

Review Research

A COMPREHENSIVE REVIEW STUDY ON HEAT TRANSFER IMPROVEMENT TECHNIQUES WITHIN TWISTED TUBES

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Abstract: Heat transfer equipment has been used in many different domestic and industrial applications. There has been a concentrated effort to create a heat exchanger design that will reduce energy requirements while saving materials and other costs. Increasing the effective heat transfer surface area or creating turbulence are two common ways to improve heat transfer and hence lower thermal resistance. The thermal Performance Factor is the ratio of the difference in heat transfer rate to the difference in friction factor and serves as a metric to assess the efficiency of heat transfer enhancement technologies. Different types of twisted tubes are used in many heat transfer improvement devices. geometrical parameters of the twisted tube encompassing the aspect ratio, twist ratio, twist direction, twist length, etc. impact the heat transfer. For Instance, oval pipes with unequal twist pitches have a thermal performance factor (1.75) and equal twist pitches have a thermal performance factor (1.98). furthermore, the thermal performance factor of the twisted tube with oval dimples is equal to 1.19 compared with the twisted tube without dimples. The thermal performance factor of the twisted tube with oval dimples is equal to 1.38 compared with the straight tube, with another improvement to the twisted tube that improves the heat transfer properties by disrupting the thermal boundary layer and destabilizing it. This paper presents a comprehensive investigation of passive heat transfer devices (twisted tubes) and their relative merits in a myriad of commercial applications.

Keywords: Heat exchanger; passive method; swirl flow; nano-fluid

1. Introduction

Most methods of improving heat transfer work by either increasing the effective heat transfer surface area or creating turbulence in the fluid moving through the device, both of which serve to lower thermal resistance[1]. While twisted tubes are utilized to generate turbulence[2], rough surfaces or extended surfaces are employed to increase the effective surface area. Typically, these changes are accompanied by an increase in pumping capacity, which can result in increased costs. Thermal Performance Factor (TPF) is the ratio of the relative effect of change in heat transfer rate to change in friction factor and can be used to assess the efficiency of a heat transfer improvement technology. as following equation. It is illustrated by the next equation;

$$TPF = \frac{Nu/Nu_o}{\sqrt[3]{f/f_o}} \quad (1)$$

where Nusselt number (Nu) and friction factor (f) are given in the following equation;

$$Nu = \frac{hD}{K} \quad (2)$$

$$f = \frac{2 \Delta p D_h}{\rho u^2 L} \quad (3)$$

This article, the purpose is to summarize the findings from many researchers who have

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studied passive heat transfer augmentation strategies by using twisted tubes equipped with their thermal Performance Factor and other important characteristics.

2. Passive Methods

Passive heat transfer enhancement techniques don't need any external power[3-4]; instead, modify the geometry of the working surface (using things like twisted tubes) to enhance the heat transfer coefficient, and in turn, significantly decrease the size of the heat exchangers. There have been a lot of passive methods used extensively in many studies, such as vortex flow devices[5-6], Swirling fluids to increase heat transfer is a rapidly developing field of study. a twisted tube is classified as a swirl-flow device, a passive approach that employs a certain shape. it causes a vortex effect in the tube's side flow and tube shell flow [7-8], which improves the heat transfer coefficient, twisted tubes play a significant role in minimizing heat exchanger size[9-15].

2.1. Twisted Elliptical Tubes

This type of twisted elliptical tube (and oval) has been the topic of many numerical, and experimental studies. the first research based on numerical analysis was prepared by Luo et al.[16] numerically examined The heat transfer between the straight outer tube and the twisted inner tube of an annular, as depicted in Fig.1. and the study is compared with an annular tube made from two straight tubes. The results show that fluid mixing in the annulus is enhanced by the inner oval twisted tube. Nu and f rise by 35% and 13% across different aspect ratios, and by 26% and 18% between different twist ratios, respectively, as the aspect ratio and twist ratio are decreased. The largest Nusselt number Nu of the twisted tube is 116% larger than that of the inner straight tube while the friction factor f is only 46% larger, and the largest thermal performance

factor (JF) = 1.9 is obtained for aspect ratio 0.4 and twist ratio 10 at $Re = 3000$, which is the largest Re in the laminar regime.

