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Citation

Abstract
In the last decade several studies on the passive techniques of convective heat transfer enhancement have been published. Heat transfer enhancement methods are commonly used in several industrial and engineering applications such as process industries, heat engine, automobile, solar collector, refrigerators, air conditions, electronic cooling, thermal power plant, chemical process industries etc. Passive techniques as compared to active techniques are advantageous, because the insert manufacturing process is very cheap and simple with easy functioning in heat exchanger. The thermohydraulic behaviour of an insert depends on the flow regime types (laminar or turbulent) regardless of the insertion configurations. The present paper contains literature survey which emphasises on the recent studies that deal with twisted tapes because, they are economic heat transfer augmentation tools.

1. Introduction

Heat transfer enhancement or augmentation techniques refer to the improvement of thermo hydraulic performance of heat exchangers. General techniques for enhancing heat transfer can be divided in three categories:

1. Passive method: such as twisted tapes, extended surfaces and rough surfaces.
2. Active method: which requires extra external power such as mechanical aids.
3. Hybrid method: includes combined application of active and passive techniques to obtain high enhancement in heat transfer rate.

Insertion of twisted tapes into a tube provides a simple passive technique for enhancing the convective heat transfer by introducing swirls into the bulk flow and by disrupting the boundary layer at the tube surface due to repeated changes in the surface geometry. Secondary flow further provides a better thermal contact between the surface and the fluid because secondary flow creates swirl and the resulting mixing of fluids improves the temperature gradient, which ultimately leads to a high heat transfer coefficient. The purpose of this review is to present the effect of twisted tape turbulators on the heat transfer augmentation, flow friction and thermal performance factor characteristics in a heat exchanger tube and pressure drop.
2. Literature Review

A summary of important investigations of twisted tape in a laminar flow is represented in Table (1). Twisted tape increases the heat transfer coefficient with an increase in the pressure drop. Different configurations of twisted tapes, like full-length twisted tape, short length twisted tape, full length twisted tape with varying pitch, reduced width twisted tape and regularly spaced twisted tape have been studied widely by many researchers.

In the laminar flow, heat transfer takes place mainly by conduction and molecular diffusion as there is no cross mixing of the fluid. The heat transfer coefficients in laminar flow were generally low. So, for a given heat transfer rate, larger heat transfer whereas will have to be provided as compared with turbulent flow heat transfer situations.

Use of twisted tapes for augmentation can be dated back to as early as up to the end of nineteenth century. One of the early researches on heat transfer enhancement by means of twisted tapes was carried out by Whitman [1].

Hong and Bergles [2] reported heat transfer enhancement in laminar viscous liquid flows in a tube with uniform heat flux boundary conditions, but their correlation has limited applicability as it is valid for a high Prandtl number (approximately 730). They reported that as much as threefold improvement in heat transfer rate using twisted tape insert in a tube.

Saha et al. [3] reported experimental data on a twisted tape generated laminar swirl flow friction factor and Nusselt number for a large Prandtl number (205 < Pr < 518) and observed that, on the basis of a constant pumping power, short length twisted tape is a good choice because in this case swirl generated by the twisted tape decays slowly downstream which increases the heat transfer coefficient with minimum pressure drop, as compared to full length twisted tape. Regularly spaced twisted tape decreases the friction factor and reduces the heat transfer coefficient because the spacing of twisted tape disturbs the swirl flow.

Lokanath [4] reported experimental data on water (240 < Re < 2300), (2.6 < Pr < 5.4) of laminar flow through horizontal tube under uniform heat flux condition and fitted with half length twisted tape. He found that on the basis of unit pumping power and unit pressure drop half length twisted tape is more efficient than full length tapes.

