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Assessment of twist tape thermal performance in heat transfer passive augmentation technique

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Abstract

Processing processes such as petrochemical, refineries, pharmaceutical, thermal, chemical, and integrated chemical industries such as the food, dairy and sugar industries have been widely used for heat exchange. Additional techniques have been used in the formulation of various twist geometry gestures such as helical film, triangular/rectangular/trapezoidal tape, HiTrain wire matrix mould, a novel turbulator with a diameter (*p*/*d*), well placed/separated broken twisted tapes, conic splitting, and other geometric tapes are well researched with Reynolds number range 13–500,000 liquid processing solutions such as ethylene glycol and turbine oil respectively. This paper also highlighted the impact of circular holes, rectangular holes, angle of entry, wavy rate and tape size in the optimal temperature parameter such as thermal enhancement factor 1.04–3 varies with Reynolds' number from 100 to 20,000. By test/numerical reading the curved ratio was calculated from 0.25 short lengths to 20 trapezoidal cuts with tape geometry through various reviews. The Jacobean matrix associated to the linear equation is given by,

$$J(X) = \begin{bmatrix} \frac{\partial f_1}{\partial T_2} & \frac{\partial f_1}{\partial T_4} \\ \frac{\partial f_2}{\partial T_2} & \frac{\partial f_2}{\partial T_4} \end{bmatrix}$$

$$\frac{\partial f_1}{\partial T_2} = -Q_h Cp_h$$

$$\frac{\partial f_1}{\partial T_4} = -Q_c Cp_c$$

$$\frac{\partial f_2}{\partial T_2} = -Q_h Cp_h - \left\{ \frac{[UA\{(T_1 - T_4) - (T_4 - T_3)\}]\left[\frac{(T_1-T_4)}{(T_2-T_3)}\right]^2}{\ln\left[\frac{(T_1-T_4)}{(T_2-T_3)}\right]^2} \right\}.$$

Compared to a blank tube, the heat transfer rate and the friction factor improved by 20% when using full-length tapes $y = 2.5$, and NNu increased 9 times to $y = 3.125$. There is a 30–40% increase using different twisted tapes. This in-depth study is common use in industrial systems to gain power.

Keywords: Heat transfer, Swirl flow, Active technique, Twisted tapes, Helical tape, Trapezoidal wings, Wire matrix, Micro-fin tube, Enhancement efficiency

1 Background

Conduction, convection and radiation are the three mechanisms by which heat is transferred. A heat exchanger is a system that allows heat to be transferred between two fluids of different temperatures. It occurs

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when a hot fluid passes through a solid wall separating two cold fluids due to a temperature difference.

Heat exchangers are commonly used in process industries for heating and cooling in evaporators, refrigerators, and other similar devices. Energy conservation is a hot subject in the heat exchanger industry these days [1]. As a result, it is essential to improve heat transfer in heat exchange equipment while minimising costs and conserving electricity. Passive augmentation methods using twisted tape are used in this case. In a Double Pipe Heat Exchanger, heat transfer enhancement would be achieved in the tube side, which is equipped with full-length twisted tapes inserts in laminar flow.

Heat exchangers are used in a variety of manufacturing and engineering settings. The design of heat exchangers is very complicated, as it necessitates an exact study of heat transfer rate and pressure drop estimates, as well as considerations such as long-term efficiency and cost. The most difficult aspect of designing a heat exchanger is making it compact and achieving a high heat transfer rate with minimal pumping capacity. Heat transfer enhancement techniques are useful in a variety of engineering applications. The high cost of energy and materials has resulted in an increased effort to produce more reliable heat exchange equipment in recent years. Furthermore, augmentation of heat transfer is often needed for miniaturization of a heat exchanger in specific applications, such as space applications. Heat transfer enhancement is a subject of great interest to researchers because it results in energy and cost savings. Heat transfer in channels has a wide range of applications in process industries and engineering. Various augmentation methods are used to strengthen traditional heat exchangers, with a focus on various forms of surface enhancement. The augmentation surface can have one or more of the following conditions that favour an increase in heat transfer rate while causing an undesirable increase in friction. [2–11]:

1. Increased turbulence intensity and disruption of boundary layer growth.
2. Increased surface area for heat transfer.
3. Swirling/rotating/secondary flow generation.

1.1 Augmentation techniques

Since there is no cross mixing of the fluid in a laminar flow, heat transfer is primarily by conduction and molecular diffusion. There were also natural convection currents. With the exception of liquid metals, the thermal conductivities of the fluids were mild. As a result, laminar flow heat transfer coefficients were generally poor.

As a result, larger heat transfer whereas will be needed for a given heat transfer rate when compared to turbulent flow heat transfer situations. As a result, in some cases, an augmentative scheme is needed to meet the size constraints placed on and to ensure efficient operation [12].

In many engineering applications, good thermal efficiency of the heat exchanger or thermal systems is needed, and numerous methods to improve the heat exchanger in the system have been developed and widely used shown in Table 1. The following conditions are created by these techniques to improve the heat exchanger rate:

1. Increasing the surface area for heat transfer.
2. Spinning and/or secondary flow generation.
3. Disruption of boundary layer formation and increased turbulence in the flowing fluid.

The following three methods Fig. 1 are commonly used to improve heat transfer in Heat Exchanger:

lopina and Bergles [27] is completed an analysis in which water is utilized a liquid single stage with twisted tapes embed in roundabout cylinder Heat exchanger. They utilizes full length tapes with twist ratio 2.5–9.2. Because of this stream way are expanded. In these they utilized a NRe $< 8 \times 10^3$ to 1.3×10^5. By utilizing twisted tapes there is an expansion in stream way which prompts dissemination way. Heat transfer rate and friction factor has improved by 20%.

They used full length twisted tape with a $y = 3.125$ tape insert, according to Hong and Bergles [36]. Water and ethylene glycol were used as fluids, with Nre ranges of 83–2460 and 13–390, respectively. When the Nre is big, tape twist has an effect on friction. The Nusselt number of a tube without twisted tapes was found to be 9 times that of a tube with twisted tapes.

Ray and Date [37] used full length twisted tapes with a twist ratio of $1.5 < y < 10$ in a square duct for NRe < 1100, with water as the fluid for the experiment, $1 <$ NPr < 50. They include Nusselt number and friction factor correlations. A square duct has better hydrothermal efficiency than a circular duct.

Gaitonde and Saha [14] Experiments on turbulent flow in circular tubes of regularly spaced twisted tapes with a factor of $3.18 < \infty$. They discovered that full length twisted tapes perform better than regularly spaced twisted tapes for NRe 5000–43,000.

Dutta and Saha [38] Laminar flow in circular tubes with regularly spaced twisted tapes with twist ratios ranging from 2.50 to 5. They discovered that full length twisted tapes perform better than regularly spaced twisted tapes for NRe 45–1150.

Suden and Wang [39] In circular tubes with twist ratios of 3, 4.5, and 6, for NRe 300–30,000, a comparison was made between twisted tapes and wire coil inserts.

