm. Minimum and maximum values of results: $Nu_{rs} = 30 - 45$ $f_{rs} = 0.0072 - 0.0079,$ $\eta_\rho = 1.1 - 1.7.$	$Nu_{rs} = 0.4141 \times 10^{-4} Re_{rs}^{0.9591} Pr_{rs}^{0.4} [0.001(H_{rs}/w)^{-0.4645}](D_b/L)^{-1.411}(D_{rs} = \text{hydraulic diameter, and } H'_{rs} \text{ is pitch})$ $f_{rs} = 0.0139 Re^{-0.1374}[(0.001 + H_{rs}/W)^{-0.001}](D_b/L)^{-0.2097}.$
Single, twin co- twisted and twin counter twisted tape. Eiamsa-ard *et al.* (2010).	Fluid: Air Parameters: $3700 \leq Re_{rs} \leq 21000$ Pitch ratios 2.5,3,3.5 and 4.0 Perforated holes N = 4, 6 and 8. Minimum and maximum values of results: $Nu_{rs} = 27 - 188$ $f_{rs} = 0.031 - 0.052,$ $\eta_\rho = 1.4.$	$Nu_{rs} = 0.473 Re_{rs}^{0.66} Pr_{rs}^{0.4}(y_{rs}/w)^{-0.9}$ and $f_{rs} = 72.29 Re_{rs}^{-0.53}(y_{rs}/w)^{-1.01}$(twin counter TT) $Nu_{rs} = 0.264 Re_{rs}^{0.66} Pr_{rs}^{0.4}(y_{rs}/w)^{-0.61}$ and $f_{rs} = 41.7 Re_{rs}^{-0.52}(y_{rs}/w)^{-0.84}$(For twin co-TT) $\eta_{rs} = 1.84 Re_{rs}^{-0.186}(y_{rs}/w)^{-0.038}$
Clockwise and counter-clockwise twisted-tape inserts. Eiamsa-ard *et al.* (2010).	Fluid: Air, Parameters: $3000 \leq Re_{rs} \leq 27000$ $y_{rs} = 3.0, 4.0,$ and 5.0. Minimum and maximum values of results: $Nu_{rs} = 43 - 265$ $f_{rs} = 0.03 - 0.052,$ $\eta_\rho = 1.34.$	$Nu_{rs} = 0.31 Re_{rs}^{0.6} Pr_{rs}^{0.4}(y_{rs}/w)^{-0.36}(1 + sin\theta)^{0.44}$ $f_{rs} = 46.39 Re_{rs}^{-0.544}(y_{rs}/w)^{-0.77}(1 + sin\theta)^{0.45}$ $\eta_{rs} = 2.93 Re_{rs}^{-0.01}(y_{rs}/w)^{-0.77}(1 + sin\theta)^{0.31}.$
Periodically varying wire coil. Eiamsa-ard *et al.* (2010).	Fluid: Air Parameters: $4600 \leq Re_{rs} \leq 20000$ Two various $y_{rs} = 3.0, 4.0$ of TT of varying three coils pitch ratios. Minimum and maximum values of $Nu_{rs} = 15 - 148$ $f_{rs} = 0.032 - 0.053,$ $\eta_\rho = 1.1 - 1.25.$	$Nu_{rs} = 0.197 Re_{rs}^{0.708} Pr_{rs}^{0.4}(1 + S)^{-0.244}$ (Decrease coil pitch ratios and TT) $Nu_{rs} = 0.186 Re_{rs}^{0.713} Pr_{rs}^{0.4}(1 + S)^{-0.249}$ (Decreasing/increasing coil pitch ratios and TT) $f_{rs} = 12.133 Re_{rs}^{-0.232} Y_{rs}^{-0.302}$ $f_{rs} = 22.366 Re_{rs}^{-0.277} Y_{rs}^{-0.449}.$
Delta-winglet twisted tapes. Eiamsa-ard *et al.* (2010).	Fluid: Air Parameters: $3000 \leq Re_{rs} \leq 27000$ $y_{rs} = 3.0, 4.0$ and 5.0. (d_{rs}/w_{rs} is Depth ratio) = 0.11, .021 and 0.32. Minimum and maximum values of $Nu_{rs} = 27 - 274$ $f_{rs} = 0.05 - 0.31,$ $\eta_\rho = 1.05 - 1.95.$	$Nu_{rs} = 0.18 Re_{rs}^{0.67} Pr_{rs}^{0.4}(y_{rs}/w)^{-0.424}(1 + d/w)^{0.982}$ (For oblique delta-winglet TT)$Nu_{rs} = 0.184 Re_{rs}^{0.67} Pr_{rs}^{0.4}(y_{rs}/w)^{-0.465}(1 + d/w)^{0.76}$(Straight D-W TT) $f_{rs} = 24.8 Re_{rs}^{-0.51}(y_{rs}/w)^{-0.566}(1 + d/w)^{1.87}$ (Oblique D-W TT) $f_{rs} = 21.7 Re_{rs}^{-0.45}(y_{rs}/w)^{-0.564}(1 + d/w)^{-1.41}$ $\eta_{rs} = 2.046 Re_{rs}^{-0.042} Pr_{rs}^{0.4}(y_{rs}/w)^{-0.0261}(1 + d/w)^{0.45}$ $\eta_{rs} = 2.1646 Re_{rs}^{-0.0435} Pr_{rs}^{0.4}(y_{rs}/w)^{-0.0304}(1 + d/w)^{0.356}.$
Dual twisted tape inserts. Eiamsa-ard *et al.*(2010).	Fluid: Air, Parameters: $4000 \leq Re_{rs} \leq 19000$ $y_{rs} = 3.0, 4.0,$ and 5.0. Minimum and maximum values of results: $Nu_{rs} = 16 - 72$ $f_{rs} = 0.03 - 0.15,$ $\eta_\rho = 0.8 - 1.2.$	$Nu_{rs} = 0.06 Re^{0.75} Pr^{0.4}(y_{rs}/W)^{-0.26}$ (For single TT inserts) $Nu_{rs} = 0.069 Re_{rs}^{0.74} Pr_{rs}^{0.4}(y_{rs}/W)^{-0.26}[1.5(s/D_{rs}) + 1]^{-0.1}$ (For dual TT inserts) $f_{rs} = 10.02 Re_{rs}^{-0.46}(y_{rs}/W)^{-0.48}$ (For single TT inserts) $f_{rs} = 30.5 Re_{rs}^{-0.56}(y_{rs}/W)^{-0.54}[1.5(s/D_{rs}) + 1]^{-0.2}$ (For dual TT inserts) $\eta_{rs} = 2.46 Re_{rs} e^{-0.08}(y_{rs}/W)^{-0.2}$
	Fluid: Air Parameters: $4000 \leq Re_{rs} \leq 20000$ Tape length ratios are 0.29, 0.43, 0.57 and 1.0.	$Nu_{rs} = 0.0664 Re_{rs}^{0.693}(Pr_{rs}^{0.4})LR^{-0.122}$ ('LR' = tape –length ratios) $f_{rs} = 2.8 Re_{rs}^{-0.386} LR^{0.19}$