Yadav [5] studied influences of the half length twisted tape insertion on heat transfer & pressure drop characteristics in a U-bend double pipe heat exchanger, experimentally. The results obtained from the heat exchangers with twisted tape insert are compared with those without twisted tape i.e. plain heat exchanger. The experimental results revealed that the increase in heat transfer rate of the twisted tape inserts is found to be strongly influenced by tape induced swirl or vortex motion. The heat transfer coefficient is found to increase by 40% with half-length twisted tape inserts when compared with plain heat exchanger. It was found that on the basis of equal mass flow rate, the heat transfer performance of half-length twisted tape is better than plain heat exchanger.

Manglik and Bergles [6] correlated heat transfer and pressure drop for twisted tape inserts with twist ratio (3, 4.5 and 6.0) for uniform wall temperature conditions using water (3.5 < Pr < 6.5) and ethylene glycol as working fluid, for laminar flow condition and explained physical description of enhancement mechanism. Depending upon the flow rate and tape geometry, the enhancement in heat transfer is due to the tube partitioning and flow blockage, the large flow path and secondary fluid circulation. They proposed laminar flow correlations for the friction factor and Nusselt number, including the swirl parameter, which defines the interaction between viscous, convective inertia and centrifugal forces.

Lin and Wang [7] investigated numerically sensitivity of the laminar convective heat transfer in a circular tube fitted with twisted tape. The effects of conduction in the tape on the Nusselt number, the relationship between the absolute vorticity flux and the Nusselt number, the sensitivity of heat transfer enhancement to the thermal boundary conditions by using secondary flow, and the effects of secondary flow on the flow boundary layer were discussed. The results reveal that for fully developed laminar heat convective transfer, different tube wall thermal boundaries lead to different effects of conduction in the tape on heat transfer characteristics.

Saha and Chakraborty [8] found that laminar flow of fluid (water) (145 < Re <1480, 4.5 < Pr <5.5, tape ratio 1.92 < y <5.0) and pressure drop characteristics in a circular tube fitted with regularly spaced, there is drastic reduction in pressure drop corresponding with reduction in heat transfer. Thus it appears that with constant pumping power a large number of turns may improve thermo hydraulic performance compared with single turn on twisted tape.

Suresh Kumar et al. [9] an experimental investigation was carried out to determine the pressure drop characteristics in a large diameter annular test section for the hydro-dynamically developed laminar flow under constant heat flux condition. The results obtained are compared under two conditions: with and without twisted tape inserts. The variations of friction factor with Reynolds number for various twist ratios along the circumference of the test section were investigated. The thermo hydraulic performance in laminar flow is better for twisted tape as compared to wire coil for the same helix angle and twist ratio.

Lokanath and Misal [10] studied the performance of a plate heat exchanger and augmented shell and tube heat exchanger for different fluids. They found that twisted tapes of tighter twists are expected to give higher overall heat transfer coefficients in the augmented shell and tube heat exchanger.

Marner and Bergles [11] were the first investigators to recognize the importance of uniform wall temperature (UWT) boundary condition to a major group of heat exchanger used in chemical industry. They studied UWT heating and cooling of Polybutene 20 (Pr = 1260-8130, Re
between 1.64 and 2.46.

Date and Singham [12] numerically investigated heat transfer enhancement in laminar, viscous liquid flows in a tube with a uniform heat flux boundary condition. They idealized the flow conditions by assuming zero tape thickness, but the twist and fin effects of the twisted tape were included in their analysis.

Bharatdwaj et al. [13] 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. Laminar to fully turbulent ranges of Reynolds numbers have been considered. The grooves are clockwise with respect to the direction of flow. Compared to smooth tube, the heat transfer enhancement due to spiral grooves is further augmented by inserting twisted tapes having twist ratios (y = 10.15, 7.95 and 3.4).

Al-Fahed et al. [14] investigated for high pressure drop and low twist ratio (y = 5.4) and, a loose fit twisted tape is a better option for the heat exchanger owing to it’s easy installation and removal for cleaning purposes. For other twist ratios tight fit gives better performance that the loose-fit twisted tapes.