Table 1 Review the most important twisted tape investigations that began in the turbulent field

Wijayanta and Mirmanto [13]	Water	NRe 4500–18,500	–	Short lenth twisted tapes inserts with twisted ratio 0.25, 0.5, 0.75 and 1	The friction factor and NNu were found to be 0.51 and 2.84 times higher than the simple tubes, respectively
Saha et al. [14]	Water	NRe 5000–43,000	NPr 4–5.5	Twist ratio is 3.18 to ∞	Twist tapes that were spaced evenly were superior to full length twist tapes
Kunlabud et al. [15]	Air	Nre 5000–15,000	–	Twisted tapes With loose fit multi-channel	The simple tube's heat transfer rates have been improved
Ahmadet al. [16]	Water	NRe 5000–16,000	–	Swirling Perforated Twisted Tape Insert	Heat transfer is easier with partially perforated twisted tape than with completely perforated twisted tape
Ganorkar and Warkhedkar [17]		NRe 5000–22,000	–	Elliptical-cut twisted tapes inserts with twist ratio 8. And major- minor axis compositions 5, 4, 3.3, 3 and 2.5	With a decreasing major to minor axis ratio, NNu and friction factor in the tube with elliptical-cut twisted tape increase
Eiamsa-ard et al. [18]	Nanofluid TiO2/Water	NRe 5400–15,200	–	Overlapped dual twisted tapes. With twist ratio 1.5, 2.0 and 2.5	With decreasing overlapped twist ratio, Nusselt number and friction factor increased
Yaningsih et al. [19]	Water	NRe 5400–17,500	–	Twisted tape Twist tape ratio 3.97 and twisted tape with perforated axial pitch ratio 0.56, 0.87 and 1.19	Twisted tape inserts with perforations have more successful than twisted tape inserts without perforations
Yaningsih et al. [20]	Water	NRe 5400–17,350	–	V cut twisted tapes insert with different width ratio 0.32, 0.38, and 0.48	Heat transfer and thermal efficiency improve when the width is reduced
Sivakumar and Rajan [21]	Water	NRe 5710–18,366	–	Triangular cut twisted tapes twist ratio 5.4. And depth of triangular cut 1.2 cm	Triangular cut twisted tapes outperform plain twisted tapes by 1.1–1.3 times
Yaningsih and Wijayanta [22]	Water	NRe 5800–18,500	–	Twisted tapes using wing with diff axes Triangular-wing chord ratio 0.31 Trapezoid-wing span ratio 0.23 Twist ratio 3.8	As compared to plain tube, the heat transfer rate increased by 1.91 times and the friction factor improved by 5.2 times
Naga Sarada et al. [23]	Air	NRe 6000–13,500	–	Twist tapes width from 10–22 mm. With twist ratio 3, 4 and 5	Inserts boost heat transfer by 36–48% as compared to plain heat transfer for maximum width. It was 33–39% for reduced width
Eiamsa-Ard [24]	Air	NRe 6000–20,000	–	Circular-ring turbulators with pitch ratio (l/D = 1.0,1.5 and 2) and twisted tape with twist ratio 3, 4, 5	When Pitch ratio 1 and Twist ratio 3 are combined, the effect is better than when they are used separately
Abdolbaqi et al. [25]		NRE 7200–32,400	–	Twin counter twisted tapes and twin co- twisted tapes with twist ratio 5, 10 and 15	The heat transfer rate of counter twisted tapes was 22.5% higher than that of co twisted tapes
Hong et al. [26]	Air	NRe 8000–22,000	–	twin overlapped twisted tapes counter large and small combinations with twist ratio 1.06, 1.56, 2.44 and 3.22	When the overlapped twisted ratio was reduced, NNu and friction factor increased
Lopina and Bergles [27]	Water	NRe $< 8 \times 10^3$ *to* 1.3×10^5	–	full length twist tapes	The rate of heat transfer has accelerated by 20%

Table 1 (continued)

Kreith and Sonju [28]	Water	NRe < 10×10^3 *to* 1×10^5	–	Twisted tapes	Tube length tapes perform 25–45% better than full-length tapes
Salam et al. [29]	Water	NRe 10,000–19,000	–	Rectangular-cut (depth 8 mm and width 14 mm) twisted tape with twist ratio 5.25	Twisted tapes with a rectangular cut improve performance by 2.3–2.9 times as compared to smooth tubes
Liao and Xin [30]	Water, Ethylene glycol and Turbine oil	NRe 80–500,000	NPr 5.5–590	twisted tape and three dimensional extended surfaces	As compared to a smooth tube, a tube with three dimensional extended surfaces and twisted tape increased average NSt by 5.8 times
Sivashanmugam and Suresh [31]	Water	NRe	–	Helical screw- tape insert with increasing and decreasing order	Empirical correlation is validated
Arunachalam and Edwin[32]	Al2O3–Cu/water Hybrid nano fluid (Peclet number 2580to 11,780)	–	–	V-cut twisted tape inserts and plain twisted tapes inserts	Simple twisted tape inserts with V-cut twisted tape inserts have a better heat enhancement than plain twisted tape inserts. Hybrid fluid has a heat transfer coefficient of 25.8% higher than water
Al-Fahed et al. [33]	Oil	–	–	Twisted tape with twist ratio 3.6, 5.4, 7.1	Low twist ratio means less pressure drop and more heat transfer
Ujhidy et al. [34]	Water	–	–	Twisted tapes	The flow structure was defined
Sivanshanmug-am and Sunduram [35]	Water	–	–	Twisted tapes with twist ratio 8.54, 5.882, 4.95 and 4.149	Tape-generated swirl flow has thermo-hydraulic characteristics. More efficient when the twist ratio is high

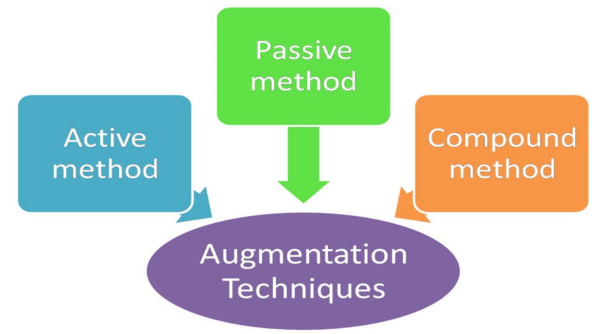

Fig. 1 Schematic representation of Thermal and Hydrodynamic boundary layer

Study of heat transfer enhancement in circular tubes with different inserts, with twist ratios ranging from 5.2 to 3.4, by Kapatkar and Padalkar [40]. They discovered that the friction factor with tapes inserts was 340–750% higher than smooth tubes for NRe 200–2000.

Klaczak [41] The use of twisted tape inserts with twist ratios ranging from 1.62 to 5.29 improves heat transfer. They discovered that low pitch twist tapes have the highest effectiveness for NRe 110–1500.

Sita Rama Raju and Naga Sarada [23] They investigated heat transfer enhancement using varying width twisted tape inserts with twist ratios of 3, 4 and 6 for NRe 6000–13,500, having different widths. They discovered that as compared to plain tube, there is a 30–40% improvement.

Greetings, Khalil et al. [42] investigate the use of twist tapes with a twist ratio of 2.77 and variable width to improve heat transfer. 690–2195 NRe They discovered that without twist tape, the total enhancement ratio is 575%.

Agarwal and Raja Rao [43] Heat transfer augmentation in circular tubes using twisted tape inserts with twist ratios of 2.41–4.84 for NRe 70–4000. The friction factor was found to be 3.13–9.71 times that of simple tubes.

Heat transfer enhancement using twisted tape in square duct by Fenget al. [44]. 3, 4 and 5 twist ratios They discovered a 5% deviation in average heat transfer when compared to experimental results.

Chaedir et al. [45] Heat transfer in a helical tube with twisted tape inserts of 3.15, 7.86 and 15.73. They discovered that for NRe 100–2000, the NPr enhancement ratio is higher at NRe 500–1000.

Lim and Hung [46] Using twisted tapes, evaluate swirl flow in a heat exchanger. Twist ratios of 2.5, 4, and 6 They developed a NNu correlation accuracy of about 15% for NRe 450–1350.

