Review on Twisted Tapes Heat Transfer Enhancement

C.Nithiyesh Kumar, P.Murugesan

Abstract— Heat transfer augmentation techniques refer to different method used to increase rate of heat transfer without affecting much the overall performance of the system. These techniques are used in heat exchangers. Some of the applications of heat exchangers are in process industries, thermal power plant, air conditioning equipment, refrigerators, radars for space vehicles, automobiles etc. In the past decade, several studies on the passive techniques of heat transfer augmentation have reported. The present paper review mainly focus on the twisted tape heat transfer enhancement and its design modification towards the enhancement of heat transfer and saving pumping power.

Index Terms— Heat transfer augmentation, Passive methods, Tape inserts, Reynolds number, Friction factor

1 INTRODUCTION

Heat transfer enhancement or augmentation techniques refer to the improvement of thermo hydraulic performance of heat exchangers. Existing enhancement techniques can be broadly classified into three different categories:

1.1 Active Techniques: These techniques are more complex from the use and design point of view as the method requires some external power input to cause the desired flow modification and improvement in the rate of heat transfer. It finds limited application because of the need of external power in many practical applications.

1.2 Passive Techniques: These techniques do not require any direct input of external power; rather they use it from the system itself which ultimately leads to an increase in fluid pressure drop. They generally use surface or geometrical modifications to the flow channel by incorporating inserts or additional devices. They promote higher heat transfer coefficients by disturbing or altering the existing flow behavior except for extended surfaces.

1.3 Compound Techniques: When any two or more of these techniques are employed simultaneously to obtain enhancement in heat transfer that is greater than that produced by either of them when used individually, is termed as compound enhancement[1]

In this paper, a review of heat transfer enhancement using twisted tape and its modification is done. This paper also gives the performance criteria of different twisted tape inserts. Finally it is expected to be the pioneer source as an intensive literature review for twisted tape swirl generator.

Abbreviation

F	Friction factor
N_u	Nusselt number
R_e	Reynolds number
S_W	Swirl parameter
S	Spacing between two twisted tapes
TT	Twisted tape
Di	Inside diameter
y	Twist ratio
HTE	Heat transfer enhancement
α	Twist angle
g	Thermal performance factor
Pr	Prandtl number
η	Thermo hydraulic efficiency
G	Mass velocity
TA	Twisted tape with alternate axis
CCTA	Clockwise and counter clockwise TA
VTT	V-Cut twisted tape
WR	Width ratio
DR	Depth ratio
STT	Serrated twisted tape
CCT	Centre cleared twisted tape
CTs/CoTs	Twin-counter/co-twisted tapes
ETT	Edgefold-Twisted Tape
WTA	Centre wing and alternate axis Twisted tape
P-TA	Peripheral cut- Alternate axis Twisted tape
O/S DWT	Oblique/ Straight – Delta winglet Twisted tape
D/I coil	Decreasing/increasing coil pitch ratio arrangement
BTT	Broken twisted tape

- *PG Scholar, Department of Mechanical Engineering, K.S.Rangasamy College of Technology, Tiruchengode, Namakkal District,Tamilnadu, India-637215 Email ID: nithiyesh@gmail.com*
- *Department of Mechanical Engineering, K.S.R Institute for Engineering and Technology, Tiruchengode, Namakkal District, Tamilnadu, India-637215*

2 TERMINOLOGY USED IN TWISTED TAPE

2.1 Thermo Hydraulic Performance For a particular Reynolds number, the thermo hydraulic performance of an insert is said to be good if the heat transfer coefficient increases significantly with a minimum increase in friction factor Thermo hydraulic performance estimation is generally used to compare the performance of different inserts under a particular fluid flow condition.

2.2 Overall Enhancement Ratio The overall enhancement ratio is defined as the ratio of the heat transfer enhancement ratio to the friction factor ratio.

2.3 Nusselt Number The Nusselt number is a measure of the convective heat transfer occurring at the surface and is defined as hd/k, where h is the convective heat transfer coefficient, d is the diameter of the tube and k is the thermal conductivity.

2.4 Prandtl Number The Prandtl number is defined as the ratio of the molecular diffusivity of momentum to the molecular diffusivity of heat.

2.5 Pitch The Pitch is defined as the distance between two points that are on the same plane, measured parallel to the axis of a Twisted Tape.

2.6 Twist Ratio The twist ratio is defined as the ratio of pitch length to inside diameter of the tube.

3. REVIEW ON TWISTED TAPE

The present paper contributes for review of twisted tape inserts. The main objective of this paper is to review the work carried on plain twisted tape, modified twisted tape, and modified twisted tape geometry.