Short-length twisted tape inserts. Eiamsa-ard et al. (2009).	Minimum and maximum values of $Nu_{rs} = 12 - 58$ $f_{rs} 0.03 - 0.05 =,$ $\eta_\rho = 0.9 - 1.17.$	
Coiled wire inserts. Promvonge (2008).	Fluid: Air, Parameters: $3000 \leq Re_{rs} \leq 18000$ Pitch ratios e 4.0, 6.0 and 8.0. $y_{rs} = 4.0, 6.0.$ Minimum and maximum values of results: $Nu_{rs} = 12 - 174$ $f_{rs} = 0.5\text{-}3.0,$ $\eta_\rho = 0.5 - 1.57.$	$Nu_{rs} = 4.47 Re_{rs}^{0.5}(Pr_{rs}^{0.4})CR^{-0.382}Y_{rs}^{-0.38}$ *and* $f_{rs} = 338.37 Re_{rs}^{-0.367}CR^{-0.887}Y_{rs}^{-0.4660}$
VW twisted tape. Mazumder and Saha (2008).	Fluid: Air Parameters: $11543 \leq Re_{rs} \leq 108166$ $y_{rs} = 2.0, 4.4$ Minimum and maximum values of results: $Nu_{rs} = 52 - 125$ $f_{rs} = 0.5\text{-}0.9,$ $\eta_\rho = 1.3 - 1.7.$	(Regular spaced TT) $Nu_{rs} = 0.023(Term1 + Term2)(1/AR + 0.1)^{0.15}\dfrac{(e/D_{rs})^{0.0541}I^{0.182}}{(p/e)^{0.754}}$ $(AR \leq 1)$ $(Short\ length\ TT) Nu_{rs} = 0.023(Term1 + Term2)(1/AR + 0.1)^{0.15}\dfrac{(e/D_{rs})^{0.01561}d^{0.122}}{(p/e)^{0.136}s^{1.120}}$ $K\left\{1 + 10^{-6}\left[\left(\dfrac{Re_{rs}^2}{Y_{rs}}\right)\left(\dfrac{\pi}{\pi - \left(\frac{4s}{D_{rs}}\right)}\right)[1 + (\pi/2Y_{rs})^2]^{0.5}\right]^{2.67}\right\}^{\frac{1}{7}}\dfrac{(e/D_{rs})^{0.0343}I^{0.178}}{(p/e)^{0.739}(AR)^{1.52}}$.
Broken twisted tape inserts. Chang et al. (2007).	Fluid: Air, Parameters: $1000 \leq Re_{rs} \leq 40000,$ $y_{rs} = 1.0, 1.5, 2.0,$ and 2.5, twist ratios y = 1, 1.5, 2, and y = 2.5. Minimum and maximum values of results: $Nu_{rs} = 50 - 350$ $f_{rs} = 0.12 - 0.25,$ $\eta_\rho = 0.98 - 1.28.$	$Nu_{rs} = Pr_{rs}^{\frac{1}{3}}Re_{rs}\left[A\{y\} + B\{y\}e^{-C\{y\}^X}\right]$ X is dimensionless axial location $A = 0.04520 + 0.30e^{-0.1410y}, B = 0.0410 + 1.280e^{-1.490y}$ $f_{rs} = -E(y) - K(y)e^{-M[y]Re},$ $E = 0.01740 + 0.2160e^{-1.207y}, K = 0.020 + 0.1610e^{-1.207y} M = 0.000340 - 0.0003210e^{-0.548y}.$
Twisted tape inserts. Chang et al. (2007).	Fluid: Air Parameters: $5000 \leq Re_{rs} \leq 25000,$ $y_{rs} = 1.56, 1.87, 2.82.$ Minimum and maximum values of $Nu_{rs} = 62 - 280$ $f_{rs} = 0.3 - 0.48,$ $\eta_\rho = 0.9 - 1.4.$	$Nu_{rs} = (0.0364 + 3.66e^{-1.11y})Re_{rs}^{(0.8 - 0.375e^{-0.31y})}Pr_{rs}^{1/3}$ $(for\ smooth\ tapes)$ $Nu_{rs} = (0.118 + 5.84e^{-1.83y})Re_{rs}^{(0.73 - 0.695e^{-1.26y})}Pr_{rs}^{1/3}$ $(for\ serrated\ tapes)$ $-f = (0.07 + 9.87e^{-1.81y})Re_{rs}e^{(-0.08 - 0.94e^{-1.23y})}.$
Circular tube inserted with classical TT. Eiamsa-ard, et al. (2006).	Fluid: Air Parameters: $5000 \leq Re_{rs} \leq 15000,$ $y_{rs} = 6.0, 8.0$ and space ratio of 1.0, 2.0, 3.0. Minimum and maximum values of results: $Nu_{rs} = 10 - 87,$ $f_{rs} = 0.1 - 0.24$.	$Nu_{rs} = 0.144 Re_{rs}^{0.697}Pr_{rs}^{0.4}(s + 1)^{-0.179}$ $f_{rs} = 3.044 Re_{rs}^{-0.80}y^{-0.0556}(s + 1)^{-0.34}$ *and* $\eta_{rs} = 3.854 Re_{rs}^{-0.151}y^{-0.043}(s + 1)^{-0.065}$
Regularly spaced twisted tape inserts. Eiamsa-ard et al. (2006).	Fluid: Air Parameters: $5000 \leq Re_{rs} \leq 20000$ $y_{rs} = 6.0, 8.0.$ Space ratios are 1.0, 2.0 3.0. Minimum and maximum values of results: $Nu_{rs} = 10 - 90$ $f_{rs} = 0.05 - 0.24,$ $\eta_\rho = 1.2 - 1.76.$	$Nu_{rs} = 0.0101 Re_{rs}^{0.929}Pr_{rs}^{\frac{1}{3}}(1 + S)^{-0.266}$ (S = Free Space Ratio) $f_{rs} = 4.413 Re_{rs}^{-0.398}(1 + S)^{-0.376}$