Liao and Xin [15] reported experimental data on the compound heat transfer enhancement technique and concluded that the enhancement of heat transfer in a tube with three dimensional internal extended surfaces by replacing continuous twisted tape with almost segmented twisted tape inserts results in a decrease in the friction factor but with a comparatively small decrease in the Stanton number. The Stanton number is defined as the ratio of heat transfer rate to the enthalpy difference and is a measure of the heat transfer coefficient.

Sheeba et al. [16] investigated the thermal performance of thermo-syphon solar water heater system fitted with helical twisted tape of various twist ratios. Conclusions made from the results that heat transfer enhancement in twisted tape collector is higher than the plain tube collector with minimum twist ratio and gradually decreases with increase in twist ratio in laminar flow.

Zhang et al. [17] performed numerical simulation to study the thermal and fluid flow of multi-longitudinal vortices in a tube induced by triple and quadruple twisted tape inserts for the Reynolds number from 300 to 1800. As compared to the plain tube, the tubes with triple and quadruple twisted tapes possessed higher heat transfer rates up to 171 % and 182 %, respectively, these accompanied with the increases of friction factors of around 4.06 to 7.02 times, respectively. In addition, the thermal performance factors of the tube inserts varied between 1.64 and 2.46.

Jian Guo et al. [18] found a center cleared twisted tape aiming at achieving good thermohydraulic performance. A comparative study between this type and the short-width twisted tape was performed numerically in laminar tubular flows. The computation results demonstrated that the tubes with center-cleared twisted tapes, the heat transfer can be even enhanced in the cases with a suitable central clearance ratio. The thermal performance factor of the tube with center-cleared twisted tape can be enhanced by 7-20% as compared with the tube with conventional twisted tape.

Agarwal and Raja Rao [19] reported experimental investigations of isothermal and nonisothermal friction factor and mean Nusselt number for uniform wall temperature (UWT) heating and cooling of servotherm oil (Pr = 195-375) in a circular tube (Re = 70-4000) with twisted tape inserts (y = 2.41-4.84). Isothermal friction factor were found to be 3.13-9.71 times the plain tube values. The Nusselt number were found to be 2.28 -5.35 and 1.21- 3.7 times the plain tube forced convection values based on constant flow rate and constant pumping power respectively. They proposed correlation representing effect of heat transfer on friction factor for practical application.

Eiamsa-ard et al. [20] investigated the effects of peripherally cut twisted tape insert on heat transfer, friction loss and thermal performance factor characteristics in a round tube. Nine different peripherally-cut twisted tapes with constant twist ratio (3.0) and different three tape depth ratios (0.11, 0.22 and 0.33), each with three different tape width ratios (0.11, 0.22 and 0.33), were tested. From the result, it is revealed that Nusselt number, friction loss and thermal performance factor are found to be increased with depth ratio and width ratio.

Patil [21] reported the friction factor and heat transfer characteristics of laminar swirl flow of pseudo plastic type power law fluid in a circular tube using varying width full length twisted tapes under uniform wall temperature conditions. He found that, from the considerations of enhanced heat transfer and savings in heat transfer and savings in pumping power and in tape material cost, reduced width twisted tapes are better for enhancing laminar swirl flow heat transfer. He has observed that 17-60% reduction in friction factor and 5-24 % reduction in Nusselt number for 15-50 % reduction in tape-width.

Klaczak [22] investigated experimentally the heat transfer for laminar flow of water in an air cooled vertical copper pipe with twisted tape inserts of various pitch value. The tests were executed for laminar flow within (110 ≤ Re ≤ 1500, 8.1 ≤ Gz ≤ 82.0 and 1.62 ≤ y ≤ 5.29). Result shows that the heat transfer increases with increase in twisted tape pitch value.

Sarma et al. [23] postulated new method to predict heat transfer coefficients with twisted tape inserts in a tube, in which the wall shear and the temperature gradients are properly modified through friction coefficient correlation leading to heat transfer augmentation from the tube wall. The eddy diffusivity expression of van Driest is modified to respond to the case of the internal flows in a tube with twisted tapes for ranges of Reynolds number corresponding to the laminar flow in tubes. The predic-tions from the present theory are compared with some correlations available in literature for twisted tape inserts.