3.1 Plain Twisted Tape

Behabadi et al. [1] experimental investigated the heat transfer coefficients and pressure drop during condensation of HFC-134a in a horizontal tube fitted with TT. The refrigerant flows in the inner copper and the cooling water flows in annulus. Also empirical correlations were developed to predict smooth tube and swirl flow pressure drop.

Syam Sundar and sharma [2] investigated the thermo physical properties like thermal conductivity and viscosity of Al_2O_3 nanofluid is determined through experiments at different volume concentrations and temperatures. From the result it is observed that, heat transfer coefficients and 'f' is higher when compared to water in a plain tube. Also a generalized regression equation is developed with the experimental data for the estimation of 'f' and 'Nu'.

Promvonge et al. [3] experimentally investigated the heat transfer rate, 'f' and 'η' of the combined devices of TT and wire coil. The experiment is carried out by arranging in two different forms: (1) D-coil and (2) DI-coil while the TT was prepared with two different twist ratios.

Klaczak [4] investigated experimentally the heat transfer for laminar flow of water in an air cooled vertical copper pipe with TT inserts of various pitch value. The tests were executed for laminar flow within $110 \le Re \le 1500$, $8.1 \le Gz \le 82.0$ and $1.62 \le y \le 5.29$. Result shows that the heat transfer increases with increase in Twisted tape pitch value.

3.2 Modified Twisted Tape

Ferroni et al. [5] experimentally analyzed, the isothermal pressure drop tests, were performed on horizontal round tube with equally spaced and short-length TT. Various test are made with $1.5 \le y \le 6$ and $30 \le S \le 50$. The Darcy friction factor associated with the tested 'y' and 'S' combinations was calculated, and a relation correlating this factor to 'Re', 'y' and 'S' was developed.

Changhong Chen et al. [6] analyzed the computational fluid dynamics (CFD) modeling for the optimization of regularly spaced short-length TT in a circular tube. The configuration parameters are given by the 'S', 'y' and 'α'. The result is made such that the mean heat transfer and flow resistance increase with an increase in α.

Yadav [7] experimentally investigated on the half length TT insertion on heat transfer & pressure drop characteristics in a U-bend double pipe heat exchanger. The experimental results revealed that the increase in heat transfer rate of the TT inserts is found to be strongly influenced by tape-induced swirl.

Eiamsa-ard et al. [8] made a comparative investigation of enhanced heat transfer and pressure loss by insertion of single TT, full-length dual TT and regularly-spaced dual TT as swirl generators. The result shows that all dual TT with free spacing yield lower heat transfer enhancement in comparison with the full-length dual TT.

Hata and masuzakib [9] investigated the TT- induced swirl flow heat transfer due to exponentially increasing heat inputs with various exponential periods and the TT-induced pressure drop were systematically measured. The influence of 'y' and 'Re' based on swirl velocity, 'Re_{sw}' on the TT-induced swirl flow heat transfer was investigated and predictable correlation was derived.

Eiamsa-ard et al. [10] studied the influences of multiple twisted tape vortex generators (MT-VG) on the heat transfer and fluid friction characteristics in a rectangular channel From the experiment it is revealed that, the channel with the 'y' and 'S' provides higher heat transfer rate and pressure loss than those with the larger 'y' and free-spacing ratio under similar operation condition.

Eiamsa-ard et al. [11] an experimental study on the mean 'Nu'; 'f' and 'g' in a round tube with short-length TT insert. The full-length twisted tape is inserted into the tested tube at a single y = 4.0 while the short-length tapes mounted at the entry test section. The experimental result indicates that the presence of the tube with short-length twisted tape insert yields higher heat transfer rate.

Eiamsa-ard et al. [12] mathematically investigated the swirl flow in a tube induced by loose-fit twisted tape insertion. Effects of the clearance ratio on 'Nu', 'f' and 'g' are numerically investigated for TT at two different twist ratios.

Thianpong et al. [13] investigated experimentally the friction and compound heat transfer behaviors in a dimpled tube fitted with a TT swirl generator, using air as working fluid. The experiments are conducted by using two dimpled tubes with different pitch ratios and three twisted tapes with three different twist ratios. It is reveal that both heat transfer coefficient and 'f' in the dimpled tube fitted with the TT, are higher than those in the dimple tube acting alone and plain tube.

Promvonge and Eiamsa-ard [14] investigated thermal characteristics in a circular tube fitted with conical-ring and a TT swirl generator. The experimental results reveal that the tube fitted with the conical-ring and TT provides 'Nu' values of around 4 to 10% and enhancement efficiency of 4 to 8% higher than that with the conical-ring alone.