External power is used in active techniques to promote the desired flow adjustment and the resulting increase in heat transfer rate. Stirrers, surface vibration, fluid pulsation, and other methods can be used to improve heat transfer in this process. Passive strategies do not need any external power; instead, they draw power from the device itself, resulting in an increase in pressure drop. Surface or geometrical changes to the flow channel, such as inserts or external devices, are often used. The term compound method refers to a technique that combines active and passive elements. The heat transfer enhancement provided by this technique is obviously greater when both passive and active techniques are used individually. However, incorporating this technique into thermal systems requires complex designs, high maintenance, and is not cost efficient [47, 48].

1.2 Functioning of twisted tape

Eiamsa-ard and Promvonge [49] has been discovered that improving heat transfer with a passive method using various forms of helical tape construction in the inner tube of a concentric double pipe heat exchanger Fig. 2 will significantly increase the heat transfer rate. In contrast to the simple tube, the maximum mean Nusselt number for the full-length helical tape with centered-rod, 150% for the full-length helical tape without rod, and 145% for the regularly-spaced helical tape, $s = 0.5$, can be increased by 160%. The swirling flow caused by the secondary flows of the fluid may explain the increased heat transfer and pressure decrease.

Yaningsih and Wijayanta [51] Modifications that are popular (T-Tri, T-Rec, and T-Tra) are twisted tape inserts Fig. 3 with triangular, rectangular, and trapezoidal wings (T-Tri, T-Rec, and T-Tra) with alternate axes that have higher heat transfer than TT. This is due to a combination of the alternative axes' flow fluid and the wings' proposed additional turbulence near the pipe's wall. The Nusselt numbers, friction factor, and thermal efficiency factor for T-Tra were the largest, followed by T-Rec and T-Tri. As inserts T-Tra is used, the highest value of thermal efficiency factor was 1.44, while the amount of friction factor and Nusselt increased to 1.91 and 5.2 times, respectively, as compared to a plain tube.

Raman Bedi et al. [52] according to experimental findings, a good swirl generator should have a higher heat transfer coefficient, lower pressure drops, and a lower friction factor. hiTrain wire matrix Fig. 4 meets all of these criteria. The simplicity of design and fabrication is one of the reasons for the widespread use of twisted tape. HiTrain wire matrix fabrication is more difficult due to the varying loop density and strength per foot length. The loops in the hiTrain wire matrix shear the fluid flow at lower Reynolds numbers (Laminar flow), resulting in a higher heat transfer coefficient, lower pressure decrease, and lower friction factor. Swirl and recirculation zones are created by twisted tape and twisted tape with baffles,

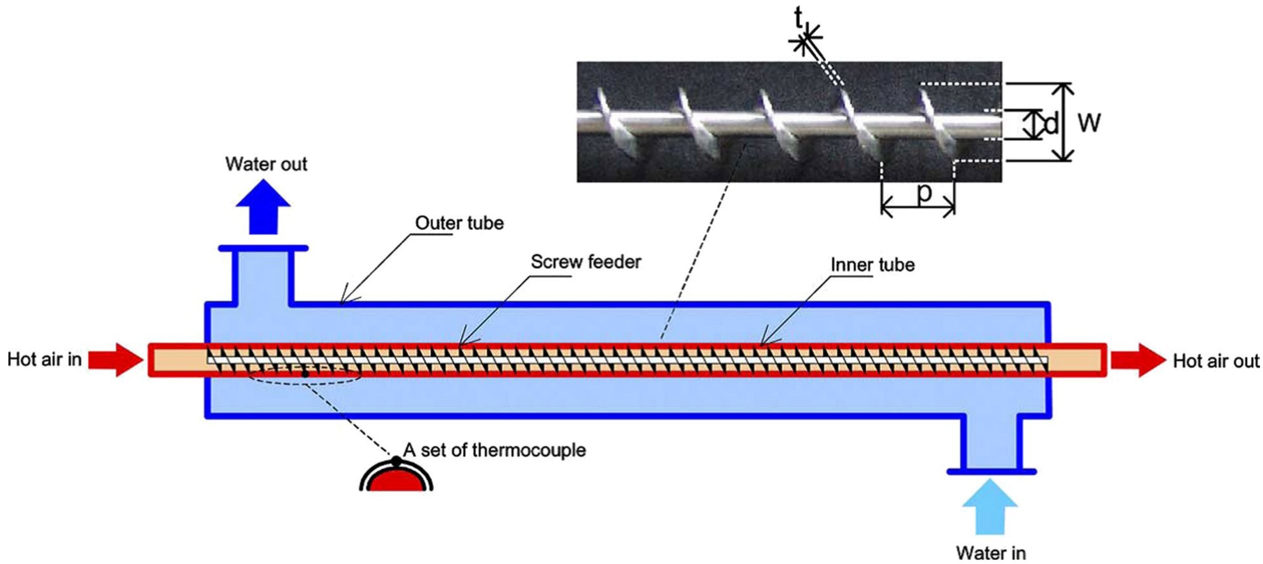

Fig. 2 Circular pipe with insert [50]

