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Research Article

Comparative study for energy saving methods using the turbulator devices and nanofluids of circular tube

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Abstract:

This paper aims to examine different methods that have been used in a heat exchanger tube to improve the rate of heat transfer in order to save energy or material requirement. Several methods can be used to increase heat transfer in heat exchangers, including swirl generation tools in the flow that alter the flow motion, disturbing the boundary layer, resulting in higher heat transfer rate, and combining nanoparticles to form nanofluid to enhance the base fluid's thermophysical properties. The effects of wire coil, twisted tape, and swirl flow generator inserts including their modifications on factors like heat transfer rate and friction factor, a number of tube inserts are reviewed in this paper. Many recent studies have been presented that show the behaviour of nanofluids inside a heat exchanger and the impact of nanoparticles shape, size, concentration and flow rate ofnanofluid on the thermal conductivity, coefficient of heat transfer, thermal resistance, and drop in pressure. The merits and demerits of using inserts and nanofluids as the heat transfer enhancementmethods are detailed for future reference in this area.This paper reviews activities related to that of the utilisation of various tube inserts and nanofluids in order to be comprehended the impact in terms of the flow of fluid and thermal performance factor.

Keywords: *Heat exchanger tube, turbulator, nanofluid, hybrid nanofluids, thermal performance factor*

Re	Reynolds number	l	Characteristic length
Nu	Nusselt number	PR	Pitch ratio
Pr	Prandtl Number	p	Pitch
PEC	Performance Evaluation Criteria	p/d	Twist ratio
TT	Twisted Tape	θ	Angle of twist
η , TPF	Thermal Performance Factor	d/w	Perforation hole diameter ratio
Nu	Nusselt number with using turbulator		
Nu_o	Nusselt number without using turbulator		
f	Friction factor with using turbulator		
f_o	Friction factor without using turbulator		

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Introduction

Energy consumption has increased due to rise inindustrial consumption, urbanization,population growth, so the researchers are involved in developing energy-saving strategies and new energy sources. Heat exchangers are widely used for domestic, industrial, and commercial purposes. Scientists are attempting to make such methods, which improves the heat transfer at the very least conceivable pressure loss[1]. These methods are classified into two types: active methods and passive methods. In an active method, external power is required to be applied on the heated surface or to the fluids, to improve the heat transfer. In long run, the active methods prove to be costlier and need higher maintenance compare to passive methods. Passive heat transfer methods not require external power and rely on altered surfaces and the addition of components (turbulence promoters) to increase heat transfer[2]. Turbulence promoters cause the flow turbulence, which aids in the elimination of the thermal boundary layer and the development of fluid amalgamation, resulting in a high heat transfer rate.

Passive method

The passive method of enhancement in heat transfer involves disrupting the flow of fluid through a change in geometry or the addition of inserts. Turbulence causes the thermal boundary layer to be disordered by altering the flow pattern due to disruption in the flow. These processes, on the other hand, increased the pumping power requirements due to increase in disturbance to the flow by the inserts. Advantage is that this method does not requiring additional external power, so in long run it will be economic and has less maintenance.

Nanofluids become a new heat transfer medium as a result of their development. Base fluids containing suspended nanoparticles of high thermal conductivity materials such as metals, metal oxides, or carbon aretermed as nanofluids[3], outperformed simple fluids in terms of thermal properties. Granqvist et al.[4] reported ultrafine particles with a size of nanometres at first. Nanoparticles became the term for these ultrafine particles later on. Nanofluids are designed using two separate methods [5]. The single-step method is one of them, while the two-venture approach is the other. Choi [6,7] was the one who first introduced nanofluids and discovered that they were a stronger heat transfer medium than normal fluids.As compared to base fluid,Lee et al. [8],Eastman et al. [9],and Yu et al. [10]researched out that adding nano composite materialin the base fluid will lead to enhance the thermal conductivity of the fluid. Brownian motion in nanoparticles as well as a reduction of the thermal boundary layer are two possible factors for improved heat transfer in case of using the nanofluids, according to Ali et al. [11].

