Journal of Engineering, Project, and Production Management
2024, 14(1), 0007

Improvement of Heat Transfer Through Use of Twisted Tape Inserts: A Review

Shrikant Arunrao Thote[1] and Netra Pal Singh[2]
[1]Research Scholar, Department of Mechanical Engineering, Oriental University, Indore, (M.P.) -453555, India,
E-mail: shrikantathote@gmail.com (corresponding author).
[2]Professor, Department of Mechanical Engineering, Oriental University, Indore, (M.P.) -453555, India,
E-mail: netrapaljadon@gmail.com

Selected paper from 2022 International Conference on Trends in Engineering, Applied Sciences and Management Engineering Management
Received May 23, 2022; revised November 1, 2022; February 18, 2023; accepted June 29, 2023
Available online November 27, 2023

Abstract: The objective of this review paper is to identify the gap in finding out the direction toward the enhancement of heat transfer and the performance of heat exchangers. Heat exchangers can be found in many applications ranging from engineering devices to household consumer appliances. Heat exchangers must offer a good heat transfer performance apart from saving energy. Heat transfer enhancement techniques help to save energy and cool hot components in the design of electronic and mechanical circuits. However, enhancement in heat transfer takes place at the cost of a bearable increase in friction losses and pressure drop. Therefore, miniature heat exchanger systems and the cost of energy, motivate industries to use energy-saving methods in their design. With aging, the most common problem in heat exchangers is the reduction in heat transfer rate. Numerous studies have proved that placing a disturbance occurs in the fluid flow path and it can help to increase the heat transfer rate in the case of worn-out heat exchangers. For decades, researchers are numerically investigating the effects of various kinds of insert tape to improve the heat transfer operation in the heat exchangers. As heat exchangers form the backbone of many industrial processes, the idea of saving energy with the design of a cost-effective tape insert motivated us to work on this area of research. The paper proposes the new model of heat exchanger with an insert having a trapezoidal cut on both sides of an insert and using the different ratios of twist experimentation that will perform and compare the output with the previous studies by using different fluid or phase change materials as a fluid to maximize the performance of heat transfer rate. Also, it aims to find out the impact on friction factor as well pressure drop in the heat exchanger when there is a change in ratios of twist. This research aims to review the findings of earlier researchers in this area and to utilize the knowledge for improving the heat transfer rate of conventional tubes in our future work.

Keywords: Heat transfer, twisted tape insert, laminar flow, flow regimes, wings, cuts.

DOI 10.32738/JEPPM-2024-0007

1. Introduction

The most common problem with heat transfer (HT) operation is the aging of heat exchangers (HE). With the aging effect, the resistance of the HE to HT increases. Replacing aged-out HEs in industries with a new one is not an easy task as it hampers production and involves investment. Industries and researchers continuously strive to overcome this problem by breaking the resistance of the fluid flow path so that rate of HT could be increased. The first gap is linked to the investigations on the inserts and as discussed, the inserts produce the maximum disturbance of flow that can intensify the mixing of fluid as well the disruption at the boundary layer. As per the literature review there are number of studies and most of them are on an experimental basis**.** The second gap is linked with the insert with a trapezoidal cut twisted tape. As there very less experimentation done by the researchers. However, few twist ratios were used to investigate the performance of heat exchangers. The third gap is associated with the efficiency of the heat exchanger. As discussed earlier, improvement in efficiency is more essential in the thermal system. Hence the need to perform a new study to improve the efficacy compared to the previous experimental performance. The main objective of this research paper is to findings of the earlier researchers using passive techniques and to utilize the knowledge for improving the heat transfer rate of conventional tubes.

2. Literature Review

To break the vicious and thermal boundary layers of the HE a disturbance is introduced in the path of fluid flow which helps to increase the HT rate (Dewan et al., 2004). Numerous engineering methods to improve the HT rate from the wall in existing HE have been introduced by many researchers (Datt et al., 2018). Wire coil, fin, dimple, and Twisted tape (TT) insert are some of the passive techniques used by researchers to improve HT rate. These techniques are not only used to improve the performance of existing HE but also in designing new compact and miniature size HE such as the ones used in solar heaters (Smith et al., 2009). To enhance HT, devices with Swirl flow and modified surfaces have been extensively used in thermal engineering (Eiamsa-Ard et al., 2013). Helical screw tape inserts / TT inserts produce turbulent flow/swirl flow in circular tubes and are recommended choices amongst researchers and designers due to their low cost, low maintenance, effective boundary layer disruption, and improved fluid mixing (Nanan et al., 2014). In some studies, non-circular (elliptical, cam-shaped) tubes have also been considered for research in cross-flow HEs. It was found that due to their non-circular shape these tubes offer low flow resistance and require less pumping power (Li et al., 2019). For centuries researchers have made use of tape inserts to improve the performance of HE as these tape inserts are inexpensive and removable which allows for easy cleaning of the tube (Lim et al., 2017). Numerous designs of tape inserts can be found in many studies undertaken by earlier authors. This study intends to look over the influence of various tape inserts (clockwise, counterclockwise, multiple inserts, wire mesh, etc) on HT augmentation. The use of wings (trapezoidal, rectangular, square, triangular) and cuts (V, center cleared) to improve the thermal performance of tubes will also be explored. The twist ratio effects, angle of attack, wing depth ratio, pitch angle, heat flux, and flow regime (turbulent, laminar, and transitional) on thermal performance, friction factor (ff), and improvement in the rate of HT of the tube will be studied and compared with the plain tube.

According to Nakhchi et al. (2021) perforated elliptic turbulators can significantly improve the thermal efficiency factor of double-pipe heat exchanger tubes. In addition, two correlations were proposed to calculate the average Nusselt number and friction loss as functions of the design parameters. By increasing the inclination angle (α) from 15 to 25 at Re = 12,000 with the same diameter ratio (d/b = 0.25), the thermal performance is increased by approximately 17.6 percent. Double-perforated inclined elliptic (DPIE) ortex generators with d/ b = 0.25 and = 25 achieve the highest thermal performance parameter (η) of 1.849 at Re = 16,000.They have several advantages over active methods, including relative simplicity, lower manufacturing costs, and lower maintenance and repair costs (Gokulnathan, 2021; Wu, 2011; Liang et al., 2020).In passive techniques, increasing flow turbulence is the key to improving heat transfer, while pressure drop or friction factor is typically kept as low as possible. The most commonly used turbulators to improve thermal efficiency are baffles, ribs, winglets, perforated turbulators, louvered strips, inclined elliptical strips, twisted tapes (Ghalambaz, 2020; Mashayekhi, 2020), and different helical inserts, rectangular turbulators (Mahani, 2021), ring inserts, and springs (Kareem, 2015; Liu, 2013). Hatami et al. (2015) used a turbulator of delta winglet to improve heat recovery from a diesel engine exhaust. They discovered that recirculation-generated flow by winglets can result in exergy recovery improved by 50% when compared to previous designs.In the analysis study, Nakhchi et al. (2020) used turbulators twisted with transverse-cut to improve the results of heat transfer with nanofluid as Cu-water. Their findings revealed that transverse-cut twisted turburators (TCTTs) with deeper cuts (b/c = 0.7) can produce more recirculation and flow disturbances, resulting in better performance when compared to other cutting shape geometries. Dagdevir et al. (2021, perforated effect and improvement of thermal efficiency on the heat exchangers by using dimpled investigated. They discovered that perforated twisted tapes with a pitch ratio (Pd/y) of 0.25 can achieve the highest thermal performance parameter of 1.42.

