Anbar Journal of Engineering Science (AJES) **Vol. 15 , No. 2 (2024) , pp. 62 ~ 81**
P-ISSN: 1997-9428 ; E-ISSN: 2705-7440 DOI: http://doi.org/10.37649/aengs.2024.152719.1096

University of Anbar

Anbar Journal of Engineering Science

journal homepage: https://ajes.uoanbar.edu.iq/

Procedures of exploitation passive techniques to boost thermal performance in circular tube heat exchangers: a comprehensive review

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PAPER INFO

Paper history:
Received: 20 / 08 /2024
Revised: 16 / 11 /2024
Accepted: 10 / 12 /2024

Keywords:
Enhancement heat transfer
Hydrothermal performance
Passive approaches
Circular tube heat exchangers
Twisted tapes
Wires coils

ABSTRACT

Heat exchangers are considered essential parts in many industrial applications. The construction process for heat exchangers is completely complex because accurate measurements of the penalty of pressure-drop and the rate of heat transfer are needed. Designing a compact heat exchanger with a high heat transfer rate, while utilizing the least amount of pumping power, is the main design challenge. The most recent investigations (including experimental results, numerical models, and analytical solutions) in the field of circular tube heat exchangers in general, and twisted tapes and wire coils in particular, are covered in this review article, which has more than 90 references. The enhancement techniques in heat exchangers tubes can generally be separated into three groups: active, passive, and hybrid (compound) approaches. This article reviews the literature on advancements made in passive enhancement approaches, with a specific focus on two types of passive promoters that employ twisted tapes and wire coils. The main contribution of this research is to highlight the behavior and structure of fluid flow and the heat transfer features for the twisted tapes and the wire coils. It also explains how these passive promoters can be used in circular tube heat exchangers to improve hydrothermal performance. Where, the installation of wire coils and twisted tapes considerably alters the flow pattern and aids in the improvement of heat transfer. Where, comprehending the behavior of fluid flow is crucial and contributes to the enhancement of heat transfer. Twisted tapes are less effective in turbulent flow than wire coils because they obstruct the flow, which results in a significant pressure reduction. When it comes to turbulent flow, the thermohydraulic performance of twisted tapes is lower to that of wire coils.

1. Introduction

It is commonly identified that heat exchangers are utilized extensively in super-heaters, economizers, domestic and industrial air conditioners, and car radiators. Also, they are widely utilized in thermo-fluid engineering laboratories, power plants, chemical processing, the food and pharmaceutical sectors, and other industrial systems that require heat energy. Heat exchangers are usually employed to exchange thermal energy between two (or more) fluids at distinct temperatures and separated by a

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solid wall [1]. Generally, heat exchangers may be categorized into three main types based on their flow arrangement: cross-flow, parallel-flow, and counter-flow. In the parallel flow heat exchanger, two streams of fluids enter at one end and travel side by side out to the other. On the other hand, it enters counterflow heat exchangers in opposite strokes of fluid. The counter-flow heat exchanger design is the most efficient in terms of heat transfer because there is a larger average temperature differential over any given unit length [1]. The current high cost of energy and materials has led to a greater focus on designing and manufacturing heat exchanger devices with higher levels of efficiency. Therefore, the primary design challenges for a heat exchanger are to make it sufficiently compresse to accomplish a great heat transfer rate while allowing its operation with a minimum power loss. Techniques of heat transfer enhancement are related for many specific engineering applications; therefore, they are divided into three main groups [2]:

(a) Active techniques.
(b) Passive techniques.
(c) Hybrid (compound) techniques.

(a) Active techniques:

This enhancing approach is usually characterized by the complexity in design and it's required external power input for the heat transfer enhancement, therefore, it has not exhibited much potential in thermal applications. Moreover, the external power is required much effort for providing in various indestrial applications. Some active techniques are created pulse by cams and reciprocating plungers, propulsion using a magnetic field instantaneously perturbs the seeded light elements in the flow stream [2].

(b) Passive techniques:

Indeed, this enhancement technique or pressure reduction thereof ultimately does not require an additional input of external energy. The regime has thus always focused on lower pumping power in conjunction with increased thermal contact (higher heat transfer coefficient) to improve the thermohydraulic efficiency of heat exchangers. In a system that incorporates a heat exchanger, an effective heat exchanger design should have minimal entropy generation [2, 3].

(c) Hybrid (compound) techniques:

Produced a super position enhancement involves active and passive methods used simultaneously to boost an improvement that is greater than the singular manners operated individually. The multiple technique includes complex design and therefore it has limited industerial applications. As active techniques consumed additional power and the hybrid techniques, leads to design complexity, this article deals with the passive techniques that present an optimization between heat transfer and pressure-drop penalty. Table 1 lists kinds of improvement techniques involving the three presented categories.

Generally speaking, the hydraulic diameter of the flow tube is lowered when certain types of inserts (turbulence promoters) are added in order to rise the rate of heat transfer. Heat transfer increase in tube flow is achieved by introducing components like ribs, wire coils, and twisted tapes. This improvement is mostly the result of the primary flow being disrupted by flow obstruction, flow partitioning, and secondary flow. The flow obstruction normally rises the penalty of pressure-drop and viscous impacts owing to a decreased free flow passage. Obstructions also rise the flow velocity and lead to a remarkable secondary flow. Moreover, secondary flow enhances the fluid-surface thermal contact because it produces swirl which rises the temperature gradient and fluid mixing, both of which lead to a high heat transfer coefficient [4].

Enhancing heat transfer can be attained through a variety of passive techniques, as listed in Table 1. Many studies that discuss passive approaches for enhancing heat transfer are obtainable in the open

Table 1. Mechanisms of enhancement techniques that can employed according to the type of heat transfer applications.

Active techniques	Passive techniques	Hybrid techniques
Mechanical aids	Treated surfaces	Extended surfaces and electrostatic fields
Surface vibration	Rough surfaces	Rough surfaces and additives
Fluid vibration	Extended surfaces	Electrostatic fields with micro-fin tubes
Electrostatic fields	Swirl flow devices	Radically grooved rotating disk
Suction or injection	Surfaces-tension devices	Extended surfaces that are treated
Additives for fluids	Coiled tubes	electrostatic fields in a bundle of treated tubes

literature. The authors of the current work, however, reached the idea to combine all the published articles on heat transfer enhancement into an individual work for the investigators who are researching in this field because the majority of studies are either implemented on turbulators inserts, tube modifications, or promote fluid mixing to enhance heat transfer. The major goal of this manuscript is to display an in-depth comprehensive review of passive techniques that can employ to boost thermal performance in circular tube heat exchangers. The circular tubes heat exchangers are classified depending on the type of secondary flow promoters (inserts) into two main types: twisted tape tubes and wire coil tubes. Therefore, in this comprehensive review, an effort has been made to summarize various research works related to heat transfer enhancement exploiting passive techniques. Twisted tape circular tubes and spirally circular tubes are the two primary sections that make up the summary of the current work.