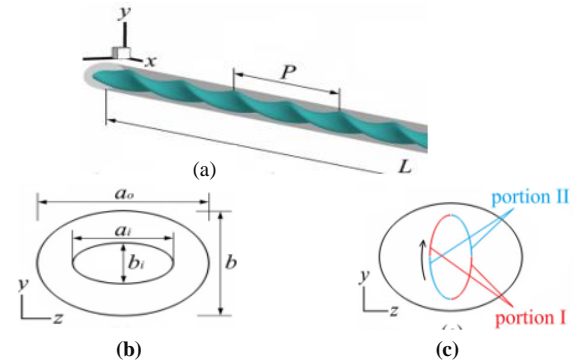


Figure 1. Shown schematically for (a) the annulus inner twisted oval tube (b) the cross-section of the oval tube (c) the direction of the inner twisted oval tube [16].

Luo and Song[17] Displayed the thermohydraulic performance of a twisted annulus composed of two oval tubes twisted in opposite directions for the heat exchanger is presented numerically. The heat transmission is considerably improved when a twist ring is employed between two twisted oval tubes with the same twist pitch in opposing directions. Nu and f are 157% and 118% bigger in twisted annuli than in straight annuli, respectively. Moreover, 1.98 is the highest thermal performance factor.

Luo et al.[18] presented a numerical study of the thermal transfer and fluid flow properties in a heat exchanger with two oval twisted pipes that twist together at different twist pitches. The results demonstrate that when the twist pitch ratio increases, the heat transmission first increases but thereafter decreases. The largest percentages of twist pitch ratio variation come from the Nu and f with 71.4% and 19.0%. when the twist pitch ratio is 1.5, the heat transfer increase is maximum. As compared to a simple straight circular pipe, the Nusselt number (Nu) is improved by 97.0% while the friction factor increases by just 43.7%. The best twist pitch ratio is 1.5, and compared to a simple circular pipe, the

TPF is 1.75 times higher straight circular pipe. Yu et al.[19] The thermal-hydraulic performance of a twisted oval tube made up of three wire coils with various cross sections (circular, equilateral, and square) is analyzed numerically, when a twisted oval tube with a wire coil was used, the Nusselt number increased by 45.92% and the friction coefficient increased by 674.86%. Also, as compared to the twisted oval tube without any additions, it improves heat transfer and reduces pump use. As a whole, the average PEC ratios for wire coils with circular, square, and equilateral triangular cross-sections are (0.7311, 0.7773, and 0.7697).

Li et al.,[20] investigated numerically the air-side heat transfer and pressure drop performance of twisted oval tube bundles with in-line configuration in cross flow. examined the effects of five geometric parameters on air-side heat transfer and pressure drop performance (the ratio of the outer major axis to the outer minor axis (A/B), twist pitch length (S), transverse tube pitch (St), longitudinal tube pitch (Sl), and number of longitudinal tube rows (Z)). The velocity and temperature ranges are repeated repeatedly along the length of the twisted oval in each half-twist pitch length, demonstrating that the oval is an independent streamer. The Nusselt and Euler number increases as the Reynolds number and the primary diameter to secondary diameter ratio increase. Nu and Eu both increase as the ratio of the outer major axis to the outer minor axis and Re increases, whereas Nu and Eu both decrease when the twist pitch length lowers.

Li et al.[21] Investigated numerically to examine the influence of TOT on the enhancement of shell-side heat transfer. Secondary flow and spiral flow can be accomplished due to the rotational movements generated by the twisting of the oval tubes. This means that heat transfer from the shell side of TOT in DTHE is increased,

also, and the boundary layer is broken. The overall heat transfer performance of the shell can be enhanced by reducing the twist pitch length and raising the aspect ratio of the inner tube simultaneously. The inner tube aspect ratio and twist pitch length of Case (10) are the highest and lowest, respectively. provides the best overall heat transmission performance. Heat transfer efficiency can be increased by 24.0% to 39.0% when twisted oval tubes are used as the inner tubes.

