A Review on the Effect of Y-Shaped Twisted Tape on Heat Exchanger Performance

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Paper History:

Received: 13th Aug. 2024

Revised: 22th Nov. 2024

Accepted: 10th Feb. 2025

Abstract
The process of increasing the heat transfer coefficient, resulting in enhancing system efficiency, is known as heat transfer enhancement. Enhancing heat transport is both economically beneficial and a considerable energy conservation problem. To improve heat transfer, many passive components are utilized within tubes, including wire plugs, enhanced surfaces, rough edges, twisted tape inserts, and liquid additives. This study evaluated twisted tape inserts, which are highly effective passive devices. Considering its numerous advantages, such as effortless maintenance, uncomplicated operation, and straightforward production. The twisted tape inserts within the tube generated a vortex and swirling flow. The interior convective heat transfer process is significantly improved. A summary of various twisting tape additives that can boost performance.

Keywords: Y-Shape Twisted Tape, Heat Exchangers, Heat Transfer Enhancement, Energy Efficiency, Thermal Performance, Convective Heat Transfer

الشريط الملتوي على شكل حرف Y وتأثيره على تحسين أداء المبادلات الحرارية - مراجعة

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الخلاصة:
تُعرف عملية رفع معامل نقل الحرارة، والتي تعمل على تحسين أداء النظام، باسم تحسين نقل الحرارة. يعد تحسين نقل الحرارة مفيدًا اقتصاديًا ويشكل تحديًا كبيرًا لتوفير الطاقة. لتعزيز نقل الحرارة، يتم استخدام مجموعة متنوعة من المكونات السلبية داخل الأنابيب، بما في ذلك سدادات الأسلاك، والأسطح الموسعة، والحواف الخشنة، وإدراج الشريط الملتوي، والمواد المضافة السائلة. تعد إدراجات الشريط الملتوي من بين الأجهزة السلبية الأكثر نجاحًا، وقد قامت هذه الدراسة بفحصها. نظرًا لفوائدها العديدة، والتي تشمل سهولة الصيانة والأداء المباشر والتصنيع البسيط. داخل الأنبوب، خلقت إدراجات الشريط الملتوي تدفقًا دواميًا ودوامة. ونتيجة لذلك، يتم تعزيز عملية نقل الحرارة بالحمل الحراري الداخلي بشكل كبير. نظرة عامة على العديد من إدراجات الشريط الملتوية التي يمكن تحسينها.

1. Introduction
Heat exchangers are essential for recovering and storing energy in a variety of sectors [1-2]. Since it can be difficult to increase heat transfer using common fluids like water and ethylene glycol, many different strategies have been developed. These methods significantly contribute to heat exchangers' improved thermohydraulic performance [3-5]. Active, passive, and compound heat transfer improvement methods are utilized in a change of disciplines, including applications include process industries, evaporators, thermal power plants, air conditioning, refrigeration, and space vehicle radiators., autos, etc. [7-6]. Methods to improve heat transfer can be divided into three groups:

- **Active Techniques:** The active technique uses an external power source to increase heat transmission. This external power input changes the flow pattern, which increases heat transmission. The application of machine-driven support such surface shaking, suction, or booster, as well as the use of an electric or magnetic flux to perturb light elements introduced in a moving brook, are a few examples of active approaches.

- Passive Techniques: This approach increases the fluid pressure drop by drawing power from within the system rather than from an external source. Typically, they use mesh inserts, convergent-divergent conical rings, wire coils, ribs, baffles, plates, twisted tape, and so on. This causes the flow through the pipe to change geometrically or on the surface. This method disrupts the real boundary layers and swirls the fluids. As a result, The system's operative surface area, residence duration, and heat transfer coefficient rise. Twisted tapes consist of metallic strips. that have been twisted to the proper dimensions and form for the desired function.

- Compound Techniques: Compound enhancement occurs when two or more of these techniques are used at the same time to improve heat transfer. The resultant improvement in heat transfer is greater than what would be created by using each technique alone.

This study aims to review the research that focused on twisted tapes and their effect on improving heat transfer. A comprehensive review of the literature on the subject would provide a more detailed analysis and evaluation of the specific effects of Y-shaped twisted tape on heat exchanger performance and the associated benefits in terms of heat transfer enhancement, energy efficiency, and operational improvements

2. Technical analysis of heat exchangers

Twisted ribbon tubing is a unique type of tubing used in heat exchangers to enhance heat transfer by creating turbulence and disrupting the flow patterns within the tubes. Here are several applications where twisted ribbon tubing is commonly used [8-11]:

- Industrial Process Heat Exchangers**: Twisted ribbon tubes are widely used in industrial settings where efficient heat transfer is required. They can be found in chemical processing, oil refineries, and petrochemical plants where heat exchangers need to handle large temperature differences and viscosities
- HVAC Systems**: In heating, ventilation, and air conditioning systems, twisted ribbon tubes can be used to enhance the efficiency of air conditioning and heating coils, allowing systems to operate more efficiently and with less energy consumption.
- Power Generation**: Power plants, especially those using steam cycles, often require high-efficiency heat exchangers. Twisted ribbon tubing in condensers and other heat exchanger systems helps increase heat transfer rates, boosting the overall efficiency of the plant.
- Automotive Radiators**: In automotive applications, twisted ribbon tubing is used in radiators and oil coolers to improve the heat dissipation capacity, which helps in managing engine temperature more effectively.
- Food and Beverage Processing**: Twisted ribbon tubing can be applied in heat exchangers in the food and beverage industry for pasteurization, cooling, and heating processes. The design allows for more consistent and faster heat transfer, crucial for maintaining product quality.
- Refrigeration Systems**: Industrial refrigeration systems that rely on high-efficiency heat exchangers benefit from twisted ribbon tubing. The enhanced turbulence aids in achieving faster cooling rates, particularly in systems dealing with phase changes like condensation and evaporation.
- Cryogenic Applications**: For processes involving extremely low temperatures, such as liquefaction of gases, twisted ribbon tubing helps in efficiently transferring heat between fluids, improving system performance and reducing operational costs.
- Waste Heat Recovery**: In waste heat recovery systems, twisted ribbon tubing is beneficial because it can help capture and reuse heat more efficiently, thus conserving energy and reducing environmental impact.
- Desalination Plants**: Twisted ribbon tubes are useful in the multi-effect and multi-stage flash distillation processes of desalination plants, where they help improve heat transfer rates in the evaporators, enhancing water recovery efficiency.

These applications all benefit from the increased heat transfer efficiency and enhanced fluid mixing that twisted ribbon tubing provides, making it valuable in any industry requiring effective thermal management.

3. Detentions

A. Performance of thermohydraulic systems:

If the coefficient of heat transfer rises, greatly with a minimal rise in resistance factor, then an insert is said to have strong performance of thermohydraulic systems for a given Reynolds number. The performance of various inserts, including twisted tape, is compared using thermohydraulic performance calculations.[12]

B. Thermo-performance factor (PF):

The Factor of Thermal Performance (PF) is a commonly used statistic to evaluate the efficacy of different heat transfer augmentation techniques. It is defined as the ratio of rising skin friction coefficient to rising heat transfer at constant pumping power for a given Reynolds number.

$$PF = \frac{\left(\frac{Nu}{Nus}\right)}{\sqrt[3]{\left(\frac{F}{Fs}\right)}}$$

C. The ratio of overall enhancement:

The ratio of the friction factor divided by the heat transfer improvement ratio is known as the overall improvement ratio. This characteristic allows the text discusses the comparison of two modified techniques with similar pressure drops as well as the use of this comparison to evaluate other passive strategies. Hwang SD et al. [13] define FP as the friction factor and Nu as the Nusselt number for plain tubes. The computed The Nusselt number as well as the friction factor for tubing. with twisted taped additions are denoted by the symbols Nus and Fs, respectively

D. Nusselt's numerical quantity:

The Nusselt number is a dimensionless quantity that can be expressed as the ratio of the convective heat transfer coefficient (h) multiplied by the diameter of the tubes (d) and divided by the thermal conductivity (k). The term "it" refers to the ratio of convection to thermal conductivity at the surface.

E.The Prandtl number:

The Prandtl number, a quantity without dimensions, is a ratio of momentum diffusion to heat diffusion.

F. Pitching:

Pitch is the measurement, made parallel to the axis of a cruel tape, of the separation amid two locations on the same level.

G. Twist ratio (y):

The twist ratio can be expressed as follows: $y = H/\ di$, where di is the internal diameter of the tube and H is its twist pitch length.

4. Overview Methodology

Although twisted tape increases the coefficient of heat transfer, it also causes a pressure droplet. Numerous students have conducted experiments and examined various designs for twisted tape inserts. Twisted tape inserts come in a variety of forms, Examples include complete, short-length, completely with varying pitch, and evenly spaced. The work of various researchers is covered in the section that follows:

The properties of laminar and turbulent flow as well as heat transmission in a duct with square sections that has twisted tape inserted were numerically predicted by Date et al. [14]. From the predicted data, an association between the frictional factor and Nusselt number for the square duct. was obtained. Heat transfer characteristics were computed under conditions of axial and peripheral constant wall heat flux. The data on laminar flow friction factor for 40 ≤ Re ≤ 1100 and 1.5 ≤ Y ≤ 10 are connected by:

$$f \times Re = 36[1+ 0.15\ ]^{1/3}$$

With nonconducting tape, the laminar flow averaged by pitch Nusselt figures for Re ≤1100, 1.5 ≤ Y ≤ 10, and 0.1 ≤ Pr < 500 are linked by:

$$\mathbf{Nu = 3.96\ [1+0.016\ Pr^{1.05} \left(\frac{Re}{Y}\right)^{1.25}\ ]^{1/2.6}}$$

Premovement al. [15] conducted an experimental investigation to examine the impact of spiral tapes placed within a tube on the improvement of heat transmission. A helical tape is inserted into a pipe to create swirl flow, which increases heat transmission. The range of Reynolds numbers is 2300 to 8800. Two helical tapes, one spaced regularly apart and the other full-length and with or without a center rod, produce the whirling movement. These tapes are placed within a heat exchanger with a concentric tube. Chilled water passes through the annulus and hot air enters the inner tube. Experimental results showed that using helical tapes instead of plain tubes resulted in higher heat transfer coefficients. Rate of heat transfer.

An experimental examination was conducted by Murugesan et al. [16] within circular tubes with y = 4.0 and 6.0, on the heat transfer and friction factor characteristics of trapezoidal cut whole length twisted tape. The investigation revealed that, when compared to plain tube, tape with a trapezoidal cut had a much higher heat transfer coefficient and friction factor. On the basis of the experimental results, correlations were created.