2. Twisted tape circular tubes:

One of the first techniques used to augment the heat transfer process in a heat exchanger with traditional tubes is twisted tape. The use of twisted tapes often creates of highly effective swirling flow. The employed swirling techniques can be in the form of inserted-local swirl promoters of twisted tape type. Many authors previously reported the twisted tape techniques to boost convective heat transfer in circular tubes. In the most recent, Bergles [5] developed heat transfer relationship based on the asymptotic technique and it's suitable for both thermal conditions, T_w = constant and q = constant, with the variety of Reynolds number ($Re > 10000$). Royds [6] examined heat transfer by radiation, conduction, and convection in his early research. He reported about how an inserted tube with a twisted tape achieves superior thermally than a simple tube. Furthermore, he demonstrated how, for low Prandtl number fluids, twisted tape with a strict twist ratio increased heat transfer rate at the expense of a larger pressure-drop penalty and an increased pumping cost. The fluid with a low Prandtl number performs greater because it has a tighter twist ratio and a thinner thermal boundary layer, which disrupts the whole thermal boundary layer and improves heat transmission as pressure decreases. Moreover, Smithberg and Landis [7] performed an experimental and analytical research on full-length twisted tape in turbulent tube flow. They developed a mathematical model of the mechanism of generated swirling by the twisted tape with utilizing water as operating fluid. The used test section contained of 1m long and 37.5mm diameter. Their outcomes showed that the circular tube fitted with a twisted tape performed superior than a simple tube for ($2000 \le Re \le 100000$) and ($0.7 \le Pr \le 10$). Their results also showed improvement in heat transfer and growing in the pressure drop. Further, Manglik and Bergles [8] established laminar flow relationships for the Nusselt number and friction factor by integrating the swirl parameters, which defined the connection between centrifugal forces, viscous, and convective inertia. Further investigation that performed by Manglik and Bergles [9] provided other correlations for full-range of laminar and turbulent flow regimes. For a friction factor, the formulated correlation described the available obtained data for three flow regimes, laminar, transitional and turbulent, within 10%. Nevertheless, because laminar to turbulent flow is a transitional state, a set of curves was desired to distinctly improve a formulated relationship for the Nusselt number. Kang et al. [10] formulated the overflowing connection for a corrugated tube with a twisted tape. The influences of the existence of twisted tape and the incline of inclination on overflowing flow can increase the heat transfer coefficient with the increase of pressure drop. Additionally, Al-Fahed et al. [11] contrasted the heat transfer coefficients and pressure drop obtained from a simple tube with a twisted tape tube where three distinct twist ratios each with two distinct widths were tested. The findings showed the influence of twisted tape tubes on enhancement heat transfer. Liao and Xin [12] published an empirical data on the compounded technique of heat transfer improvement and carried out that the heat transfer augmentation in a tube fitted with 3D inner expanded surfaces by replacing continuous twisted tape with nearly segmented twisted tape adds resulted in a decline in the friction factor but with a relatively minor decline in the Stanton number. Where the Stanton number was described as the heat transfer rate ratio to the enthalpy variance and it was a calculate of the heat transfer coefficient. Lishan [13] indicated in his analytical study on twisted tape in laminar flow that the twisted tape curvature induced centrifugal forces and promotes the secondary flow circulation. He also illustrated that the temperature distribution in the flow field was seen to be strongly affected by Prandtle number, Reynolds number and the ratio between pitch twisted tapes to the inner tube diameter. Thus, both Nusselt number and friction factor rised with supplement of any passive techniques. Many passive techniques analysed in previous decades, it was found that the twisted tape was efficient on laminar flow and the helical wire on turbulent flow. In a circular laminar flow with a twisted tape, Saha et al. [14] reported experimental data on the friction factor and Nusselt number with a great Prandtl number (205 < *Pr* < 518). When compared to full-length twisted tape, they observed that short-length twisted tape had a lower pressure drop and a slow decay of generated swirl, making it a greater option for pumping power. This allows for an increased heat transfer coefficient. Twisted tape performed better thermo-hydraulically in laminar flow than wire coil due to its dominating thermal resistance covering the entire cross-section, rather than just a thin wall area. This suggests that a twisted tape insert likely blended the bulk flow effectively. According to Wang and Sunden [15], who observed relationships for ethyl glycol and polybutene (1000 ≤ *Pr* ≤ 7000), wire coil was operative for big Prandtl number fluids (*Pr* > 30) and twisted tape was operative for small Prandtl number fluids (*Pr* > 30), considering into account the total enhancement ratio. In contrast to the findings of Manglik and Bergeles [8], their results demonstrated validity for comparatively higher Prandtl number values. The properties of heat transmission and pressure loss in horizontal dual pipes equipped with twisted tapes were examined by Naphon [16]. The test involved two sections with varying pitches (2.5, 3 cm) and inner and outer diameters (8.10, 9.54 mm) respectively. Twisted tapes were created from 1mm thick aluminium strips and 2000mm long. Cold and hot water were utilized as operating fluids on the shell and tube sides, respectively. Mass flow rates ranging from 0.01 to 0.07 kg/s and 0.04 to 0.08 kg/s, respectively, were conducted for the test runs. The outcomes attained from the tube with twisted tape were contrasted to those obtained from tubes without twisted tape. The tube-side pressure drop and heat transfer coefficient were offered in terms of the friction factor and Nusselt number based on the experimental data. Noothong et al. [17] empirically investigated the impacts of the twisted tape addition on flow friction features and heat transfer in a concentric dual pipe heat exchanger. Twisted tape was located inside the internal test tube of the heat exchanger with various twist ratios (5 and 7). The experiments were conducted under the same inlet condition and inner tube Reynolds number, varying from 2000 to 12000. The outcomes showed that the increase in the rate of heat transfer was notably affected by tape-produced swirl or vortex motion. The twisted tapes were configured from stainless steel strips of 1 mm thickness and 19.5 mm width. The highest Nusselt numbers for the thermal improvement with twist ratios 5 and 7 were 188% and 159%, respectively, greater than for the smooth tube. Pethkool et al. [18] experimentally performed the impact of louvered strips mounted in a parallel-flow concentric dual pipe heat exchanger on the performance of heat transfer and friction factors. The louvered strips, made of brass, the louvered strips were 0.5 mm thick and 9 mm wide were placed in the inner tube of the heat exchanger, serving as turbulators. The tubes were fitted with louvered turbulators, with 17, 26, and 31 degrees of inclined louvered stripes installed. The investigate involved hot water discharging across the inner tube and cold water flowing across the annulus. The Reynolds number varied from 6000 to 65000 for cold water and 8000 for the hot water flows, with inlet hot and cold-water temperatures were 55°C, and 20°C, respectively. The incidence of strips at 17, 26, and 31 degrees increased average heat transfer by 133%, 186%, and 246%, respectively, for Reynolds numbers 6000 to 65000. Additionally, installing inclined strips increased friction factors by 119, 145, and 167% by installing the inclined strips of 17, 26, and 31 degrees, respectively.

Eiamsa-Ard et al. [19] provided an experiment on the heat transfer features and pressure drops of water flow across a circular tube with twisted tapes. Pitch length (20 mm) and thickness (1 mm) are the geometric parameters of the stainless steel twisted tape. Twisted tapes with free spacing of $2P$, $3P$, and $4P$ were positioned within the tubes, and the experiments were conducted under the same conditions at the tube inlet with the inner Reynolds number ranged between 2300 and 7500. The outcomes showed that at the narrow regular spaced twisted-tape length ($S = 2P$) contrasted to the larger regular spaced twisted-tape lengths ($S = 3P$ and 4P), higher heat transfer values were obtained. The greatest heat transfer from full-length twisted tapes was around 157%, while over the plain tube, it rose to approximately 144% for $S = 2P$, 136% for $S = 3P$, and 120% for $S = 4P$. As the Reynolds number rose, the pressure decreases in the inner tube became significantly. Regularly spaced twisted-tape adds, $S = 2P$, $3P$, and $4P$, could reduce the pressure drop by about 90%, 120%, and 440%.