Mengna et al. [15] investigated experimentally the Pressure drop and compound heat transfer characteristics of a converging-diverging tube with evenly spaced TT (CD-T tube). Swirl was generated by evenly spaced twisted-tape elements which vary in twist ratio and rotation angle.

Eiamsa-ard et al. [16] experimentally investigated on the 'HTE' and 'f' characteristics in a double pipe heat exchanger fitted with regularly TT insert. By comparing the result with plain tube, it is evident that the heat transfer coefficient increased with 'y' and 'S'.

Saha et al. [17] experimentally investigated the HTE and pressure drop characteristics in the tube with regularly spaced TT element. From the result, it is observed that 'Pinching' of tape rather than in connecting the tape element with rods is better proposition from thermohydraulic point of view.

3.3 Modified Geometry Twisted Tape

Wei Liu et al. [18] investigated numerically the HTE and 'f' characteristics of laminar flow in a tube with short-width and CCT. It is given that CCT is good technique in lamina flow and the heat transfer can be enhanced with a change in central clearance ratio.

Eiamsa-ard and wongcharee [19] experimentally investigated HTE, 'f' and 'g' characteristics of CuO/water nanofluid and modified 'TA'. The use of nanofluid with the TA provides considerably higher 'Nu' and 'g' than that of nanofluid with the PTT.

Eiamsa-ard et al. [20] studied the effect of 'Nu', 'f' and 'g' behaviors of tubes fitted with C-CTA. The results reveal that, 'Nu', 'f' and 'g' associated by TA are higher than those associated by PTT.

Murugesan et al. [21] investigated experimentally the 'HTE', 'f' and 'g' characteristics of tube fitted with VTT. The obtained results show that the mean Nusselt number and the mean 'f' in the tube with 'VTT' increases with in decrease 'y'.

Eiamsa-ard et al. [22] experimentally investigated the influences on 'Nu', 'f' and 'g' of CT/CoT tapes fitted in tube. The (CTs) are used as counter-swirl flow generators while (CoTs) are used as co-swirl flow generators. The results also show that the CTs are more efficient than the CoTs for HTE.

Eiamsa-ard et al. [23] present an experimental study of turbulent heat transfer and flow friction characteristics in a circular tube equipped with C–CC TT. The results shows that the HTE of the C–CC TT increases with the decrease of twist ratio and the increase of twist angle values.

Zhang and Mao [24] carried out the 3D numerical and experimental study of the heat transfer characteristics and the pressure drop of air flow in a circular tube with ETT and STT inserts. From the experimental study it is found that the 'η' slowly decreases as the 'y' and 'S' increases.

Eiamsa-ard et al. [25] presented an investigation of the effect of twisted tape with serrated edge insert. The use of the STT leads to higher heat transfer rate and friction factor than that of the TT for all cases. The 'g' of the STT tube under constant pumping power is above unity.

Saha [26] experimentally studied the heat transfer and the pressure drop characteristics of rectangular and square ducts with TT insert with oblique teeth. From experiment it is found that, the axial corrugation in combination with TT with oblique teeth performs better than those without oblique teeth.

Eiamsa-ard et al. [27] experimentally studied the effects of the twisted tapes consisting of WT-A in a tube. It is found that, 'Nu', 'f', 'g' provided by the WT-A is higher than other type of tapes.

Eiamsa-ard and seemawute [28] experimentally investigated the effect of PT-A on the fluid flow and HTE characteristic. From the result, it is revealed that the PT-A offer the maximum thermal performances at constant pumping power.

Eiamsa-ard et al. [29] investigated 'HTE', 'f' and 'g' characteristics in a tube fitted with DWT. Influences of the O-DWT and S-DWT arrangements are also described. The obtained results show that the thermal performance factor in the tube with O-DWT is greater than that with S-DWT.

Eiamsa-ard et al. [30] Investigated the Effects of PTT insert on heat transfer, 'f' and 'g' characteristics in a round tube. Nine different PTT with 'y', different 'DR' and different 'WR' were tested. From the result, it is revealed that 'Nu', 'f' and 'g' are found to be increased with 'DR' and 'WR'.

Radhakrishnan. et al. [31] made experimental investigation on 'HTE', 'f' and 'g' of thermosyphon solar water heater system fitted with full- length twist, twist fitted with rod and spacer fitted at the trailing edge. Conclusions made from the results show that 'HTE' in TT collector is higher than the plain tube.

Bharatdwaj et al. [32] experimentally determined pressure drop and heat transfer characteristics of flow of water in a 75 start spirally grooved tube with twisted tape insert are presented. It is found 'HTE' in spiral tube is higher when compared to plain tube.