Gu et al.[22] studied numerically to enhance heat transmission between adjacent tubes. Eleven different twisted elliptical tube heat exchangers were constructed and simulated, each with two tube configurations, but their twisted elliptical tubes have different aspect ratios and twist pitches. Five coupling vortex systems, five parallel vortex systems, and one smooth round-tube scheme (R10.8) were among the designs considered. The Nusselt number increased by 132.8 percent as a result of an increase in Reynolds number, aspect ratios, and a decrease in twisted pitch. In addition, increases in turbulence and secondary flow are seen with an increase in both aspect ratio and twisted pitch of a twisted elliptical tube, as well as with concurrent flow and an irregular channel in coupling vortex systems. which in turn increases the maximum and mean Nusselt numbers by 9.5 and 7.8 percent, respectively. A 6.4% and 4.9% increase in maximum and mean Nu f 1/3 over the parallel-vortex system P12.3S50, respectively.

Gu et al.[23] The numerical study of the twisted elliptical tube was carried out using a new coupling-vortex chessboard tube arrangement (TETHXs-CV). According to the data, there is a 12.8% rise in the number of Nusselts and a 9.9% increase in the number of Nu f 1/ 3 in all double vortex plots. To maximize efficiency, the twist pitch and aspect ratio should be as close to one as possible. Alternatively, the Nusselt number and

the coefficient of friction both rise as the twist pitch and aspect ratio are reduced.

Tan et al.[24] investigated numerically the heat transfer and fluid flow characteristics in a shell-side twisted oval tube heat exchanger. and were analyzed to determine geometric parameters like aspect ratio (a/b) and twisted pitch length. found that as P and A/B are increased, also increase the Nusselt number and the friction factor. This is noted that a higher (A/B) ratio leads to improved overall heat transfer performance on the shell side. The heat transfer and pressure drop discrepancies between the numerical results and the experimental values are 4.01% and 3.98%, respectively. Increasing A/B results in a greater spiral flow, while increasing P decreases it. It is shown that when A/B increases, the amplitude of the circulation flow increases while it reduces as P increases.

Cheng et al.[25] Investigated the heat transfer and flow properties of water flowing within a twisted oval tube (TOT) at Reynolds numbers between 50 and 2000. Using three-dimensional numerical research, examine how changing certain geometric parameters affects the operation of a twisted oval tube in the condition of constant wall temperature. Changing from laminar to turbulent flow in a twisted oval tube, as shown by the Re at 500. outcomes show that higher Reynolds numbers result in more pressure and heat transfer. At a flattening factor of 2.0, a twisted pitch of 0.33, and a Reynolds number of 350, an oval tube's performance is 1.7. As the oval tubes were flattened, their efficiency increased, but as the pitch ratio of their twists increased, it dropped.

Tan et al.[26] the researchers used both numerical and experimental techniques to examine the heat transfer coefficient and pressure drop of a twisted oval pipe heat exchanger. The experimental results demonstrate

that, in comparison to the smooth circular tube, the heat transfer process can be improved, while at the expense of an increment in pressure drop. also, the results of the numerical analysis demonstrate the presence of secondary flow in the twisted oval tubes and show that the heat transfer coefficient and friction factor rise with increasing a/b but decrease with increasing P . Due to this secondary flow, the velocities and temperatures in the oval twists are changed. In this way, the efficiency of convective heat transfer is improved by decreasing the synergy angle between the velocity vector and the temperature gradient.

Zhang et al.[27] studied experimentally the heat transmission properties for steam condensation on horizontal twisted elliptical tubes (TETs) with varying structural properties. At a steam saturation temperature of about 100.5 C, and with the wall subcooled to a temperature range of about 2 C to 14 C, the experiments were conducted. Condensation is found to decrease the heat transfer coefficient in experiments, and increasing the sub-cooling in the wall for all pipes has this effect. When the ellipticity is 0.86, the condensation heat transfer coefficient can reach its maximum value of 34%. A smooth circular tube doesn't allow for as many condensations as an elliptical one with an ellipticity of 0.77.