Radial guide vane swirl generator. Yilmaz et al.(2003).

Fluid: Air
Parameters:
$200 \leq Re_{rs} \leq 11000$
Angular vane angle (θ_{rs}) = 15°, 30°, 45°, 60° and 75°.
Minimum and maximum values of results:
$Nu_{rs} = 67 - 392$
$f_{rs} = 3.5 - 16.8$, $\eta_\rho = 1.67$.

$Nu_{rs} = 0.133 Re_{rs}^{0.65}(Pr_{rs})^{0.4}(1 + tan\theta)^{0.405}$
$(\,swirl\ generator\ with\ conical\ deflection\,)$
$Nu_{rs} = 0.313 Re_{rs}^{0.360}(Pr_{rs})^{0.40}(1 + tan\theta)^{0.3970}$
$(\,swirl\ generator\ with\ spherical\ deflection)$
$Nu_{rs} = 0.368 Re_{rs}^{0.562}(Pr_{rs})^{0.40}(1 + tan\theta)^{0.459}.$
$(swirl\ generator\ with\ nil\ deflection)$

Square duct with twisted tape inserts. Ray and Date (2001).

Fluid: Air
Parameters:
$30 \leq Re_{rs} \leq 11,00$
$y_{rs} = 1.5$ to 10,
$Pr_{rs} = 0.1$ to 500.
Minimum and maximum values of results:
$Nu_{rs} = 5 - 120$
$f_{rs} = 0.3 - 1.2$.

$Nu_{rs} = 3.96[1 + 1.6 \times 10^{-2} Pr_{rs}^{1.05}\left(\frac{Re_{rs}}{Y}\right)^{1.25}]^{\frac{1}{26}}$ $Sw_s{'}$ is notational

swirl parameter $Sw_s = \left(\frac{Re_{rs}}{Y}\right)^{\frac{1}{4}}\left[\frac{1+0.01Y^4}{Y^8}\right]^{\frac{1}{4}}$,

$f_{rs} = 36 Re_{rs}[1 + 0.15\, S_w]^{1/1.3}$

Vertical pipe with twisted tape. Klaczak, A.(2000).

Fluid: Air
Parameters:
$110 \leq Re_{rs} \leq 1500$
y_{rs} =1.63 to 5.28.
G_{rs}= 8.1- 82.0.
Minimum and maximum values of results:
$Nu_{rs} = 3.0 - 10$.

$Nu_{rs} = 1.239 Gz^{(0.514 y_{rs}^{-0.27})} y_{rs}^{0.30}$
(For $8.1 \leq Gz \leq 82, 58 \leq Sw \leq 1900, 2.06 \leq Pr_{rs} \leq 2.73$)
$Nu_{rs} = 0.858 Pr_{rs}^{0.3} Sw^{0.3}\left(\frac{\eta_{ar}}{\eta_w}\right)^{0.14}$

Twisted tape geometry Working fluid: Water	Parameters/optimum ranges	Correlations

SRT-4 twisted tapes insert. Hong et al. (2019).

Fluid: Water
Parameters:
$5000 \leq Re_{rs} \leq 10000$
Rib pitch to diameter ratios at 0.27–1.53, rib height to diameter ratios at 0.02–0.056 and corrugation angles at 9.2°–37.0°
$Nu_{rs} = 27.4\% - 39.5\%$
$f_{rs} = 2.66 - 10.07$,
η_ρ =1.59 and 1.49.

$Nu_{rs} = 0.134 Re_{rs}^{0.78799}\left(\frac{e}{d}\right)^{0.331}\left(\frac{p}{d}\right)^{-0.105}\left[\frac{90^0-\emptyset}{90^0}\right]$ and
$f_{rs} = 2.9134 Re_{rs}^{-0.065}\left(\frac{e}{d}\right)^{0.972}\left(\frac{p}{d}\right)^{-0.313}\left[\frac{90^0-\emptyset}{90^0}\right]^{1.004}$

Multiple- twisted tapes. Piriyarungrod et al. (2018).

Fluid: Water
Parameters:
$6000 \leq Re_{rs} \leq 20000$
(y/w=2.5, 5, 10, 15, 20 and 25)
Nu_{rs} =1.13, 1.18, and 1.2
$f_{rs} = 0.14 - 0.20$
$\eta_\rho = 1.2$.

$Nu_{rs} = \dfrac{\left(\frac{f}{8}\right)(Re - 1000)Pr}{1 + 12.7\left(\frac{f}{8}\right)^{\frac{1}{2}}(Pr^{\frac{2}{3}} - 1)}.$

$f_{rs} = 0.136 Re_{rs}^{-0.25}$

Typical twisted tape inserts. Maddah et al. (2014).

Fluid: Water/ Nanofluid
Parameters:
$5000 \leq Re_{rs} \leq 21000$
y_{rs} =1.03 to 4.
Minimum and maximum values of results:
$Nu_{rs} = 50 - 210$
$f_{rs} = 0.04 - 0.075$,
$\eta_\rho = 1.3 - 1.89$.