The effectiveness of methods used to improve the efficiency of heat exchangers can be determined by using Webb's Performance Evaluation Criteria (PEC) [12], which consider thermal gain and hydraulic losses. The heat exchanger's efficiency can be measured by comparing the Nusselt number and friction factor of the tube with inserts/nanofluids to the tube without inserts/nanofluids. The heat exchanger's PEC or thermal performance factor (TPF) is as follows:

$$\eta = \frac{(\frac{Nu}{Nu_o})}{(\frac{f}{f_o})^{1/3}} \quad (1)$$

Effects of using the enhancement technique

Various heat transfer enhancement methods each have their own set of benefits and drawbacks. They come in a variety of geometrical configurations and construction complexity, and they work in a variety of flow and thermal conditions. This review is categorised as follows based on these criteria.

1.1 Effect of turbulators device on heat transfer

The most encouraging strategies to improve heat floware the use of turbulator devices in the flow. By developing secondary flow as vortices of an established axial flow, turbulator devices decrease the boundary layer thickness. Secondary flow in the periphery of the walls aid in adjusting the velocity profile. Wire coil, helical screw, and twisted tape were used as turbulator instruments, and their detailed reviewed are described as follows:

3.1.1 Twisted tape inserts

Alam T et al. [13] used twisted tapes to improve heat flow in the solar water heater tubes. The impact of twist ratio (3–12) on multiple mass flow rates has been reported. This approach increased the Nusselt number and friction factor over the smooth tube in the ranges of 18-70% and 87-132%, individually. Thianpong C et al. [14]studied the impact of twisted tape in the dimple tube combination in the turbulent region as shown in Fig.1. They studied three distinctive twisted tapes of varying twisted ratiosas well as two special dimple tubes with different dimple pitch ratios (0.7 and 1.0). When it comes to the performance factor, the twisted tape and dimple tube impacts were found to be significantly higher than dimple or twist tape in plain tube working alone. In a heat exchanger tube, Bhuiya et al. [15] studied twisted tapes combining two together in a plain tube termed as double counter twisted tapes (Fig. 2). They focused on four different double-twisted tape combinations of twist ratio ranging from 1.95 to 7.75.When double-counter twisted tape was used instead of smooth tube, the Nusselt number improved by 240% and rise in friction factor by 285%.

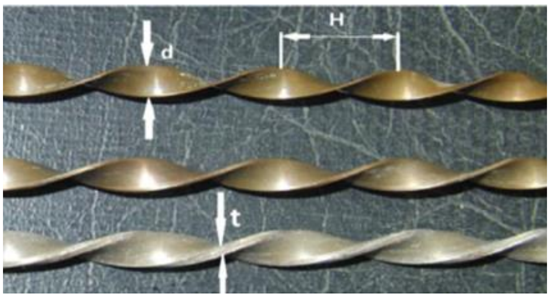


Fig. 2. Twisted tape [15]

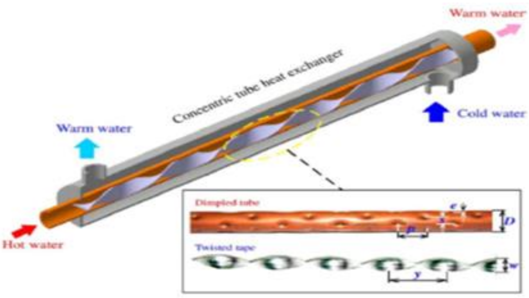


Fig. 1. Twisted tapes inside dimple tube [14]

3.1.2 Twist ratio

Fuskele and sarviya[16] experimentally investigated the impact of twist ratio on the heat transfer rate and friction factor using the twisted tape with continuous cut edges as shown in Fig.3. They used the twisted tape inserts of two twist ratios (3,5) with rectangular cuton the edges. They concluded that when the analysis of twist ratio was considered, it was observed that a lower twist ratio provides a better heat transfer and greater friction factor since the turbulence strength and flow distance achieved by a lower twist ratio was greater as those obtained by a higher twist ratio. For a Reynold number of 4000, the performance ratios for twist ratios 5 and 3 were 1.56 and 1.46, respectively.Patil et al. [17]conducted experiments to better understand how the twist ratio affects heat transfer as shown in Fig.4. They came to the conclusion that as the twist ratio is reduced, heat transfer increases. In addition, using twisted tape in plain tube for laminar flow region will save energy.