Jassim NA and associates [17] investigated the effects of twisty tape inserts in heat exchangers using laminal tube flow with different twisting and pitch ratios through experimentation. When tubes with twisted tape were compared to with a twisting ratio of 5, the rate of heat transmission in plain tubes increased from (50.54% to 52.22%), (52.42% to 55.15%), (52.41% to 56.98%), and so on. Within a heat exchanger with concentric tubes Chang et al. [18] Conducted a practical study to ascertain the axial distribution of Thermal conductivity and resistance to fluid flow in tubes equipped Caused by a broken and distorted adhesive tape. The experiments' twist ratios are 1, 1.5, 2, 2.5, or infinity (∞). The Reynolds number spans from 1000 to 40,000,000. The tube connected to the damaged and twisted tape shows an elevation in average Fanning friction factors and local Nusselt numbers as the twist ratio drops. The heat transfer coefficients, mean Fanning friction factors, and thermal performance factors in the tube fitted with the broken twisted tape are increased by 1.28–2.4 times, 2-4.7 times, and 0.99–1.8 times, respectively, compared to the tube fitted by the smooth twisted tape. Correlations between The Nusselt value and the cooling friction coefficient were determined for tubes equipped with fractured twisted tapes.

An experimental study was supported out by Meyer JP et al. [19] using Rotating cassettes with an aspect ratio of (5, 7) Because of the increasing swirl degree of flow, the Nusselt number rises gradually from 920 to 6700 and is 12–15% higher than the plain one. For copper pipe with square-edged intake and tape inserts.

N. Piriyarungrod and others [20] examined the effects of curved twisted tapes on heat transfer for four different ratios (3.5, 4.0, and 4.5) and four angles (0.0, 0.3, 0.6, and 0.9) of rotation. Enhancing heat transfer while decreasing friction loss rose as the spill angle and twist ratio decreased. At a Reynolds number of 6000, The superior (PF) of 1.05. was provided by the tube with a twisting ratio of 3.5 and a taper angle of 0.9. Tusar M. et al. [21] assessed the influence of tape-twisted heat transfer tabs on the airflow through a pipe with a consistent wall thermal flux. They conducted experiments at different Reynolds values ranging from 3642 to 21857. Based on the results of the study, twisting tapes enhance heat transfer at lower Reynolds numbers and twist ratios. It exceeds a simple tube, as evidenced by the greatest value, which is roughly 1.16 times at Re-5000.

An experimental study on the Thermal conduction of a nanofluid inside an enclosed area a U-tube heat exchanger with a twisted tape insert was conducted by Durga P V and Gupta AVSSKS [22].Under different operating conditions, the coefficients of heat transfer and associated The heat exchangers' friction factors are computed using volume fractions ranging from 0.01% to 0.03%, Reynolds numbers between 3000 and 30,000, and twist ratios between 5 and 20. Twisted tape inserts increase the friction factor by 1.23 times and The Nusselt value of a tube carrying a nanofluid with a concentration of 0.03% has increased by 31.28%. as compared to water flow. Sundar LS and associates [23] FeO_3-Oil Experimental evaluations of nanofluid stream properties and heat transfer were conducted at mass stream rates ranging from 0.04 kg/s to The flow rate is 0.208 kilograms per second, the fractions range from 0.05% to 0.5%, and the Prandtl numbers range from 440 to 2534.The results indicate that, in comparison to the pure fluid, The Nusselt value for the nanofluid with a concentration of 0.5% is increased by 8.94% and 13.48% for flow rates of 0.0416 kg/s and 0.208 kg/s, respectively. At a flow rate of 0.208 kg/s and a concentration of 0.5 vol% nanofluid, the resistance factor effect is 1.21 percent greater than that of the pure fluid. Asaf Yadav [24], a researcher aged 20, conducted a study on the impact of half-length twisting tape inserts on heat exchange along with pressure loss in double-tube U-twist heat exchangers. Heat transfer rates are enhanced by approximately 40% when half-length twisted tape inserts are used in place of a typical heat exchanger. While the mass flow rate is constant, half-length tape inserts work more efficiently in the transport of heat. than simple heat exchangers; however, as the pressure decreases, smooth tubes outperform half-length twisted tapes. In terms of heat performance, standard heat exchangers are 1.3–1.5 times more effective than half-length twisting tape.

Eiamsa-ard S and Seemawute P [25] conducted an analytical and empirical study on a fading swirl stormy flow created by three various twisting ratios of short twisted tapes inserted into the test section (3, 4, and 5). The findings show that, for the same twist ratios and within the Range of Reynolds numbers: 5200–15,300, short tape inserts perform less well thermally than full-length tape. SK Gugulothu. [26] computational fluid dynamics was used to analyze a ribbed tube featuring various inlays of twisted tape in a turbulent zone with uniform heat flow. ANSYS Fluent (17.1) was used for the simulations. When it comes to heat transfer, friction factor, and (PF), Half-period tape is not as effective as full-length twisted tape. overall.