Yaningsih et al. (2018) found the slant angle effect at different values of 25, 20, and 15 and also developed the empirical correlations based on experimental results. They discovered that the louvered strips increased heat removal and friction loss by 77.0 and 335.0 percent. For the enhancement of inside pipes of heat transfer for laminar flow and turbulent flow regimes, Rivier et al. (2015) investigated the proposed effects of newly elliptic turbulators at various Reynolds numbers They came to conclude that turbulators with a bend angle of 60 have a higher thermal efficiency factor. Nakhchi et al. (2021) conducted research and found the effect of newly designed rotated inclined elliptic vortex generators on the improvement of the thermal performance of the double pipe heat exchangers (DPHEX) in a turbulent flow regime. The effect of louvered strip inserts for the slant angles 15˚, 20˚, and 25˚ on the intensification of heat transfer for the turbulent flow using single-phase was studied by Yaningsih et al. (2018). They discovered that using these inserts improved the thermal performance factor in the range of 1.00-1.12. Many studies have recently been performed on the heat exchangers with double-pipe to improve their efficiency for different applications (Padmanabhan et al., 2021).

Huu-Quan et al. (2021) investigated the flat inner pipe's effect. They discovered that the vortex generators are extremely sensitive to the Reynolds number. When the Reynolds number is less than 7000, the total heat transfer, thermal efficiency, and performance factor can be improved by about 2.9 percent, 2.7 percent, and 16.8 percent, respectively, by using a small aspect ratio of flat inner pipes. Li et al. (2020) investigated the effect of MgO-Ag/water hybrid nanofluid on the novel corrugated tube called sinusoidal hairpin DPHEX. Singh et al. (2021) used the conical wire coil to improve heat transfer from hybrid nanofluids in an experimental study on the DPHEX. They looked into the effects of diverging and converging wire coil turbulators. The analysis revealed that the maximum Nusselt number (Nu) improvements were approximately 171 percent, 152 percent, and 139 percent, respectively. In an experimental study, Thejaraju et al. (2020) used a novel para winglet tape vortex generator and discovered a maximum of 407 percent increase in Nusselt number for air-air heat exchangers. Suri et al. (2017) used multiple square-perforated twisted tapes to investigate heat transfer intensification inside a heat exchanger pipe. According to the literature review, rotating turbulators can significantly improve the thermal performance of heat exchanger pipes.

However, they have received less attention than other turbulators, as shown by Zhang et al (2016). Sui et al. (2018) investigated the viscoelasticity-based of mass transfer and heat transfer of a liquid micropolar past an extended surface in the presence of slip circumstances. Sheikholeslami et al. (2018) investigated the nanoparticle's impact on solidification growth with radiation using the heat transport performance of phase change materials. Mabood et al. (2016) used the Soret effect and radiation to study the micropolar liquid motion in the mass and heat transport through an extended area bordered by a non-Darcian permeable media. Pal et al. (2011) inspected the effects on the non-Darcy magnetohydrodynamic unsteady coupled convection energy transfer and mass past an expanding plate by radiation and chemical reactions. Hayat et al. (2016) developed a model for Maxwell nanomaterial unsteady radiative propulsion over a stretched sheet. Dogonchi et al. (2019) used the technique of finite-difference control volume to investigate the nanofluid motion within a rhombus cavity which is partially heated with thermal radiation. Karthikeyan et al. (2013) investigated the effect of radiation on magnetohydrodynamic thermal convection past a vertical sheet in a permeable stretching sheet and discovered that increasing the parameter of radiation decreases the thickness of the boundary layer and increases the heat transport rate. Hsiao et al. (2014) presented a study on the mixed effects of convection and thermal radiation in multimodal physical properties with nanofluids. Naz et al. 2020, used the computational software of Mathematica to provide solutions with numerical values for the magneto hydrodynamic (MHD) arreaunano liquid motion over the cylinder. Waqas et al. (2019) used generalized differential quadrature method (GDQM) to investigate the behavior of the flow with the influences of thermal radiation and an MHD stretching surface for the Cassonliquid. Sohail et al. (2020) investigated the Maxwell nano liquid flow with various effects such as a gyrotactic microbe, entropy generation, and radiation using an optimal homotopy analysis approach. Because it is a strong method, the GDQM is now widely employed in fluid flow systems. Many researchers have used GDQM to evaluate their numerical examples and have found it to be extremely convenient, accurate, and efficient.

3. HT Enhancement Using TTs

Abolarin et al. (2019) investigated the performance of a clockwise and counter-clockwise TT (CCCTT) insert made of copper plate strips with a twist ratio of 5. Researchers connected the clockwise TT with anti-clockwise TT at dissimilar relation in gradient viz: 0º, 30º, and 60º respectively. As working fluid water was used for Reynold's number (Re) ranging from 300-11404 and the experiment was conducted with constant heat flux. Effect of CCCTT insert, conduction angle, and heat flux on transitional flow and laminar flow was observed and it was found that an increase in conduction angle maximizes the HT in the transitional flow where as a maximization in heat flux increased the HT when the flow is laminar. Bartwal et al. (2017) developed a novel circular ring insert with wire mesh in a circular tube to increase the HT rate. The wire meshes were designed with 3 grades 4, 9, and 16 for 3 values of pitch ratio 2, 3, and 4 respectively. As the working fluid air was used for Re as variation range from 5000- 40000. Researchers found that the circular ring wire mesh was an effective passive HT enhancement insert that could be used in many applications. The outcome indicates that maximum enhancement of HT was obtained through a circular ring wire mesh insert of grade 16 and pitch ratio of 2. A maximum thermal enhancement factor of 2.84 was obtained with wire mesh of grade 9 and a pitch ratio of 3. Deshmukh et al. (2016) investigated the performance of a circular tube with a curved delta wing vortex generator. The vortex generator was made of 0.5mm thickness of a sheet of aluminum and cut into a triangular shape with a circular base. The strips were attached to two opposite ends of a central rod with the help of cotton strings and adhesives. The effect of the pitch to projected length ratio (p/pl), angle of attack (α), and pitch to inner tube diameter (b/d) was investigated. The curved shape of the insert offered a higher fluid mixing. The average Nusselt number (Nu) was in the range of 5.0-15.0. The highest Nu augmentation was observed for α= 60º, p/pl =2.1, and b/d =1.0 for the entire range of Re.