Ujhidy et al. [24] have studied laminar flow of water in
coils and tubes containing twisted tapes and helical static elements and proposed a modified Dean number that takes into account the curvature of the spherical line cut out by the helical element from the tubular housing. The Dean number is a measure of the magnitude of the secondary flow.

Suhas V. Patil et al. [25] investigated experimentally heat transfer and friction factor characteristics in a concentric double pipe heat exchanger (square duct inner and circular tube outer) using full length twisted tapes of different twist ratios. The data were taken for Reynolds number well in the laminar region (Re = 30-1100) with twisted tapes of twist ratios (y = 2.66 and y = 3.55). Experiments were carried out for constant wall temperature boundary condition using Ethylene glycol as working fluid. The results showed that as twist ratio decreases, the twisted tape gives better heat transfer enhancement. Isothermal friction factors were found to be 6 to 13 times the plain duct values. Mean Nusselt number for the twisted tapes are higher than those for the plain duct around 6.0 and 5.30 times for y = 2.66 and y = 3.55 respectively. The experimental result shows that Nusselt numbers are found to be 5.44 - 7.49 and 2.46 - 4.88 times the plain square duct forced convection values based on constant flow rate and constant pumping power criteria respectively, for y = 2.66.

Monheit [26] conducted a comparative study of the thermal performance of ordinary full-width full-length twisted tapes, using tapes with modified surface configurations. The modified tape was either a tape with circular holes on its surface or one with slits along its edges. For laminar flow heat transfer to the lubricating oil (Re: 560 – 3500, Pr: 5150 – 450) such modifications offered no advantage over ordinary twisted tape.

Wang and Sunden [27] reported correlations for ethyl glycol and polybutene (Pr. No.1000-7000). They also concluded by considering the overall enhancement ratio, twisted tape is effective for small Prandtl number fluids and wire coil is effective for high Prandtl number fluids.

A. V. N. Kapatkar et al. [28] investigated experimentally heat transfer and friction factor of a smooth tube fitted with full length twisted tape inserts for laminar flow have been studied under uniform wall heat flux condition. The experiments have been carried out to study the tape fin effect by using full length tape inserts of different materials namely Aluminum, Stainless steel and insulated tape. The tapes have twist ratios from 5.2 to 3.4. It is found that, for the flow in smooth tubes, full length twisted tapes yield improvement in average Nusselt number, for Reynolds number range of (200 to 2000). For Aluminum tapes, the maximum improvement in Nusselt number range from 50% to 100%; for Stainless steel tapes, maximum improvement in Nusselt number range from 40% to 94% and for insulated tapes, maximum improvement in Nusselt number range from 40% to 67%.

Tariq et al. [29] found that in a laminar flow the introduction of turbulent promoters, such as an internally threaded tube, is not efficient compared with a twisted tape insert on the basis of the overall efficiency. Heat transfer coefficient in internally threaded tube is approximately 20 percent higher than that in smooth tube.

Lishan You [30] carried out a numerical study to predict the velocity and temperature distributions in fully developed, constant property, laminar flows in tubes containing twisted tape inserts. The swirl flow was simulated by following the helically twisted flow path in the partitioned tube represented by a semi-circular cross-section geometry using the finite volume method. For the heat transfer problem, both the uniform wall temperature (UWT) and uniform heat flux (UHF) boundary conditions at the tube wall were considered. Results for the variations in the velocity and temperature fields with flow Reynolds number and tape twist ratio were presented; the temperature distributions also reflected the influence of fluid Prandtl number. The twisted-tape induced swirl flow field is characterized by a single longitudinal vortex that breaks up into two counter-rotating helical vortices with increasing Re or decreasing twist ratio. Correspondingly, both the friction factor and Nusselt number increase substantially.