Chang et al. [33] experimental study that comparatively examined the spiky twisted-tape insert (swirl tube) placed in

ISSN 2229-5518

a tube. The dispersed rising air bubbles in the plain tube and the centrifugal-force induced coherent spiral stream of coalesced bubbles in the swirl-tube core considerably modify the pressure-drop and heat-transfer performances from the single-phase conditions.

Eiamsa-ard et al. [34] experimentally investigated the 'HTE' and 'f' effect in C-CC TT in heat exchanger. The experimental result revealed that heat transfer rate and 'f' is high compared to PTT.

Chang et al. [35] experimentally examined the turbulent heat transfer in a swinging tube with a STT insert under seagoing conditions. This swirl tube swings about two orthogonal axes under single and compound rolling and pitching oscillations. Synergistic effects of compound rolling and pitching oscillations with either harmonic or non-harmonic rhythms improve heat transfer performances.

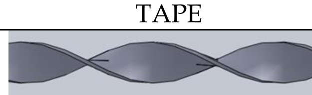
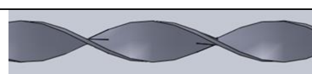
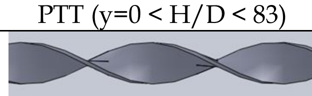
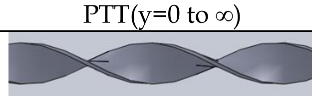
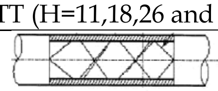
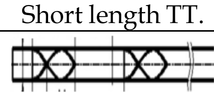
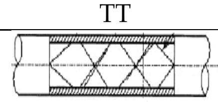
Murugesan. et al. [36] experimentally investigated the heat transfer and 'f' characteristics of trapezoidal –cut TT with y= 4.0 and 6.0. From the experiment it is revealed, that there was a significant increase in heat transfer coefficient and 'f' for tape with trapezoidal-cut.

Chang et al. [37] Studied experimentally on compound heat transfer enhancement in a tube fitted with STT. The serrations on two sides of the TT with twist ratio 'y' = 1.56, 1.88, 2.81 ∞ are the square-sectioned ribs with the identical rib-pitch and rib-height. From the experiment it is revealed that the friction factor and heat transfer rate is comparatively high than PTT.

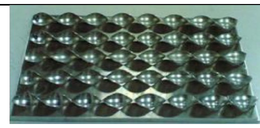
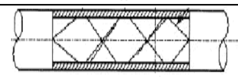
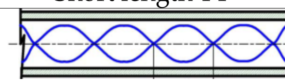
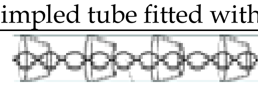
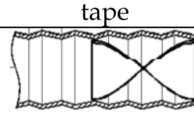
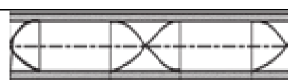
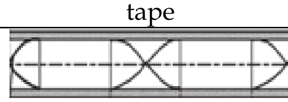
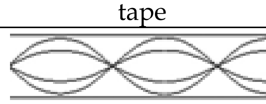
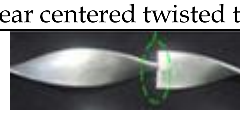
Chang et al. [38] made an experimental study in measuring the axial heat transfer distributions and the pressure drop coefficients of the tube fitted with BTT. From the experimental result it is revealed that local 'Nu' and mean 'f' in the tube fitted with the BTT increase as the 'y' decreases.

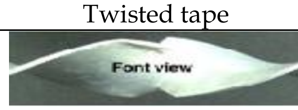
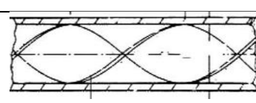
The summary of the above work is given in the table 1.0 based on the classification of the tape, type of flow, observation and comment.

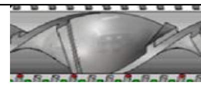
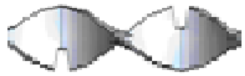
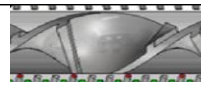
Table 1.0 Summary of Important Investigation on Twisted Tape