Ebrahimi et al.[28] A numerical study of the thermal and fluid patterns within twisted oval tubes (TOTs) with walls maintained at a constant temperature. water's thermo-physical properties change depending on temperature, Values of Reynolds number between 500 and 1100. The thermal-hydraulic performance of twisted oval tubes is evaluated, and the outcomes are discussed in terms of the field synergy principle and entropy formation. Although TOTs are superior in terms of heat transfer, their increased

efficiency results in a more significant pressure drop. Increased convective heat transfer is assumed to be the direct effect of the secondary flow induced by the tube-wall twist, leading to better heat transfer performance. Better heat transfer for TOTs has also been demonstrated with lower irreversibility and more synergy among velocity and temperature leading to enhanced heat transfer for TOTs.

BHATTACHARYYA et al.[29] studied numerically and experimentally the fluid flow and heat transfer through a heat exchanger using a circular twisted tube. The experiments were carried out at three various lengths and pitch ratios and for different Reynolds numbers (from 100 to 50,000). As the Nusselt number increases by around 50% on average compared to the smooth tube, the twisted geometry provides the largest improvement in heat transfer for small pitch ratios and large length ratios. The friction factor is minimized when the length-to-pitch ratio and the pitch-to-length ratio are reduced and are enhanced when the Reynolds number is raised. The results show that an increase in heat transfer rate can be achieved at a low performance cost by using a length ratio that is larger than the pitch ratio.

Abdul Razzaq et al.[30] presented numerically the thermal performance of a double-pipe heat exchanger formed twisted tubes. The effects of changing the twist ratio (5, 10, 15) and the Reynolds number (from $Re=5,000$ to $30,000$) were studied. According to the findings, the optimal performance of the heat exchanger occurs at a flow rate of 0.4962 and a value of $Tr=5$. On top of that, managed to boost productivity by 13% generally. In the case where $Tr=5$ and 0.082 is being moved. According to the numerical results, a twist ratio of 5 provides the best thermal-hydraulic performance.

Ali et al.[31] An experimental investigation about how inner pipe twist affects the overall performance of a double-pipe heat exchanger. studied the effects in both parallel and counterflow directions. Elliptical plane pipes and twisted pipes replace the inner pipe. The Reynolds number (Re) for all of the tests is somewhere between 5000 and 26,000. The results demonstrate that assuming all pipes are twisted enhances the heat exchanger's overall performance for both flow directions. Compared to the original pipe, the biggest increase in Nusselt number is around 2.2 for counter-flow and 1.8 for parallel flow. At $Re=26,000$, the highest performance boosts for the parallel and counter flow are, respectively, 1.63 and 1.90.

Li et al.[32] Numerical simulations were run to examine the flow of air through a set of nested tubes constructed from an elliptically twisted pipe. It was observed that the flow in an elliptical twisted tube is parallel to the tube wall, demonstrating the occurrence of spiral deformation in this geometry. A higher aspect ratio was likewise associated with a rise in both the Nusselt Number and the Euler Number. In general, as Re increases, twist pitch decreases, and as the Nusselt Number decreases, Re increases. Another factor in the improved heat transfer is the generation of annular and spiral flow along the tube wall.

Bhattacharyya et al.[33] heat transfer behavior in an elliptical pipe is studied numerically. The findings showed that an increase in heat transfer with decreased performance may be achieved by decreasing the twist pitch. If Reynold's number increased, better heat transmission. There are significant gains in efficiency between a twist ratio of 0.87 and 1.0.

Prajapati et al.[34] This study evaluates Twisted Tube heat exchangers in terms of design, performance, and economic science, and finds

that they outperform more conventional designs for copper and reactive metals.

2.2. Twisted Non-Circular Tubes

For example (square, triangular, pentagonal, and hexagonal) twisted shapes.

revealed in this study by Cheng et al.[35]that the thermal performance of twisted tubes is significantly affected by the cross-section in laminar flow but is barely affected by the cross-section in turbulent flow. This is because the primary element affecting the heat transfer of twisted tubes in laminar flow is the secondary flow created by the twisted tubes. but in the turbulent flow, When the Reynolds number is raised, the fluid speed rises while the influence of the secondary flow decreases. The velocity of the fluid is the main factor influenced by thermal performance in turbulent flow.