Zdaniuk et al. [20] experimentally evaluated eight improved tubes and one plain tube. For use in condenser applications, copper-nickel was used to make all of the tubes. The included angle (β = 41°) was produced by the internal fins, which had thicknesses of 0.48 mm at the bottom and 0.2 mm at the top. Eiamsa-Ard et al. [21] again developed an experimental examination for the features of fluid flow and heat transfer, utilizing louvered strips that placed in a concentric tube heat exchanger. The stainless steel louvered strips generated turbulent flow, increasing the heat transfer rate of the tube. The tube's flow rate ranged from 6000 to 42000 Reynolds numbers, with turbulent flow devices consisting of louvered strips with two arrangements, forward and backward, and also louvered strips had three different inclined angles (15°, 25°, and 30°). The strips were added in the inner tube of heat exchanger, with hot water flowing across the inner tube and cold water flowing in the annulus. The results showed that the utilize of louvered strips resulted in greater heat transfer rates than simple tubes. Average Nusselt number and friction loss augmented by 284% and 413%, respectively, with the inclined forward louvered strip; increases of 263% and 233% were attained with the backward louvered strip. The louvered strip with a backward display resulted in a greater overall improvement ratio (9% - 24%) compared to a forward arrangement. Zdaniuk et al. [22] employed a linear regression technique to associate the empirically governed Fanning friction factors and Colburn j-factors for water flow in helically-finned tubes. The experimental data involved eight improved tubes with spiral inclines ranging from 25° to 48°, fin startings from 10 to 45, fin height/ diameter ratios from 0.0199 to 0.0327, and Reynolds numbers between 12000 and 60000. The logarithms of friction and Colburn j-factors in helically-finned tubes were found to be connected by linear integrations involving a constant and the same five factor groupings. Excellent outcomes were attained when the suggested functional association was tested using independent empirical data. In a U-bend dual pipe heat exchanger, Yadav [23] investigated the impacts of a half-length twisted tape addition on pressure drop features and heat transfer in heat exchangers. Using a half-length twisted tape, a 0.8 mm thick stainless steel strip, was added into the heat exchanger's inner test tube, creating swirling flow. The results showed that tape-induced swirl or vortex motion significantly impacted the twisted-tape inserts' rised heat transfer rate. When half-length twisted tape adds were used instead of a simple heat exchanger, the heat transfer coefficient augmented by 40%. The half-length twisted tape's heat transfer performance outperformed the plain heat exchanger due to equivalent mass flow rate, while the flat tube's heat transfer performance outperformed the half length of twisted tape based on the penalty of pressure-drop.

Smith and Promvonge [24] conducted an experimental examination of the impact of twisted tape with a indented-edge on the behaviour of pressure losses and heat transfer under a constant heat flux condition with a scope of Reynolds numbers from 4000 to 20000. They used serrated twisted tape (STT) to induce swirling airflow and found that the Nusselt number boosted with the depth ratio of the STT, but reduced with a higher width ratio. The STT tube's heat transfer rate was 72.2% higher than basic tubes and 27% higher than twisted tape tubes. The thermal performance factor of the STT tube with fixed pumping power was greater than one, indicating its superiority over twisted tape or plain tubes. The peripheral influence of cut-twisted tape within circular pipes on hydrothermal performance was experimentally outlined by Wongcharee et al. [25] using water as working fluid in the range of Reynolds numbers between 1000 and 20000. In their experimental investigation, nine kinds of twisted tapes were probed with altering ratios of both depth and width, alongside traditional twisted tapes. The article goaled to study the hydrothermal performance within heat exchanger tubes fitted with twisted tapes under various flow conditions. The findings stated that twisted tapes notably rose both friction factors and rates of heat transfer in comparison with the conventional twisted tapes and also smooth pipes under the laminar flow regime. The key reason of using these developed twisted tapes was to generate secondary flows (with high strength of disturbance) near the developed pipe surface. The results revealed that the employment of twisted tape rose heat transfer rates within 2.6 times in turbulent conditions and 12.8 times in laminar conditions, causing the greatest hydrothermal performance factors of 1.29 and 4.88, respectively.

Other numerical investigation reported by Guo et al. [26] to study the characteristics of hydrolic-thermal performance within a circular pipe fitted with a center cleared twisted tape under the laminar flow regime. The technique of center cleared twisted tape enhanced convection heat transfer in laminar flow regime, potentially increasing thermal efficiency between 7 and 20%