S. Jaishankar et al. [31] experimentally determined friction factor and heat transfer characteristics of thermosyphon solar water heater system with full length twisted tape with rod and spacer fitted at the trailing edge. Results obtained conclude that the heat transfer enhancement in twisted tape collector is higher than the plain tube collector.

Wongcharee and Eiamsa-ard [32] reported the thermohydraulic characteristics of the circular tubes equipped with alternate clockwise and counterclockwise twisted-tapes (TA) for the Reynolds number ranging from 830 to 1990 with three different twist ratios (3, 4 and 5) were inserted individually into the uniform wall heat flux tubes, where water was utilized as the working fluid. The obtained results revealed that, Nusselt number, friction factor and thermal performance factor associated by TA were higher than those associated by typical twisted tape. Among the tapes examined, the one with the smallest twist ratio of 3 was found to be the most efficient for heat transfer enhancement.

Suvanjan et al. [33] presented the experimental friction factor and Nusselt number data for laminar flow through a circular duct having integral transverse ribs and fitted with centre-cleared twisted-tape. Predictive friction factor and Nusselt number correlations were also presented. The major findings of this experimental investigation are that the centre-cleared twisted tapes in combination with transverse ribs perform significantly better than the individual enhancement technique acting alone for laminar flow through a circular duct up to a certain amount of centre-clearance.

Sami et al. [34] presented the application of a mathematical model for simulation of the swirling flow in a tube induced by elliptic-cut and classical twist tape inserts. Effects of the twist ratio (2.93, 3.91, and 4.89) and cut depth (0.4, 0.8, and 1.4 cm) on the heat transfer enhancement and friction factor in laminar flow are numerically investigated. The simulation was carried out using commercial CFD package (FLUENT-6.3.26) in the laminar flow regime for the Reynolds number ranging from 200 to 2100. The results showed that the heat transfer rate and friction factor in the
tube equipped with elliptic-cut twist tape are significantly higher than those fitted with classical twist tape.

Table (1). Summary of important investigations of twisted tape in laminar flow.