3.1.3 Modified twisted tape

Rahimi et al. [18]conducted research to determine the effect of a modified twisted tape insert on heat transfer characteristics. In their research, they used plain, perforated, notched, and jagged type of twisted tapes. The results obtained from experimental research and CFD analysis analysed that

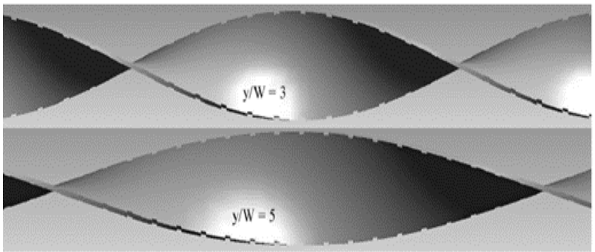


Fig. 3. Continuous rectangular cut twisted tape inserts [16]

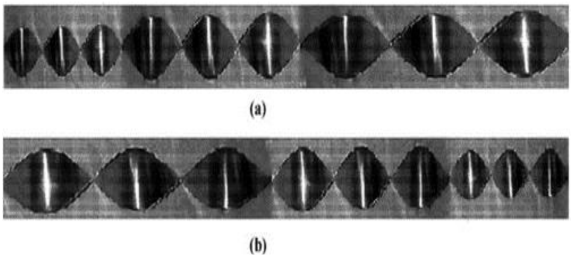


Fig. 4. Twisted tape (a) pitch increasing; (b) pitch decreasing [17]

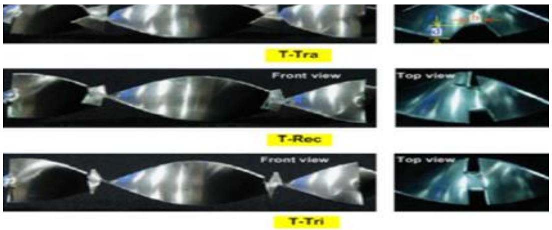


Fig. 5 Twisted tape with trapezoidal wings [20]

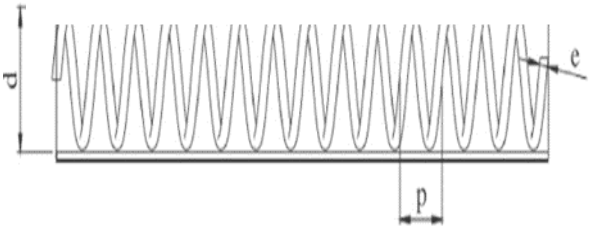


Fig. 6. Coiled wire insert [21]

twisted tape which is jagged has the high TPF which is1.21 since the greater turbulence generated nearto thesurface of tube.Shubanian et al. [19] studied at how three different types of tube inserts improved heat transfer in an air cooler: butterfly, typical, and jagged twisted tape. The Nu/Nu_0 ratio of a butterfly insert is better than that of a classicaland jagged type of twisted tape insert when Re was in the vicinity of 4000-16000. When Re is low, the friction factor is high, and it appears to decrease as Re increases. At a Re of 4000, the highest TPF achieved for classical,jaggedand butterflyinserts were 1.03, 1.23, and 1.62, respectively also twist ratio,Reand inclination angle all affect TPF.Wongcharee et al.[20] analysed the impact of twisted tapes having alternate-axes and trapezoidal wings in the tube as shown in the Fig. 5. These inserts changed the Nusselt number by 2.84 and friction factor the most by 8.02 times, as contrasted to smooth tube.

3.1.4 Coiled wire inserts

San et al. [21] (Fig. 6)examined the impact of coiled wire asinsert in tube heat exchanger (Fig. 6). Wire diameter by tube inner diameter ratio (0.0725-0.134) and twist ratio (1.304-2.319)are set as parameters of coiled wire for study. The analysis shows that with an increase in p/d, the Nusselt number decreases.The use of wire coil embed initiates segregated flow in addition to the secondary flow through the wire coil, according to Promvonge [22]. The combined energy of secondary flow as well as the segregated main flow results in a significant enhance in heat transfer and lower drop in pressure.