Dhamane et al. (2014) inspected the potential of a TT insert with a wavy shape in a circular tube with air as the working fluid to enhance the HT. The wave-width of 24, 16, and, 13 mm respectively were used by the authors. Researchers found that HT enhancement varied from 9-43% with changing wave width. Reduction in wave width also caused the Nu as well as the ff to increase. Overall enhancement varied from 1.38-1.43. Researchers concluded that wavy TT inserts are an attractive option for improving HT and saving pumping power. The nature of wavy TT created a centrifugal force due to the spiral motion of the fluid which caused HT enhancement. Ibrahim et al. (2011) investigated the effects of twist ratio and spacer length on HT and friction factor (ff) performance of a tube with a helical screw insert. As the working fluid water was used for Re 570-1310. From the outcome, increases of the Nu by an increase in Re, and with a reduction in the values of the ratio of twist and spacer length. It was found that the ff improves for a constant Re with decreasing values of the ratio of twist and spacer length. The performance of a circular tube with a helical twist insert was found to be better when compared to a plain tube. Jian et al. (2011) evaluated the attainment of a typical TT with short-width and center-cleared TTs. Researchers examined the conclusion of tape width ratio and the ratio of central clearance on HT and ff. Results reveal that a higher width ratio produced a higher Nu and thus enhancement of HT in short-width TTs. The same was true for the ff. In the case of the thermal performance factor, researchers found that there was initially a decrease in the value of the thermal performance factor with decreasing width ratio & but it started to increase with the width ratio decreasing beyond 0.3. For Nu and thermal performance factor for center cleared TT, ff reduced with reducing width but a different response was observed. These two values initially increased with reducing width ratio and then started decreasing. Researchers concluded that with a better center clearance ratio the performance of center cleared TT could be further improved.

Meyer et al. (2018) performed a study to evaluate the performance of a TT insert inside a circular tube with water as the working fluid. Researchers placed a TT having square-edged geometry at the inlet of the tube and experimented with 3 dissimilar ratios of twist 5, 4, and 3 at a consistent heat flux of 4, 3, and 2 kW/m^2. Results shows an increase in the ff with a reduction of the ratio of twist. When Re and twist ratio was kept constant, the ff again decreased with an increase in the heat flux. Wongcharee et al. (2011) evaluated the performance of two distinct types of TT inserts (i) Typical TT and (ii) TT with an alternate axis (TA). Both tapes had ratios of twist as5, 4, and 3 respectively. Researchers correlate the performance of these two tapes based on the equivalence of thermal performance factor, ff, Nu. Nu, ff, thermal performance was found to be higher in TT with alternate clockwise and counter clockwise tape (TA) than TT and the values increased with decreasing twist ratio. Khwanchit et al. (2011) accomplish a study to examine the ramification of alternate axes of TT insert for HT rate, ff, and thermal performance. The tape insert was placed inside a circular tube and was designed to offer a twist ratio of 4 with three different shapes of wing cuts: trapezoidal, triangular, and rectangular with a ratio of wing-chord as 0.3, 0.2, and 0.1 respectively. As compared to a tube all different wing shapes and alternate axes TT inserts performed better to improve the HT rate and ff. Results show that alternate axes of TT and wings of trapezoidal gave the maximum value of Nu, ff, and thermal performance factor as 2.84, 8.02, and 1.42 for the 0.3 as the ratio of wing-chord. It was found that TT inserts with alternate axes and wings perform better than typically TTs and TTs with alternate axes. Liu et al. (2018) achieve a simulation using PIV software to study the performance of conical strip inserts in a circular tube. The effect on the performance with the number of strips with the conical (n), angle of central (α), pitch (p), and angle of slant (θ) on HT was evaluated. The Nu and ff with multiple conical inserts were concluded to enhance by 2.54-7.63, and 2.4-28.74 times more than the plain tube. The highest overall HT enhancement was reported with n=4, $\alpha = 50^o$, $\theta = 30^o$, and p= 40mm for Re less than 600. Multiple conical strip inserts can help to obtain low flow resistance.

4. Experimental Studies on TT

Bhuiya et al. (2012) examined HT performance in a tube with a double-helical tape insert and further extended his work to re-examine the same phenomenon with a triple-helical tape insert. For the first case, the researchers used the different helix angles of 28^o, 21^o, 15^o, and 9^o inside a tube for double-helical tape and observed pressure drop and HT effects for Re between 22,000- 51,000. Nu and ff improved by 30.5 % and 170% correlated to a plain tube. For a helix angle of $9^o$with a high Re maximum thermal performance was achieved for a double helical tape insert. In the case of a triple-helical tape insert, researchers used helix angles of 9^o, 13^o, 17^o, and 21^o for the same range as Re. Nu and ff were found to improve by 4.5 and 3.0 times compared to a plain tube. Murugesan et al. (2010) measured the execution of typical TTmade up of wire nails. Three different turns ratio were selected; 2, 4.4, and 6.TT consisting of wire nails showed maximum outcomes in terms of Nu (1.08- 1.31), ff (1.1-1.75), and thermal performance (1.05-1.13) correlated to typical TT. The authors concluded that the performance of TT with wire nails increased due to the following reasons: (i) It provided a common swirling effect similar to typical TT (ii) It provided an additional turbulence flow due to the nails. Piriyarungrod et al. (2018) compared the performance of a single TT insert with multiple TTs of different numbers (N = 2, 3, 4, 5, and 6) with twist ratios of (y/w = 2.5, 5, 10, 15, 20 and 25). Results show that the highest Nu, ff, and thermal performance factor was obtained for multiple TTs with N= 6 (highest number) and y/w = 2.5 (smallest twist ratio). Murugesan et al. (2011) examined the performance of a TT insert with a V-cut TT insert for a twist ratio of 2, 4.4, and 6. The outcomes of TT (V-cut) were also evaluated for three different combinations of the ratio of width and ratio of depth. Thermal performance, ff, and HT of TT (V-cut) were better than a plain TT insert. The effect of depth ratio on HT augmentation was more pronounced than the width ratio in the case of V-cut TT insert. Ponnada et al. (2019) executed the outcomes of a typical TT with PTT and PATT with twist ratios of 5, 4, and, 3 under a constant heat flux. For Re ranging from 3000-16000, for conducting the experiment water was used as the working fluid. Researchers compared the performance of these 3 tape inserts based on the values of temperature performance factor, ff, and, HT rate. For TT, PTT and, PATT these values were obtained as (1.433, 1.396, 1.24), (19.1%, 17.6%, 15.85%) and, (48.12 %, 44.3 %, 33%) respectively.