$Nu_{rs} = 0.056 Re_{rs}^{0.72}(Pr_{rs})^{0.4}(\pi\phi_{rs} + 1)^{2.75}(1 + \frac{\pi}{2TR})^{1.1} GPR^{-0.75}$
('ϕ_{rs}' volume concentration, TR: Twist Ratio)$f_{rs} = 0.375 Re_{rs}^{-0.24}(1 + 3\pi\phi_{rs})^{0.6}(1 + \frac{\pi}{TR^{1.4}})GPR^{-0.35}$

Schematic diagram of Classic twisted tape. Karami *et al.* (2012).	Fluid: Water, Parameters: $4021 \leq Re_{rs} \leq 16{,}118$ (y/w = 1.76 to 3.53) $Nu_{rs} = 147.827$ $\eta_\rho = 1.76$.	$Nu_{rs} = 90.2 + 14.7Re - 3.72Re - 0.276Re^2 - 0.539Re \times R$
Geometries of twisted tapes. Murugesan *et al.* (2012).	Fluid: Water, Parameters: $2000 \leq Re_{rs} \leq 12000$ $y_{rs} = 2.0, 4.4$ and 6.0. Minimum and maximum values of results: $Nu_{rs} = 18 - 130$ $f_{rs} = 0.03 - 0.29$, $\eta_\rho = 1.05 - 1.5$.	$Nu_{rs} = 0.027e^{0.8620} Pr_{rs}^{0.33} Y_{rs}^{-0.215}$ and $f_{rs} = 2.642 Re_{rs}^{-0.474} Y_{rs}^{-0.302}$
Tubes equipped with twin twisted tapes. Zhang *et al.* (2012).	Fluid: Water Parameters: $300 \leq Re_{rs} \leq 1800$ Helical screw breadth is 7.50, 120, 150 and 200mm. Minimum and maximum values of results: $Nu_{rs} = 8.2 - 13.5$ $f_{rs} = 0.2 - 1.3$, $\eta_\rho = 1.6 - 2.3$.	$Nu_{rs} = 0.128 Re_{rs}^{0.723} Pr_{rs}^{0.4}(e_p)^{-0.188}(e_w)^{0.318})$ $, Nu_{rs} = 0.139 Re_{rs}^{0.723} Pr_{rs}^{0.4}(e_p)^{-0.198}(e_w)^{0.339}$ $Nu_{rs} = 2.0358 Re_{rs}^{0.2380}(\alpha^*)^{0.0492}$ (TTT), ("α^a" clearance ratio of the TT) $Nu_{rs} = 1.5689 Re_{rs}^{0.2629}(\alpha^*)^{-0.0773}$ (Quadruple TT), $f_{rs} = 1.09 Re_{rs}^{-0.098}(e_p)^{-0.198}(e_w)^{0.547}$, $f_{rs} = 1.680 Re_{rs}^{-0.127}(e_p)^{-0.198}(e_w)^{0.636}$ $f_{rs} = 111.2919 Re_{rs}^{-0.7236}$
Left–Right various spacer length tape. Jaisankar *et al.* (2011).	Fluid: Water Parameters: $200 \leq Re_{rs} \leq 1600$ $y_{rs} = 3.0, 5.0$ spacer length(mm) 100, 200, 300. Minimum and maximum values of results: $Nu_{rs} = 4.0 - 23$ $f_{rs} = 0.03 - 0.09$, $\eta_\rho = 1.21 - 1.41$.	(For phase 1) $Nu_{rs} = 0.783 Re_{rs}^{0.44} Pr_{rs}^{0.589} Y_{rs}^{.305}(1 + S/D_{rs})^{-0.124}$ and $f_{rs} = 1212.69 Re_{rs}^{-0.904} Y_{rs}^{-0.955}(1 + S/D_{rs})^{-0.0515}$ (For phase 2) $Nu_{rs} = 0.617 Re_{rs}^{0574} Pr_{rs}^{0.574} Y_{rs}^{.309}(1 + S/D_{rs})^{-0.129}$ and $f_{rs} = 13.11.69 Re_{rs}^{-0.904} y_{rs}^{-0.955}(1 + S/D_{rs})^{-0.374}$.
Alternate clockwise and counter-clockwise twisted tape inserts. Wongcharee and Eiamsa-ard (2011).	Fluid: Water Parameters: $830 \leq Re_{rs} \leq 1990, y_{rs} = 3.0, 4.0$ and 5.0. Minimum and maximum values of results: $Nu_{rs} = 11 - 64$ $f_{rs} = 0.25 - o.62$, $\eta_\rho = 2.2 - 5.4$.	$Nu_{rs} = 0.0017 Re_{rs}^{0.996} Pr_{rs} Y_{rs}^{-0.5437}$ and $f_{rs} = 10.7564 Re_{rs}^{-0.387} Y_{rs}^{-1.054}$.
Helical screw-tape. Ibrahim (2011).	Fluid: Water Parameters: $570 \leq Re_{rs} \leq 1310$, $y_{rs} = 2.17, 3.33, 4.3$ and 5.0. Spacer lengths of 100, 200, 300, and 400 mm. $Nu_{rs} = 9 - 21$, $f_{rs} = 0.04 - 0.18$.	$Nu_{rs} = 6.11 Re_{rs}^{0.199}(1 + x)^{-0.064} Y_{rs}^{-0.3118}$ and $f_{rs} = 54.41 Re_{rs}^{-0.87}(1 + x)^{-0.045} Y_{rs}^{-0.146}$
V-cut Twisted tapes inserts. Murugesan *et al.* (2011).	Fluid: Water Parameters: $2000 \leq Re_{rs} \leq 12000$ $y_{rs} = 2.0, 4.4$ and 6.0. width ratio = 0.34 and 0.43 Minimum and maximum values of results: $Nu_{rs} = 20 - 128$ $f_{rs} = 0.08 - 0.29$, $\eta_\rho = 1.02 - 1.29$.	$Nu_{rs} = 0.0296 Re_{rs}^{0.853} Pr_{rs}^{0.33} Y^{-0.222}(1 + [d_e/w])^{1.148}(1 + [w/W])^{-0.715}$ or tubes fitted with $v - cut\ TT$) $f_{rs} = 8.632 Re_{rs}^{-0.615} y_{rs}^{-0.269}(1 + [d_e/w]^{2.477})[1 + [w/W]^{-1.914}]$