Mahato et al.[36] examined the Gnielinski and Blasius correlations and compared them with thermal performance for numerical results for water flowing inside a twisted square duct. Experiments were conducted on ducts with the fully developed laminar flow with the following boundary conditions: water at a constant wall temperature, twist ratios of 16.5, 11.5, and 7.5, Reynolds numbers of 100 - 6000, and Prandtl numbers of 8 and 10. According to the numerical outcomes, the Nusselt number is higher than the correlation values, and the friction factor is lower, in the twisted square duct. The average Nusselt number was found to be 25.56 percent, 33.21 percent, and 37.73 percent higher than predicted for twist ratios of 16.5, 11.5, and 7.5, respectively. Heat transfer coefficients for the square twisted duct improved with a decrease in the twist ratio and a rise in the Prandtl number. Bhadouriya et al.[37] heat transfer and flow properties were examined by conducting an experimental and numerical analysis of airflow within an annulus created from an interior

twisted square duct and an exterior circular pipe, as shown in Fig.2. The annulus's inner wall was maintained at a constant temperature while the outside pipe was insulated. Experiments were conducted using twist ratios of 10.6 and 15. Numbers of the Re varied from about 600 to 60000. At a Reynolds number of 3000, the flow changes from laminar to turbulent. By changing the pipe's outside diameter, researchers were able to examine how the annulus variable affected the friction factor as well as heat transfer. For lower annulus parameters, larger values of Nu and friction factor were located at a given twist ratio. The results are significant because they can be used to develop a compact twin-pipe heat exchanger.



Figure 2. Photo for twisted square duct[37].

Bhadouriya et al.[38] heat transfer and airflow properties within a twisted square duct were examined by way of numerical simulation and experimental. Air with boundary conditions of a constant wall temperature, a twist ratio of (11.5 to 16.5), and a Reynolds number of (600 to 70000) were used for the experiments. It was found that at a $Re = 3000$, the flow behavior will change from laminar to turbulent. The results are significant enhancements in heat transfer and pressure reduction in both laminar and turbulent flow regimes up to a Re of 9500. Heat transfer and pressure drop are improved by 11.5 compared to a straight square duct. For a situation of uniform wall temperature, numerical studies are conducted with twist ratios of 2.5, 5, 10, and 20, and Prandtl values from 0.7 to 20. At a twist ratio of 2.5 and a Reynolds number of 3000, the maximum value is produced. Nusselt

number 20 is the highest value for a given Prandtl number.

Mushatet et al.[39] performed a numerical method for solving the turbulence in the flow field. Heat transfer and flow field analysis use the governing equations of momentum, continuity, and energy. Heat exchangers using twisted triangular tubes, enhanced turbulent heat transfer. The performance of a twisted triangular tube 1 m in length with a hydraulic diameter of 0.03 m was measured across a range of twist ratios (5, 10, 20) and Reynold's numbers (5000 - 25000). According to the outcomes of the analysis, a twisted tube is more efficient in heat transfer than a smooth one. Most of the gains in heat transfer and decrease in friction losses can be attributed to the twisted ratio.

Wang et al.[40] Three twisted square ducts were studied for experimental and numerical analysis (twisted uniform, twisted divergent, and twisted convergent)for the square duct. The experimental and theoretical findings show that the span-wise distribution of the local heat transfer coefficient varies uniquely due to twisting, whereas the axial distribution varies for convergent and divergent geometries. Heat transport is shown to improve with a twisted divergent duct but worsens with a twisted convergent duct.

Pozrikidis [41] investigated the Stokes Flow in a twisted tube for a square cross-section. It demonstrates how the secondary flow develops over the tube cross-section and how the helical corrugations impact the axis flow rate.

Tang et al.[42] Tri-lobed and oval twisted tubes were used to examine turbulent flow and heat transfer. Additionally, various twisted spiral tubes' cross sections, twist pitches, twist directions, and lobe counts were studied for their impacts. Tubes with bigger out-scribed circle

diameters were found to have higher Nusselt number and friction factor values.

RASHED et al.[43] in this study, the water flow and heat transfer in the twisted heat exchanger were analyzed numerically. The results demonstrate that the heat exchanger's outer duct may induce a swirl flow over its entire length. It also resulted in the reassembly of the boundary layer on the inner pipe wall. Additionally, the Nusselt number rose by 20% due to the twist angle, and the friction factor increased due to the decrease in the annular gap of the heat exchanger.