Gunes et al. [24,25,26]experimentally analysed the impact of coiled wire as inserts in a tube heat exchanger.Thecoiled wire insert used had a cross section of triangular in shape, placed eccentrically, and was 1 mm apart of tube's inner wall. The TPF was improved more than one when wire coiled was used. At Re = 3858, the highest TPF of 1.36 was obtained [23]. Experiments were carried out at distances of 1 mm, 2 mm apart of tube's inner wall taking pitch ratio of 1, 2 and 3 to verify the effect of the coil's distance apart of tube wall. TPF increased as pitch ratio and wire distance from tube wall decreased, according to their findings [24].Nusselt number and friction factor in coiled wire inserts were investigated using parameters such as varying the Re, pitch ratio,the equilateral triangle's side length to tube diameter ratio,and coiled wire and wall’s distance to tube diameter ratio. A Taguchi technique was used to optimise the tube's design parameters with wire coiled inserts. Each goal was optimised independently before being combined.The best results were obtained when the Re = 19800, pitch ratio

= 1, coiled wire and wall's distance to tube diameter ratio = 0.0357, and the equilateral triangle's side length to tube diameter ratio = 0.0714 [25].

Martinez et al. [26] investigated at how wire coil inserts responded to thermal behaviour in Newtonian and non-Newtonian fluids. The wire coil insert had no effect up to Re = 500, according to the results. Non-Newtonian fluids normally move at low Re. As a result, using a wire coil insert to improve non-Newtonian fluid heat transfer is not a good idea.Chang et al. [27]carried out a research using the grooved and ribbed wire coils in tube heat exchanger. The ribs created an unsteady separated flow through the grooves, which improved thermal efficiency. The TPF of the 45^{o}, 90^{o} rib, 45^{o} and 90^{o} groove were all greater than one, with the 45^{o} groove performing better for various coil pitch to inner diameter ratios.

3.1.5 Conical tube inserts

Kongkaitpaiboon et al. [28](Fig. 7)analysed using the perforated conical rings (PCRs) in tubular type heat exchanger. The impact of the number of drill holes (four, six, and eight) and the pitch ratio (4, 6, and 12) is investigated. Since it restricts the growth of the thermal boundary layer, PCRs increase the heat transfer rate by 137% as compared to smooth tubes. Promvonge [29] observed that conical-nozzles increase heat transfer in a circular tube by adding a boundary layer interruption, that leads to superior tumultuous mixing between the wall and core region, thereby improving the convective process. Diverging conical rings have been shown to provide greater heat transfer compared to converging or converging-diverging conical rings clusters because they show higher re-flow and larger contact surface territory between both the fluid and the heating wall surface as the fluid decelerates from diverging conical rings.

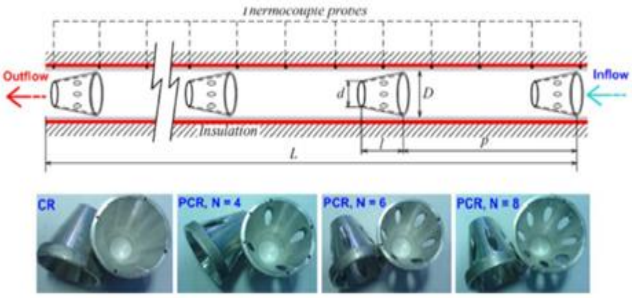


Fig. 7. Perforated conical rings [28]

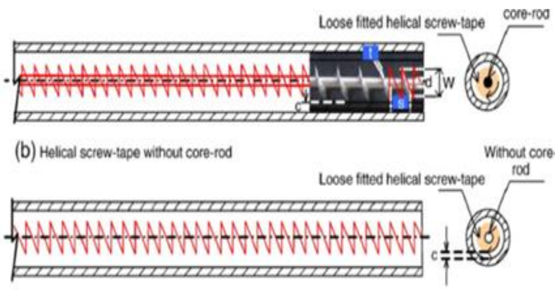


Fig. 8. Helical tape insert [30]

3.1.6 Helical screw inserts

The experimental analysis of the concentric double pipe type of heat exchanger was conducted by Eiamsa-ard et al. [30] using a helical screw-tape with core rod and also without core rod taken into consideration, as shown in Fig. 8. The helical screw tape's width and clearance are 17mm and 4mm, respectively. Loose-fit helical tape was mounted in the inner pipe of the heat exchanger with or without the core rod. When loose-fit helical tape with and without rods was used, the Nusselt number enhanced by 230% and 340%, respectively.The twisted-rings insert in tube heat exchanger was analysed by Thiangpong et al.[31].The impact of twisted ring with width ratio and pith ratio in the ranges of 0.05–0.15 and 1–2, respectively were investigated. The overall thermal efficiency factor was found to be 1.24, with the width ratio (0.15) and pitch ratio (1.0).