Zhu JD and Chen H [27] reported that the triple twisting tape can increase heat transmission performance Comparing to single tape Upon insertion, they display a resistance increase ranging from 8.7 to 6.5 times and from 1.8 to 4.5 times. In the study conducted by Promthaisong P et al. [28], The way five-channel twisting tape causes spiraling corrugated tubes to behave thermally was examined. Pressure loss and turbulent heat transfer were examined using equations involving dual twisted tape inserts with varying pitches.

Aghaie, A., and others [29] investigated heat transfer with a nanofluid in a circular tube under steady-state conditions, utilizing the ANSYS Fluent software version 16.1. As the Reynolds number increases, the relative Nusselt number decreases. for every scenario that is being looked into.

Eiamsa-ard S. et al. [30] conducted experimental research on helically twisted tape; Yongsiri K. [31] assessed three twisting ratios of helical tape:2, 2.5, and pitch ratios: Reynolds numbers range from 6000 to 20,000 for 1, 1.5, and 2. The heat transfer coefficient and friction factor rose As the ratio between tape twisting and spiral pitch decreased, The thermal performance shows a reverse pattern at Reynolds number 6000, reaching has a spiral pitch ratio of 2, a twisting ratio of 3, and a maximum (PF) of 1.29.

Nagarajan PK, Sivashanmugam P, and [32] looked at a fully extended helical screw element with a range of twist ratios and helical screw inserts of different lengths and twisting ratios. In the study, The performance analysis results showed that, for a given twist ratio, Right-left helical bolt inserts enhance heat transfer efficiency to a greater extent compared to straight conical twists. The performance percentages achieved were 2.85 and 2.97, respectively. Inserts of twisted tape with a range of hole shapes, such as square, holes that are rectangular and elliptical, as well as twisting tape with a rod and spacer, were investigated by numerous investigators, With the studies conducted by Vijayan et al.[33], Ananth J et al. [34], Ananth J et al. [35], Hajara O et al. [36], Gawande KR et al. [37], Chavan H V et al. [38], are among the studies by Gnanaraj D et al. Another researcher looked into twisting tapes with incisions resembling those reported by, The authors Hasanpour A et al. [39] and Sarviya RM et Fuskele V [40] ,Kumar B et al. [41] have conducted studies on this topic. Researchers such as Abeens M and others [42], Gugulothu SK [43], Tabatabaei Kia S per al. [44], Chang SW with Guo MH [45], and Easmatara S per al. [46]; as well as Uzagare N with Bansod P [47] examined twisted tape inserts with stripes and ribs or baffled. Bhuiya, Kumar A. [48], Singh Suri AR et al. [49]Numerous other researchers looked into compound twisted tape and various heat transfer improvement methods[50-54], including Salam B et al. [55], The authors Nanan K et al. [56], Patil S V et al. [57-58], Elasmar'd S et al. [59], and Patel MJ et al. [60] have conducted studies on the topic.The flow of air through a heat exchange pipe that has two V-cut twisting inserts is characterized by turbulence. was studied by Lin ZM and coworkers [61]. was simulated using a computer model designed. More vortex flow in the V-cuts, which more effectively breaks up thermal viscous layers and accelerates heat transfer, improved the thermal performance and Nusselt number for the 5000–15000 Reynolds number range and 0.62.8 cut ratios. Under laminar flow circumstances, the novel concept of the centrally hollow thin twisted tape was investigated by Li P et al. [62]. The novel tape type achieves 28.1 percent better overall heat transmission than traditional twisted tape. In laminar flow scenarios, the cross-hollow twisted tape is appropriate, the National Institute of Standards and Technology in the United States claims. Eiamsa-ard S. and Saysroy A. [63] The simulation involved the use of square-cutout twisted tapes and a continuous heat flux wall to model three-dimensional tube flows. Kumar A. and his colleagues [64] A helical coil was utilized to assess the thermal conductivity characteristics of a dual-pipe heat exchanger. The average Nusselt number index grew by 85% and 34%, respectively, despite the larger reduced pressure. for twisted tape with holes. The authors of the study are Mashoofi N. et al. [65] improved the heat transfer performance factor and reduced pressure loss for axially perforated twisting tape with different hole diameters by using numerical methods.

Zheng L et al.'s study [66] Utilized CFX15.0 software to quantitatively evaluate the impact of dimpled tapes on the heat transfer of nanofluid with varying restrictions. The findings indicated that the utilization of dimples improves convective heat transfer by 25.53 percent in comparison to smooth tape, with a maximum enhancement of 58.96 percent. S. Elasmar'd and others. [67] examined several resources, including the twist relation, the angles of the tube dimples, and the fluid constriction of TiO2-water nanoparticles. The results of the experiment showed that the combination of Twisted tapes with dimpled tubes provided higher heat transfer rates than dimpled tubes alone. The results also showed that the concentration, twist ratio, and dumbbell angle of the TiO2-water Nano fluid had a substantial effect on thermo-hydraulic performance. A 45-degree dimple angle resulted in the most increase in heat transfer. The Nusselt number rose in response to a decreasing twist ratio and an increase in Nano fluid concentration. Using Nano fluid with = 0.15 allowed for the highest thermo-hydraulic presentation of 1.258 over the investigated variety.

Saysroy A, Eiamsa-ard S. [68] heat transfer also thermal presentation of right-angled-cut twisted tapes inside a circular pipe were numerically compared to that of steady twisted tapes inside the same pipe. the impact of warped-tape geometries with square cuts. The main conclusions be situated that pressure loss and heat transfer rise with decreasing ratios of the width of perforations to the width of tape and perforated length-to-tape width ratios, whereas thermal performance factor rises with increasing perforated width-to-tape width ratios.