Makarov et al.[44] studied the effect of the helium-xenon gas combination on heat transmission in twisted tubes with a square cross-section. Heat transmission rate and hydraulic resistance were found to be affected by the cross-section form and twist step of the twisted tube.

Soleimani et al.[45] used natural gas as the testing fluid to evaluate on the heat transfer and pressure loss in a heat exchanger. According to their findings, using a twisted tube instead of a straight one can cut the length of a gas coil by as much as 25%.

Dong et al.[46] studied the thermal properties and flow properties of high-viscosity thermal of oil and water in a Ti-alloy helical twisted tube, the heat transfer efficiency of the spiral twisted tube heat exchanger is greatly enhanced for both turbulent flow and laminar flow. The heat exchanger made of spiral twisted tubes proved excellent for laminar flow. Finally, a heat transfer correlation for a spiral twisted tube heat exchanger was obtained with an error of less than 10%. There was a maximum discrepancy of - 25% between the experimental outcomes and the classical correlations for the thermal properties of the helical twisted tube.

2.3. Twisted Tube with Nanofluid

The performance of the heat exchanger was enhanced by employing a hybrid approach with the twisted tube and nanofluids.[47-49].

Mahato et al.[50] Numerical analysis was performed on the friction factor and heat transmission of a nanofluid of Al₂O₃/water inner a twisted square duct (TSD). A steady heat flux is applied to the exterior walls. Using a twisted duct with a square cross-section, a fully developed three-dimensional laminar flow is created inside the flow region for a Reynolds number of 600 to 2000 and a nanoparticle concentration range of 0.5% to 1%. It compared the heat transfer and friction (f) for water/Al₂O₃ flow in a twisted square duct to water flow in a straight square duct. Once the nanoparticle concentration in the base fluid reaches a certain threshold, the concentration begins to decline. By increasing the Prandtl number and reducing the twist ratio, it was discovered that the Nusselt number may be raised. However, with an ever-increasing Reynolds number, the friction factor decreases.

Abdul Razzaq et al.[51] studied the thermal characteristics and turbulent flow numerically with nanofluid (Al₂O₃-Water) in a twisted tube. it used Nanoparticles of (Al₂O₃) with pure water as work fluid. Nanoparticle concentrations in volume were also investigated (0.05, 1%,2.5%, 4%) at a twist ratio of Tr=5. As the nanofluid concentration in a given volume increases, the heat transfer rates increase, and the twisted ratio decreases (Tr). higher performance for the heat exchanger when the twist ratio is decreased. Moreover, the efficiency of the heat exchanger is enhanced when the nanofluid is used at 6%, as its Reynold number achieves a maximum of 30000 at volume concentrations of 4%. Furthermore, when the volume concentration of nanofluids and the Reynold number increase, so does the pressure loss.

Mushatet et al.[52] studied numerically on the heat transfer and fluid flow properties within the elliptical twisted tube at various nanofluid volume concentrations. this analysis was performed for four different concentrations of nanofluids (=0.05, 1%, 2.5%, and 4%) and a range of Reynolds numbers (5000-30000). The findings show an improvement in heat transfer performance between the twisted elliptical tube and the plain tube. The concentration of nanofluid in a given volume has an impact factor on this increase. The pressure decrease is due to the elliptical tube's twist. $\phi = 4\%$ and Tr=5, twisted elliptical tubes show their highest thermal-hydraulic performance.

Shahsavari et al.[53] Investigated the enhancement of the efficiency of a double-pipe heat exchanger (DPHE) by using nanofluid (NF) and twisted tubes. Within the tube, a steady laminar flow of cold Cu O (NF) exists, while hot water flows steadily around the annulus. employ a water-based carboxymethyl cellulose solution with a mass concentration of 0.5% mass percent. Performance metrics are analyzed and compared to those obtained with smooth DPHE, as well as the impacts of Reynold's number, the nanoparticle volume concentrations, and the twist pitch. A greater Re to improves heat transfer and heat exchanger efficiency but increases pressure drop and pumping power, as shown by these findings. Research indicates that the NF outperforms the base fluid in all cases except those where is less than 1.5% and Re is equal to 500. In addition, it was shown that the overall hydrothermal performance of NF varies in a rising-falling pattern following the twist pitch. Thermally, DPHE with a twist has superior performance than DPHE without a twist, with the highest value of 2.671 obtained for $\phi = 3\%$, twist pitch=4 mm, and Re = 2000.