Chaurasia et al.[32](Fig.9)experimentally analysedusing the double strip helical screw tape in tube heat exchanger for enhancing the thermal performance at various twist ratio (1.5, 2.5,3)and the Reynolds number ranging between 4000 to 16000.When compared to helical screw tape with a single strip, the results show a higher Nusselt number and friction factor. The TPF had a higher value at 2.5 and 3 twist ratios, as well as at higher Reynolds numbers, while it had the highest value at 2.5 twist ratio and 16000 Reynolds number.

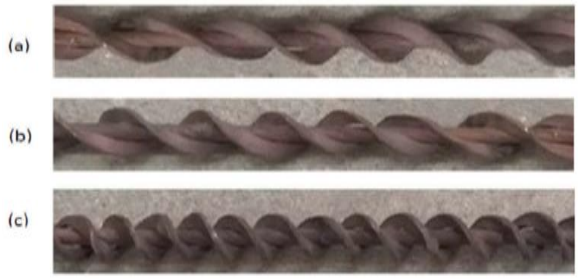


Fig. 9. Double strip helical screw tape, a. y = 3, b. y = 2.5, c. y = 1.5 [32]

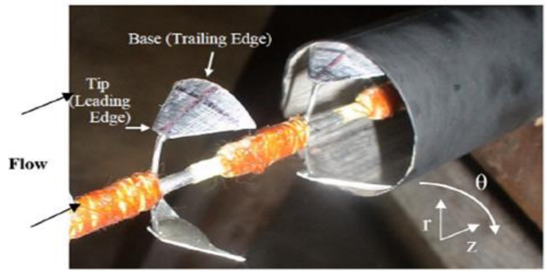


Fig. 10. Delta wing vortex generator insert [33]

3.1.7 Wings and winglet twisted tape

Deshmukh et al.[33]studied the thermal behaviour characteristics of flow through a tube using a curved delta form vortex generator shown in Fig.10instead of twisted tape inserts. The insert consisted of a rod in center with curved delta wings placed at different points. For variousangle of attack,height to tube inner diameter ratio, and thepitch to projected length ratios, the effects on averageNusselt number and average friction factor were investigated. The Nusselt number enhancement compare to plain tube was reported between 1.3 and 5.0, with TPF ranging from 1.0 to 1.8.Eiamsa-ard et al. [34]studied the thermal performance of twisted tape having centre cut wings. The wings were built with three different attack angles (43^o, 53^o, and 74^o) along the centreline. The most effective tape was found to be centre cut twisted tape with 74^o inclined wings, which had a TPF of 1.4.

1.2 Effect of using the Nanofluid

The impact of nanofluids on different forms of heat exchangers has been studied extensively. Nanofluids are often used to optimizethe thermal performance of heat exchangers in a variety of fields.

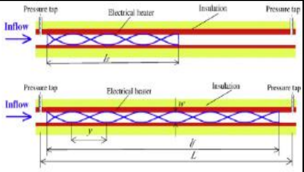
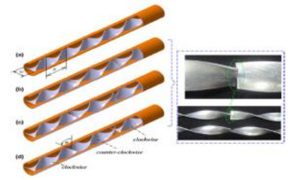
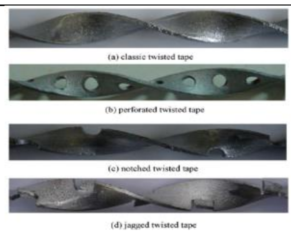
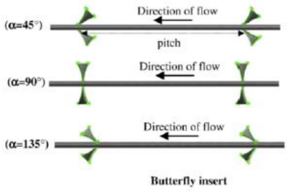
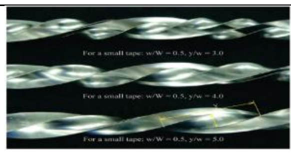
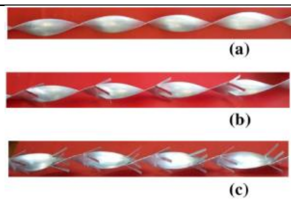
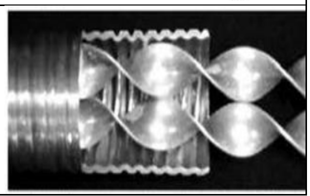
For copper concentric tube type of heat exchanger, Khedkar et al. [42]studied the effects of TiO_2 nanofluid. An increase in the flow rate of nanofluid resulted in an improvement of overall coefficient of heat transfer. Reddy and Rao [43]performed experiments to evaluate the Nusselt number and friction factor for TiO_2 nanofluid flows through a double pipe type of heat exchanger using the helical coil as insert and also without using the coil. The addition of helical coils also enhanced coefficient of heat transfer due to the greater than before flow path length needed to move fluid in a helical path, as well as the creation of turbulence and swirl in the moving fluid, which causes successful particle amalgamation. In comparison to longer pitch length helical coils, shorter pitch length will improve fluid swirl and increase heat transfer rate more significantly. Helical coils cause flow disorder, resulting in high friction factors. Chougule et al. [44] observed a modest rise in friction factor for carbon nanotube (CNTs) nanofluid in circular tubes relative to water due to the low volume fractionof nanoparticles. Because of the unpredictability and irregular particles motion in a fluid, a tube with a wire coil as an insert reported a higher increase in Nusselt number owing to the rise in energy swapping pace.El-Maghlany et al. [45]experimentally analysed the effect of Cu nanofluid using a double tube heat exchanger using the inward tube rotating. Rotation of the internal tube has a stronger impact on pressure drop than nanofluid flowing through a fixed tube.