<table>
<thead>
<tr>
<th>Authors</th>
<th>Working fluid</th>
<th>Configuration of twisted tape</th>
<th>Type of investigation</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hong and Bergles [2]</td>
<td>Water (3 &lt; Pr &lt; 7) (83 &lt; Re &lt; 2460) Ethylene Glycol (84 &lt; Pr &lt; 192) (13 &lt; Re &lt; 390)</td>
<td>Full-length twisted tape</td>
<td>Experiment in circular tube</td>
<td>Nu is function of twist ratio, Re and Pr. Friction is affected twist tape only at high Re. Nu is (9) times that of empty tube.</td>
</tr>
<tr>
<td>Saha et al. [3]</td>
<td>Fluids with (205 &lt; Pr &lt; 518) Water (240 &lt; Re &lt; 2300) (2.6 &lt; Pr &lt; 5.4)</td>
<td>Twisted tape (regularly spaced)</td>
<td>Experiment in circular tube</td>
<td>Pinching of twisted tape gives better results than connecting thin rod for thermohydraulic performance. Reducing twist width gives poor results; larger than zero phase angle not effective. On unit pressure drop basis and on unit pumping power basis, half-length twisted tape is more effective than full-length twisted tape.</td>
</tr>
<tr>
<td>Lokanath [4]</td>
<td>Water (240 &lt; Re &lt; 2300) (2.6 &lt; Pr &lt; 5.4)</td>
<td>Full-length and half-length twisted tapes</td>
<td>Experimental in horizontal tube</td>
<td>On unit pressure drop basis and on unit pumping power basis, half length twisted tape is more efficient than full-length twisted tape.</td>
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<tr>
<td>Manglik and Bergles [6]</td>
<td>Water (3.5 &lt; Pr &lt; 6.5) Ethylene Glycol (68 &lt; Pr &lt; 100)</td>
<td>Three different twist ratios: 3, 4.5 and 6</td>
<td>Experiment in isothermal tube</td>
<td>Larger number of turns may yield improved thermohydraulic performance compared with single turn.</td>
</tr>
<tr>
<td>Saha and Chakraborty [8]</td>
<td>Water (145 &lt; Re &lt; 1480) (4.5 &lt; Pr &lt; 5.5)</td>
<td>Twisted tape (regularly spaced) (1.92 &lt; y &lt; 5.0)</td>
<td>Experiment in circular tube flow</td>
<td>Observed relatively large values of friction factor. Measured heat transfer in annulus with different configurations of twisted tapes.</td>
</tr>
<tr>
<td>Marner and Bergles [11]</td>
<td>Polybutene 20 (15.1 ≤ Re ≤ 575) (1260 ≤ Pr ≤ 8130)</td>
<td>Twisted tape (y = 5.4)</td>
<td>Experiment in circular tube flow</td>
<td>The greatest improvement for heating was for the internally finned tube where Nusselt numbers ranged from 3 to 4 times the plain tube values at corresponding Graetz numbers.</td>
</tr>
<tr>
<td>Bharatwaj et al. [13]</td>
<td>Water</td>
<td>Spirally grooved tube with twisted tape (y = 10.15, 7.95 and 3.4)</td>
<td>Experiment in circular tube flow</td>
<td>For low twist ratio resulting low pressure drop, tight fit will increase more heat transfer.</td>
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<tr>
<td>Al-Fahed et al. [14]</td>
<td>Oil</td>
<td>Twisted tape (y = 3.6, 5.4 and 7.1) and microfin</td>
<td>Experiment in single shell and tube heat exchanger</td>
<td>For high twist it is different. Microfins are not used for laminar.</td>
</tr>
<tr>
<td>Liao and Xin [15]</td>
<td>Water Ethylene Glycol Turbine oil (80 &lt; Re &lt; 50000)</td>
<td>Segmented twisted tape and three dimensional extended surfaces</td>
<td>Experiment in circular tube flow</td>
<td>In a tube with three-dimensional extended surfaces and twisted tape increases average Stanton number up to 5.8 times compared with empty smooth tube.</td>
</tr>
<tr>
<td>Sheeba et al. [16]</td>
<td>Water (3000 ≤ Re ≤ 23000)</td>
<td>Helical twisted tape (y = 3, 4, 5 and 6)</td>
<td>Experiment in circular tube flow</td>
<td>Heat transfer and pressure drop are higher in twisted tape collector compared to the plain one. As the twist ratio increases, the swirl generation decreases and minimizes the heat transfer and friction factor.</td>
</tr>
<tr>
<td>Zhang et al. [17]</td>
<td>Water (300 ≤ Re ≤ 1800)</td>
<td>Multiple regularly spaced twisted tapes</td>
<td>Numerical study in circular tube</td>
<td>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.</td>
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<tr>
<td>Jian Guo et al. [18]</td>
<td>Water</td>
<td>Center-cleared twisted tape short width</td>
<td>Numerical study in circular tube</td>
<td>Center - cleared twisted tape is a promising technique for laminar convective heat transfer enhancement.</td>
</tr>
<tr>
<td>Agarwal and Raja Rao [19]</td>
<td>Servo therm oil (70 ≤ Re ≤ 4000) (195 ≤ Pr ≤ 375)</td>
<td>Twisted tape (y = 2.41-4.84)</td>
<td>Experiment in circular tube flow</td>
<td>Nusselt number for augmented tube is more than plain tube.</td>
</tr>
<tr>
<td>Authors</td>
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<tr>
<td>Eiamsa-ard et al. [20]</td>
<td>Water (103 (\leq) Re (\leq) 2 \times 104)</td>
<td>Peripherally-cut twisted tape ((y = 3.0))</td>
<td>Experiment in circular tube flow</td>
<td>Nusselt number, friction loss and thermal performance factor are found to be increased with increase in depth ratio. Peripherally-cut twisted tape provides high thermal performance factor with constant pumping power. The reduced width twisted tapes are better for enhancing laminar swirl flow heat transfer. Observed that 17-60% reduction in friction factor and 5-24% reduction in Nusselt number for 15-50% reduction in tape-width. The ratio NuT / Nu has the highest value when the pitch of twisted-tapes was the smallest. The heat transfer coefficient increases with increase in twist tape pitch value. The effects of various parameters except the fin effects enhancing the value of heat transfer coefficients. The laminar flow regime with tapes could be treated successfully for a wide range of parameters (3 (&lt;) Pr (&lt;) 400), (2.5 (&lt;) H/D (&lt;) 10).</td>