S.No	AUTHOR NAME	TYPE OF FLOW	CONFIGURATION OF TAPE	OBSERVATION	COMMENT
1.	Behabadi et al.	Turbulent	 PTT (y=6, 9, 12 and 15)	Decrease in 'y' increase the heat transfer rate. Pressure drop increases with reduction in 'y'	It is observed that the TT with 'y' = 9 gives the best 'g' with minimum pressure drop.
2.	Syam Sundar & sharma	Turbulent	 PTT (y=0 < H/D < 83)	No increase in pressure drop or 'f' when compared to water.	The maximum 'g' in the result is obtained at y=5.
3.	Promvonge et al.	Turbulent	 PTT(y=0 to ∞)	The heat transfer and 'f' is more efficient in TT than wire coil.	At low Re, with y=3 the thermal performance is higher.
4.	Klaczak	Laminar	 PTT (H=11,18,26 and 36)	The ratio NuT/Nu has the highest value when 'H' was the smallest.	The heat transfer coefficient increases with increase in twist tape pitch value
5.	Ferroni et al.	Turbulent	 Short length TT.	'f' and 'Nu' is low for short length TT and the performance is good.	The multiple short length twist tape performance is high compared to other.
6.	Chang et al.	Turbulent	 Regularly spaced short length TT	Heat transfer and flow resistance increase with an increase in the 'α'.	The larger 'α' yields a higher heat transfer value and a greater flow resistance.
7.	Yadav	Laminar	 Half length TT	On unit pressure drop basis and on unit pumping power basis, half length TT is more efficient than full-length TT.	On unit pressure drop basis, the heat transfer performance of smooth tube is maximum followed by half-length TT.

ISSN 2229-5518

8.	Eiamsa-ard et al.	Turbulent	 Regularly spaced dual TT	The 'f' from the dual TT increases up to 23% over the single twisted tape.	The 'f' tends to decrease with the rise of 'Re' and 'y'.
9.	Hata & Masuzakib	Turbulent	 PTT (y = 2.39–4.45)	The values of ΔP become linearly higher with an increase in the Re_d, and also influence of 'y' and 'Re' based on swirl velocity, Re_{sw}	Overall enhancement ratio increases with tighter twist ratio and decreases with increase in Reynolds number.
10.	Eiamsa-ard et al.	Turbulent	 Multiple TT	'Nu' increases in the range of 170% and 'f' in the range of 1.45 and 5.7. Heat transfer rate is 1.4 than the plain tube.	The channel with the smaller 'y' and 'S' provides higher heat transfer rate and pressure loss.
11.	Eiamsa-ard et al.	Turbulent	 Short length TT	The value of f and heat transfer rate ranges from 1.76-1.99, 1.16- 1.27.	Short length TT is better than full length TT on basis of 'g'
12.	Eiamsa-ard et al.	Turbulent	 Loose fit TT	Nu/Nu0 decreases with increase in Re.	The TT with tight fit gives high heat transfer rate but decrease in the 'f'.
13.	Thianpong et al.	Turbulent	 Dimpled tube fitted with TT	Heat transfer and 'f' increases with 'y' decreases.	Dimpled tube with TT gives higher heat transfer coefficient than TT.
14.	Promvonge & Eiamsa-ard	Turbulent	 Conical ring with twisted tape	With y= 3.75 the 'η' is 1.96.	Combined device increases the thermal performance.
15.	Mengna et al.	Turbulent	 TT in CD tube	At Y=4.762 and θ= 180° the best heat transfer and friction factor is obtained.	Converging diverging (CD) tube with TT creates swirling motion to fluid and increase the time of contact.
16.	Eiamsa-ard et al.	Turbulent	 Regularly spaced twisted tape	Heat transfer coefficient and friction factor increases with increase in space ratio.	
17.	Saha et al.	Laminar	 Regularly spaced twisted tape	Pinching of tape rather than connecting tape element give high 'g'.	Uniform pitch performs better than gradually decreasing pitch.
18.	Wei liu et al.	Laminar	 Clear centered twisted tape	CCT gives 'g' value 7-20% more than TT.	CCT gives more fluid flow and optimal 'f'.
19.	Eiamsa-ard& Wongcharee	Laminar	 Alternate axis Twisted tape	'Nu' increases with increase in 'Re' and fluid concentration.	TA makes more swirl in fluid flow with increased efficiency.
20.	Eiamsa-ard et al.	Laminar	 Clockwise and counter clockwise TA	At y=3 and Re=830, more efficient heat transfer is obtained.	Friction factor in TA increases with decrease in twist ratio.