For practical applications, researchers found PATT as an effective passive tape inset to save energy and operating costs. Datt et al. (2019) reviewed the works of different researchers related to the hydrodynamic and thermal performance of inserts as TT. Researchers observed the performance of an insert is affected by the twist pitch and the twist angle. Insertion of rods and spacers into the insert also affects the drop in pressure of the fluid flow. TTs with spacers produce less drop in pressure correlated to full-length insert or TT with rods. TT (V-cut) shows greater performance than typically TTs towards the thermal performance, ff, and, Nu. Lastly, their studies reveal that multiple TTs have better performance than TTs of any other shape. Chokphoemphun et al. (2014) investigated the performance of small double and triple co and counter TT inside a circular tube. All TTs had a width of 0.8mm and were made of aluminum with two distinctive twist ratios of4.5 and 4 respectively. The tapes were twisted in two distinct aspects to obtain right twist and left twist tapes. The study was performed for a circular tube with dissimilar combinations by placing the TTs (duo or triple) i.e either all were left twist tapes (LL / LLL) or a combination of left and right twist tapes (LR / LRL). For Re between 5300-24000, Nu ranged from 1.01-1.52, and ff was 1.24-1.77 more than that of a tube without an insert. A smaller twist ratio gave a better performance. Results reveal that counter TTs (LR / LRL) show better values of Nu, ff, and thermal performance in comparison to co-twisted (LL / LLL) tape inserts. Chokphoemphun et al. (2015) experimented to evaluate HT and pressure loss characteristics of a single, double, triple, and quadruple TT insert in a circular tube. Quadruple, triple, and, double TTs were designed 4 as a ratio of a twist whereas the single TT insert was designed for two twist ratios of 4 and 5 respectively. All tapes were twisted in two dissimilar aspects to produce the twist in the right-left direction independently. 8 different combinations apply with multiple TTs as 4T4, 4T3, 4T2, 4T1, 3T2, 3T1, 2T2, and, 2T1 respectively. For Re 5300- 24000, the values of ff and Nu were 1.9-4.1 and 1.15-2.12 more than the tube.

The quadruple TT inserts (4T4) showed a higher thermal performance compared to other inserts. Liu et al. (2013) reviewed to study the effects of different tape inserts on HT rate. Researchers found that TTs with multiple short-length placed with regular spacing can help to achieve lower pressure drops in comparison to a full-length TT insert of the same ratio of twist. Insert with TT were found to execute greater inflow in the case of laminar than the inflow of turbulence in the exchangers. Ribs and conical nozzles performed better with turbulent flow. Their findings reveal that helical screw tapes can produce better HT efficiency than TTs. Sarada et al. (2010) experimented with TTs of five different widths (26, 22, 18, 14, and 10 mm) and twist ratios of 3, 4, and 5 respectively. The tapes were made of aluminum and inserted inside a 27.5 mm diameter tube to give a sliding effect. Care was taken that the tape inserts do not scratch the inner walls of the tube when they were axially slid. Researchers inserted braces into the tape at certain lengths to maintain a fixed gap between the tapes and the tube wall boundary. The overall enhancement with 26 mm TT varied from 1.35-1.62 and with 10mm TT the enhancement was 1.08-1.18 times the plain tube itself. Researchers concluded that even a 10mm TT insert can be helpful to improve the HT coefficient and can also result in material savings. Smith et al. (2010) examined the performance of three various kinds of tape inserts in a copper tube. The first two tapes dual and single TT in full-length without free air spacing which had a twist ratio of 3, 4, and 5 whereas the third was a dual TT with regular-spaced with a ratio of space as 2.25, 1.5, 0.75, and, 0 respectively. For dual TT, the HT rate was greater than TT with full-length. Singh et al. (2018) experimented with the performance of a multiple square perforated TT (MSPTT) inset with square wings inside a tube made of GI pipe.

With air as the working medium, the experiment was conducted for Re between 5000- 27000. Researchers monitored the performance of the tape insert for different perforated width ratios, pitch ratios, and wing depth ratios. Compared to a plain tube, the tube with MSPTT inserts with square wings showed an HT and ff enhancement of about 6.96 and 8.34 times. The highest enhancement in HT was obtained for an insert for the following specifications: perforated width ratio =0.25, pitch ratio =2.5 and wing width depth =0.167 respectively. Researchers also found that tape of dual twisted with a minimum ratio of space gave better results than a dual TT with high space ratios. The use of a dual TT with a smaller space ratio was more effective in increasing the HT rate compared to a single full-length TT. Some of the notable contributions in the presented line of work are mentioned in the Table 1.