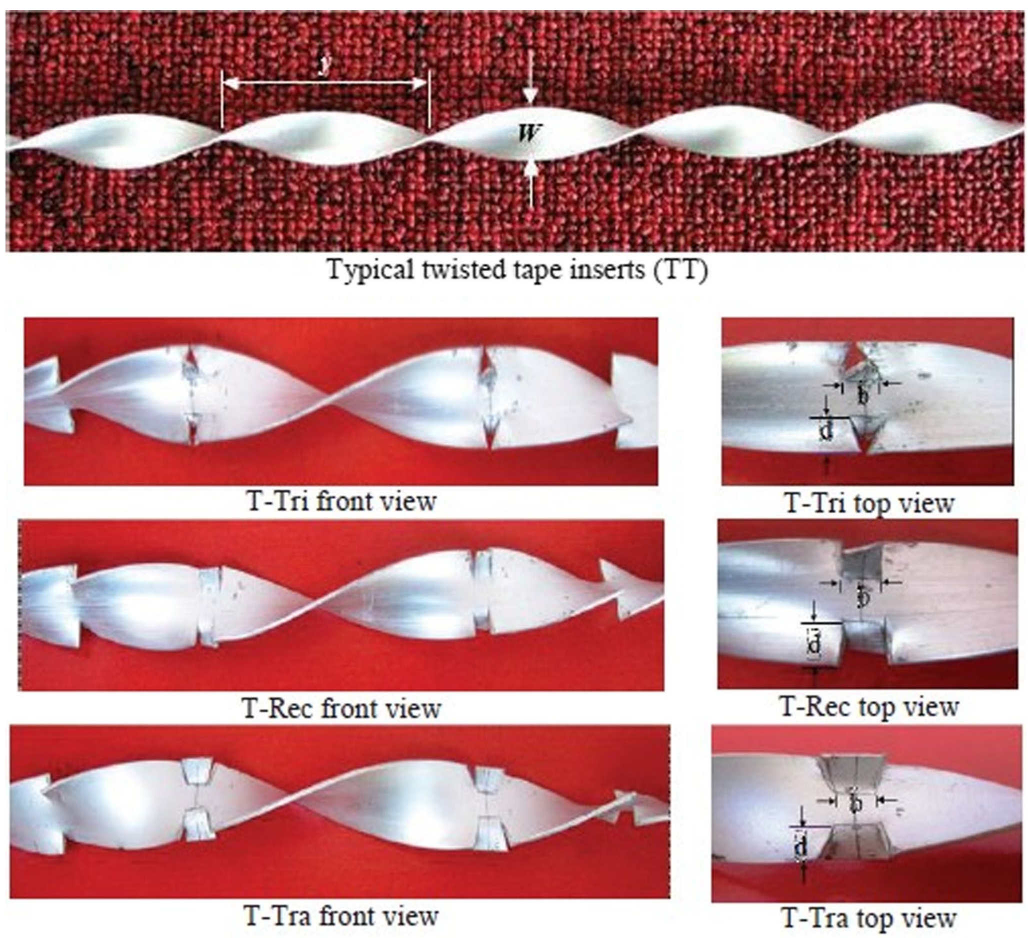

Fig. 3 Types of Augmentation Technique

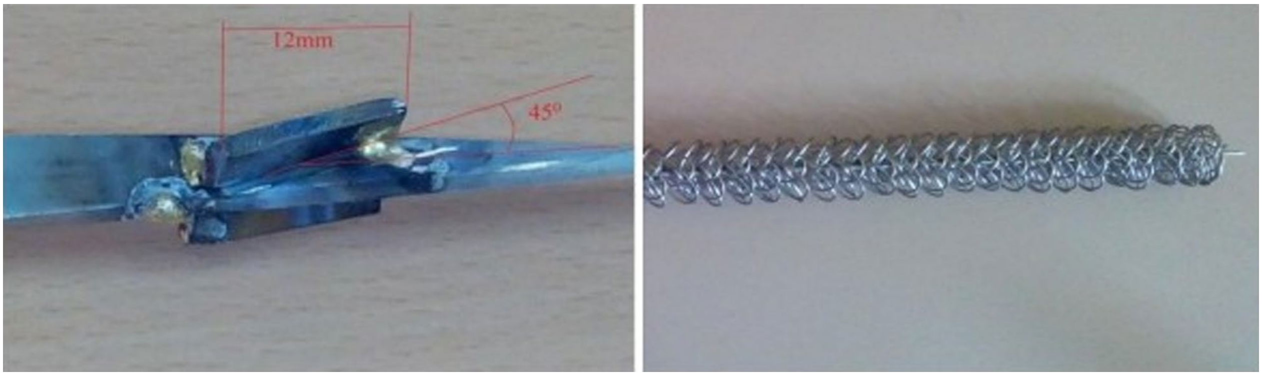

Fig. 4 A concentric tube heat exchanger with a helical tape and the concept of the helical tape's geometric parameters [49]

resulting in increased pressure and friction. Experiments with nano-fluid as additives should be applied to the turbulent area to investigate the fluid flow properties of twisted tape baffles and hiTrain wire matrix.

Nalavade et al. [53] the most important factors in this analysis, Nu and f, both increase as the pitch to tube diameter ratio (p/d) decreases. The CFD simulation results show that the novel turbulator with (p/d) 0.54 and a 90° angle of twist performs better, with TPF ranging from 1.28 to 1.43 and PEC ranging from 0.95 to 1.27 over the Reynolds number range tested. CFD simulation was used to investigate the impact of variations in twist angle. The heat transfer rate increases as the angle of twist decreases. The results show that as the angle of twist decreases, both the Nusselt number and the friction factor increase. The turbulator Fig. 5 with a pitch-to-diameter ratio (p/d) of 0.54 and a 30° twist angle (θ) performs better. The friction factor is 4.94–5.71 times that of the smooth tube, and the TPF is 1.43–1.60 times that of the smooth tube.

Al-Fahed et al. [54] the data shows a modest improvement in both heat transfer and pressure drop coecients for the microfin tube evaluated in this paper over the plain values. For laminar low conditions, this form of microfin is not recommended. According to the heat transfer results, twisted-tape inserts are an effective method for increasing heat transfer. The heat transfer rate rises as the twist ratio rises. The twist ratio had a direct relationship with the effect of width. The tight-fit tape provides higher heat transfer values than the loose-fit tape for twist ratios of 3.6 and 5.4. The loose-fit geometry Fig. 6 has a higher heat transfer value than the tight-fit geometry for y 7.1. To improve heat transfer in laminar flow, Bhattacharyya [55] provided numerical friction factor and Nusselt number results. As swirl flow, a square channel with angular cut wavy tape is used.

1.3 Comprehensive study of twisted tape parameter to affect the energy transfer

Bhuiya et al. [56] investigated the heat transfer and friction factor characteristics of flow through a circular tube in a turbulent area using twisted tape of various porosities.

Aldali et al. [57] Comprehensive investigation of heat transfer and pressure drop for laminar flow in an inner circular tube, taking into account twist ratio and twist tape thickness.

Lui et al. [58] published a systematic study on the passive augmentation technique for heat transfer enhancement in pipe heat exchangers. The results of comparative experiments on twisted tape of various configurations and geometries have been discussed. The effect of wire

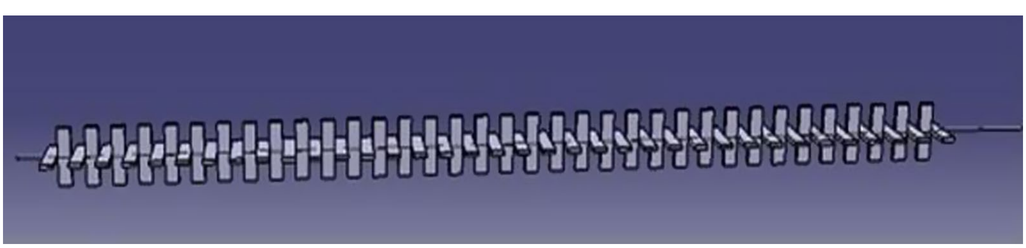

Fig. 5 Tube insert by using the T-TT, Tri, T-Rec, and T-Tra [51]