Peripherally-cut and alternate axis twisted tape. Seemawute *et al.* (2010).	Fluid: Water Parameters: $5000 \leq Re_{rs} \leq 20000$ Peripherally- cut TT with alternate axis 1.25, 1.11 and 1.02. Minimum and maximum values of $Nu_{rs} = 45 - 275$ $f_{rs} = 0.12 - 0.5$, $\eta_\rho = 1.05 - 1.25$.	$Nu_{rs} = 0.422Re_{rs}^{\,0.544} Pr_{rs}^{\,0.4} \left(\dfrac{w}{W}\right)^{-0.148}$ $f_{rs} = 59.08Re_{rs}^{\,-0.615} \left(\dfrac{w}{W}\right)^{-0.18}$.
Right-Left helical twist with ratio 4.89 Right -Left helical twist ratio 3.91 **TT with left- right - helical screw. Nagarajan *et al.* (2010).**	Fluid: Water Parameters: $200 \leq Re_{rs} \leq 3000$ $y_{rs} = 2.93$ to 4.89 Minimum and maximum values of results: $Nu_{rs} = 38192$ $f_{rs} = 0.02 - 0.25$, $\eta_\rho = 1.2 - 1.83$.	$Nu_{rs} = 0.3962(Y)^{-0.3866} Pr_{rs}^{\,0.3} (Re_{rs})^{0.6717} (Pr_{rs})^{0.4}$ $\left(\dfrac{\mu}{\mu^w}\right)^{0.14}$ $Nu_{rs} = 2.81(Y_{L-R})^{-0.3966} Pr_{rs}^{\,0.3} (Re_{rs})^{0.478} (Pr_{rs})^{0.4} (\mu/\mu_w)^{0.14}$ $f_{rs} = 739.2(Y_{rs})^{-0.634} (Re_{rs})^{-1.013} (y_{rs}/w)^{-0.2}$
Spiky twisted tapes. Chang *et al* (2009).	Fluid: Water, Parameters: $5000 \leq Re_{rs} \leq 15000$ Stream ratio 0.004 to 0.01 Minimum and maximum values of results: $Nu_{rs} = 40 - 510$ $f_{rs} = 0.5 - 1.6$, $\eta_\rho = 1.2 - 4.1$.	$N_{rs} = (0.323 + 0.1366 \times e^{-1164 \times AW}) \times Re_{rs}^{\,0.79 - 0.135 \times e^{-1074 \times AW}}$
Dimple tube with twisted tape inserts. Thianpong *et al.* (2009).	Fluid: Water Parameters: $12000 \leq Re_{rs} \leq 44000$ $y_{rs} = 3.0, 5.0,$ and 7.0 Minimum and maximum values of results: $Nu_{rs} = 55 - 457$ $f_{rs} = 0.06 - 0.24$	$Nu_{rs} = 0.014Re^{0.93} (Re_{rs})^{-0.93} \left(\dfrac{y_{rs}}{w}\right)^{-0.12} Pr_{rs}^{\,0.3}$ $f_{rs} = 9.1Re_{rs}^{\,-0.37} (Re_{rs})^{-0.11} \left(\dfrac{y_{rs}}{w}\right)^{-0.2}$
Twisted tape inserts. Sharma *et al.* (2009).	Fluid: Water Parameters: $3500 \leq Re_{rs} \leq 8500$ $0 \leq H/D \leq 15$, $4.5 \leq Pr \leq 5.5$ Minimum and maximum values of results: $Nu_{rs} = 30 - 90$ $f_{rs} = 0.04 - 0.09$, $\eta_\rho = 1.2 - 1.4$.	$Nu_{rs} = 3.138 * 10^{-3} (Re_{rs})(Pr_{rs})^{0.6}(1.0 + H_{rs}/D_{rs})^{0.03}(\phi + 1)^{1.22}$ $(0 < H_{rs}/D_{rs} < 15,\ 3500 < Re_{rs} < 8500,\ 4.5 < Pr_{rs} < 5.5,\ 35 < Tb < 40)$ $f_{rs} = 173(Re_{rs})^{-0.96}(1.0 + H_{rs}/D_{rs})^{2.15}(\phi + 1)^{2.15}$
Dimple tube fitted with twisted tape inserts. Bharadwaj *et al.* (2009).	Fluid: Water Parameters: $12000 \leq Re_{rs} \leq 44000$ $y_{rs} = 3.0, 5.0,$ and 7.0. Minimum and maximum values of results: $Nu_{rs} = 20 - 160$ $f_{rs} = 0.01 - 0.13$, $\eta_\rho = 0.9 - 1.48$.	(For $Y_{rs} = 10.16$, $Re_{rs} < 7000$, Clockwise twist) $Nu_{rs} = 0.1949Re_{rs}^{\,0.71145}$, $Nu_{rs} = 0.6916Re_{rs}^{\,0.535}$ $Nu_{rs} = 0.02564Re_{rs}^{\,0.93750}$ $Nu_{rs} = 0.01887Re_{rs}^{\,0.9724}$, $f_{rs} = 15.88Re_{rs}^{\,-0.75975}$ $f_{rs} = 8.029Re_{rs}^{\,-0.6367}$, $f_{rs} = 0.021Re_{rs}^{\,-0.0}$ $f_{rs} = 0.061Re_{rs}^{\,-0.1015}$
Helical Screw with twist ratio 1.95 with 100mm spacer length Helical Screw with twist ratio 1.95 with 200mm spacer length Helical Screw with twist ratio 1.95 with 300mm spacer length Helical Screw with twist ratio 1.95 with 400mm spacer length **Helical screw twisted tape inserts. Sivashanmugam and Suresh (2007).**	Fluid: Water Parameters: $2700 \leq Re_{rs} \leq 13500$ $y_{rs} = 1.95,\ 2.93,\ 3.91$ & 4.89. Spacer length 100, 200, 300 and 400mm. Minimum and maximum values of results: $Nu_{rs} = 40 - 155$ $f_{rs} = 0.07 - 0.11$, $\eta_\rho =$	$Nu_{rs} = 0.258Re_{rs}^{\,0.554} (Pr_{rs})(Y_{rs})^{-0.042}(1 + s/D_{rs})^{-0.042}$ and $f_{rs} = Re_{rs}^{\,-0.384} Y_{rs}^{\,-0.852}(1 + s/D_{rs})^{-0.047}$