Table 1. Impact of twisted tape on enhancement of heat transfer rate

Sr. No	Author	Working Fluid	Summary
1	Abolarin et al. (2019)	Water	Researchers evaluated the development of a CCCTT insert and encountered that increasing the conduction angle increases HT in transitional flow while increasing the heat flux increases HT in laminar flow.
2	Bartwal et al. (2017)	Air	Researchers developed a novel circular ring insert with wire mesh in a circular tube to improve HT. A maximum thermal enhancement factor of 2.84 was obtained with wire mesh of grade 9 and a pitch ratio of 3.
3	Deshmukh et al. (2016)	Water	The performance of a wing vortex generator with delta curved in a circular tube for different angles of attack (α), ratio of pitch to projected length (*p/pl),* and pitch to the inner diameter of the tube (*b/d)* was investigated. The highest Nu augmentation was obtained for $\alpha = 60^o$, p/pl =2.1, and b/d =1.0 for the entire range of Re.
4	Dhamane et al. (2014)	Air	Researchers concluded that wavy TT inserts are an attractive option for improving HT and saving pumping power. The nature of wavy TT creates a centrifugal force due to the spiral motion of the fluid which causes HT enhancement.
5	Ibrahim et al. (2011)	Water	The effects of the ratio of twist and spacer length on heat transmission and ff performance of a tube with a helical screw insert reveal that the circular tube with a helical twist insert outperforms the plain tube.
6	Meyer et al. (2018)	Water	The performance of a circular tube with an insert TT was investigated. The outcomes show that with the decrease in the ratio of the twist, the ff increased. When Re and twist ratio was kept constant, the ff decreased as rising the magnitude of heat flux.
7	Jian et al. (2011)	Air	Researchers compared the outcomes of a typical insert with short-width and TTs with center cleared. For TT of center cleared the ff reduced with reducing width. Researchers concluded that with a better center clearance ratio the performance of TT with center cleared could be further maximized.
8	Wongcharee et al. (2011)	Water	Researchers evaluated the attainment of two distinct kinds of inserts (i) tape with typical twisted (TT) and (ii) alternate axis TT. Thermal performance, ff, and, Nu was analyzed to be maximum in TA than TT and the values increased by minimizing the ratio of twist.
9	Khwanchit et al. (2011)	Water	Researchers performed a study to examine the ramification of alternate axes for the insert on thermal performance, ff, and, HT rate. Wings of shapes such as trapezoidal, rectangular, and, triangular with dissimilar wing-chord ratios were used in this study. It was found that alternate axes inserted with trapezoidal wings perform better than typically TTs and alternate axes with TTs.
10	Liu et al. (2018)	Water	Researchers carried out a simulation using PIV software to studythe performance of conical strip inserts in a circular tube. Results show that multiple inserts with conical strips can help to obtain low flow resistance.
11	Bhuiya et al. (2012) (a)	Air	HT performance in a tube with a double-helical insert tape was examined. Maximum thermal performance was achieved for a double helical tape insert with a 9^o of the helix angle with a high Re.
12	Bhuiya et al. (2012) (b)	Air	Compared to a plain tube Nu and ff were found to improve by 4.5 and 3.0 times with a triple-helical tape insert.

Table 1. Impact of twisted tape on enhancement of heat transfer rate (continued)

Sr. No	Author	Working Fluid	Summary

13	Murugesan et al. (2010)	Water	Researchers correlated the performance of a typical TT with a TT consisting of wire nails. Authors ended that the outcomes of wire nails TT increased due to the following reasons: (i) It provided a common swirling effect similar to typical TT (ii) It provided an additional turbulence flow due to the nails.
14	Piriyarungrod et al. (2018)	Air	Multiple twist tapes with varied numbers (N) and twist ratios (y/w) were compared to the performance of a single TT insert. The results reveal that multiple TTs with the highest number (N=6) and shortest twist ratio (y/w = 2.5) have the maximum Nu, ff, and thermal performance factor.
15	Murugesan et al. (2011)	Water	The performance of TT inserts with V-cut TT inserts V-cut TT inserts were evaluated by researchers. The V-cut TT inserts outperformed a plain TT insert in terms of heat transmission, ff, and thermal performance.
16	Ponnada et al. (2019)	Water	For practical applications, the researchers found that PATT (alternate axis perforated TT) was a successful passive tape insert to save energy and operating costs.
17	Datt et al. (2019)	Air	The study reveals that any other shape of TTs has no better performance than multiple TTs.
18	Chokphoemphun et al. (2014)	Air	The performance of small double and triple co and counter TT inside a circular tube was examined. In comparison to co-twisted (LL / LLL) tape inserts, the results suggest that counter TTs (LR / LRL) have improved Nu, ff, and thermal performance.
19	Chokphoemphun et al. (2015)	Air	An experiment to evaluate heat transmission and characteristics of pressure loss of a quadruple, triple, double, and, single TT insert in a circular pipe were carried out. The insert with a quadruple twist (4T4) provided a higher thermal performance compared to other inserts.
20	Liu et al, (2013)	--	Researchers concluded that multiple short-length TTs placed at regular spacing can help to achieve lower pressure drops in comparison to a full-length TT insert of the same ratio of twist.
21	Sarada et al. (2010)	Air	Researchers experimented with TTs of five distinct widths and ratios of twist. The tapes were made of aluminum and inserted inside a 27.5 mm diameter tube to give a sliding effect. Researchers concluded that even a 10mm TT insert can be helpful to maximize the HT coefficient and also result in material savings.
22	Smith et al. (2010)	Air	Researchers found that dual twisted inserts with a lower ratio of space gave greater results than the dual TT with high space ratios. The use of a dual twisted insert with a lower ratio of space was more effective in increasing HT rate correlated to single TT with full-length.
23	Singh et al. (2018)	Air	Researchers evaluated the performance of perforated TT inserts in multiple squares with wings of squares shape. Compared to a plain tube, a tube with perforated TT inserts in multiple squares with wings in squares shape showed an HT and ff enhancement of about 6.96 and 8.34 times.

5. Conclusion

HEs execute an essential role in HT operation and are the basic building elements of a large number of industrial processes. However, their performances tend to decline with age. Researchers and industry experts have found a simple solution to tackle this problem. By inserting a tape in the path of fluid flow they have succeeded in improving the HT operation for old HEs. This paper investigates the thermal performance of a tube by the impact of various tape inserts in the tube. Through our investigation, we found that TT inserts help to improve the performance of HT of HEs compared to a tube. Inserts with TT with alternate axes are better in performance than a typical TT. Effects of conduction angle and heat flux on flow regime (transitional, laminar) show that transitional flow is affected by conduction angle, whereas, laminar flow is affected by heat flux. The influence of different wing shapes on HT augmentation showed that for a particular wing-chord ratio, trapezoidal wing TT is better than rectangular, triangular, and square wings TT .It was also inspected that better HT performance was obtained in the case of tubes with the many numbers of TT inserts (Multiple inserts) with the lowest ratio of twist. Short-length TTs placed at regular spacing were found to achieve lower pressure drops correlated to a full-length insert TT. Results of some studies reveal that material and cost savings can be achieved by using TTs of smaller widths and lengths. With these findings, we wish to investigate the performance of HT of conventional tubes with different tape inserts and also analyze the outcomes of phase-change-material on HT operation in our future work.

Author Contribution

Shrikant Arunrao Thote collected the previous several research article to find out the gap and contributes to conceptualization, methodology, data collection, analysis, draft preparation, and manuscript editing. Netra Pal Singh contributed to draft preparation, manuscript editing, and supervision. All authors have read and agreed with the manuscript before its submission.