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<tr>
<td>Patil [21]</td>
<td>Pseudo plastic (power law fluid)</td>
<td>Varying width full length twisted tape</td>
<td>Experiment in circular tube flow</td>
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<tr>
<td>Klaczak [22]</td>
<td>Water (110 (\leq) Re (\leq) 1500)</td>
<td>Peripherally- cut twisted tape (1.62 (\leq) y (\leq) 5.29)</td>
<td>Experiment in circular tube flow</td>
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<tr>
<td>Sarmar et al. [23]</td>
<td>Water lubricant Turbinol XT-32 (300 &lt; Re &lt; 3000) (5 &lt; Pr &lt; 400)</td>
<td>Twisted tape</td>
<td>Theoretical study in circular tube flow</td>
<td>The isothermal friction factor for the flow with the twisted tape inserts are 340% to 750% higher as compared with those of smooth tube flow. Efficiency lower for threaded tube than twisted tape, but better than some fluted geometries. Good promoter of turbulence.</td>
</tr>
<tr>
<td>Ujhidy et al. [24]</td>
<td>Water</td>
<td>Twisted tape</td>
<td>Experiment in channel</td>
<td>Expained flow structure. Proved existence of secondary flow in tubes with helical static elements. As twist ratio decreases, the twisted tape gives better heat transfer enhancement. Mean Nusselt number for the twisted tapes are higher than those for the plain duct.</td>
</tr>
<tr>
<td>Suhas V. Patil et al. [25]</td>
<td>Ethylene Glycol (30 (\leq) Re (\leq) 1100)</td>
<td>Full length twisted tape (y = 2.66 and y = 3.55)</td>
<td>Experiment in double pipe heat exchanger inner (square duct) outer (circular tube)</td>
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<tr>
<td>Monheit [26]</td>
<td>Lubricant oil (560 (\leq) Re (\leq) 3500) (450 (\leq) Pr (\leq) 5150)</td>
<td>Ordinary full-width full-length twisted tape and modified surface tape</td>
<td>Experiment in circular tube flow</td>
<td>Modifications offered no advantage over ordinary twisted tape. 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. Full length twisted tapes yield improvement in average Nusselt number. The isothermal friction factor for the flow with the twisted tape inserts are 340% to 750% higher as compared with those of smooth tube flow. Efficiency lower for threaded tube than twisted tape, but better than some fluted geometries. Good promoter of turbulence.</td>
</tr>
<tr>
<td>Wang and Sunden [27]</td>
<td>Water (0 (&lt;) Re (&lt;) 2000) (0.7 (&lt;) Pr (&lt;) 3.0)</td>
<td>Twisted tape</td>
<td>Experiment in circular tube flow</td>
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<tr>
<td>Kapatkar et al. [28]</td>
<td>Water (200 (\leq) Re (\leq) 2000)</td>
<td>Full length twisted tape (3.4 (\leq) y (\leq) 5.2)</td>
<td>Experiment in circular tube flow</td>
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<tr>
<td>Tariq et al. [29]</td>
<td>Air (1300 (&lt;) Re (&lt;) 104)</td>
<td>Twisted tape</td>
<td>Experiment in internally threade tube</td>
<td>Heat transfer coefficient in internally threaded tube approximately 20 per cent higher than that in smooth tube. The highest local shear stress on the tape surface is on the side of the primary vortex. The average wall shear stress does not change much with the twist ratio; therefore, Re has a greater influence on the friction factor than twist ratio. Nu number is 13.5% higher than peripheral cut and friction factor is given as 14.85. This is well effective for laminar flow only. Nu increases with increase in Re and fluid concentration. Alternate axis twisted tape makes more swirl in fluid flow with increased efficiency. The centre-cleared twisted tapes in combination with transverse ribs perform significantly better than the individual enhancement technique acting alone for laminar flow through a circular duct up to a certain amount of centre-clearance. Heat transfer rate and friction factor in the tube equipped with elliptic-cut twist tape are significantly higher than those fitted with classical twist tape.</td>
</tr>
<tr>
<td>Lishan You [30]</td>
<td>Water (20 (&lt;) Re (&lt;) 1200) (1 (&lt;) Pr (&lt;) 80)</td>
<td>Twisted tape (y = 3.6,12,(\infty))</td>
<td>Numerical study in circular tube</td>
<td></td>
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<tr>
<td>S. Jaishankar et al. [31]</td>
<td>Water</td>
<td>Twisted tape with rod and spacer</td>
<td>Experiment in circular tube flow</td>
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<tr>
<td>Wongcharee and Eiamsa-ard [32]</td>
<td>Water (830 (&lt;) Re (&lt;) 1990)</td>
<td>Alternate clockwise and counterclockwise twisted tapes (y = 3.4 and 5)</td>
<td>Experiment in circular tube flow</td>
<td></td>
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<tr>
<td>Suvanjan et al. [33]</td>
<td>Water (15 (&lt;) Re (&lt;) 1000)</td>
<td>Center-cleared twisted tape (y = 2.5)</td>
<td>Experiment in circular duct having integral transverse ribs</td>
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<tr>
<td>Sami et al. [34]</td>
<td>Water (200 (&lt;) Re (&lt;) 2100)</td>
<td>Elliptic- cut and classical twisted tape (y = 2.93, 3.91, and 4.89)</td>
<td>Numerical study in circular tube</td>
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</table>
3. Conclusions