	Fluid / Parameters	Correlations
Twisted tape inserts with conical-ring. Promvonge et al. (2007).	Fluid: Water Parameters: $6000 \leq Re_{rs} \leq 26000$ $y_{rs} = 3.75$ and 7.5. Minimum and maximum values of results: $Nu_{rs} = 125 - 223$ $f_{rs} = 4 - 6.1$, $\eta_\rho = 1.2 - 1.9$.	$Nu_{rs} = 1.365 Re_{rs}{}^{0.433} Pr_{rs}{}^{0.40} \left(d_{rs}/D_{rs}\right)^{-1.230} Y_{rs}{}^{-0.0530}$ *and* $f_{rs} = 24.870 Re_{rs}{}^{-0.430} \left(d_{rs}/D_{rs}\right)^{-3.990} y_{rs}{}^{-0.160}$
Horizontal pipe with helical ribs. Naphon et al. (2006).	Fluid: Water, Parameters: $15000 \leq Re_{rs} \leq 60000$ $y_{rs} = 3.1$–5.5 Minimum and maximum values of results: $Nu_{rs} = 40 - 110$ $f_{rs} = 1.0 - 1.6$, $\alpha = 2.5 - 6.6$.	$Nu_{rs} = 0.648 Re_{rs}{}^{0.36} \left[1 + \frac{D}{R}\right]^{0.245} (Pr_{rs})^{1/3}$ *for* $Pr_{rs} > 3$ *and* $f_{rs} = 3.517 Re_{rs}{}^{-0.414} \left[1 + \frac{D}{H}\right]^{1.045}$
Twisted tapes with different twist ratios. Sivashanmugam & Suresh (2006).	Fluid: Water Parameters: $2700 \leq Re_{rs} \leq 13500$ $y_{rs} = 1.95, 2.93, 3.91$ and 4.89. Minimum and maximum values of results: $Nu_{rs} = 11 - 80$ $f_{rs} = 0.1 - 0.6$	$Nu_{rs} = 0.467 Re_{rs}{}^{0.4774} Pr_{rs}. Y_{rs}{}^{-0.053}$ and $f_{rs} = 32.415 Re_{rs}{}^{-0.598} Y_{rs}{}^{-0.7986}$
Helical screw tape. ivashanmugam et al. (2006).	Fluid: Water Parameters: $200 \leq Re_{rs} \leq 3000$ Minimum and maximum values of results: $Nu_{rs} = 10 - 70$ $f_{rs} = 0.1 - 0.55$, $\eta_\rho = 1.3 - 1.82$.	$Nu_{rs} = 0.725(Re_{rs})^{0.568}(y_{rs})^{-0.788}(Pr_{rs})^{1/3}(\mu_b/\mu_w)^{0.14}$ (heating) $Nu_{rs} = 1.365(Re_{rs})^{0.517}(y_{rs})^{-1.05}(Pr_{rs})^{1/3}(\mu_b/\mu_w)^{0.14}$ (cooling)
Regularly spaced twisted tape inserts. Saha et al. (2004).	Fluid: Water Parameters: $80 \leq Re_{rs} \leq 500$ $y_{rs} = 2.692$ to 4.615, Aspect ratio = 1, 0.5, 0.333, $Pr_{rs} = 80$ to 500. Minimum and maximum values of results: $Nu_{rs} = 6 - 150.5$ $f_{rs} = 0.5 - 1.0$, $\eta_\rho = 1.0$-1.32.	$Nu_{rs} = 5.172 \left\{ \left[\begin{array}{c} (1 + 0.08932 Gz^{0.9125})^{2.5} + \\ \left[8.2273 \times 10^{-6}\left(\frac{Re_{rs}}{\sqrt{y_{rs}}}. Pr^{0.565}\right)^{2.655}\right] \\ +1.5638 \times 10^{-15}(Re_{rs} Ra)^{2.18} \end{array} \right]^{2.0} \right\}\left(\frac{\mu_b}{\mu_w}\right)^{0.14}$ $[1 + (2\theta/\pi)^{0.1346} l^{0.183}/(P/e)^{0.584}] \times B,$ $f_{rs} = 45.8129\left[1 + 10^{-6}\left(\frac{Re_{rs}}{\sqrt{y_{rs}}}\right)^{2.67}\right]^{\frac{1}{7}}(AR)^{-1.39} \times [1 + (2\theta/\pi)^{0.1859} l^{0.226}/(P/e)^{0.612}] \times A.$
Twisted tape geometry Working fluid: Oil	Parameters/optimum ranges	Correlations
Circular with center-cleared twisted tapes. Saha et al. (2012).	Fluid: Oil Parameters: Rib Pitch: 2.0437, 5.6481, Rib Height = 0.07692, 0.1026. Centre clearance = 0, 0.2, 0.4, 0.6 Minimum and maximum values of results: $Nu_{rs} = 0.022 - 1.2$ $f_{rs} = 30 - 165$, $\eta_\rho = 1.2 - 1.48$.	$Nu_{rs} = 0.0032 Re_{rs}{}^{0.986} Pr_{rs}{}^{0.4}(y_{rs}/W)^{-0.594}$ (For alternate clockwise and counter clockwise TT) $Nu_{rs} = 0.005 Re_{rs}{}^{1.139} Pr_{rs}{}^{0.4}(y_{rs}/W)^{-0.521}$ (For TTT inserts) $f_{rs} = 12.886 Re_{rs}{}^{-.304}(y_{rs}/W)^{-0.896}$ $f_{rs} = 6.559 Re_{rs}{}^{-.303}(y_{rs}/W)^{-0.674}$ (For TTT inserts)