Funding

No funding was received for this study.

Institutional Review Board Statement

Not applicable.

References

Abolarin, S. M., Everts, M., and Meyer, J. P. (2019). Heat transfer and pressure drop characteristics of alternating clockwise and counter-clockwise twisted tape inserts in the transitional flow regime. *International Journal of Heat and Mass Transfer,* 133, 203–217.

Bartwal, A., Gautam, A., Kumar, M., Mangrulkar, C. K., and Chamoli, S. (2017). Thermal performance intensification of a circular heat exchanger tube integrated with compound circular ring-metal wire net inserts. *Chemical Engineering and Processing- Process Intensification,* 124, 50-70.

Bhuiya, M. M. K., Ahamed, J. U., Chowdhury, M. S. U., Sarkar, M. A. R., Salam, B., Saidur, R., Masjuki, H. H., and Kalam, M.A. (2012). Heat transfer enhancement and development of correlation for turbulent flow through a tube with triple-helicaltape inserts. *International Communications in Heat and Mass Transfer*, (39), 94–101.

Bhuiya, M. M. K., Chowdhury, M. S. U., Ahamed, J. U., Khan, M. J. H., Sarkar, M. A. R., Kalam, M. A., Masjuki, H. H., and Shahabuddin, M. (2012). Heat transfer performance for turbulent flow through a tube using double helical tape inserts. *International Communications in Heat and Mass Transfer*, (39), 818–825.

Chang, S. W., Cai, W. L., and Syu, R. S. (2016). Heat transfer and pressure drop measurements for tubes fitted with twin and four twisted fins on the rod. *Experimental Thermal and Fluid Science,* 74, 220–234.

Chokphoemphun, S., Hinthao, C., Eiamsa-ard, S., Promvonge, P., and Thianpong, C. (2014). Thermal performance in a circular tube with co/counter-twisted tapes. *Advance Material Res*earch, 931–932, 1198–1202.

Chokphoemphun, S., Pimsarn, M., Thianpong, C., and Promvonge, P. (2015). Thermal performance of tubular heat exchanger with multiple twisted-tape inserts. *Chinese Journal of Chemical Engineering,* 23 (5), 755–762.

Dagdevir, T. and Ozceyhan, V. (2021). An experimental study on heat transfer enhancement and flow characteristics of a tube with plain, perforated, and dimpled twisted tape inserts. *International Journal of Thermal Sciences,* 159, 106564.

Datt, R., Bhist, M. S., Kothiyal, A. D., Maithani, R., and Kumar, A. (2018). Effect of the square wing with combined solid ring twisted tape inserts on heat transfer and fluid flow of a circular tube heat exchanger. *International Journal of Green Energy,* 15(12), 663-680.

Datt, R., Kumar, A., Bhist, M. S., Kothiyal, A. D., and Maithani, R. (2019). Hydrodynamic and thermal performance of twisted tape insert provided in heat exchanger tubes: a review. *Frontiers in Heat and Mass Transfer,* 12.

Deshmukh, P. W., Prabhu, S. V., and Vedula, R. P. (2016). Heat transfer enhancement for laminar flow in tubes using curved delta wing vortex generator insert. *Applied Thermal Engineering,* 106, 1415-1426.

Dewan, A., Mahanta, P., Sumithra, R. K., and Kumar, S. P. (2004). Review of passive heat transfer augmentation techniques. *Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy,* 218(7), 509-527. Doi: 10.1243/0957650042456953

Dhamane, N. B., Nalawade, D. B., and Dange, M. M. (2014). Performance Analysis of Wavy Twisted Tape Insert for Heat Transfer in a Circular Tube. *International Journal for Technological Research in Engineering,* 1 (6).

Dogonchi, A. S., Waqas, M., and Ganji, D. D. (2019). Shape effects of Copper-Oxide (CuO) nanoparticles to determine the heat transfer filled in a partially heated rhombus enclosure: CVFEM approach. *International Communications in Heat and Mass Transfer,* 107, 14–23.

Eiamsa-Ard, S. and Wongcharee, K. (2013). Heat transfer characteristics in micro-fin tube equipped with double twisted tapes: effect of twisted tape and micro-fin tube arrangements. *Journal of Hydrodynamics,* 25(2), 205- 214.

Eiamsa-ard, S., Thianpong, C., Eiamsa-ard, P., and Promvonge P. (2009). Convective heat transfer in a circular tube with a short-length twisted tape insert. *International Communications in Heat and Mass Transfer*, 36, 365–371.

Eiamsa-ard, S., Thianpong, C., Eiamsa-ard, P., and Promvonge, P. (2010). Thermal characteristics in a heat exchanger tube fitted with dual twisted tape elements in tandem. *International Communications in Heat and Mass Transfer*, 37, 39–46.

Ghalambaz, M., Arasteh, H., Mashayekhi, R., Keshmiri, A., Talebizadehsardari, P., and Yaïci, W. (2020). Investigation of overlapped twisted tapes inserted in a double-pipe heat exchanger using two-phase nanofluid. *Nanomaterials,* 10, 1656.

Ghalambaz, M., Mashayekhi, R., Arasteh, H., Ali, H. M., Talebizadehsardari, P., and Yaïci, W. (2020). Thermo-hydraulic performance analysis on the effects of truncated twisted tape inserts in a tube heat exchanger. *Symmetry,* 12, 1652.

Gokulnathan, E., Pradeep, S., Jayan, N., Bhatlu, M. L. D., and Karthikeyan S. (2021). Review of heat transfer enhancement on helical coil heat exchanger by additive passive method. *Materials Today: Proceedings,* 37(2), 3024–3027.

Guo, J., Fan, A., Zhang, X., and Liu, W. (2011). A numerical study on heat transfer and friction factor characteristics of laminar flow in a circular tube fitted with center-cleared twisted tape. *International Journal of Thermal Sciences*, (50), 1263-1270.

Hatami, M., Ganji, D., and Gorji-Bandpy, M. (2015). Experimental investigations of diesel exhaust exergy recovery using delta winglet vortex generator heat exchanger. *International Journal of Thermal Sciences,* 93, 52–63.

Hayat, T., Qayyum, S., Waqas, M., and Alsaedi, A. (2016). Thermally radiative stagnation point flow of Maxwell nanofluid due to unsteady convectively heated stretched surface. *Journal of Molecular Liquids,* 224(Part A), 801–810.

Hsiao, K. L. (2014). Nanofluid flow with multimedia physical features for conjugate mixed convection and radiation. *Computers & Fluids,* 104, 1–8.