Sarafraz et al. [46]had used biological nanofluid in a double-pipe type of heat exchanger. The base solvent was ethylene glycol-water in equal proportion and the nanomaterial volume fractions were 0.1%, 0.5%, and 1%. The Nusselt numberimproved by 67% at a volume fraction of 1%, according to the findings. Kumar et al. [47] experimentallystudied the effects of an Al_2O_3-water nanofluid on TPF in a square mini-channel with a protrusion barrier. The use of the protrusion barrier in combination with the Al_2O_3-water nanofluid yielded a TPF of more than 2, according to the results.Using alumina nanofluid, researchers studied the effects of twist ratio of inserts, volume concentration of nanoparticles and varying the Reynolds number on coefficient of heat transfer and friction factor [48]. The comparison of experimental findings to other studies revealed a high level of comprehension. At the Reynolds number of 22,000, hybrid nanofluid provided a 51% increase in Nusselt number for aspect ratio one of longitudinal strips [49].

3.2.1 Effect of using the Hybrid Nanofluid

Hybrid nanofluids outperform base fluids like water, ethylene glycol and mineral oils, as well as nanofluids having only single type of nanoparticles, in terms of thermal performance and thermophysical properties.These nanofluids are a new type of nanofluid created by a mixture of nanoparticles dissolved in one or more base fluids. Hybrid nanofluids have been shown to be a viable replacement for existing base fluids, particularly those that operate at extremely high temperatures. There are two kinds of hybrid nanofluids: 1. Nanoparticles of different kinds (two or more) in base fluid. 2. Other are compound nanoparticles [44][51][52][53].

Hamid et al. [54]analysed the hydrothermal performance of TiO_2 + SiO_2 nanofluid with wire inserted in a circular tube numerically and experimentally, reporting a heat transfer augmentation of up to 254%. Hybrid materials exhibit as single phase materials but have distinct physical and chemical properties. Hybrid nanofluids have a range of benefits, including improved thermal properties by the synergistic effect of combination of nanoparticles or composite nanoparticles.These properties are impossible to achieve in a nanoparticle's composition. Hybrid nanofluids, according to studies, have better rheological and thermal properties compared to nanofluids. Hybrid nanofluids, on the other hand, are more difficult and expensive to make. As a result, their use in industrial applications is restricted[55][56][57][58].