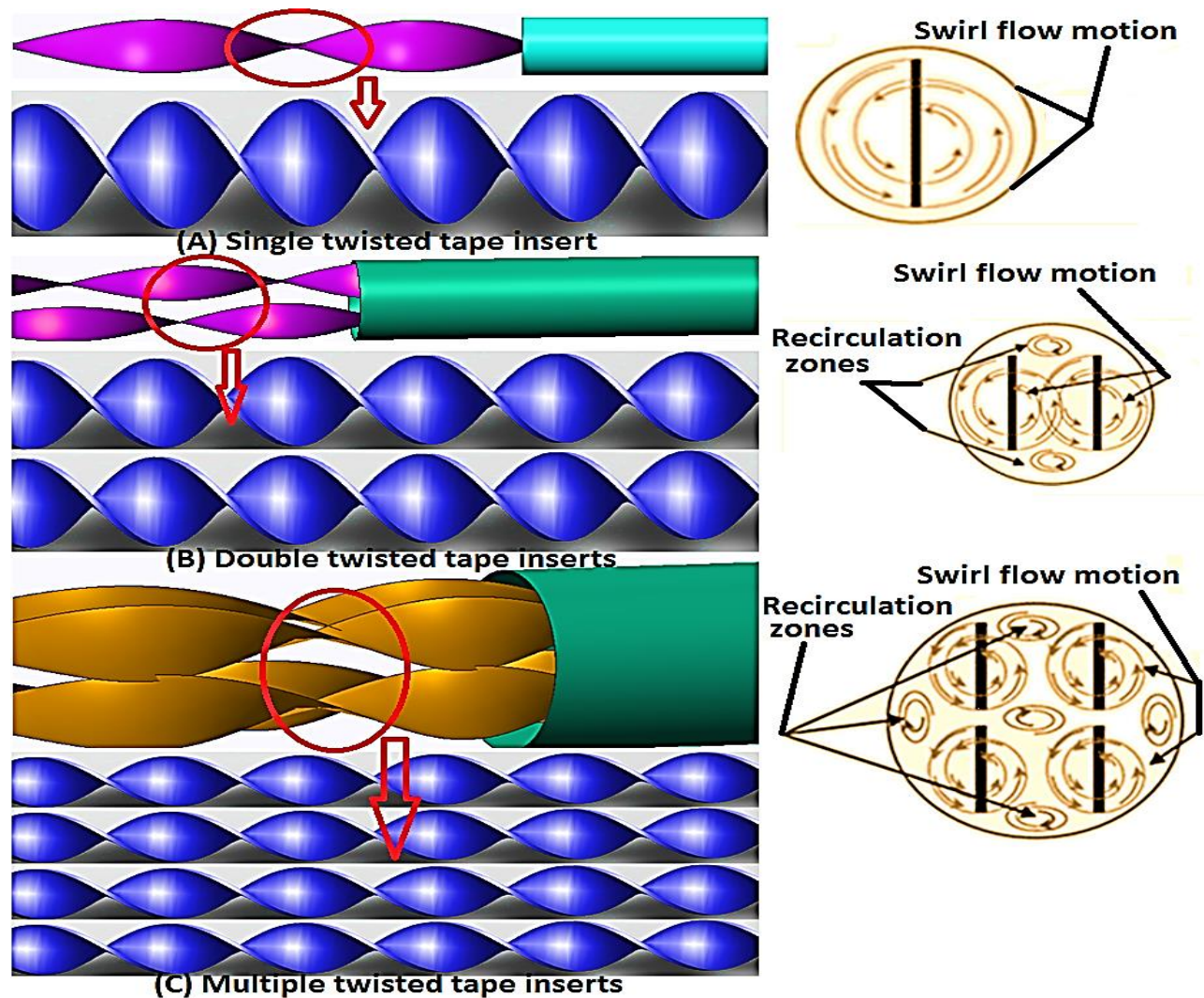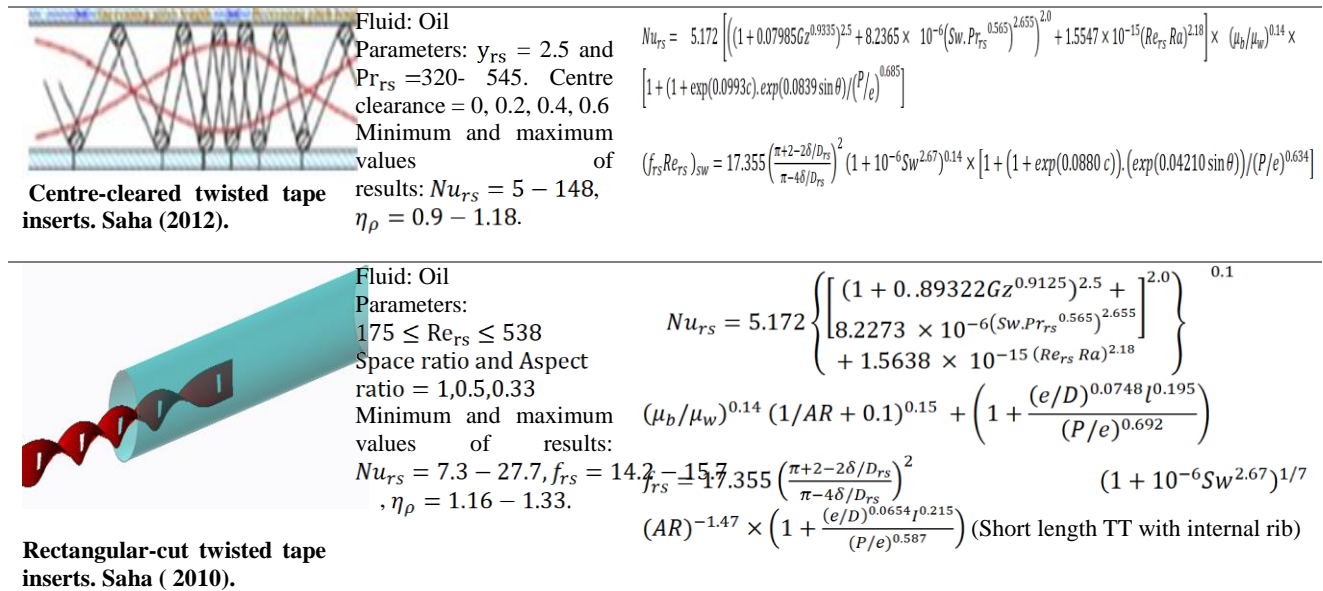|		
Centre-cleared twisted tape inserts. Saha (2012).	Fluid: Oil Parameters: $y_{rs} = 2.5$ and $Pr_{rs} = 320 - 545$. Centre clearance $= 0, 0.2, 0.4, 0.6$ Minimum and maximum values of results: $Nu_{rs} = 5 - 148$, $\eta_\rho = 0.9 - 1.18$.	$Nu_{rs} = 5.172 \left[\left((1 + 0.07985 Gz^{0.9335})^{2.5} + 8.2365 \times 10^{-6} (Sw. Pr_{rs}^{0.565})^{2.655} \right)^{2.0} + 1.5547 \times 10^{-15} (Re_{rs} Ra)^{2.18} \right] \times (\mu_b/\mu_w)^{0.14} \times$ $\left[1 + (1 + exp(0.0993c)).exp(0.0839 \sin\theta)/(P/e)^{0.685} \right]$ $(f_{rs}Re_{rs})_{sw} = 17.355 \left(\frac{\pi+2-2\delta/D_{rs}}{\pi-4\delta/D_{rs}} \right)^2 (1 + 10^{-6} Sw^{2.67})^{0.14} \times \left[1 + (1 + exp(0.0880 c)).(exp(0.04210 \sin\theta))/(P/e)^{0.634} \right]$
Rectangular-cut twisted tape inserts. Saha (2010).	Fluid: Oil Parameters: $175 \leq Re_{rs} \leq 538$ Space ratio and Aspect ratio $= 1, 0.5, 0.33$ Minimum and maximum values of results: $Nu_{rs} = 7.3 - 27.7, f_{rs} = 14.2 - 157$, $\eta_\rho = 1.16 - 1.33$.	$Nu_{rs} = 5.172 \left\{ \left[\begin{array}{l} (1 + 0..89322 Gz^{0.9125})^{2.5} + \\ 8.2273 \times 10^{-6} (Sw.Pr_{rs}^{0.565})^{2.655} \\ + 1.5638 \times 10^{-15} (Re_{rs} Ra)^{2.18} \end{array} \right]^{2.0} \right\}^{0.1}$ $(\mu_b/\mu_w)^{0.14} (1/AR + 0.1)^{0.15} + \left(1 + \frac{(e/D)^{0.0748} l^{0.195}}{(P/e)^{0.692}} \right)$ $f_{rs} = 17.355 \left(\frac{\pi+2-2\delta/D_{rs}}{\pi-4\delta/D_{rs}} \right)^2$ $(1 + 10^{-6} Sw^{2.67})^{1/7}$ $(AR)^{-1.47} \times \left(1 + \frac{(e/D)^{0.0654} l^{0.215}}{(P/e)^{0.587}} \right)$ (Short length TT with internal rib)