Huu-Quan, D., Rostami, A. M., Rad, M. S., Izadi, M., Hajjar, A., Xiong, Q. (2021). 3D numerical investigation of turbulent forced convection in a double-pipe heat exchanger with the flat inner pipe. *Applied Thermal Engineering*, 182, 116106.

Ibrahim, E. Z. (2011). Augmentation of laminar flow and heat transfer in flat tubes using helical screw-tape inserts. *Energy Conversion and Management,* (52), 250–257.

Kareem, Z. S., Jaafar, M. M., Lazim, T. M., Abdullah, S., and Abdulwahid, A. F. (2015). Passive heat transfer enhancement review in the corrugation. *Experimental Thermal and Fluid Science*, 68, 22–38.

Karthikeyan, S., Bhuvaneswari, M., Rajan, S., and Sivasankaran, S. (2013). Thermal radiation effects on MHD convective flow over a plate in a porous medium by perturbation technique. *Applied Mathematics and Computational Intelligence*, 2(1), 75–83.

Li, Z., Shahsavar, A., Niazi, K., Al-Rashed, A. A., and Rostami, S. (2020). Numerical assessment on the hydrothermal behavior and irreversibility of MgO-Ag/water hybrid nanofluid flow through a sinusoidal hairpin heat-exchanger. *International Communications in Heat and Mass Transfer*, 115, 104628.

Li, P., Liu Z., Liu W., and Chen G. (2015). Numerical study on heat transfer enhancement characteristics of tube inserted with centrally hollow narrow twisted tapes. *International Journal of Heat and Mass Transfer 88 (Supplement C),* 481–491.

Liang, J., Nielsen, K.K., Engelbrecht, K., and Bahl, C. R. (2020). Heat transfer figures of merit for mapping passive regenerator performance to active regenerator cooling power. *Applied Thermal Engineering,* 181, 115993.

Lim, K. Y., Hung, Y. M., and Tan, B. T. (2017). Performance evaluation of twisted-tape insert induced swirl flow in a laminar thermally developing heat exchanger. *Appl. Therm. Eng. 121 (Supplement C)*, 652–661.

Liu, S. and Sakr, M. (2013). A comprehensive review on passive heat transfer enhancements in pipe exchangers. *Renewable and Sustainable Energy Review*, 19, 64–81.

Liu, P., Zheng, N., Shan, F., Liu, Z., and Liu, W. (2018). An experimental and numerical study on the laminar heat transfer and flow characteristics of a circular tube fitted with multiple conical strip inserts. *International Journal of Heat and Mass Transfer 117 (Supplement C),* 691–709.

Mabood, F., Ibrahim, S. M., Rashidi, M. M., Shadloo, M. S., and Lorenzini, G. (2016). Non-uniform heat source/sink and Soret effects on MHD nonDarcian convective flow past a stretching sheet in a micropolar fluid with radiation. *International Journal of Heat and Mass Transfer*, 93, 674–82.

Mahani, R. B., Ahmadi, A., Hezaveh, H. M., Sepehrirad, M., and Talebizadehsardari, P. (2021). Investigating the effects of different innovative turbulators on the turbulent flow field and heat transfer of a multi-phase hybrid nanofluid. *Journal of Thermal Analysis and Calorimetry*, 143, 1755–1772.

Meyer, J. P. and Abolarin, S. M. (2018). Heat transfer and pressure drop in the transitional flow regime for a smooth circular tube with twisted tape inserts and a square-edged inlet. *International Journal of Heat and Mass Transfer*, 117, 11–29.

Murugesan, P., Mayilsamy, K., and Suresh, S. (2010). Heat transfer and friction factor studies in a circular tube fitted with twisted tape consisting of wire-nails. *Chinese Journal of Chemical Engineering,* 18(6) 1038—1042.

Murugesan, P., Mayilsamy, K., Suresh, S., and Srinivasan, P. S. S. (2011). Heat transfer and pressure drop characteristics in a circular tube fitted with and without a V-cut twisted tape insert. *International Communications in Heat and Mass Transfer*, (38), 329–334.

Nakhchi, M. and Rahmati M. (2020). Entropy generation of turbulent Cu–water nanofluid flows inside thermal systems equipped with transverse-cut twisted turbulators. *Journal of Thermal Analysis and Calorimetry,* 143, 2475–2484.

Nakhchi, M. E., Hatami, M., and Rahmati M. (2021). Experimental evaluation of performance intensification of double-pipe heat exchangers with rotary elliptical inserts. *Chemical Engineering and Processing - Process Intensification,* 169, 108615. doi.org/10.1016/j.cep.2021.108615

Nakhchi, M. E., Hatami, M., and Rahmati, M. (2021). Experimental investigation of performance improvement of double-pipe heat exchangers with novel perforated elliptic turbulators. *International Journal of Thermal Sciences,* 168, 107057. doi.org/10.1016/j.ijthermalsci.2021.107057

Nanan, K., Thianpong, C., Promvonge, P., and Eiamsa-ard, S. (2014). Investigation of heat transfer enhancement by perforated helical twisted-tapes. *International Communications in Heat and Mass Transfer*, (52), 106–112.

Naz, R., Tariq, S., Sohail, M., and Shah, Z. (2020). Investigation of entropy generation in stratified MHD Carreaunanofluid with gyrotactic microorganisms under Von Neumann similarity transformations. *The European Physical Journal Plus,* 135, 178.

Padmanabhan, S., Reddy, O. Y., Yadav, K. V. A. K., Raja, V. B., and Palanikumar, K. (2021). Heat transfer analysis of double tube heat exchanger with helical inserts. *Mater. Today: Proc.*

Pal, D. and Mondal, H. (2011). Effects of SoretDufour, chemical reaction, and thermal radiation on MHD non-Darcy unsteady mixed convective heat and mass transfer over a stretching sheet. *Communications in Nonlinear Science and Numerical Simulation,* 16(4), 1942–1958.

Piriyarungrod, N., Kumar, M., Thianpong, C., Pimsarn, M., Chuwattanakul, V., and Eiamsa-ard, S. (2018). Intensification of thermo-hydraulic performance in heat exchanger tube inserted with multiple twisted tapes. *Applied Thermal Engineering,* 136, 516–530.