21.	Murugesan et al.	Turbulent	 V –cut Twisted tape	Influence of 'DR' was more dominant than 'WR' for all 'Re'.	V cut TT gives higher transfer rate and friction factor than plain tube.
22.	Eiamsa-ard et al.	Turbulent	 Twin-counter/co-twisted tapes	'Nu', 'f' and 'g' increases with decrease in 'y'.	Heat transfer rate in tube with CTs are higher than those with CoTs.
23.	Eiamsa-ard et al.	Turbulent	 Clockwise and counter clockwise TA	Heat transfer rate of the CCTA increases with decrease of twist ratio.	Counter clockwise cut in twisted tape creates more of fluid inside the tube
24.	Zhang & Mao	Turbulent	 Edgefold Twisted tape	The highest performance of this TT is 140% when gap width reduces to 1 mm.	ETT with minimum α gives maximum thermal performance.
25.	Eiamsa-ard et al.	Turbulent	 Serated Twisted tape	Heat transfer rate is 1.77 times higher than that of plain tube.	STT increases turbulence intensity and breaking down the boundary layer.
26.	Saha	Turbulent	 Oblique teeth Twisted tape	At constant pumping power, the heat transfer rate is 1.55	TT with oblique teeth show high performance than TT without Oblique teeth.
27.	Eiamsa-ard et al.	Turbulent	 Centre wing and alternate axis Twisted tape.	Nu, f and g are higher in WTA than plain TT.	WTA will create the effect of swirling flow, and strong collision of the streams.
28.	Eiamsa-ard & Seemawute	Turbulent	 Peripheral cut- Alternate axis Twisted tape	Heat transfer rate by using PTA is 184%.	PTA provides maximum thermal performance at constant pumping power.
29.	Eiamsa-ard et al.	Turbulent	 DWT	'Nu' and 'f' increases with decrease in 'Re'.	DWT can replace any of the TT to reduce size of the heat exchanger.
30.	Eiamsa-ard et al.	Laminar	 PTA	'Nu', 'f' and 'g' increased with increase in depth ratio.	PTA provides high 'g' with constant pumping power
31.	Radha Krishnan et al.	Laminar	 TT with rod and spacer	'Nu' is 13.5% higher than PTT and 'f' is given as 14.85.	This is well effective for laminar flow only.
32.	Bharatdwaj et al.	Laminar	 Spirally grooved tube with TT	Heat transfer enhancement is increased due to swirl flow.	Spirally grooved tube will be well effective only with TT inside the tube.
33.	Chang et al.	Turbulent	 Spiky Twisted tape	HTE and 'g' of spiky TT is higher than that of PTT.	
34.	Eiamsa-ard et al.	Turbulent	 CCTA	Heat transfer rate is 219% of the plain tube.	

35.	Chang et al.	Turbulent	 Serated Twisted tape	Synergic effect of rolling and pitching oscillations improve heat transfer rate.	Serrated tube cause swirl motion and oscillation to the flow and increases 'g'.
36.	Murugesan et al.	Turbulent	 Trapezoidal cut TT	By the trapezoidal cut TT, the 'f' and 'g' increases with decrease in twist ratio.	Trapezoidal cut TT, increase in HTE value with constant pumping power.
37.	Chang et al.	Turbulent	 Serated Twisted tape	Nu and f increases as the twist ratio decreases.	Serration in the tube cause swirling in the boundary layer of the tube.
38.	Chang et al.	Turbulent	 Broken twisted tape	By using broken TT, the f= 2-4.7 and g= 1.8.	Broken TT increase the fanning factor with decrease in twist ratio.

CONCLUSION

This review has considered heat transfer and pressure drop investigations of the various twisted tape placed in heat exchangers. Almost all possible research subjects have been summarized on the case in the literature, such as heat transfer and pressure drop studies according to plain twisted tape, modified twisted tape, and modified twisted tape geometry.

A twisted tape and modified twisted tape inserts mixes the bulk flow well and therefore performs better in laminar flow, because in laminar flow the thermal resistant is not limited to a thin region. The result also shows twisted tape insert is more effective in laminar flow, and pressure drop penalty is created during turbulent flow.

In case of twisted tape with modified geometry, more turbulence is created during the swirl of fluid and gives higher heat transfer rate compared to plain twisted tape and modified twisted tape. The result shows that for modified twisted tape geometry, the heat transfer rate is higher with reasonable friction factor for both laminar and turbulent flow.

These conclusions are very useful for the application of heat transfer enhancement in heat exchanger networks.

REFERENCE

[1] V. Hejazi, M.A. Akhavan-Behabadi and A. Afshari, Experimental investigation of twisted tape inserts performance on condensation heat transfer enhancement and pressure drop, International Communications in Heat and Mass Transfer, Vol. 37 (2010), pp. 1376–1387.

[2] L. Syam Sundar and K.V. Sharma, Turbulent heat transfer and friction factor of Al_2O_3 Nanofluid in circular tube with twisted tape inserts, International Journal of Heat and Mass Transfer, Vol. 53 (2010), pp. 1409–1416.

[3] S. Eiamsa-ard, P. Nivesrangsan, S. Chokphoemphun and P. Promvonge, Influence of combined non-uniform wire coil and twisted tape inserts on thermal performance characteristic, International Communications in Heat transfer, Vol. 37 (2010), pp. 850–856.