In addition, a large number of researchers have worked with perforated rings [59–70], circular rings [71,72], helical twisted tapes [73], twisted tapes [74–75], and longitudinal inserts [76,77], among other materials. The study of Hassan et al. [78] involved perforated rings with holes in the shapes of squares, triangles, and diverging and converging conical rings. According to their observations, the Nusselt number rises in a solid diverging ring. Plate fin heat exchangers with perforated baffles were examined by Boukhadia et al. [79] Hole shapes include round, rectangular, and triangular. Their results indicate that, in comparison to the unbaffled example, the circular perforated baffle had the greatest TPF (2.14), followed by the rectangle Perforated baffles (TPF = 1.57) and triangular (TPF = 1.46). The influence of hole angles on insert efficiency was studied by Acherjee et al. [80].

When compared to all other angles, Nu and TPF for 65° inclined hole insert tubes are substantially greater. In a study conducted by Pandey et al. [81], circular holes were placed above Y-shaped additions with varying diameters. Afterwards, Pandey and Singh [82] suggested making triangle holes in a Y-cut longitudinal insert by using different perforation indices (PI). Jatoth and Ravinder the study explores heat transfer and friction factor in double-pipe heat exchangers using twisted tape, finding that dimpled twisted tape improves heat transformation, lowers parameters, and reduces pressure drop despite higher convection heat transfer coefficient.[83] Atoth Heeraman, Ravinder Kumar, Prem Kumar Chaurasiya The study explores the impact of twisted tapes with large holes on a tubular heat exchanger's heat transmission, pressure drop, and thermal boosting factor, revealing increased Nusselt number and friction factor.[84] Abhishek Singh, Mohan Gupta, Dharmendra Kumar Tiwari, The study explores the impact of spirally fluted ducts on hotness exchange, thermal presentation, and isothermal friction in a coaxial duct hotness evaporator, revealing a technique for improving heat transfer.[85]

5. Conclusion

Summary of current efforts

1. Types of additives used to improve heat transfer:
   - Many different additives, such as perforations or others, have been used to improve the heat transfer performance of tubular heat exchangers.
   - In some cases, the region around the edges was less turbulent than the central region, resulting in a decrease in heat transfer.
   - This was observed in previous tests that used twisted ribbons as additional components.
2. Thermal performance issues:
   - Studies have noted an increase in pressure drop near the walls, resulting in poor thermal performance.
   - High frictional factors were recorded in several studies that used conical rings and different types of vortex generators, contributing to the poor performance.
3. Previous studies on Y-shaped zigzag additives:
   - According to the authors, only two studies have been conducted on Y-shaped perforated AM. [66,71].
   - Previous studies also showed that these geometries caused significant pressure drops.

6. Future recommendations for improvement:

1. **Optimize the design of the inserts**:
   - Further studies could be conducted to develop new additive geometries that combine improved heat transfer with reduced pressure drop.
   - Emphasis should be placed on designing additives that maximize turbines in peripheral areas without affecting performance in central areas.
2. **Test new materials**:
   - It is advisable to experiment with materials with different surface properties to reduce friction and increase heat transfer efficiency.
   - It is possible to use techniques such as micro-coatings or porous materials to improve overall thermal performance.

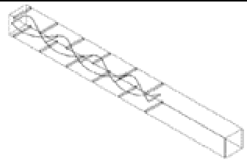
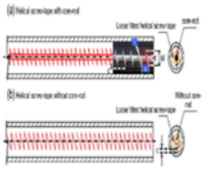
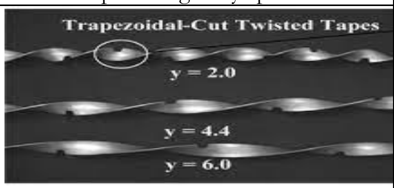
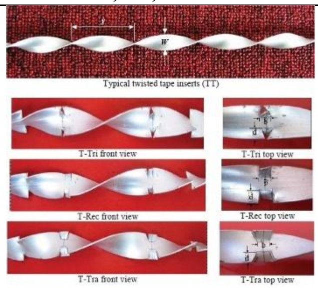
List of Symbols

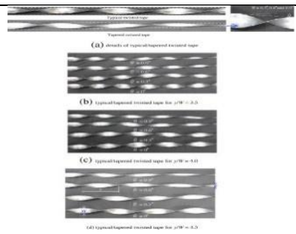
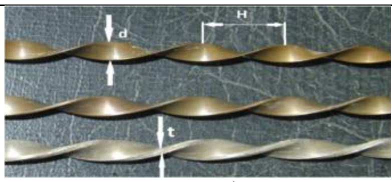
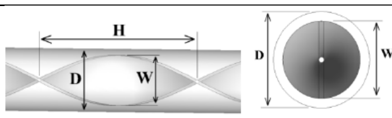
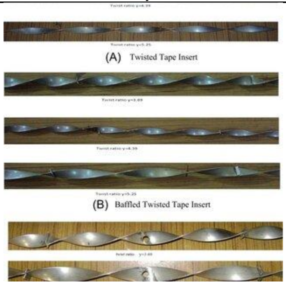
Re Reynolds number: [-]
Nu Nusselt number: [-]
Nus The Nusselt number for a simple, unadorned tube.
f Friction factor: [-]
fsthe friction coefficient of a conventional plain tube
P r Prandtl number: [-]
y the twist ratio
di is the internal diameter of the tube
H is the twist pitch length
PI (Surface perforation area) / (Total area of the surface)