compared to the traditional setups tubes. Lei et al. [27] investigated the enhancement of heat transfer within tubes using modified twisted tapes, revealing that these tapes increased the Nusselt number by 76.2 – 149.7% and the friction factor by 380.2 – 443.8% across a Reynolds number range of 6000 to 28000, with performance ratio values consistently exceeding 1.0, indicating superior overall performance compared to conventional twisted tapes. Thianpong et al. [28] reported the insertation of perforated twisted tapes (PTTs) with parallel wings to boost the efficiveness of heat transfer in heat exchanger tubes. They tested the impact of ratios of wing depth and hole diameter of PTTs on both pressure drop and heat transfer. Where, the PTTs were designed with the different ratios of wing-cut and hole diameter to create secondary flows near the tube's wall to demolite the thermal boundary layer. The ouctomes revealed that the existence of wings and perforations meaningfully influenced on the rate of heat transfer and friction factors. The greatest depth ratio of PTTs yieled in higher both heat transfer and friction factors compared to standard twisted tapes. Smith et al. [29] further investigated the impacts of Circular-Ring Turbulators (CRTs) and twisted tape vortex-creators within a circular pipe for combining these techniques on the thermo-hydrolic performance factor. The combined these promoted techniques increased the Nusselt number, friction factor, and thermal performance by 25.8%, 82.8%, and 6.3%, respectively, compared to CRT alone. They attained the most optimal thermal performance factor with a pitch ratio of 1.0 and a twist ratio of 3. The impact of triple twisted tapes on friction factor and heat transfer performance in a circular tube was analysed by Bhuiya et al. [30]. They used mild steel inserts with distinct twist ratios (1.92, 2.88, 4.81 and 6.79) and Reynolds numbers (7200 to 50200) to analyze their effects. The study found a positive correlation between the friction factor, Nusselt number, and thermal improvement efficiency with reducing twist ratio. The primary goal was to optimize heat transfer rates using the vortical flow induced by triple twisted tapes. The study found that utilizing triple twisted tape adds significantly increased the Nusselt number and friction factor in tubes, with values ranging from 1.73 to 3.85 times higher than plain tubes. The friction factor of a tube with triple twisted tape adds was found to be significantly higher level, reaching values 1.91 to 4.2 times greater than that of a basic tube under similar Reynolds numbers. Additionally, The thermal enhancement efficiency consistently exceeded one, indicating that heat transfer enhancement from inserts outperformed the escalation in friction factor. Mokkapati and Lin [31] investigated the efficiency of diesel exhaust heat recovery system in Ruby, Alaska , focused on enhancing the heat recovery process by incorporating twisted tapes. They compared the heat transfer capabilities of standard basic tube heat exchangers with and without twisted tape additions and assessed the impact of distinct twisted tape shapes on efficiency. The study found that incorporating twisted tape inserts in the concentric tube heat exchanger meaningfully improved heat transfer rates, reaching 235.3% and 67.26% contrasted to simple tube and annularly perforated tube heat exchangers without twisted tapes. Thianpong et al. [32] empirically examined the impact of single, dual, triple, and quadruple twisted-tape adds on heat transfer and pressure loss features in a circular tube with a heat-fluxed wall. Their research addressed features of flow friction factor and heat transfer for turbulent airflow with Reynolds numbers in the range between 5300 and 24000. The experimental outcomes stated a positive correlation between Nusselt number and numbers of twisted-tape even with the highest Reynolds numbers, suggesting an improvement in the performance of heat transfer. The Nusselt number of pipes with twisted tapes meaningfully boosted compared to plain pipes from 1.15 to 2.12 times, with a resonable increase in friction factors. The thermal development factor of the inserted tube with double-twisted tapes was better than that of smooth pipe, the quadruple counter-twisted tape adds established the greatest thermal performance. In addition, the utilization of titanium dioxide nanofluid and overlapped doubled- twisted tapes (O-DTs) to augment the rate of heat transfer in the turbulent pipe flow regime (Reynolds numbers of 5400 to 15200) were examined by Kiatkittipong et al. [33]. Their study found that the use of O-DTs with reduced twist ratios raised swirl strength and turbulent kinetic energy, therefore increasing the overall hydrolic-thermal performance. Additionally, incorporating O-DTs with TiO_2 nanofluid at raised volume concentrations extended contact surface area and thermal conductivity, causing a significant heat transfer improvement of 9.9% to 11.2% and a thermal performance enhancement of up to 4.5% contrasted to O-DTs alone. Furthermore, Dual-twisted tapes with 30°V-designed ribs were applied in an experiment by Tamna et al. [34] to augment heat transfer in a circular tube. These twisted tapes create combined vortex generators. The analysis achieved that increasing Reynolds number and blockage ratio produce to improved pressure loss and heat transfer in the V-ribbed twisted tapes, revealing enhanced thermal properties. The highest friction factor and heat transfer showed in the V-ribbed twisted tape with a blockage ratio of 0.19, while the V-ribbed twisted tape achieved a greatest thermal enhancement factor of approximately 1.4 at 0.09. Bhuiya et al. [35] explored The influences of corrugated dual counter twisted tapes on the liquid friction and heat transfer properties within a heat exchanger tube. Counter swirl flow inducers were utilized with twisted tapes of varying porosities with Reynolds numbers changing from 7200 to 50,000. The experiments took place in turbulent flow conditions in a cylindrical tube, with air as the occupied fluid. The outcomes presented that the thermal conductivity of the channel and the friction coefficient augmented significantly with perforated double counter twisted tapes. The friction coefficient, Nusselt number, and thermal intensification effectiveness increased with porosity reduced, except for a specific porosity of 1.2%. They also found that heat transfer rate and friction coefficient were 80-290% and 111-335% greater than smooth channels, respectively. Suri et al. [36] experimentally analysed the influence of several square corrugated twisted tapes of a heat exchanger circular tube on the Nusselt number and friction factor across a scope of Reynolds numbers ranging from 5000 to 27,000. The enhancement of thermo-hydrulic performance in comparison with a plain circular pipe was assessed by analyzing some geometrical parameters such as, the ratio of wing depth, the number of twisted tapes, width ratio, and the ratio of twist. The investigation attained that both Nusselt number and pressure drop increased with rising Reynolds numbers. The combination of square wings with the addition of twisted tapes led to superior heat transfer due to turbulent streams near the tube surface. The study also indicated that the improvement in the rate of heat transfer and friction factor meaningful correlated with increasing Reynolds numbers and wing depth ratios, confirming the effectiveness of inserted square-wing twisted tapes in improving heat transfer efficiency. Characteristics of hydrolic-thermal performance for a smooth pipe fitted with overlapped-multiple twisted tapes were systematically studied by Hong et al. [37]. The influences of Reynolds numbers, twisted tape numbers (3 to 5), and overlapped twisted ratios (0.74 to 2.97) on the behaviours of airflow and heat transfer within the pipes equipped with multiple twisted tapes were also probed under turbulent internal airflow regime (Reynolds numbers varying from 5800 to 19200). The experimental outcomes discovered that the high values of Nusselt number and friction factor were occurred in the case of multiple twisted tapes in comparison with smooth pipe with increasing the number of twisted tapes and declining the ratio of overlapped twists. Yaningsih et al. [38] also explored the influence of V-cut twisted tapes (VTTs) on thermal performance in a single-phase turbulent flow heat exchanger. The detailed comparison in terms of the thermal performance among pipe with VTTs, pipe with a standard twisted tape, and a smooth pipe was carred out with varying the width ratios of the V-cut twisted tapes. The resultes concluded that pipe with VTTs offered the greatest thermal effectiveness in compared to plain pipe and standard twisted tape pipe with decreasing the width ratio of the VTTs. Additionally, the employment of the VTTs resulted increasing in friction factor, which reached up to 3.48 times compared with the smooth pipe. The maximum obtained thermal performance was by 1.4 times, thus that highlighted the VTT's effectiveness in improving heat transfer in the heat exchanger. In addition, an experimental investigated was carried out by Meyer and Abolarin [39] to study the characteristics of thermal-hydrolic performance in a circular tube fitted with twisted tapes. Their study covered three different flow regimes namely: Laminar, transitional, and turbulent flow regimes also it achieved with twist ratios of 3, 4, and 5. Results displayed that as twist ratios reduced and the Colburn j-factors increased, leading to an earlier transition from laminar to transitional flow regime. Moreover, Superior heat flux delayed the transition when the heat flux changed and twist ratio was constant. Additionally, friction factors rised as the twist ratio declined, and an rise in heat flux with a constant twist ratio and Reynolds number led to a reduce in friction factor. More recently, Hong et al. [40] numerically investigated the thermal and fluid flow features of various twisted tapes (MTTs) within sinusoidal rib tube (SRT) heat exchangers to improve exhaust gas heat. The research focused on the impact of geometric factors such as the number of tapes and the configurations of tapes in the SRT. The findings revealed that sinusoidal rib tube heat exchangers with multiple twisted tapes demonstrated higher heat transfer efficiency compared to conventional spirally corrugated tube arrangements. The SRT alone enhanced heat transfer by 27.4% to 39.5%, but also increased friction loss from 49.4% to 74.7%. Moreover, The combined impact of longitudinal vortexes generated by SRT and MTTs produced elevated Nusselt numbers and friction factors, resulting in SRTs with MTTs surpassing the performance of SCT by 1.43-1.87 times and 2.66-10.07 times, respectively. Feng et al. [41] examined the heat transfer features of hydrocarbon fuel within circular tubes, focusing on boiling or pseudo-boiling under related pressures and pyrolysis processes. They analyzed convection heat transfer of a hydrocarbon fuel like kerosene in horizontally positioned circular tubes equipped with twisted-tape adds and subjected to supercritical pressures. The researchers proposed a modified Gnielinski correlation pertaining to the Nusselt number in a horizontal tube featuring twisted-tape includes to increase heat transfer efficiency. They discovered that the characteristics of convection heat transfer of kerosene-type hydrocarbon fuel in circular tubes fitted with twisted tapes adds resulted in an enhanced heat transfer rate contrasted to simple tubes. This enhancement was clarified to differences in heat transfer influenced by quick changes in thermal properties corresponding to temperature variations. Furthermore, A well-formulated experimental relationship for the Nusselt number in tubes equipped with twisted-tape adds was suggested, enriching the understanding of heat transfer mechanisms within such configurations. Again, Fagr et al. [42] numerically and empirically examined the impact of twisted tapes of decreased tapered designs on the flow and heat transfer features of a tube. Experimental procedures involving constant heat flux and turbulent flow within a range of $10000 \leq Re \leq 40000$. They discovered that the Nusselt number improved when the length of the tapered region (l) decreased or the final width (FW) increased. This increase was attributed to the elongated trajectory of the fluid, resulting in intensified swirling and improved flow intermixture. Additionally, an increase in FW reduced the gap between the tube's surface and the coiled tape, facilitating superior intermixture near the tube boundary. The study found no significant difference in the Nusselt number among different coiled tape configuration. Singh and Sarkar [43] examined an experiment on Al_2O_3 and TiO_2 hybrid nanofluid in a dual-tube heat exchanger using improved V-cuts twisted tape adds. They assessed the impact of twisted tape turbulator and hybrid nanofluid on heat transfer and pressure drop characteristics. Outcomes presented that the friction factor and Nusselt number increased with reducing twist ratios, width ratios, nanofluid inlet temperatures and rising depth ratio. Significant enhancements were observed in the Nusselt number and friction factor, reaching 132% and 55% improvements respectively. The factor of thermal performance and the values of entropy generation ratio also exceeded unity for the hybrid nanofluid with modified twisted tape, indicating favorable hydrothermal properties.