[4] A. Klaczak, Heat transfer by laminar flow in a vertical pipe with twisted-tape inserts, Heat and Mass Transfer, Vol. 36 (2000), pp. 195-199, Springer-Verlag 2000.

[5] P. Ferroni, R.E. Block, N.E. Todreas and A.E. Bergles, Experimental evaluation of pressure drop in round tubes provided with physically separated, multiple, short-length
twisted tapes, Experimental Thermal and Fluid Science xxx (2011) xxx–xxx.

[6] Yangjun Wang, Meiling Hou, Xianhe Deng, Li Li, Cheng Huang, Haiying Huang, Gangfeng Zhang, Changhong Chen and Weijun Huang, Configuration optimization of regularly spaced short-length twisted tape in a circular tube to enhance turbulent heat transfer using CFD modeling, Applied Thermal Engineering, Vol. 31 (2011), pp. 1141-1149.

[7] Anil Yadav, Effect of half length twisted tape turbulator on heat transfer & pressure drop characteristics inside a double pipe U-bend heat exchanger, Jordan journal of Mech. & Industrial engg., Vol. 3 No.1 (2009), pp. 17-22.

[8] S. Eiamsa-ard, Chinaruk Thianpong , Petpices Eiamsa-ard and Pongjet Promvonge, Thermal characteristics in a heat exchanger tube fitted with dual twisted tape elements in tandem, International Communications in Heat and Mass Transfer Vol. 37 (2010), PP.39–46.

[9] K. Hataa and S.Masuzakib, Twisted-tape-induced swirl flow heat transfer and pressure drop in a short circular tube under velocities controlled, Nuclear Engineering and Design, xxx (2010) xxx–xxx, NED-5980.

[10] S. Eiamsa-ard, Study on thermal and fluid flow characteristics in turbulent channel flows with multiple twisted tape vortex generators, International Communications in Heat and Mass Transfer, Vol. 31 (2010), pp. 644–651.

[11] S. Eiamsa-ard, Chinaruk Thianpong, Petpices Eiamsa-ard and Pongjet Promvonge, Convctive heat transfer in a circular tube with short-length twisted tape insert, International communication in Heat and Mass Transfer, Vol. 36 (2009), pp. 365-371.

[12] S. Eiamsa-ard, K. Wongcharee and S. Sripattanapipat, 3-D Numerical simulation of swirling flow and convective