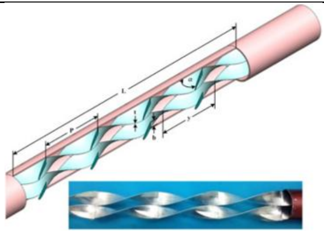
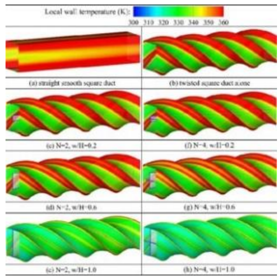
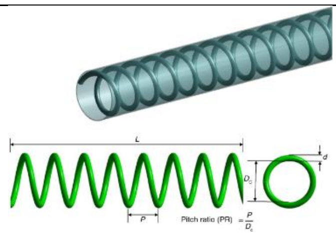
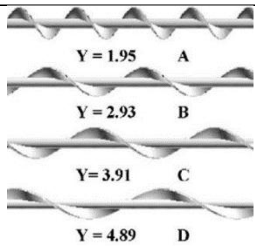
List of Abbreviations

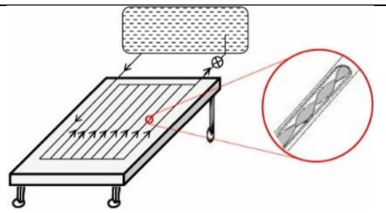
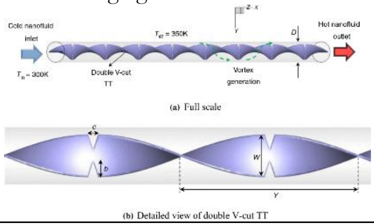
CFD Computational fluid dynamics
TKE Turbulence kinetic energy
TPF Thermal Performance factor

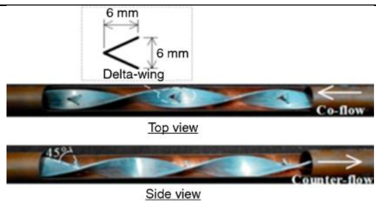
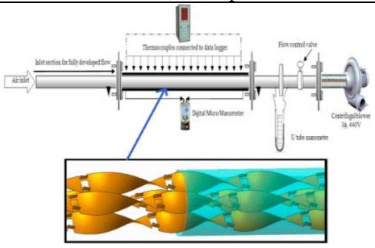
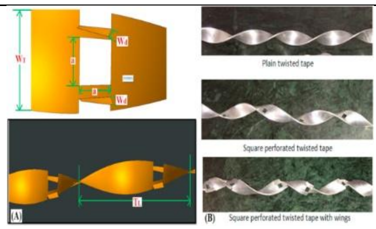
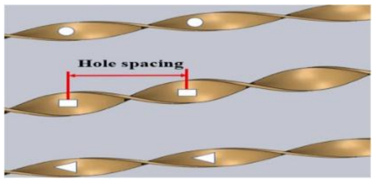
Table (1): The text provides a summary of the literature review on the thermal-hydraulic efficiency of tape with twisted inserts.

No.	Author	Research type	Condition	Tape dimension	Observation and results
1	Date and others [14].	Numerically	$40 \leq Re \leq 1100$	 square-sectioned duct with twisted tape inserted	the laminar flow with a pitch average The correlation between the Nusselt numbers for Re ≤1100, 1.5 ≤ Y ≤ 10, and 0.1 ≤ Pr < 500 is given by $Nu = 3.96\,[1+0.016\,Pr^{1.05}\,(\frac{Re}{Y})^{1.25}]^{1/2.6}$
2	Promvonge et al. [15]	experimental	Reynolds values range from 2300 to 8800 air.	 The spinning motion is created by two helical tapes, one full-length and with or without a center rod, and the other spaced regularly apart.	According to experimental results, heat transfer coefficients were higher when helical tapes were used in place of plain tubes. Speed at which heat is transferred.
3	Murugesan et al. [16]	experimental	a Reynolds number in the 200–2100 range.	 circular tubes with y = 4.0 and 6.0 are filled with trapezoidal-cut, full-length twisted tape.	The study found that tape with a trapezoidal cut had a significantly Increased heat transfer coefficient and resistance factor than plain tube. Relationships were established based on the experimental findings.
4	Jassim NA and associates [17]	experimental	Water, Re=300–1100	 Typical y/w for cruel tape (TT) is 3.5, 4, 4.5, and 5.	Heat transfer rates increase in comparison to a simple tube, ranging from 50.54% to 52.22% at the twisted tape of 5, 52.42% to 55.15% at the twisting of 4.5, and 52.41% to 569.8% at 3.5.
8	Chang et al. [18]	experimental	Reynolds numbers range from 1000 to 40,000,000.	 Tubes equipped with twisted tape that is broken. There are five twist ratios in the experiment: 1, 1.5, 2, 2.5, or ∞.	As the twist percentage decreases, the tube with broken twisted tape suffers a rise in local Nusselt values and overall Fanning friction factors. When compared to the flat twisted tape tube, heat transfer coefficients, mean Fanning friction factors, and thermal presenting factors in the breaking twisted tape tubes are 1.28-2.4, 2-4.7, and 0.99-1.8 times greater, respectively.