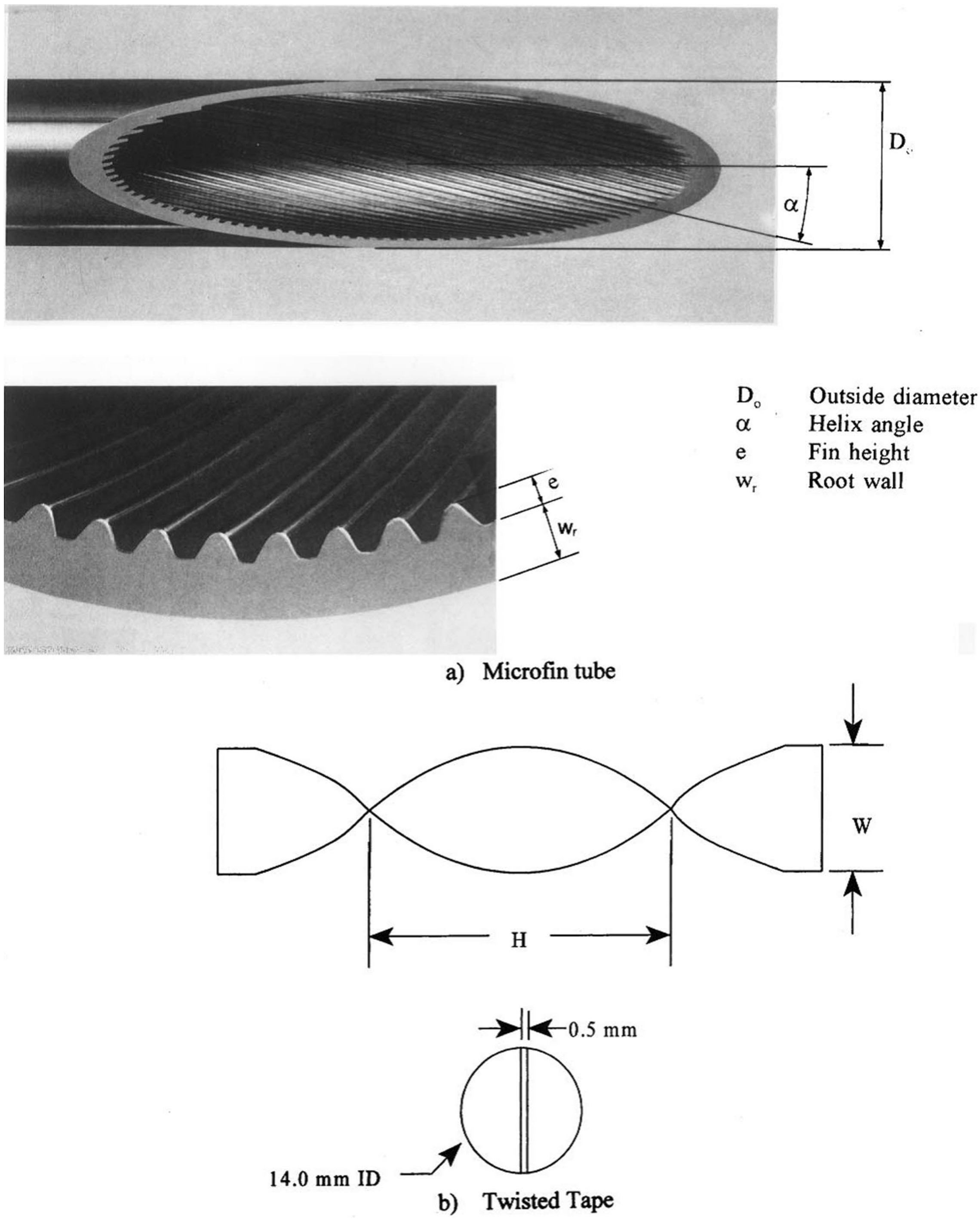

Fig. 6 Baffled Twisted Tape and hiTrain wire matrix with 14 mm outer diameter, 1.2–1.6 mm centre wire diameter, 190–210 loops per foot and length 825 mm [52]. **a** Microfin tube, **b** Twisted tape

coils, wings, swirl flow, fins, and a conical ring on heat transfer thermal efficiency factor was also addressed.

Eiamsa et al. [59] carried out an experimental study on the thermal efficiency of a tube heat exchanger with twisted tape coupling (co-coupling and counter coupling) configuration. Also, look into the effect of the coupling width ratio and twist ratio on the exchanger's thermal efficiency.

Salam et al. [60] used a circular tube with a rectangular cut twisted tape insert to test tube side water fluid in turbulent flow. The friction factor, heat transfer coefficient, and enhancement efficiency have all been studied.

Skullong et al. [61] investigated the same twist ratio (TR = 4) in a coupled co-twistred tape with V-shaped ribs in the edges. The work was done in a round tube using V-ribs twist tape as a vertex generator in a turbulent flow with air as the fluid.

Ariwibawo [62] investigated the heat transfer coefficient and heat load effectiveness of a hairpin heat exchanger with twisted tape.

Durga Prasad [63] investigated the Al_2O_3/water nanofluid U-tube heat exchanger with trapezoidal cut twisted tape insertion experiments.

Under a uniform heat flux condition, Eiamsa-ard et al. [64] investigated the effect of perforated helical twisted tape on heat transfer, thermal efficiency, and friction characteristics.

In the transitional flow regime for circular tubes, Meyer and coworkers [65] investigated heat transfer and pressure drop with twisted tape insert and square edged inlet. Experiments were carried out using Reynold numbers 400–11,400 and various twist ratios.

Heat transfer parameters performance and turbulent forced convection in circular pipe using modified twisted tape were recorded by Boonloi and coworkers [66]. To minimise pressure drop, the general twisted tape is punched with a rectangular hole. The effect of hole size and twist ratio on numerical data in the chaotic regime for single and double tape has been investigated.

In a research on the thermal efficiency of twist tape adjusted with different conical cut inserts in laminar flow, Salman et al. [67] presented a comparative study. Twist tapes with quadrant, parabolic half, and triangular cuts were used to maintain the same twist ratio across the cut depth.

Patil et al. [68] used several twist tape inserts to investigate the efficiency of heat transfer parameters in circular pipes with co-swirl and counter-swirl orientations. The experiment involved single, twin, and four twisted tapes with different twist ratios.

Using uniform/non-uniform twisted tape inserts in tube side with alternate axis, Eiamsa-ard [69] established empirical correlation for heat transfer characteristics evaluation criterions. In addition, the heat transfer rate of the presented uniform twisted tape alternate axis with smaller length is higher than the larger one.

Experimental investigation by Azmi [70] to investigate the enhancement effect in flat plain tube along co and counter twisted tape.

In the simple tube, Bhattacharyya et al. [71] numerically investigated heat transfer with twisted tape at different angles of 180°, 160°, and 140°. The predicted outcome was used to boost the solar heater's heat rate.

Hung et al. [72] test the output of twisted tape in a laminar flow in a heat exchanger using two separate condition variables and continuous pumping power as measurement criteria. The heat duty ratio, Nusselt number, effective ratio, and heat transfer efficiency of twist tape inserts were all examined.

The output of an absorber tube with an oblique delta-winglet twisted tape insert with twist ratios of 1, 2, 3, 4 within the Reynolds number range of 3000–9000 was investigated by Rawani et al. [73].

In a shell and tube heat exchanger, Gui et al. [74] conducted an experimental study on oil flowing in transfers groove tubes with twisted tape geometry as continuous tape, discontinuous tape, and perforated tape.

2 Main text

2.1 Basic parameters and equations

Boundary layer concept: The component of a moving fluid in which the fluid motion is influenced by a rigid boundary is known as the boundary layer. When a uniform velocity fluid flow enters a pipe, fluid layers adjacent to the walls slow down as they would on a plane surface, and a boundary layer forms at the entry.

Thermal boundary layer: Assume that a continuous stream of fluid is flowing parallel to the plate. Assume that the stream entering the plate has a velocity and temperature Too, and that the plate's surface temperature Tw remains unchanged. Assume Tw is greater than the amount of fluid heated by the pan. Figure 7 shown boundary layer forms. The velocity of the outer boundary layer ranges from $u=0$ at the wall to $u=uo$ at the outer boundary layer. The hydrodynamic boundary layer, denoted by line OA, is a type of boundary layer. The temperature of the fluid near the plate's surface is changed by heat transfer from the plate to the fluid, resulting in a temperature gradient. The temperature gradient is also layer nere to the wall, and the

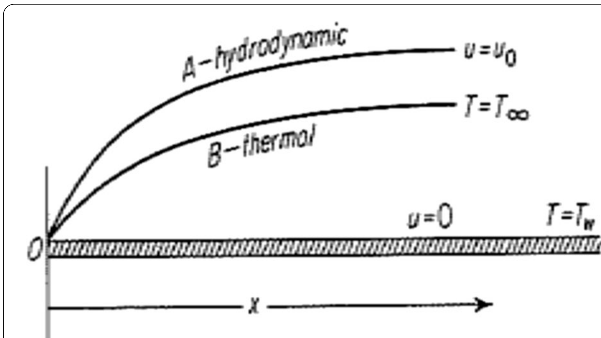

Fig. 7 Central circular rod with mounted plates [53]

temperature inside the layer ranges from T_w at the wall to T at the layer's outside boundary. The thermal boundary layer is the name given to this layer.

$$\Delta T_{\mathrm{LMTD}} = \frac{\Delta T_1 - \Delta T_2}{\ln(\Delta T_1/\Delta T_2)} \tag{1}$$

Hydraulic diameter

It's the ratio of four times the conduit's cross sectional area to the wetted perimeter in the test section.

The hydraulic diameter (D_h) of a plain tube can be calculated as follows:

$$D_h = 4\frac{\pi D_i^2/4}{\pi D_i} \tag{2}$$

Reynolds number

It's the inertial force to Viscus force ratio, and it's dimensionless. The flow geometry and Reynolds number influence the fluid's behaviour in terms of heat transfer characteristics.