heat transfer in a circular tube induced by means of loose-fit twisted tapes, International communication in Heat and Mass Transfer Vol. 36 (2009), pp. 947-955.
[13] Chinaruk Thianpong, Petpices Eiamsa-ard, Khwanchit Wongcharee and Smith Eiamsa-ard, Compound heat transfer enhancement of a dimpled tube with a twisted tape swirl generator, International Communications in Heat and Mass Transfer Vol. 36 (2009), pp. 698–704.
[14] P. Promvonge and S. Eiamsa-ard, Heat transfer behaviors in a tube with combined conical ring and twisted-tape inserts, International Communications in Heat and Mass Transfer Vol. 34 (2007), pp. 849–859.
[15] HONG Mengna, DENG Xianhe, HUANG Kuo and LI Zhiwu, Compound heat transfer enhancement of a converging-diverging tube with evenly spaced twisted-tapes, Chinese Journal of Chemical Engineering, Vol. 15 No.6 (2007), pp. 814—820.
[16] Smith Eiamsa-ard, Chinaruk Thianpong and Pongjet Promvonge, Experimental investigation of heat transfer and flow friction in a circular tube fitted with regularly spaced twisted tape elements, International Communications in Heat and Mass Transfer Vol. 33 (2006), pp. 1225–1233.
[17] Saha, S. K, Dutta, A. and Dhal, S. K., Friction and heat transfer characteristics of laminar swirl flow through a circular tube fitted with regularly spaced twisted-tape elements, International Journal of Heat and Mass Transfer, Vol. 44 (2001), pp. 4211-4223.
[18] Jian Guo, Aiwu Fan, Xiaoyu Zhang and Wei Liu, A numerical study on heat transfer and friction factor characteristics of laminar flow in a circular tube fitted with center-cleared twisted tape, International Journal of Thermal Sciences Vol. 50 (2011), pp. 1263-1270.
[19] K.Wongcharee and S. Eiamsa-ard, Enhancement of heat transfer using CuO/water nanofluid and twisted tape with alternate axis, International Communications in Heat and Mass Transfer Vol. 38 (2011), pp. 742–748.
[21] P. Murugesan, K. Mayilsamy, S. Suresh and P.S.S. Srinivasan, Heat transfer and pressure drop characteristics in a circular tube fitted with and without V-cut twisted tape insert, International Communications in Heat and Mass Transfer Vol. 38 (2011), pp. 329–334.
[22] S. Eiamsa-ard, C. Thianpong and P. Eiamsa-ard, Turbulent heat transfer enhancement by counter/co-swirling flow in a tube fitted with twin twisted tapes, Experimental Thermal and Fluid Science Vol. 34 (2010), pp. 53–62.
[23] Smith Eiamsa-ard and Pongjet Promvonge, Performance assessment in a heat exchanger tube with alternate clockwise and counter-clockwise twisted-tape inserts, International Journal of Heat and Mass Transfer Vol. 53 (2010), pp. 1364–1372.
[24] CUI Yong-zhang and TIAN Mao-cheng, Three-Dimensional Numerical Simulation of Thermal hydraulic Performance of a circular tube with Edgefold-Twisted-Tape Inserts, Journal Of Hydrodynamics, , Vol. 22 No. 5 (2010), pp. 662-670.
[25] Smith Eiamsa-ard and Pongjet Promvonge, Thermal characteristics in round tube fitted with serrated twisted tape, Applied Thermal Engineering Vol. 30 (2010), pp. 1673-1682.
[26] S.K. Saha, Thermohydraulics of turbulent flow through rectangular and square ducts with axial corrugation roughness and twisted-tapes with and without oblique teeth, Experimental Thermal and Fluid Science Vol. 34 (2010), pp. 744–752.
[27] S. Eiamsa-ard, K. Wongcharee, P. Eiamsa-ard and C. Thianpong, Thermohydraulic investigation of turbulent flow through a round tube equipped with twisted tapes consisting of centre wings and alternate-axes, Experimental Thermal and Fluid Science Vol. 34 (2010), pp. 1151–1161.
[28] P. Seemawute and S. Eiamsa-ard, Thermohydraulics of turbulent flow through a round tube by a peripherally-cut twisted tape with an alternate axis, International Communications in Heat and Mass Transfer, Vol. 37 (2010), pp. 652–659.
[29] S. Eiamsa-ard, K. Wongcharee, P. Eiamsa-ard and C. Thianpong, Heat transfer enhancement in a tube using delta-winglet twisted tape inserts, Applied Thermal Engineering, Vol. 30 (2010), pp. 310–318.
[30] S. Eiamsa-ard, Panida Seemawute and K. Wongcharee, Influences of peripherally-cut twisted tape insert on heat transfer and thermal performance characteristics in laminar and turbulent tube flows, Experimental Thermal and Fluid Science, Vol. 34 (2010), pp. 711–719.
[31] S. Jaisankar, T.K. Radhakrishnan and K.N. Sheeba, Experimental studies on heat transfer and friction factor characteristics of thermosyphon solar water heater system fitted with spacer at the trailing edge of twisted tapes, Applied Thermal Engineering Vol. 29 (2009), pp. 1224–1231.
[32] Bharadwaj, A.D. Khondge and A.W.Date, Heat transfer & pressure drop in spirally grooved tube with twisted tape insert, J. Heat Transfer, Vol. 52 No.5 (2009), PP. 1938-1944.
[33] S.W. Chang, Arthur William Lees and Hsien-Tsung Chang, Influence of spiky twisted tape insert on thermal fluid performances of tubular air–water bubbly flow, International Journal of Thermal Sciences Vol. 48 (2009), pp. 2341–2354
[34] B. Silapakijwongkul, S. Eiamsa-ard and P. Promvonge, Effect of clockwise and counterclockwise twisted-tape turbulators on heat transfer augmentation inside a double pipe heat exchanger. International Energy Journal.
[35] S.W. Chang, Tong-Miin Liou, Jin Shuen Liou and Kun-Tse Chen, Turbulent heat transfer in a tube fitted with serrated twist tape under rolling and pitching environments with applications to shipping, Journal of Ocean Engineering, Vol. 35 (2008), pp. 1569-1577.
[36] P. Murugesan, K. Mayilsamy, S. Suresh and P.S.S. Srinivasan, Heat Transfer And Pressure Drop Characteristics of Turbulent Flow in a Tube Fitted With

Trapezoidal-Cut Twisted Tape Insert, International Journal Of Academic Research, Vol. 1. No. 1 (2009), PP. 123-128

[37] S.W. Chang, Yih Jena Jan and Jin Shuen Liou, Turbulent heat transfer and pressure drop in tube fitted with serrated twisted tape, International Journal of Thermal Sciences Vol. 46 (2007), pp. 506–518.

[38] S.W Chang, Tsun Lirng Yang andJin Shuen Liou, Heat transfer and pressure drop in tube with broken twisted tape insert, Experimental Thermal and Fluid Science Vol. 32 (2007), pp. 489- 501.