9	Meyer JP et al. [19]	experimental	Water, Re= 400–11400	The copper pipe has been modified with the addition of tape and now has a square-edged opening.	The Nusselt number is 12–15% larger than the simple one and rises progressively from 920 to 6700.
10	Piriyarung rod [20]	experimental	Re= 20,000 - 6,000 Air	 Twisted tape that taper with = 0.0, 0.3, 0.6, 0.9 then y/W = 3.5, 4.0, 4.5	When using 0.9° taper angle and 3.5 twisting ratio on Reynolds number 6000 tapered cruel tape, the highest thermal performance efficiency of 1.05 was achieved.
11	Tusar M et al. [21]	experimental	Re= 3642 - 21857 Air in ANSYS Fluent (SST) k-ω	 The standard twisted tape (TTT) inserts y/w = 2.93, 3.91, and 7.6.”	Twist ratios of 3.46 cause increases of 20% to -62%, 185% to -245%, and 0.9 to 1.2 in Nusselt numbers, friction factors, and TPF, respective. At a twist ratio of 7.6, the ratio grew by 10 to 30%, 128% to 183%, and 0.95 to 1.05, respectively.
12	P. V. Durga Prasad [22]	experimental	(3000 < Re < 30000) WaterAl_2O_3 Concentrations between 0.01 to 0.03	twist-tape additions with a y/w ratio of 5,20	The Nusselt number of entire pipes rises by 31.28% for vol. 0.03 percent. However, it also has in comparison to water.1.23 times greater resistance
13	Sundar et al., continuous [23]	experimental	Re=50–350 Gr=(500–3000) Pr=(440–2534) Oil with Fe_3O_4	 Standard twist-tape (y/w = 5, 10, and 15).	Using twisted tape inserts with a quantity of five enhances the Nusselt value for the 0.5% nanofluid by 23.86%. The resistance factor cost has an influence that is 1.44 times greater than the impact of the basic fluid.
14	Yadav [24]	experimental	Mass flow rate of turbulent tube oil: 4, 8, 12, 18, 24, 30	Twisted semi-length tape with y/w=7 (2-piece)	Half-length twisted tape additions enhance the heat transfer coefficient by 40% compared to a conventional heat exchanger. whereas smooth tube heat transfer exceeds half-length twisting tape in terms of unit the pressure drop. Simple heat exchangers have a thermal efficiency that is 1.3-1.5 times larger than half-length twisting tape.
15	Seemawut & Eiamsaarde [25]	experimental &numerical l	Water Re=5200-15300	 The abbreviation STT stands for short tape. The values of y/w are 3, 4, and 5.	Full-length tapes with y/w=4 and 5 have greater TPF due to a significant increase in heat transmission relative to an increase in friction factor.
16	Gugulothu SK et al. [26]	Numerical	Fluid Turbulent Air Re= 25000-110000 in ANSYS	 Twisted tape in full and half lengths, with y/w=0.14, 0.27, and 0.36	in comparison to a tape with twists that is half the length. The numerical findings indicate that the use of full-length tapes with twists leads to an increase in heat transfer, frictional factor, and efficiency within the range of Reynolds numbers that range from 25000 to 110000.

17	Zhu JD et al. [27]	Numerical	Air Re= 2000–20000 turbulent model in ANSYS K–ε	 Triple- and double-twisted tapes	When compared to a single tape and double tape inserts, the tube with triple twisted tapes can increase resistance by a factor of 8.7 to 6. and enhance heat transmission ability by 14.4–9.4 times, respectively.
18	Promthaisong and colleagues [28]	Numerical	The ANSYS Fluent simulation uses the realizable k-epsilon turbulence model to analyze the airflow at Reynolds numbers ranging from 5000 to 15000 for air.	 Twisted tape with five channels, y/w = 0.10,0.20,0.30,0.44, 0.44	The damage caused by pressure was approximately 2.82–21.34 times greater, while the enhancement in heat transfer was around 1.34–3.22 times higher compared to the simple tube. When a five-channel twisted tape is inserted into spiral corrugated tubing that does not have twisting tape, the thermal performance coefficients increase to a maximum of 1.16 times at a Reynolds number of 5000, surpassing that of smooth tubes.
19	Aghaie A and others [29]	Numerical	Relative humidity (RNG) Al_2O_3/water Re 5000–20000 in ANSYS Fluent K -ε	Twisted single and double tape with y/w=2,3, 4	The increase in heat transfer is higher with dual twisted tapes inserted than with single twisted tapes. Inserting single and multiple inserts can enhance heat transfers by up to 595 percent and 290 percent, respectively, at low Reynolds numbers.
20	Eiamsa-ard and associates [30]	Experimental	Re= 6000–20,000 Air	 Helical pitch relations p=1, 1.5, 2 correspond to helical tape H-T y/W=2, 2.5, 3.	When the tape with a twisted ratio of three and a helical pitching ratio of two is used, the TPF (twists per foot) is 1.29.
21	Yongsiri [31]	Experimental	Re=6000–20,000 Air	Spirally tape H-T H-TA on an alternate axis with P/d = (1.0-2); modify pitch to y/w = 3.	Compared to H-T, H-TA has a thermal TPF and heat transfer of around 14.1% and 1.9% higher, respectively. The H-TA has a larger area of contact due to its higher swirl intensity and improved fluid mixing in the general direction of the pipe wall.
22	Sivashanmugam P, Nagarajan P[32]	Numerical	Re = 200–400 Water	 Helical screw inserts with varying lengths twisting ratio and a completely helical screw element with a range of twist ratios.	The study's performance research revealed that the highest performance ratios were 2.85 and 2.97. This indicates that, for a specific twist ratio (also known as right-left helical screw inserts), heat transfer rates are enhanced more rapidly compared to straight helix twists.