Ponnada, S., Subrahmanyam, T., and Naidu S. V. (2019). A comparative study on the thermal performance of waterin a circular tube with twisted tapes, perforated twisted tapes, and perforated twisted tapes with an alternate axis. *International Journal of Thermal Sciences,* (136), 530–538

Rios-Iribe, E. Y., Cervantes-Gaxiola, M. E., Rubio-Castro, E., Ponce-Ortega, J. M., González-Llanes, M. D., Reyes-Moreno, C., and Hernández-Calderón, O. M. (2015). Heat transfer analysis of a non-Newtonian fluid flowing through a circular tube with twisted tape inserts. *Applied Thermal Engineering*, *(Supplement C),* 84, 225–236.

Rivier, M., Sebastian, P., Goli, T., Raffray, G., and Collignan, A. (2015). Heat transfer enhancement of a circular tube heat exchanger fitted with an elliptic shaped turbulator designed in the context of developing countries. *Applied Thermal Engineering,* 81, 92–101.

Sarada, S. N., Raju, S. R. K., Radha, K., and Sunder, L. S. (2010). Enhancement of heat transfer using varying-width twisted tape inserts. *International Journal of Engineering, Science and Technology*, 2(6), 107-118.

Sheikholeslami, M., Ghasemi, A., Li, Z., Shafee, A., and Saleem, S. (2018). Influence of CuO nanoparticles on heat transfer behavior of PCM in solidification process considering radiative source term. *International Journal of Heat and Mass Transfer*, 126, 1252–64.

Singh, S. A. R., Kumar A., and Maithani, R. (2018). Experimental investigation of heat transfer and fluid flow behavior in multiple square perforated twisted tape with square wing inserts heat exchanger tube. *Heat and Mass Transfer,* 54, 1813–1826.

Singh, S. K. and Sarkar, J. (2021). Thermohydraulic behavior of concentric tube heat exchanger inserted with conical wire coil using mono/hybrid nanofluids. *International Communications in Heat and Mass Transfer*, 122, 105134.

Singh, V., Chamoli, S., Kumar, M., and Kumar, A. (2016). Heat transfer and fluid flow characteristics of heat exchanger tube with multiple twisted tapes and solid rings inserts. *Chemical Engineering and Processing,* 102,156–168.

Sohail, M., Naz, R., and Abdelsalam, S. I. (2020). On the onset of entropy generation for a nanofluid with thermal radiation and gyrotactic microorganisms through 3D flows. *Basic Science Engineering,* 45, 045206.

Sui, J., Zhao, P., Cheng, Z., and Doi, M. (2018). Influence of particulate thermophoresis on convection heat and mass transfer in a slip flow of a viscoelasticity-based micropolar fluid. *International Journal of Heat and Mass Transfer*, 119, 40–51.

Suri, A. R. S., Kumar, A., and Maithani, R. (2017). Heat transfer enhancement of heat exchanger tube with multiple square perforated twisted tape inserts: experimental investigation and correlation development. *Chemical Engineering and Processing: Process Intensification,* 116, 76–96.

Thejaraju, R., Girisha, K., Manjunath, S., and Dayananda, B. (2020). Experimental investigation of turbulent flow behavior in an air to air double pipe heat exchanger using novel para winglet tape. *Case Studies in Thermal Engineering,* 22, 100791.

Vashistha, C., Patil, A. K., and Kumar, M. (2016). Experimental investigation of heat transfer and pressure drop in a circular tube with multiple inserts. *Applied Thermal Engineering* (Supplement C), 96, 117–29.

Waqas, M., Jabeen, S., Hayat, T., Khan, M. I., and Alsaedi, A. (2019). Modeling and analysis for magnetic dipole impact in nonlinear thermally radiating Carreau nanofluid flow subject to heat generation. *Journal of Magnetism and Magnetic Materials,* 485, 197–204.

Wongcharee, K. and Eiamsa-ard, S. (2011). Friction and heat transfer characteristics of laminar swirl flow through the round tubes inserted with alternate clockwise and twisted tapes twisted-tapes. *International Communications in Heat and Mass Transfer,* (38), 348–352.

Wongcharee, K. and Eiamsa-ard, S. (2011). Heat transfer enhancement by twisted tapes with alternate axes and triangular, rectangular, and trapezoidal wings. *Chemical Engineering and Processing*, (50), 211–219.

Wu, H., Wang, J., and Tao, Z. (2011). Passive heat transfer in a turbulent channel flow simulation using large eddy simulation based on the lattice Boltzmann method framework. *International Journal of Heat and Fluid Flow,* 32(6), 1111–1119.

Xiuzhen, L., Zhu, D., Yin, Y., Tu, A., and Liu, S. (2019). Parametric study on heat transfer and pressure drop of a twisted oval tube bundle with the inline layout. *International Journal of Heat and Mass Transfer*, (135), 860–872

Yaningsih, I., Wijayanta, A.T., Miyazaki, T., and Koyama, S. (2018). Thermal hydraulic characteristics of turbulent single-phase flow in an enhanced tube using a louvered strip insert with various slant angles. *International Journal of Thermal Sciences,* 134, 355–362.

Zhang, C., Wang, D., Ren, K., Han, Y., Zhu, Y., Peng, X., Deng, J., and Zhang, X. (2016). A comparative review of self-rotating and stationary twisted tape inserts in the heat exchanger. *Renewable and Sustainable Energy Reviews*, 53, 433–449.

Shrikant Arunrao Thote has completed his M. Tech in 2012 from Rashtrasant Tukadoji Maharaj Nagpur University, Nagpur (MH)-India. He is a lifetime member of Indian Society of Heating, Refrigerating and Air Conditioning Engineers, Indian Society for Technical Education & Quality Circle Forum of India, and member of International Association of Engineers. Now he is doing a Ph.D. from the Department of Mechanical Engineering, Oriental University- Indore (MP) - India.

Netra Pal Singh has completed B.Sc. (Math) in 1995 from Agra University (UP), B. E. in Mechanical Engineering in 2000 from OIST, Barkatullah University Bhopal (MP), M.E. in Mechanical Engineering in 2002 from MNREC (NIT) Allahabad (UP) and Ph.D. in Mechanical Engineering in 2013 from Jamia Millia Islamia University, New Delhi. He has published more than thirty papers in national and international journals and conferences. He also acquired the best paper award at the national conference (TAME-12) from Haryana Government. He is a member of Foreign Invested Enterprise and a lifetime member of Indian Society for Technical Education & Fluid Mechanics and Fluid Power. He was also recognized as a Chartered Engineer, India from the Institution of Engineers, Kolkata. He has worked as a research associate on the ARDB project for three years at IIT Delhi. He has more than twenty-one years of experience in Research, Industry & Teaching and now he is working as a Professor in the Department of Mechanical Engineering, Oriental University- Indore (MP) – India