Reynolds number is defined mathematically as,

$$\mathrm{NRe} = \frac{D_i u \rho}{\mu} \tag{3}$$

In a fluid, it is the ratio of convective to conductive heat transfer. The increase in Nusselt number indicates improved convectional heat transfer.

The local Nusselt number for a plain tube can be defined as,

$$\mathrm{NNu} = \left[\frac{hD_i}{k}\right] \tag{4}$$

Since the insert provides resistance to fluid movement through the tube, the pressure drop would be higher than if the tube were not inserted. Pumping capacity would also be higher than it would be for a tube without an insert. The pressure drop, mass flow rate, and density of the air passing through the tube all play a role.

$$P_m = \frac{\Delta P \times m^{\cdot}}{\rho} \tag{5}$$

2.2 Swirl flow device

Swirl flow or secondary flow circulation on axial flow in a channel is generated by these. Swirl flow devices Fig. 8 include helical twisted tape, twisted ducts, and various types of alternative.

insert having 0.5 mm width [54]

Pitch: Linear distance between two twists, denoted by 'H'.

Twist ratio: It is the ratio of twist tape pitch to tube within diameter, denoted by the letter 'y'. This is dimensionless term [75].

$$\mathrm{y} = \mathrm{H}/\mathrm{D} \tag{6}$$

The number of revolutions: The number of 360° revolutions of twisted tapes is denoted by N.

The swirl parameter (Sw), which is defined as, describes the strength of the secondary motion induced by the twisted tape [76].

$$S_W = \frac{(\text{centrifugal force})(\text{convective inertia force})}{(\text{viscus force })^2} \tag{7}$$

Heat transfer enhancement

In heat exchanger, heat transfer between a wall and the fluid is given by

$$Q = hA(T_w - T_f) \tag{8}$$

$$Q_p = (hA)_p(T_w - T_f) \tag{9}$$

The ratio of (hA) augmented surface to that of plain surface is defined as enhancement ratio. Denoted by E.

$$E = \frac{hA}{(hA)_p} \tag{10}$$

The heat transfer enhancement ratio divided by the friction factor ratio yields the overall enhancement ratio. This parameter is often used to compare various passive strategies, allowing two different approaches for the same pressure drop to be compared. The overall enhancement ratio is calculated as follows [75]:

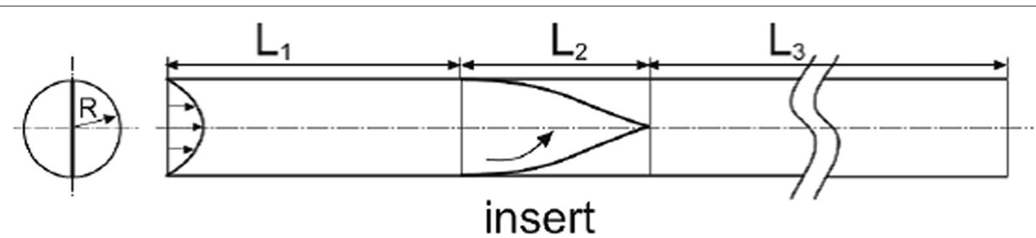

Fig. 8 Microfin structured tube with Twisted tape insert having 0.5 mm width [54]

$$\eta = \frac{\mathrm{Nu}/\mathrm{Nu}_0}{(f/f_0)^{1/3}} \tag{11}$$

Constant pumping power is used to test it. R stands for performance parameter. At constant pumping power, it is known as the ratio of Nusselt number for twisted tape to that of plain tape.

$$R = \frac{\mathrm{NNu}}{\mathrm{NNu_p}} \tag{12}$$

2.3 Mathematical modeling [77–79]

Hypothesis

To expand the mathematical model, we look at this simple idea to do the following:

- Merchant performance in a consistent state governing.
- Transmission of heat to the environment is ignored.
- HE is considered to be a system with illuminated parameters.
- Two flows in the liquid phase and does not change the phase.

Modelling equations:

By taking heat balance of hot and cold fluid, we get,

$$Q_h\,Cp_h\,(T_1 - T_2) = Q_c\,Cp_c(T_4 - T_3)$$
$$Q_h\,Cp_h\,(T_1 - T_2) = UA\Delta T_{lm}$$
$$Q_h\,Cp_h\,(T_1 - T_2) = \frac{UA\{(T_1 - T_4) - (T_2 - T_3)\}}{\ln\frac{(T_1 - T_4)}{(T_2 - T_3)}}$$

The heat exchanger's mathematical model has been constructed, and it includes a heat balance equation for the two material fluxes Q_h and Q_c, as well as an expression for transferred heat flow. The overall heat exchange coefficient, U, has a standard expression as the overall HTC, which may be given by Eq. (3), for the heat flow transported in the heat exchanger.

$$U = \frac{1}{\left\{\left(\frac{1}{h_i}\right)\left(\frac{d_e}{d_i}\right) + \left(\frac{d_e}{2k}\right)\ln\left(\frac{d_e}{d_i}\right) + \left(\frac{1}{h_o}\right)\right\}}$$

Equation represents a system of two non linear equations with two variables having the form [77–82],

$$f_1(T_2, T_4) = 0, \quad f_2(T_2, T_4) = 0$$
$$f_1 = Q_h\,Cp_h\,(T_1 - T_2) - Q_c\,Cp_c\,(T_4 - T_3)$$
$$f_2 = \{Q_h\,Cp_h\,(T_1 - T_2)\} - \left\{\frac{UA\{(T_1 - T_4) - (T_2 - T_3)\}}{\ln\frac{(T_1 - T_4)}{(T_2 - T_3)}}\right\}$$

2.4 Experimental/numerical studies on passive technique using twisted tape

With an increase in pressure drop, twisted tape increases the heat transfer coefficient. Complete-length twisted tape, short length twisted tape, full length twisted tape with varying pitch, reduced width twisted tape, and regularly spaced twisted tape are all examples Table 2 of twisted tape have already been configured.

Different researchers have used different output ratios for multi-tube heat exchangers [92],

$$R_1 = \frac{(\mathrm{St}/\mathrm{St_s})}{(f/f_s)^{1/3}}, \tag{13}$$

$$R_2 = \frac{q}{q_s} = \frac{h}{h_s}, \tag{14}$$

$$R_3 = \frac{(\mathrm{Nu}/\mathrm{Nu_s})}{(f/f_s)^{1/3}}. \tag{15}$$

$$R_3 = \left(\frac{f}{f_s}\right)^{1/3}\mathrm{Re} \tag{16}$$

The friction factor, f, and the Stanton number, St, without the subscript, refer to the rough surface, while the subscript, s, refers to the smooth surface. When heat transfer between two fluids is considered, the ratio of heat transfer coefficients for rough and smooth surfaces, h/h_s, in (14) is replaced by the ratio of total heat transfer coefficients, U/U_s. The heat transfer coefficient h_s or U_s in (14) is calculated for smooth surfaced tubes at the Reynolds number Re_s, which is determined by (16).