Labib et al. [44] experimentally and numerically evaluated the thermal efficiency enhancement, pressure drop features, and fluid dynamics in a dual-tube heat exchanger with twisted tape adds for turbulent flows with Reynolds numbers changing from 15000 to 50000. The influence of different twist ratios on the various metrics of heat exchanger performance was also examined using a closed loop with variable flow rates of hot and cold water. The results indicated that the presence of twisted tapes gradually enhanced convective heat transfer compared to typical heat exchangers without twist tapes. Further, the differences in twist ratios including, 7.5, 6, and 4.5, significantly affected the thermal performance of heat exchangers, illustrating the importance of twisted tapes in enhancing heat transfer. However, the use of twisted tapes also led to an increase in pressure drop across the tube, which disrupted the normal fluid flow. Additionally, Wang et al. [45] explored how the eccentric placement of twisted tapes affected on the thermal performance within a cylindrical tubes. They evaluated the influence of variations in tape width, such as 20, 18, 16, 14, and 12 mm, for thermal conduction efficiency with a constant twist ratio of 2.0. The Nusselt number, a critical factor in flow analysis, was studied using computational methods within a Reynolds range of 2600 to 8760. The examination showed that off-centre twisted tapes had higher heat transfer performance contrasted to simple tubes, especially in low Reynolds regions. In addition, tubes with twisted tapes on the wall surface as opposed to tapes positioned in the center displayed an rise in the Nusselt number; this rise was more pronounced for narrower tape widths. The study also found that the Nusselt numbers increased as the tape width increased, although values for 18 mm and 20 mm were closely ranged at low Reynolds numbers. Wong and Tiong [46] numerically investigated the thermal and flow features of TiO_2 nanofluid within circular and square ducts using different twisted tape formations. The study evaluated the thermal efficiency of TiO_2 nanofluid in ducts using single and triple twisted tape adds, considering various co- and counter-arrangements. The study found that the circular channel achieved the maximum Nusselt number augmentation using a counter-triple twisted tape configuration, while the square channel showed optimal augmentation with a co-triple twisted tape configuration. The circular tube with single twisted tape and 1.5% nanofluid showed the greatest thermal performance factor of 1.286, indicating enhanced efficiency. Multiple twisted tape inserts in the square duct resulted in better thermal efficiency and lower friction factor, making it suitable for heat transfer applications.

3. Spirally circular tubes:

In many industrial applications, spirally circular tubes are regarded as one of the most common techniques for thermal enhancement that is both economical and effective for the overall heat transfer. The following presented works are some of the relevant studies that deal with this type of turbulence promoters. Garimella et al. [47] expressed the performance of spirally enhanced tubes in the region of turbulent flow ($20000 < Re < 100000$). The results showed that the increase in heat transfer was attended by a very small increase in the friction factor, proving the effectiveness of these secondary flow promoters. Anand et al. [48] conducted an experimental investigation on forced convective condensation inside coiled, doubly fluted tubes. This study examined two separate doubly fluted tubes, and the results of the studies indicated that the two had noticeably different condensation coefficients. Garimella et al. [47] involved the performance of spirally improved tubes in the region of turbulent flow ($20000 < Re < 100000$). The outcomes displayed that the increase in heat transfer was attended by a very small rise in the friction factor, proving the effectiveness of these secondary flow promoters. Anand et al. [48] performed an experimental examination on forced convective condensation inside coiled, doubly fluted tubes. This study examined two separate doubly fluted tubes, and the results of the studies indicated that the two had noticeably different condensation coefficients. A process governing condensation in each tube was suggested by comparing the anticipated values with the experimentally measured values. This mechanism may be connected to the flutes' form. In addition, Oliver and Shoji [49] established in an experimental research that for Reynolds numbers less than 2000, high Prandtle number fluids ($30 < Pr < 9020$) during laminar flow were possible. The experiment was conducted in a circular tube by the authors using a wire coil arrangement. When contrasted to a flat tube, they obtained that heat transport was improved four times. Once more, Garimella and Christensen [50] have examined the fluid flow in annuli created by nestling smooth outer tubes inside spirally fluted, indented, and ribbed tubes. To gain a better comprehending of the development of the swirl in the bulk flow, detailed temperature profile measurements and flow visualization investigates were conducted for the laminar, transitional, and turbulent flow regimes. The most effective inner tubes with flutes were revealed to be those that induced secondary flow, which enhanced convective heat transfer. The use of a wire coil insert to increase turbulent flow was investigated by Arici and Asan [51]. They discovered that the heat transmission for the wall-attached wire coil adds was reduced when the wire coil's pitch increased while maintaining a constant Reynolds number. An opposite behavior was noted in the case of misplaced wire coils, where a rise in pitch led to an rise in heat transmission. Further, Ravigururajan and Bergles [52] have advanced formulated relationships of the heat transfer coefficient and friction factor that were commonly used. The data of heat transfer from the relationship concurred completely with the review data by including the roughness type and Prandtl number. Inaba and Ozaki [53] demonstrated in their study that heat transfer was improved even downstream of the wire coil by the turbulent flow created by the wire coil. They also created an empirical relationship between the Prandtl number and the Nusselt number. The length of the wire coil was found to be proportionate to the pressure decrease. They also stated that a great heat transfer coefficient and relatively minor pressure drop because of the leading edge influence close to the tube entrance and the turbulent flow downstream of the wire coil. Silva et al. [54] experimentally measured the local heat transfer coefficient in a pipe with a helical wire inserted tube using the naphthalene sublimation method. The 5.93 m long and 65 mm internal diameter PVC pipe was employed in their experimental examination. The findings demonstrated that a rise in the Nusselt number of roughly (45%–65%) was followed with a rise in the friction factor of between 25% and

30%. In an experimental research on tubular heat exchangers, Milenkovic and Vasijevic [55] used a wire coil with a 60° helix angle, a 1 mm wire diameter, and a 14 mm helical pitch. The inner and outer diameters were 16 mm and 26 mm, respectively. For forced convection heat and turbulent flow throughout a range of 2300 ≤ *Re* ≤ 22000, the experimental findings of the convective heat transfer coefficient along the pipe with the friction factor were provided. For Re < 10000, the improvement in the heat transfer coefficient was around 80%, while for *Re* > 10000, it was approximately 40%. When a large fluid pressure drop was acceptable and the heat exchanger's size could not be altered, these helical promoters might be employed.