23	Vijayan & Gnanaraj [33]	Experimental	Double-pane solar water heating system with Re=200–1750, y/w=3. Aqua	twisted Cut-wing tape using the rod or gap.	When comparing whole linear wing-cut tapes with twists to flat wing-cut twisty tapes with rods or spacers at the ends, the latter has a lower Nusselt value. Complete geometries have less friction than horizontally wing-cut tapes that are twisted with rods or gaps.
24	Ananth [34]	Experimental	Re=Water (200–1200)	Thermosyphon solar panels left-right pipe insert with gap and a rod at a regular rate of y/w = 30.	Twists increase total immediate thermal performance by 53.3% to 38.7% and reduce the drop in pressure by 47.2% to 8.9% as compared with a standard tube collection.
25	Ananth [35]	Experimental	Water (Re=400–1200)	 Solar heater twist with thermosyphon that has a spacer and rod of different lengths (y/w=30).	The Nusselt number falls with increasing rod and spacer length in comparison to full-length twist, whereas the pressure drops increases with reducing rod and insertion length.
26	Hajare et al. [36]	Experimental	Re: 7500 - 13000 Air	Rectangular-hole twisted tapes (W/D) = 0.35, 0.44, 0.53, 0.62, and 0.71 y/w=2.5	By eliminating the rectangular hole and instead twisting the tape, the convective heat transfer performance increased by 1.40 while simultaneously reducing flow friction. A twisted tape with a rectangular hole exhibit approximately 1.50 times the thermal efficiency compared to a regular twisted tape.
27	Deshmuk and Gawande [37]	Experimental	Re = 10000-19000 Air	Rectangular hole in twisted tape	Nusselt values in tubes with rectangular-hole twisting tape inserts increased by 2.3-2.9 times when compared to smoothness tubes, although at the expense of 1.4-1.8 times higher friction values.
28	Hasan pour et al. [39]	Experimental	Water Re=5000-15000	The coiled tube consists of V-cut and U-cut twisted tapes, with a y/w ratio ranging from 3.5 to 3.7. 	During the studies, it was observed that the V-cut TT in the corrugated tube had a larger size compared to both the empty curved tube (increasing from 1.50 to 2.2) and the normal TT (increasing from 1.15 to 1.40).
29	Kumar etal.[41]	Experimental	Re=2700–23400	V-cuts twisted perforations with y / w=2 -6 Air	A maximum of 1.58 is determined for the thermo-hydraulic performance measure. A maximum improvement of 2.99 is reported for the Nusselt number.
30	Gugulothu SK [45].	Experimental	Water Re = 4000-36000.	The average tape TTT, perforation PTT, and baffle bTT year on year are 3.69, 4.39, and 5.25, respectively.	The thermal performance factor tends to rise as the taper twist ratio decreases. The largest increases in friction factor and Nusselt number were seen in the Instances of perplexed and punctured bewildered tape.

31	Bansod & Nivedita [47]	Experimental	Re= 6000–13000 Air	 Copper and Aluminum V-Jagged Twisted Tape	The heat transfer coefficients for copper and aluminum with V-Jagged Twisted Tape are 52–90% higher and 50–75% higher respectively than for plain tube, while the friction factor is reduced.
32	Suri et al. [49]	Experimental	Re= 5000–27000 Air	 several perforations in square wings with twisted tapes (4)	The Nusselt number and friction factor are said to increase by up to 6.96 and 8.34 times, respectively, when associated to a normal circular tube. The Nusselt number and the coefficient of friction factor have well-established correlations.
33	Bhuiya and associates [51]	Experimental	Re= 50200 - 7200 Air	The porosity of double-perforated counter-twisted tape are: Rp = 1.2, 4.6, 10.4-18, and 18.6%.	The heat transfer rate and coefficient of friction were determined to be 80-290% and 111-335% greater, respectively, compared to plain tubes. By utilizing constant fan power, a thermal efficiency of 1.44 was attained.
34	ZM Lin et al. [61]	Numerical	Air CFD Re=50–600	 With a rectangle winglet, the tape is twisted.	Friction and Nusselt values increase by approximately 289.1% and 76.4%, respectively, whereas the associated TPF factor varies between 1.25 and 1.85.
35	A. Kumar and others [67]	Numerical	The turbulent model Water, ANSYS 14.5 K-ε	 A tape that is twisted and has holes in it	In comparison to the naked tape the mean heat transfer coefficient has risen by 82%. Similar to this, the average pressure drop for the twisted tape with holes is higher than that of regular twisted tape by 8.7%, 9.1%, and 10.02% for holes that are 1 mm, 3 mm, and 5 mm, respectively.

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