Researcher	Insert	Parameter	Re	Nu/Nu_o	f/f_o	TPF	Fluid	Insert image
Eiamsa-ard et al.[35]	Different lengths of twisted tape	Tape to test section length ratio - 0.29, 0.43, 0.57 and 1, Twist ratio- 4	4,000-20,000	1.16 1.22 1.27	1.76 1.88 1.99	0.95 0.98 1.00	Air	
Eiamsa-ard et al.[36]	Alternate clockwise and counter clockwise	Twist ratio – 3–5, Twist angle – 30°-90°	3,000–27,000	1.8 2.18 2.52	3.58 5.26 6.62	1.18 1.26 1.35	Water	
Rahimi et al.[18]	Classical, perforated, notched and jagged twisted tape	Pitch length- 50mm,Width – 15mm, Thickness- 1mm, Twist ratio – 2.94.	2,950-11,800	1.92 1.60 1.86 2.49	4.85 4.4 4.62 6.51	0.99 0.85 0.97 1.21	Water	
Shabanian et al.[19]	Twisted tape with butterfly	Angle: 45°-135°, Diameterof rod-1.9 mm, Pitch – 60mm,Thickness- 0.5 mm.	4,021-16,118	5.08	18.3	1.6	water	
Eiamsa-ard et al.[37]	Coupling twisted tape	Small tape twist ratio– 3, 4, 5, Large tape twist ratio– 4.	6,000-20,000	-	-	1.08 1.03 0.99	Water	
Promvonge et al.[38]	Winglet vortex generator	Angle of attack-30°, R_B = 0.2, 0.15 and 0.1, Twist ratio- 4 and 5.	4,000 - 30,000	3.22 3.03 2.82	9.44 7.31 5.34	1.52 1.55 1.62	Air	
Eiamsa-ard et al.[39]	Counter double twisted tape	Width- 4mm, Twist ratio- 3,4 and 5	5,650 – 17,000	4.8 4.5 4.2	12.5 12 10.8	2.05 2 1.95	Water	

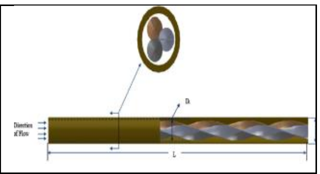
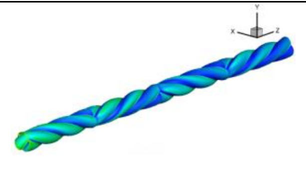
Bhuiya et al.[40]	Triple twisted tape	Twist ratio- 1.92, 2.88, 4.81 and 6.79	7,200-50,200	1.73 to 3.85	1.91 to 4.2	1.10 to 1.44	Air	
Tang et al.[41]	Twisted spiral tube	Pitch length- 200 mm.	8,000–21,000	1.4	1.2	1.18	Water	

Table1. Few effective inserts and their performance summary

Conclusion

Following are some significant findings that can be taken from the review:

- The use of the inserts has been shown to cause physical disruptions. The swirling movement caused by the tape's twisted structure disturbs the boundary layer close to the wall, improving rate of heat transfer, as per various types of inserts.
- Helical screw tape has shown to have a better heat transfer compare to that of typical twisted tape due to the combination of making a short pitch-length screw, which results in stronger swirling and takes longer time for the fluid to pass through the tube.
- Use of wire coils in heat exchanger particularly for the pre-heaters,fire tube boilers and oil cooling systems, that can improve the heat transfer with minimal loss of pressure.
- The heat transfer rate is increased by using a turbulator with conical nozzles, but it requires a lot of pumping power. This form of turbulator is useful for lower Reynolds numbers, which minimise frictional losses.
- Twisted tape perforation decreases pressure drop by a significant level, also the fluid discharged through it increases turbulence in the flow. Creating a square shape cut at the edge of tape, on the other hand, allows the vortex and secondary flow to be distributed, rising the turbulence at the heated surface.
- Most researchers have found that the intensification of nanoparticles enhances the thermal performance of nanofluids. These additions, though, can be precise up tothe maximum values of nanoparticle concentration values, and anything beyond that has a negative impact to heat transfer. As a result of increased forced convection due to fluid disturbance, improved mixing, and collision of nanoparticles, nearly all results revealed that as the flow rate of nanofluid increases, so does the rate of heat transfer.
- Nanoparticle stability in the base fluid is critical for performance, and new methods to avoid thickening and deposits must be created.
- The effectiveness of a heat exchanger with perforated inserts ranges from 2.24 to 2.68, while the effectiveness of inserts apart from perforated inserts only exceeds the desirable estimation of one in the Reynolds number scale. The higher TPF output of perforated inserts is possible as the fluid jets emitted through the holes, which improve the heat transfer while reducing frictional losses significantly.For Reynolds numbers less than 13000, the helical screw tape outperforms most insert geometries, while for Reynolds numbers beyond that, the tube having the alternate clockwise and anti-clockwise curved tapes performed better.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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