Moreover, Rahai et al. [56] studied the influence of a wire coil add on the augmentation of fluid mixing in a turbulent jet flow from a Bunsen burner, where the pitch spacing to wire diameter ratio is equal to unity. According to their experimental findings, the fluid mixing process at the near flow zone of the jet has significantly increased. They also explored how different coil pitch spacing affected the fluid mixing process. In an additional experimental research, wire coil inserts with a turbulent flow regime were examined by Rahai and Wong [57], utilizing air as the operating fluid. They illustrated that while the mean velocity was decreased, fluid mixing and kinetic energy were boosted by the wire coil inserts with big spacing. Additionally, they demonstrated that raising the wire coil's pitch length raised the enhancement ratio overall. However, as the Reynolds number raised from 5000 to 45000, the overall improvements ratio fell. Further, an experimental study on heat transfer and pressure drop for laminar flow in spirally improved tubes was given by Rainieri et al. [58]. The study considered five different spiral tube geometries. The researchers discovered that for spiral tubes, a Reynolds number of less than 2000 can cause a transition from laminar to turbulent flow. Significant heat transfer increase accompanied this early flow shift by assuming values from 1.1 to 6 in the Reynolds number scope of 300-1800. In order to highlight the augmentation of heat transfer and the rise in friction factor in the laminar flow field, the results were also compared with those of earlier studies and with expectations for the flat tube. The heat transfer and friction factor data for single-phase flow in a dual concentric tube heat exchanger with a helical tape add were experimentally observed by Eiamsa-Ard et al. [59]. The doubled concentric tube heat exchangers utilize cold water across the annulus and hot air across the inner tube with the low Reynolds numbers ranging from 2300 to 8800. To compare the attained Nusselt numbers and friction factors with previous data (Dittus 1930, Moody 1944) for axial flows in the sample tube, the study investigated the effect of helical inserts on heat transfer rate and friction factor for counter-flow heat exchangers. The outcomes presented that using the helical insert resulted in a greatest percentage advance of 165% in heat transfer rate contrasted to the simple tube. Hussain [60] experimentally studied the improvement of heat transfer in pipes using helical wire insert. The test section consisted of flat carbon steel pipe of 1 m long and 4.15 cm internal diameter and the wire diameters were 1.5, 2.0, 2.5, 3.0 mm. Three different helical wires length of 0.33 m, 0.67 m and 1.0 m were investigated for different pitches to wire diameter ratios of 8, 10, 13, 15, 17, 20, and 22 with the scope of Reynolds numbers from 6000 to 30000. The findings presented that the heat transfer enhancement rate for helical wire with a diameter of 3 mm at the pitch to wire diameter 17 was 9%, 14%, 31%, and 267% compared to other techniques like twisted tape, bulged tube, twisted tape, and smooth tube respectively. Additionally, the helical wire produced a greater friction factor than other types. In other experimental investigation of Naphon and Sriromruln [61], they studied characteristics of heat transfer and the pressure drop in horizontal dual pipes with and without coiled wire add. The inner and outer diameters of the micro-fin tube were 8.92 mm and 9.52 mm, respectively. A 1-mm-diameter iron wire was bent to create the coiled wire, which has a 7.80 mm coil diameter. The operating fluids on the shell side and the tube side were, respectively, cold and hot water. The test runs were conducted at mass flow rates for hot and cold water, which ranged from 0.04 to 0.08 kg/s and 0.01 to 0.07 kg/s, respectively. The temperatures of the hot and cold water at the intake were 40°C and 45°C, respectively, and ranged from 15°C to 20°C. Comparisons were made between the outcomes of the flat and micro-fin tubes and the micro-fin tube with coiled wire insert. Once more, The characteristics of heat transmission and pressure loss in horizontal dual pipes with helical ribs were conveyed by Naphon et al. [62]. Nine test sections were studied, and each had a distinct characteristic parameter for the tube diameter to helical rib height ratio of 0.12, 0.15, and 0.19, and for the helical rib pitch to diameter ratio of 1.05, 0.78, and

0.63. Cold and hot water were used as working fluids on the shell side and the tube side, respectively. During the testing, the mass flow rates for hot and cold water changed from 0.01 to 0.1 kg/s and 0.01 to 0.1 kg/s, respectively. The input cold and hot water had temperatures between 15°C and 20°C and 40°C and 50°C, respectively. The outcomes from tubes with helical ribs were contrasted with those from tubes without helical ribs. It was discovered that the helical ribs significantly impacted the increases in pressure drop and heat transfer. The friction features and heat transfer in turbulent flow in a circular tube with a crimped surface and constant heat flux that has a helical tape add were described by Eiamsa-Ard and Promvonge [63] based on experimental data. Heat transfer development was anticipated in the experiment due to the whirling flow generated by the helical tape and the flow turbulence along the tube wall caused by the wavy surface. The Reynolds numbers at the tube inlet, which varied from 3000 to 9200, were the basis for the examinations. The outcomes demonstrated that compared to the plain tube, the heat transfer rate from the wavy surface and helical tape add was much greater. It was also discovered that the tubes with wavy surfaces alone had Nusselt number and friction factor of 3.0 and 50 times above the basic tube, respectively, whilst the tubes with both helical tape and wavy surfaces together had Nusselt number and friction factor of 4.2 and around 110 times. Greater heat transfer rates and friction factors—roughly 57% and 125%, respectively—were achieved using the helical tape in conjunction with the wavy-surfaced tube. Gunes et al. [64] empirically considered the heat transfer and pressure drop of a tube including coiled wire adds in the turbulent flow region ($4105 \leq Re \leq 26\,400$). The wire thickness of 6 mm with three-pitch ratios (1, 2, and 3) and two different distances (1 mm and 2 mm) for the coiled wire was examined in details. The results stated that a obviously rise in the rate of heat transfer and penalty of pressure-drop when adopting inserted coiled wires independently on the tube's wall compared to a smooth tube. The Nusselt number and friction factor improved as the distance and pitch ratio of the adds decreased. At a Reynolds number of 4220, a coiled wire with P/D = 1 and s = 1 mm had the optimal development efficiency of 50%, highlighting the thermal benefits of using these inserts across varying Reynolds numbers. Zachár [65] focused on improving heat transfer rates in helically coiled-tube heat exchangers. They studied the impact of geometrical factors, flow conditions, and thermal boundary conditions on heat transfer efficiency in laminar and transitional flow regimes. They also evaluated the influence of helical corrugation on the external surface of the heat exchanger coils to improvement heat transfer rates on the interior side of the tube wall. The study found that the distribution of temperature within the corrugated tube had a higher degree of uniformity than a smooth tube heat exchanger due to the additional swirling motion generated by the corrugated wall. The presence of helical corrugation mitigated horizontally oriented layers in temperature distribution, improving heat transfer efficiency and mixing due to intensified secondary flow. the impact of coiled wire adds on on heat transfer enhancement and friction factor in a dual-pipe counter-flow heat exchanger configuration was empirically studied by Kumar et al. [66]. The experiment also examined the effect of Reynolds number and coiled wire geometric properties on heat transfer improvement and fanning friction factor. The outcomes presented that coiled wire inserts improved the heat transfer coefficient when engine oil flows through a horizontal tube. Experimental relationships were expressed to predict the improvement in heat transfer, with a reasonable accuracy within a 20% margin. The behaviour of the Fanning friction factor and its influence on the Reynolds number was examined numerically by Muñoz-Esparza and Sanmiguel-Rojas [67] in their study of laminar flow within pipes with wire coil inserts. They compared the analysis of experimental and numerical results across different Reynolds numbers, highlighting the shift from laminar to turbulent flow regimes and the influences of wire coils on flow stability. They also explored the influence of wire coil pitch on the friction factor through parametric analyses. The results revealed linear instability within the Reynolds number range of $500 < Re < 550$, leading to unsteady flow and disruption of the expected periodic axial pattern. This instability affected both the friction factor and flow characteristics. The presence of wire coils also hindered flow axisymmetric properties, highlighting the significant impact of these inserts on flow stability and behavior. Naphon [68] examined the heat transfer and flow features of a horizontal spiral-coil tube using of numerical simulations and experimental approaches. The tube was made by twisting an 8 mm diameter conventional copper tube into a spiral-coil with five rolls. The operating fluids were hot and cold water, and the turbulent flow and heat transfer features were replicated operating the standard k-ε two-equation turbulence typical. They found that the Nusselt number and pressure loss per unit length in the spiral-coil tube were 1.49 and 1.50 times greater, respectively than in a conventional tube. Additionally, Higher mass flow rates of cold water resulted in a increase in the average Nusselt number, which directly influenced the cold water's ability to remove heat. The analysis also presented that the numerical and experimental outcomes agreed well.