This review paper discusses the considerable experimental and numerical works which have been done on heat transfer augmentation through internal inserts in circular tube. This paper reviews the investigation carried out by various researchers in order to enhance the heat transfer, nusselt number, and friction factor by the use of circular tubes with inserts of different shapes, sizes and orientation. According to the above researches, we can summarize the conclusions as follows:

1. Heat transfer rate will increases with increase contact surface area of twisted tape insert in the tube with fluid. When researchers increases the contact surface area of twisted tape with making a cut, drill hole, parabolic cutting, and many more etc, than heat transfer rate in heat exchanger will be increases.

2. Different modifications can affect heat transfer and friction factor characteristics differently. The twisted tapes with a center wing and alternate axes can cause the highest heat transfer enhancement coefficient, which is 24% higher than the typical twisted tape.

3. In Full length twisted tape, heat transfer rate increases increase in friction factor also observed.

4. Twisted tapes, especially full length and tight-fit twisted tapes can enhance heat transfer effectively. For example, the use of twisted tape with the twist ratios of 5.0 and 7.0 can induce 188% and 159% higher Nusselt numbers respectively. But loose-fit twisted tapes can save materials prominently with little influence on heat transfer.

5. Twisted tape with uniform pitch, performs better than gradually decreasing length tape.

6. Twisted tapes also have negative effects that can cause higher pressure drops. To balance the heat transfer and friction factor, some researchers have conducted studies and have recommended modified twisted tapes, like perforated twisted tapes, which can result in a slightly higher heat transfer enhancement coefficient. Further studies should put emphasis on this issue.

7. Twisted tape with gradually decreasing pitch, Poor performance as compared to uniform pitch tape.

8. In Short length twisted tape, low friction factor and low Nusselt number observed as the length of the tape reduces, friction factor reduces and heat transfer coefficient also reduces.

9. Tight fit and lose fit tapes, Tapes having tight fittings give more frictional loss, whereas reduced Width and centrally located loose fit tape gives better result.

References