Eltaweel et al.[54] in this study the heat exchanger tube was tested in two different cross-sectional configurations: a standard circular tube and a twisted tube. uses two distinct working fluids distilled water and multiwalled carbon nanotube/water (NF). At 12.8% and 12.5% the twisted tubes improve system performance in distilled water with (MWCNT/water) NF compared to circular tubes, and by 34% for MWCNT with the twisted tubes in comparison to traditional circular tubes with pure water-filled. Khoshvaght-Aliabadi and Arani-Lahtari [55] studied the Al₂O₃/water nanofluid to determine its flow and heat transfer properties in twisted square channels. The concentration of nanofluids ranges from 0% to 4% by volume, and the Reynolds number is from 600 to 1800. The outcomes demonstrate that the thermal-hydraulic performances of the TSCs are significantly impacted by differences in twist pitch. It is also shown that larger concentrations of nanofluid suggest increased values of the friction factor(*f*) and, also the Nusselt number (Nu).

Sun et al.[56] the thermal expansion of a twisted belt installed on the outside of thread pipes was analyzed utilizing a variety of nanofluids as the check fluid, with varied mass fractions. In order to achieve the highest heat transmission and friction factor (*f*), used an improved tube and a (Cu/water) nano-fluid with a mass fraction of 0.05%.

Omidi et al.[57] In this investigation, researchers examine at how incorporating nanoparticles and twisted tubes affects heat transmission and fluid flow. The results show that a twisted tube with an insert improves the Nusselt number (by as much as 43%) and the friction factor (by as much as 2.8 times more than a smooth tube) but has no discernible impact on thermal performance. Both the heat transmission and thermal performance of empty twisted tube and plain tube but has no

discernible impact on thermal performance. Both the heat transmission and thermal performance of empty twisted tubes and plain tubes are improved by the addition of nanoparticles.

Khoshvaght-Aliabadi et al.[58] present and analyze experimentally and numerically a novel sketch of curved ducts called the twisted duct (from type spirally-coiled). According to the data, the best performance index of 1.39 is achieved by the twisted duct (from type spirally-coiled) at $t_p = 0.05$ m and $c_p = 0.025$ m, where the Graetz number is the largest. Moreover, the improvement is more pronounced as the nanoparticle concentration rises. When using the 1.0% nano-fluid in the twisted duct (from type spirally-coiled tube) when ($t_p = 0.05$ and $c_p = 0.025$) meters the performance index may rise to 1.88.

2.4. Twisted Tube with Add Another Influence

Vortex flow devices (swirl) have been proven to improve fluid mixing and consequently convective heat transfer by disrupting the thermal boundary layer close to the walls. However, extra influence within the twisted tube could potentially raise the pressure difference. as a result, investigators have responded by exploring various designs for Influence to reduce pressure drops.

Wang et al.[59] studied The numerically of heat transfer and fluid flow properties inside a twisted tube with oval dimples to improve heat transfer performance, as indicated in Fig.3. found that the longitudinal vortex created behind the dimple significantly improved fluid mixing inside the tube compared to a similar twisted tube without dimples. maximum increases of 26.68% and 19.96% in Nusselt number and friction factor, respectively, for a twisted tube three-start with a dimple, as compared to a twisted tube three-start without dimples, are observed. The thermal efficiency of the tube with oval dimples can be

increased by a factor of up to 1.19 when compared to the three-start twisted tube without dimples. The three-start twisted tube with oval dimples can increase thermal performance by a ratio of up to 1.38 compared to a straight tube.