Fig. 4 Fluid flow pattern (A) single tape insert (B) double tape insert (C) multiple tape insert

4. CONCLUSIONS

This article presents a critical review of work done in the area of hydrodynamic and thermal performance using twisted tapes. The effect of various twisted tape inserts parameters on hydrodynamic and thermal performance are discussed in detail. The following conclusions can be drawn:

1. The applications of twisted tape inserts in a heat exchanger tube are an efficient method to enhance the heat transfer to fluid flow in the round heat exchanger tube. The reduction of the twist pitch values and tube diameter ratio tends to increase the heat transfer rate and pressure drop as well.

2. The twist angle is the most significant structural factor. A higher twist angle leads to larger hydrodynamic and thermal performance. More the twist angle, the higher tangential velocity will be created. As the twist angle increases, the hydrodynamic and thermal performance decreases slowly.

3. Reducing values of the twist pitch to tube diameter ratio, lead to increased values of heat transfer rate and pressure drop as well. Swirl flow helps in decreasing the boundary layer thickness of the hot air flowing and rises thee residence time of hot air in the inner tube.

4. Augmentation of thermal performance in full length twisted tape is better than the twist fitted with rod and spacer. The decrease in heat transfer augmentation in twist fitted with rod is minimum compared to twist fitted with rod is minimum compared to twist fitted with spacer. The decrease in pressure drop is better for twist fitted with spacer compared to twist fitted with rod.

5. V-cut twisted tape offered a higher local Nusselt number, local friction factor and also thermal hydraulic performance as compared to plain twisted tape. In addition, the influence of the depth ratio was more dominant than that of the width ratio for all the flow parameters.

6. Using any kind of twisted tape leads to thermal hydraulic improvement which is more substantial for lower values of excess air flow rate. Comparison of heat transfer performance shows that the improvement of convection heat transfer coefficient is more than total heat transfer coefficient.

7. Among the entire twisted tape elements examined, the multiple twisted tape inserts have the maximum value of hydrodynamic and thermal performance than that of other twisted tape shapes for the examined range of twisted tape parameters.

NOMENCLATURE

D_{rs}	Diameter of Tube $[m]$
d_{rs}	Director diameter $[m]$
P_{rs}	Wetted perimeter $[m]$
e_{rs}	Diameter of wire $[m]$
h_{rs}	Heat transfer coefficient $(W/m^2\,K)$
S_{rs}	Swirl parameter (m)
q_{rs}	Heat flux (W/m^2)
G_{rs}	Graetz number
f_{rs}	Friction factor
$P_{rs}/\ H_{rs}$	Rib pitch ratio
Pr_{rs}	Prandtl number
g	Acceleration due to gravity
CFD	Computational fluid dynamics
HET	Heat exchanger tube
TT	Twisted tape
TTT	Typical Twisted tape
WVG	Winglet type vortex generators
PCR	Perforated conical- ring
Re_{rs}	Reynolds number
Nu_{rs}	Nusselt number
$y_{rs}\&Y_{rs}$	Twist ratio of TT
R_{rs}	Rayleigh number

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