Where Nu_0 and f_0 are the Nusselt number and friction factor of the plain tube, respectively, the PEC [93] is defined as follows:

$$\mathrm{PEC} = \frac{\mathrm{Nu}/\mathrm{Nu}_0}{(f/f_0)^{1/6}} \tag{17}$$

Table 2 Summarises the most important twisted tape investigations that began in laminar flow

Author	Working fluid	NRe	NPr	Twist tape geometry	Remark
Hong and Bergles [36]	Water, ethylene glycol	Water—NRe, 83–2460; Ethylene Glycol- NRe, 13–390	Water—NPr, 3–7 Ethylene Glycol-NPr, 84–192	Full length twist tapes	Friction is affected by tape twist when at high NRe
					Nusselt is 9 times that tube without twist tapes
Saha et al. [38]	–	NRe 45–1150	NPr 205–518	Twisted tapes regularly spaced with twisted tapes ratio 2.5–5	In terms of thermo-hydraulic efficiency, pinching twisted tape outperforms connecting thin rod
Agarwal and Raja Rao [83]	Viscus fluid (Servothe rm oil)	NRe 70–4000	NPr 195–375	Twisted tapes inserts with twist ratio 2.41–4.84	The friction factor increased by 3.13–9.71%
Ray and Date [37]	Water	NRe 100–3000	NPr < 500	Full-length twisted tape have width equal to side of duct	Square ducts have better hydrothermal efficiency than circular ducts
Klaczak [41]	Water	NRe 110–1500	–	Twisted tape insert (in air cooled vertical copper pipe) with twist ratio 1.62–5.26	When the pitch of twisted-tapes was the lowest, effectiveness was at its peak
Kapatkar et al. [84]	Water	NRe 200–2000	–	Twisted tapes with twist ratio 5.2–3.4	Stainless steel, insulated, and aluminium strengthen NNu
Wang and Sunden [39]	Water, Ethylene glycol	NRe 300–30,000	Water NPr-3 to6.5 Ethylene glycol NPr-68–100	Twisted tapes with twist ratio 3,4.6 and 6	In the absence of pressure drop, twist tapes outperformed wirecoil inserts
Sarma et al. [85]	–	NRe 300–3000	NPr 3–400	Twisted tape Twisted ratio of 2.5	Due to the twisted tape, eddy viscosity becomes more powerful than kinematic viscosity
Khalil et al. [86]	Water	NRe 690–2195	NPr 2.9–3.55	Triangular cut Twist tapes with twist ratio 2.77and width (1.5, 3, 4.5)	The pumping power and overall enhancement ratio are directly proportional to NNu
Chang et al. [87]	Air	NRe 1000–40,000	–	Broken twisted tapes insert with twist ratio 1, 1.5, 2, 2.5 or ∞	This paper looks at heat transfer coefficients, pressure drop factors, and thermal efficiency
Chang et al. [88]	polytetraf luoroethy lene	NRe 1500–14,000	–	Single, twin And Triple twisted tapes	When laminar and turbulent flow were present, single and triple twist tape were successful
Sivashanmugam and Suresh [89]	Water	NRe 2700–13,500	–	Helical screw- tape insert with increasing and decreasing order	The heat transfer coefficient and friction factor increased with the twist ratio of 1.95, resulting in a high NNu
Durga prasad and Deepak [90]	Al2O3/ Water Nanofluid	NRe 3000 to30000	–	Trapezoidal cut(H/D = 5) twisted tape with twist ratio between 5 and 20	Nano fluids have a higher heat transfer efficiency than water
Eiamsa-Ard et al. [91]	Water	NRe 3700–21,000	–	Twin counter twisted tapes and twin co- twisted tapes with twist ratio 2.4,3, 3.5 and 4	Twin counter-twisted tapes outperform twin co-twisted tapes in terms of performance

Author not specified the fluid, NRe, NPr

The numerical simulation was used to calculate the PEC in a tube of triple or quadruple twisted tapes. For all twisted tapes, it was discovered that the PEC value rises as the Reynolds number rises. Tubes with twisted tapes of clearance ratio $a^{*}=0.35$ perform better in terms of total heat transfer than tubes with twisted tapes of other clearance ratios.

The highest level of thermal performance factor [71, 100], which have a measure of heat transfer augmentation, have one of the main parameters in heat exchanger design, as shown by variations of overall enhancement efficiency (η) against Reynolds number for different twist ratios at constant entrance angle 180°. In comparison to entrance angle ($\alpha=160°$ and 140°), the percentage increase in enhancement factor for entrance angle ($\alpha=180°$) twisted tapes was around 17% and 46%, respectively.

The thermo-hydraulic output parameter (η) [55] was found to be efficient from an energy standpoint and enhancement efficiency was greater than unity for the entire computational investigation on angular cut wavy tape of different twist ratios. In the low laminar area, angular cut wavy tape with a wavy ratio of $y=1.0$ and β 45° angle was far more dominant than the other tapes measured. Also, as the Reynolds number rises, angular cut wavy tape with a wavy ratio of 3.0 and β 45° angle shows some promise. The effect of heat transfer enhancement due to the wavy tape was more dominant than the effect of increasing friction, and vice versa, according to the enhancement efficiency above unity.

3 Conclusions

According to the review, the passive method heat transfer augmentation techniques using twist tape could result in secondary swirl flow generation. The thermal enhancement factor has increased as the twist ratio has decreased, but this is dependent on the geometry of the tape. The increased heat transfer and pressure decrease may be explained by the swirling flow caused by the secondary flows of the fluid. This type of microfin is not recommended for laminar low conditions.

The turbulence near the pipe's wall was increased by a combination of the alternate axes' flow fluid and the wings' turbulence. A successful swirl generator should have a higher heat transfer coefficient, lower pressure drops, and a lower friction factor, according to experimental findings in Fig. 9 and Table 3 sumerized for laminar flow region. The Nusselt number and the friction factor increase as the angle of twist decreases. As a consequence, when compared to turbulent flow heat transfer situations, larger heat transfer whereas will be needed for a given heat transfer rate. In comparison to plain tube, heat transfer rate and friction factor improved by 20% when full length tapes $y=2.5$ were used, and NNu increased by 9 times at $y=3.125$. There is a 30–40% increase by using different width twisted tape inserts.

In terms of output, twin counter-twisted tapes outperform twin co-twisted tapes. On twisted tape in different configurations and geometries, the findings of comparative studies have been discussed. It was discovered that the PEC value increases as the Reynolds

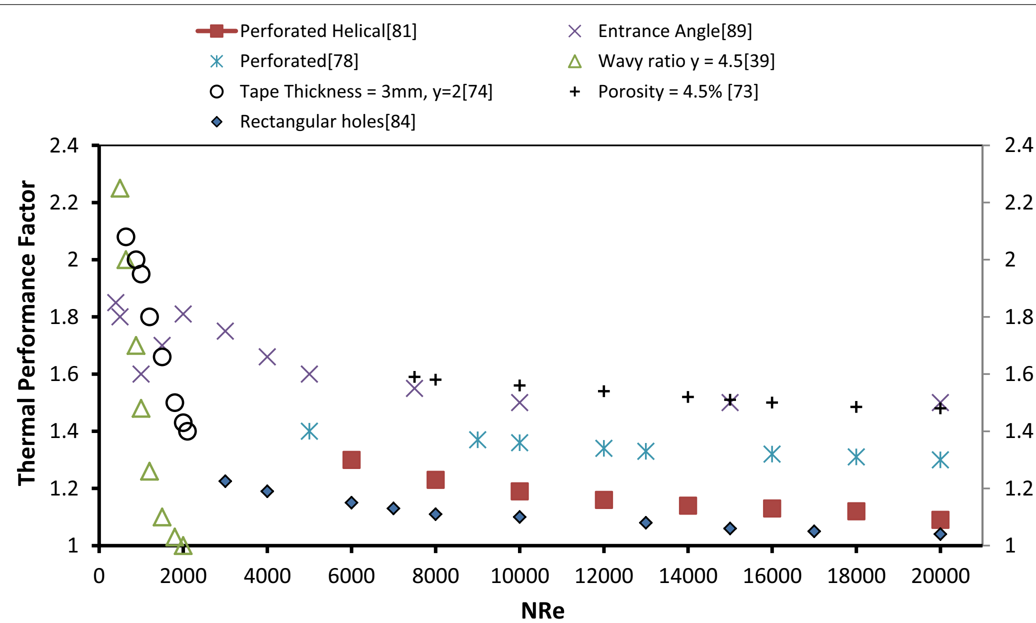

Fig. 9 Comprehensive study of different geometries of twist tape in I—laminar, II—Transitional, III—turbulent region