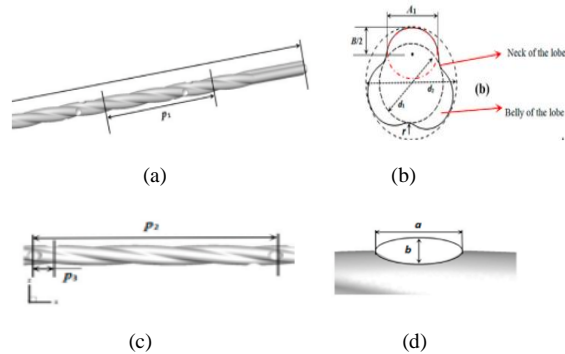


Figure 3. The physical model for (a) a three-start twisted tube with a dimple, (b) a cross-sectional tube, (c) the dimple pitch (p_2) and the twist pitch (p_1), (d) the dimple shape [59].

Alsulaie et al. [60] examined the effect an obstruction on the inner wall of a twisted circular tube would have on its hydraulic and thermal performance. Nusselt number increases when the obstacle elevation to the hydraulic diameter of the tube (OHR) increases, and vice versa, because more air is being swirled around inside the tube. The TPF (thermal performance factor) values registered are more than 1. The optimum value of the thermal performance factor (TPF) is at (OHR = 0.625).

Samruaisin et al. [61] Swirl flow generators, such as twisted tubes or twisted tapes, are used to improve thermal efficiency. Heat transmission, pressure drop, and thermal performance were among the aspects that were experimentally studied in conjunction with twisted tubes and twisted tapes. The efficiency of the merged devices is evaluated in relation to those of a twisted tube and a plain circular pipe. The experimental results show that the Nusselt number (Nu), friction factor (f), thermal performance, and Re are all significantly better for a twisted tube with a twisted tape when

compared to a plain circular pipe or a twisted tube without twisted tape.

Eiamsa-ard et al. [62] It is numerically studied how combining a three-start spirally twisted tube with a triple-channel twisted tape can improve heat transfer. Conclusion: The Outcome Indicates Nusselt values are improved by as much as (1. 23%, 6.7%, 10%, and 17%) in twisted tubes using twisted triple-channel tape inside a belly-to-belly layout compared to twisted tubes without tape.

3. Conclusions

From the current review, it can be deduced that the increase in heat transfer happens in all cases as a result of a decrease in the flow cross-section area, an increase in turbulence intensity, and an increase in tangential flow established by different types of twisted tubes. influence the improvement of heat transfer significantly. in the case of double-twisted tubes twist direction is also an important parameter since the counter-swirl operates better than the co-swirl, some studies have also employed enhancement techniques that combine the twisted tube and dimple have been employed to get better heat transfer performance in laminar and turbulent flows. the results have indicated that the dimple can increase TPF by over one. compared with the twisted tube without a dimple.

In laminar flow, the high influence of the twisted tube cross-section on the heat transfer rate was determined. whereas the shape has a diminished influence in turbulent flow. Since passive methods are inexpensive to implement and need little in the way of ongoing maintenance and easy setup, they have found widespread used in different industries.

the TPF decreases with increase in Reynolds Number. Twisted tube performs well when water

and nanofluid are employed as working fluid due to the larger density of the liquid.

This review includes the studies done by many investigators on the use of twisted tubes to improve heat transfer characteristics in tube heat exchangers however, future studies could concentrate on areas associated with outer tube geometries with other enhancements such as obstacles, fins, etc.

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Abbreviations

a/b	Aspect ratio
D	Diameter
D_h	Hydraulic diameter
f	Friction factor
f_o	Friction factor for straight tube
h	heat transfer coefficient
k	Thermal conductivity
L	Length
NF	Nano-fluid
Nu	Nusselt Number
Nu_o	Nusselt Number for straight tube
ΔP	Pressure drop
P	Pitch
Re	Reynolds numbers
TETs	Twisted elliptical tubes
Tr	Twist ratio
TSD	Twisted square duct
TOTs	Twisted oval tubes
TPF	Thermal performance factor
u	Velocity
ρ	Density
μ	Dynamic viscosity

Conflict of interest

The authors report no conflicts of interest regarding the publication of this manuscript.

Author Contribution Statement

Baraa Mohammed proposed the hypothesis of the paper and researched the literature. Saad Najeeb Shehab reviewed and analyzed the literature. Baraa Mohammed wrote the manuscript.

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