Experimental research was achieved by Saeedinia et al. [69] to study the penalty of pressure-drop and the rate of heat transfer of CuO-based oil nanofluid laminar flow within a flat tube with various wire coil additions while keeping a fixed heat flux. The nanofluid was dispersed CuO nanoparticles in base oil and stabilizing it using an ultrasonic apparatus, with particle volume fraction varying from 0.07% to 0.3%. The effects of Reynolds number, coil pitch, wire diameter, the concentration of nanofluid particles, and heat flux on hydrolic-thermal performance were assessed. The findings showed that the combination of coil wires boosted the rate of heat transfer and pressure drop penalty using a specific concentration of nanoparticles. The results also revealed that the characteristics of heat transfer and pressure drop of CuO/based oil displayed a 45% rise in the coefficient of heat transfer and a 63% rise in the penalty of pressure drop at the maximum value of examined Reynolds number within a pipe fitted with coiled wires with the greatest wire diameter. The study successfully also predicted the Nusselt number and friction factor of nanofluid flow within tubes fitted with coiled wires, anticipating the results with an error margin of ±20%. In related research, Pongsoi et al. [70] evaluated the effect of various fin pitches on the thermal conductivity of wavy spiral fin-and-tube heat exchangers, finding that a fin pitch of 4.2 mm provided optimal heat transfer efficiency with minimal pressure drop losses for larger fin pitches. Additionally, the characteristics of frost creation in a spirally-coiled circular fin-tube heat exchanger in comparison with a flat plate finned tube heat exchanger were explored by Lee et al. [71]. The frost thickness and the growth rate of frost in spirally-coiled circular fin-tube heat exchangers were examined, considering some related variables such as, relative humidity, airflow rate, inlet air temperature, and fin pitch. The thickness of frost and the growth rate of frost within the spirally-coiled circular fin-tube heat exchanger were mainly impacted by these tested parameters such as, relative humidity, inlet air temperature, and airflow rate. Relative humidity was considered the most significant impact on frost improvement. Moreover, A predictive experimental relationship was expressed to determin frost thickness within the heat exchanger with considering some significant factors such as, Reynolds number, Fourier number, humidity ratio, and dimensionless temperature. However, the relationship showed disagreements of 4.32% and 3.96% in mean and average deviations , respectively, compared to the actual data measured. Once more, Pongsoi et al. [72] examined the impact of fin pitch on the air-side heat transfer efficiency and frictional properties of L-footed spiral fin-and-tube heat exchangers under high Reynolds numbers changing from 4000 to 15000. The examination absorbed on heat transfer rates, fin effectiveness, heat exchanger execution, air-side heat transfer coefficient, pressure loss, and frictional properties of the heat exchangers. The investigate attained that the air-side heat transfer coefficient and Colburn factor remained unchanged by fin pitch, but it did influence the average heat transfer rate, pressure loss, and friction factor. They also found minor discrepancies in the energy equilibrium between air and water within the L-footed spiral fin-and-tube heat exchangers, with relative errors diminishing below 5%. Additionally, they determined the varieties for fin efficiency to be between 0.87 and 0.94, and for heat exchanger effectiveness to be between 0.14 and 0.36. Deshpande and Sali [73] experimentally calculated the efficiency of heat transfer in a Spiral Tube Heat Exchanger (STHE). The STHE, containing of copper coils arranged in a spiral shape, was created to increase heat transfer effectiveness. The heat exchanger was worked by a water pump, using three spiral coils in a specific design. They presented that the STHE effective heat transfer due to its close dimensions and great thermal transfer efficiency. To ensure the system's stability, the inlet temperatures and flow rates of hot and cold water were carefully controlled. Kiatpachai et al. [74] explored how different fin pitches affected the air-side efficiency of serrated welded spiral fin-and-tube heat exchangers, particularly those with a Z-shaped flow formation and two rows of tubes. They examined fin pitches of 3.6 mm, 4.2 mm, and 6.2 mm, noting that these variations had a significant impact on both the heat transfer coefficient and the friction factor. The study revealed that reducing the fin pitch led to a notable increase in pressure loss, which in turn affected the overall performance of the heat exchangers.

Similarly, Vahidifar and Kahrom [75] investigated the characteristics of hydrolic-thermal performance in a horizontal dual-pipe heat exchanger equipped with wire coil and rings. The influences of coil pitch and wire configuration on heat transfer enhancement, especially in laminar flow regime, were tested. Results indicated wire coils were more efficient than rings in relations of heat transfer efficiency and frictional effects. Rings disrupted the boundary layer, causing increased flow turbulence and heat transfer compared to wire coils. Wire coils and rings had greater heat transfer rates and friction factors than flat tubes. Wire coils also induced swirl flow, boosting heat transfer, while rings promoted turbulence and roughness, enhancing heat transfer efficiency. Naphon [76] examined the heat transfer and flow features of nanofluids in horizontally spiralled tubes. A spiral coil was created by transforming a traditional copper tube into a spiral coil with varying curvature ratios (0.035, 0.043, and 0.06). Factors like curvature, nanofluid concentration, and hot water temperature were considered in heat transfer features and pressure drop analysis. The Nusselt number augmented by 21.29%, 29.02%, and 34.07% for volume concentrations of 0.01%, 0.025%, and 0.05%, respectively, compared to water as the operational fluid. The friction factor of nanofluids as the operational fluid slightly rises contrasted to water as the operating fluid. The flow resistance characteristics of a six-start spirally crimped tube were explored by Jin et al. [77], examining the influences of geometrical factors on the tube's flow resistance, such as pitch, corrugation depth, fluid features, and Reynolds number. The heat transfer performance of the six-start spirally crimped tube was found to be better than that of the circular and four-start spirally corrugated tubes, corresponding to the outcomes. Moreover, An increase in pitch reduced pressure drop and resistance coefficient, while excessive corrugation depth increased resistance. Fluid properties had no significant impact on flow resistance, with the ratio of resistance coefficients remaining consistent across various working media. Hosseini et al. [78] inspected the effects of incorporating turbulators, such as twisted tape and wire coil, within a circular tube heat exchanger. The study found that incorporating turbulators like twisted tape and wire coil into a circular tube heat exchanger can increase the flow rate by 2% to 14%, respectively. Furthermore, the concurrent integration of twisted tape and wire coil at a mass rate of 1 lit/s of saline water optimized the efficiency of the system, resulting a productivity boost of up to 9.7%. Again, Reddy et al. [79] performed a search on fluid flow and heat transfer features in a tube heat exchanger utilizing a helically coiled tube at various fluid flow rates. They generated a model of the heat exchanger in PRO-E 5.0, generated a mesh in ICEM-CFD, and performed a CFD analysis in Fluent 14.0. The study found that incorporating semi-circular baffles in the helical tube improved heat transfer coefficients by nearly 10%. Additionally, increasing cold-water flow rate while maintaining a constant rate of hot-water flow rate increased the Reynolds number, enhancing the Nusselt number. Khaligh et al. [80] examined heat transfer in a heat exchange apparatus using spirally-coiled twisted channels with nanofluid. The study examined the efficiency of heat exchange apparatus using nanofluid within spirally-coiled twisted ducts using water and Cu/water as operating fluids. The efficiency of helical tubes was significantly enhanced by optimizing twist-pitch and coil-pitch factors, achieving peak performance values of 1.39 for water and 1.88 for nanofluid. Researchers further improved thermal efficiency by incorporating turbulators, such as helical wires. In a study by Youssef et al. [81], a cylindrical energy storage tank utilizing solar assistance with phase change material (PCM) was systematically investigated by focusing on some geometrical and operational parameters including, tank structure, PCM type, fluid temperature, and flow rate. The study suggested some passive techniques to enhance heat transfer like incorporating fins and adding high thermal conductivity particles to reduce PCM melting time. Further, the design of tested heat exchanger with PCMs aimed to effectively harness solar or ambient energy for an indirect solar-assisted heat pump system was evaluated. The results stated that the fins significantly shortened the PCM melting duration, while a PCM heat exchanger equipped with spiral-wired tubes enhanced both heat transfer effectiveness and storage capacity. The turbulent flow features and heat transfer uses of a twisted dual-pipe heat exchanger with four distinct lobed cross sections was examined by Omidi et al. [82]. They modified the geometrical parts of both inner and outer tubes of the dual-pipe heat exchangers and estimated their performance based on heat transfer rates and pressure losses. The study obtained that the number of lobes in the tubes affected the results. A higher lobe count led to reduced heat transfer and pressure drop, as long as one tube remained smooth. The study found that a 3-lobed cross-section for the inner and outer tubes improved performance evaluation criterion by over 200%. However, under certain conditions, such as using a lobe number of 6 for the inner tube, the performance evaluation criterion could drop to 0.8. Abdelmagied [83] numerically considered the thermal performance criteria of Al_2O_3 nanofluid in double spirally coiled tubes to develop heat transfer efficiency and energy conservation. The analysis focused on analyzing convection heat transfer, frictional losses, Nusselt number, heat transfer coefficient, and heat transfer per unit pumping power within a double spirally coiled tube heat exchanger. They revealed that increasing the concentration of Al_2O_3 nanofluid led to a marginal increase in the Nusselt number contrasted to the essential fluid at an equivalent Reynolds number. At a Reynolds number of 10000, the Nusselt number for Al_2O_3 nanofluid with a 2% concentration was 29% better than water. The heat transfer coefficient due to convection for Al_2O_3 nanofluid concentrations of 2%, 1%, and 0.5% also exceeded that of water at the similar Reynolds number, resulting in improvements of 41.17%, 18.82%, and 11.76% for the inner tube side and 30.6%, 15.1%, and 7.5% for the annulus side. Computational models were used by Nadila et al. [84] to verify the increased heat transport within a tubular structure with spiral corrugation. The active, passive, and compound methods was compared, with a preference for the passive method due to its capability to rise heat transfer without external power inputs. They used several mesh dimensions and the grid convergence index methodology to diminish mathematical formulation discrepancies for spiral corrugated tubes. The analysis found that increasing heat transfer in spiral ribbed tubes requires decreasing mathematical inaccuracies. It also highlighted the effectiveness of passive techniques for improving heat transfer, such as spiral corrugated tubes, which rise heat transfer rates without external energy inputs. Ferraris and Marcel [85] analysed the frictional pressure drop in helical channels for both single-phase and two-phase flow, focusing on boiling water flow within helical tubes. They created prognostic tools to estimate pressure drop in helical tubes, pointing to provide reliable relations for curved tubes in one-pass steam generators. The two associations applied to both laminar and turbulent states presented optimal agreement with experimental data for single-phase flow within helical channels. These correlations discovered a mean deviation of 3.75% for the laminar state and 2.11% for the turbulent state,demonstrating their precision in forecasting pressure loss. A new prognostic mechanism, the FEMA correlation, showed an average discrepancy of 7.4% compared to experimental data. Tian et al. [86] studied an analysis of the fluid dynamics and thermal conduction properties within a spiral double-pipe heat exchanger. The researchers used computational simulations to explore how various factors influence heat transfer efficiency, particularly in spiral dual-pipe heat exchangers compared to conventional double-pipe heat exchangers. The study focused on the different types and concentrations of nanoparticles affecting on the thermal conductivity. Their findings indicated that rising the volumetric density of nanoparticles and reducing their size significantly improved the rate of heat transfer. Interestingly, the type of nanoparticle had only a slight effect on heat transfer at Reynolds numbers below 16000, but at higher Reynolds numbers, the pressure-drop penalty became more pronounced with changes in nanoparticle volume fractions.