Table 3 Numerical/experimental findings of modified tape in the laminar region are summarized

Authors	Fluid	Configuration of tape	Type of investigation	Observations
Bhattacharyya et al. [71]	Water	Twisted tape angle = 180 and small twist ratio = TR 18.0	Numerical evaluation	Periodic change of direction of swirl
				Heavy collision of the mixed fluids behind the varying location
				Lead to mixing of superior quality
				Better heat transfer, compared with the typical twisted-tape
Meyer and Abolarin [65]	Water 2.9 < Pr < 6.7	Twisted tape twist ratio = TR 3,4 & 5	Experimental in a circular tube	Flow regimes of laminar, transitional and turbulent
				Friction factors increased as the twist ratio decreased
				Standard deviation method in which the temperature deviations determined
Bhattacharyya et al. [55]	ethylene glycol Nre = 100–2000	Angular cut wavy tape (angles = 45°)	Experimental in a square channel	Angular cut wavy tape with small wavy ratio significantly better
				Useful in designing tubes
Boonloi and Jedsadaratanachai [66]	Fluid	modified-twisted tapes (rectangular holes) TR = 1, 1.5, 2, and 4)	Circular Tube Geometry	The maximum thermal enhancement factor is around 1.39 and 1.31 for the double twisted
				Tape and single twisted tape, respectively, at Re = 3000, LR = 0.78, and TR = 1
Salman et al. [67]	SiO2 and TiO2 Nanofluids	Conic Cut Twist Tape TR = 2.93	Experimental in a circular tube	Over the range investigated (Re = 220–1500), the Maximum thermal performance factor of 5.13 is found SiO2 and TiO2 nanofluids of different volume concentration in plain tube give good enhancement in Nusselt number compared to deionized water
Saha and Dutta [9]	Water 2.5 < Pr < 5.18	Short length, Full length, Smoothly varying pitch, Regularly Spaced Twisted tapes	Experimental in a circular tube	Friction and Nu low for short length tape
				Short length tape requires small pumping power
				Multiple twist and single twist has no difference on thermohydraulic performance
				It was observed that twisted tape is effective in laminar flow
Ray and Date [37]	Water 100 < Re < 3000 Pr < 5.0	Full-length twisted tape with width equal to side of duct	Numerical work for square duct	Proposed correlations for friction and Nu
				Higher hydrothermal performance for square duct than circular one

Table 3 (continued)

Authors	Fluid	Configuration of tape	Type of investigation	Observations
				Local Nusselt number peaks at crosssections where tape aligned with diagonal of duct
Lokanath and Misal [94]	Water $3.0 < Pr < 6.5$ lube oil ($Pr = 418$)	Twisted tape	Experiment in plate heat exchanger and shell and tube heat exchanger	Large value of overall heat transfer coefficient produced in water-to-water mode with oil-to water mode
Ujhidy et al. [34]	Water	Twisted tape	Experiment in channel	Explained flow structure
				Proved existence of secondary flow in tubes with helical static elements
Wang and Sunden [39]	Water $0 < Re < 2000$ $0.7 < Pr < 3.0$	Twisted tape	Experiment in circular tube flow	Both inserts effective in enhancing heat transfer in laminar region compared with turbulent flow
				Twisted tape has poor overall efficiency if pressure drop is considered
Suresh Kumar et al. [95]	Water	Twisted tape	Experiment in large-diameter annulus	Observed relatively large values of friction factor
				Measured heat transfer in annulus with different configurations of twisted tapes
Saha and Chakraborty [96]	Water $145 < Re < 1480$ $4.5 < Pr < 5.5$	Twisted tape regularly spaced $1.92 < y < 5.0$	Experiment in circular tube flow	Larger number of turns may yield improved thermohydraulic performance compared with single turn
Ray and Date [7]	Water	Twisted tape	Numerical study in square duct	Higher Prandtl numbers and lower twist ratios can give good performance
Guo et al. [97]	Water	Center-cleared twisted tape Short width	Numerical study in circular tube	Center-cleared twisted tape is a promising technique for laminar convective heat transfer enhancement
Zhang et al.[93]	water	multiple regularly spaced twisted tapes	Numerical study in circular tube	The simulation results verify the theory of the core flow heat transfer enhancement which leads to the separation of the velocity boundary layer and the temperature boundary layer, and thus enhances the heat transfer greatly while the flow resistance is not increased very much
Kumar et al. [98]	water	Twisted tape	Numerical study in a square ribbed duct with twisted tape	Rib spacing and higher twist ratio for high Prandtl fluids and for low Prandtl fluid rib spacing should be higher and twist ratio should be lower
Liao and Xin [99]	Water,Ethylene glycol, Turbine oil $80 < Re < 50,000$	Segmented twisted tape and three dimensional extended surfaces	Experiment in tube flow	In a tube with three-dimensional extended surfaces and twisted tape increases average

Table 3 (continued)

Authors	Fluid	Configuration of tape	Type of investigation	Observations
				Stanton number up to 5.8 times compared with empty smooth tube
Al-Fahed and Chakroun [33]	Oil	Twisted tape with twist ratios 3.6, 5.4,7.1 and microfin	Experiment in single shell and tube heat exchanger	For low twist ratio resulting low pressure drop, tight fit will increase more heat transfer
				For high twist it is different
				Microfins are not used for laminar
Saha et al. [38]	Fluids with $2.05 < Pr < 5.18$	Twisted tape (regularly spaced)	Experiment in circular tube	Pinching of twisted tape gives better results than connecting thin rod for thermohydraulic performance
				Reducing tape width gives poor results; larger than zero phase angle not effective
Saha and Bhunia [11]	Servotherm medium oil $45 < Re < 840$	Twisted tape (twist ratio $2.5 < y < 10$)	Experiment in circular tube	Heat transfer characteristics depend on twist ratio, Re and Pr
				Uniform pitch performs better than gradually decreasing pitch

number increases for all twisted tapes. In terms of overall heat transfer, tubes with twisted tapes of clearance ratio 0.35 outperform tubes with twisted tapes of other clearance ratios.

List of symbols

NRe: Reynolds's number; NPr: Prandtl number; NNu: Nusselt number; *T*: Temperature (K); *u*: Velocity (m/s); *D*: Diameter (m); *h*: Heat transfer coefficient ($Wm^{-2}\ K^{-1}$); *k*: Thermal conductivity ($Wm^{-1}\ K^{-1}$); Pm: Pumping power; ΔP: Pressure drop (Pa); *m*: Mass flow rate ($kg\ s^{-1}$); *Q*: Heat transfer rate (W); *A*: Surface area (m^2); *E*: Enhancement ratio; *f*: Friction factor.

Greek symbols

u: Viscosity ($m\ s^{-1}$); ρ: Density ($kg\ m^{-3}$); η: Overall enhancement ratio.

Subscripts

f: Fluid; p: Plain; 0: Without.

Abbreviations

CFD: Computational fluid dynamics; TPF: Thermal performance factor; PEC: Performance evaluation criterion.

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Authors' contributions

PBD was a major contributor in writing the manuscript, analyzed and interpreted. JK—data regarding the augmentation techniques and formulation. VAB performed the background and literature data. RNM contributed his skill for editing, presentation and collection of required data. All authors read and approved the final manuscript.

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Declarations

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