Keawkamrop et al. [87] investigated the effect of crimped coiled fin-and-tube on the performance of heat exchangers with small tube diameters under the range of Reynolds number between 1500 and 6400. They examined how variations in fin pitches and fin outer diameters affected on the characteristics of heat transfer and friction factors. The results revealed that the fin pitch and outer diameter had a slight influence on the Nusselt number and Colburn j-factor, also they significantly influenced on the friction factor. The influence of twisting step-pitch, three-bladed spiral tube-triple turbinate tube, and elliptical spiral tube-oval turbinate tube-elliptical helical tube on the hydrothermal performance of tube was examined by Talebi and Lalgani [88]. The results observed that the effect of changing geometrical properties such as, the pitch steps and tube diameters on the hydrothermal performance. Further, the findings demonstrated that the spirally corrugated tube with eight starts had greater thermal efficiency than other tube configurations. The results also found that maintaining consistent pitch steps within the spiral tube was more effective than varying them. The SST k-ω model provided accurate predictions of the heat transfer and friction factors in a triple spiral tube with a uniform torsion step. Chompookham et al. [89] examined the hydrothermal performance of a tubular heat exchanger with an advanced serrated wire coil (SWC) insertion. The use of diverse SWC inserts with variable coil diameters and pitch lengths to inspect the properties of turbulent airflow and convection heat transfer. The results revealed that the SWC inserts boosted the penalty of pressure drop and convective heat transfer. The Nusselt number and friction factor were significantly influenced by the pitch length and the coil diameter. The addition of SWC inserts resulted in advancements in the Nusselt number and friction factor by 1.75-2.46 and 3.31-8.16 times, respectively, when compared to standard smooth tubes. Kapse et al. [90] empirically studied the thermo-hydraulic efficiency of a coiled wire passive insert within a circular copper tube test section for internal turbulent flow. They examined the impact of coiled wire adds on heat transfer rates and pressure drop in cold water, showing that spiralled wires create vortices that rise heat transfer. The research estimated Nusselt numbers, friction factors, and thermal enhancements to assess their effectiveness in heat transfer improvement applications. They recognized that tubes with coiled wire adds presented a notable enhancement in heat transfer, with Nusselt numbers ranging from 98.83 to 269.7, compared to 63.7 to 194, for smooth tubes. This increase was particularly noticeable at greater Reynolds numbers, demonstrating that the heat transfer enhancement intensifies with Reynolds numbers. Additionally, the friction factor decreased from 0.0528 to 0.0349 as Reynolds numbers increased, indicating reduced pressure drop within the experimental section.

4. Conclusions

In this review paper, strenuous efforts have been achieved to survey the recent published articles in the scope of heat transfer improvement using certain passive methods. A comprehensive research has been achieved to estimate the performance evaluation criterion for two passive inserted promoters: twisted tape tubes and wire coil tubes. Based upon the investigation, the following summarized conclusions are drawn:

Although the application of heat transfer augmentation procedures frequently results in superior heat transfer, there is a trade-off between higher pumping power and a greater pressure-drop penalty. Further, heat transfer augmentation depends upon working flow regimes (laminar, transitional, and turbulent). Furthermore the application of passive augmentation techniques, such as wire coil tubes and twisted tape tubes, considerably alters the flow pattern and aids in the improvement of heat transfer. Where, comprehending the behavior of fluid flow is crucial and contributes to the development of heat transfer.

Inserted twisted tapes may effectively mix and flip the direction of main flow and encourage the creation of secondary flows. As a result, they work superior in a laminar flow than any other passive approach. Performance of twisted tape is also influenced by fluid characteristics like Prandtl number. When compared to other passive approaches like wire coil, twisted tape will not perform well thermohydraulically if the Prandtl value is large, about $Pr > 30$.

In the case of turbulent flow, the twisted tape promoters are efficient up to a certain Reynolds number range, but not beyond it. Thus, twisted tapes are less effective in turbulent flow than wire coils because they obstruct the flow, which results in a significant pressure reduction. The thermohydraulic performance of twisted tapes is lower to that of wire coils under turbulent flow regime. On the other hand, The wire coil promoters work more efficiently in turbulent flow than in laminar flow. In turbulent flow regime, wire coils perform better thermohydraulically than twisted tapes.

The Prandtl number has a considerable impact on the thermal performance of wire coils. The wire coils perform well if the Prandtl number is large because it indicates that the thermal boundary layer is thinner than the hydrodynamic boundary layer and that the wire coils may readily break through it. As a result, there is a significant pressure increase and heat transfer.

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