A Review on the Combined Heat Transfer Enhancement Techniques

Sagar S. Thosre
M.Tech. (Heat Power Engg.), Department of Mechanical Engineering,
Government Collage of Engineering, Karad,
Maharashtra, India.

Omkar C. Nikam
M.Tech. (Heat Power Engg.), Department of Mechanical Engineering,
Government Collage of Engineering, Karad,
Maharashtra, India.

Nitin V. Sali
Associate Professor, Department of Mechanical Engineering,
Government Collage of Engineering, Karad,
Maharashtra, India.

Abstract
Enhancing heat transfer mechanism are used in many industrial application like heat exchanger, air conditioning, chemical reactor and refrigeration systems. Therefore several techniques have been promoted to enhance heat transfer rate and to decrease the size and cost of equipment especially the heat exchanger. This paper summarizes the important result regarding various combination of heat transfer enhancing techniques use in heat exchanger, channels like twisted tape with nanofluid, grooved or corrugated tube with nanofluid, grooved or corrugated tube with twisted tape inserts, wire coil inserts and nanofluid, Twisted tape inserts with wire coil inserts, etc. The authors hope that this review can help to readers to research in future in various sectors. At last, the paper identifies the opportunities for future research.

Keywords: twisted tape inserts, nanofluid, grooved or corrugated tube, wire coil inserts, tube in tube heat exchanger.

Introduction

Heat transfer devices have been used for the conversion and recovery of heat in many industrial and domestic applications. Some examples are boiling of liquid and condensation of steam in power plants, thermal processes involved in pharmaceutical and chemical industries, sensible heating and cooling of milk in dairy industries, heating of fluid in concentrated solar collector and cooling of electrical machines and electronic devices among others. Enhancing the performance of a heat transfer device is therefore of great interest since it can result in energy, material and cost saving. Heat transfer enhancement techniques generally reduce the thermal resistance either by increasing the effective heat transfer surface area or by generating turbulence in the fluid flowing inside the device. Rough surfaces or extended surfaces are used for the purpose of increasing the effective surface area whereas inserts, turbulatorsetc. are used for generating the turbulence. These changes are usually accompanied by an increase in pumping power which can results in higher cost. The effectiveness of a heat transfer enhancement technique can be evaluated by the Thermal Performance Factor (TPF) which represents the ratio of the relative effect of change in heat transfer rate to change in friction factor.

The use of **twisted tape inserts** is one of the important passive methods of heat transfer enhancement. Twisted tapes are generally the metallic strips which are twisted in some specific shape and dimensions and inserted across the flow. They are also considered as swirl flow devices and act as turbulators used to impart swirl flow which leads to the increase in heat transfer coefficient. Pitch and twist ratio are the important parameters used to study the performance of twisted tapes. Pitch of a twisted tape is the length between two points on a plane, parallel to the axis of the tape whereas twist ratio of a twisted tape is the ratio of pitch to inside diameter of the tube. Several experimental and numerical studies have been carried out by various scientists and researchers on heat transfer augmentation using twisted tapes.
Low thermal conductivity of process fluid hinders high compactness and effectiveness of heat exchangers, although a variety of techniques is applied to enhance heat transfer. Improvement of the thermal properties of energy transmission fluids may become a trick of augmenting heat transfer. An innovative way of improving the thermal conductivities of fluids is to suspend small solid particles in the fluids. Various types of powders such as metallic, non-metallic and polymeric particles can be added into fluids to form slurries. The thermal conductivities of fluids with suspended particles are expected to be higher than that of common fluids.
The applications of **Wire coil inserts** are like oil cooling devices, preheaters or fire tube boilers. They advantages of wire coil inserts in comparison to other heat exchanger performance enhancement techniques can be their low cost, they don’t change mechanical strength of original plain tube, their installation and removal is easy and they can be installed in the existing heat exchanger with smooth tube.

In condensation and evaporation, it is found that Tube with inner **grooves** could perform better compared to Tube without grooved. Heat transfer coefficient for grooved Tube is higher than that of Tube without grooved. In such a way there are various techniques to enhanced heat transfer rate.

Review:

In the following section we have give the review of various heat transfer enhancement techniques one by one.

Twisted Tape Inserts with Nanofluid:

Sharma et al. (2009) [1]: Experimental investigation to study heat transfer and friction characteristics in the transition range of flow of Al2O3 nanofluid through a tube and equipped with twisted tape inserts. It was obtained from the results that convective heat transfer coefficient was increased in Al2O3 nanofluid flow as compared to water flow. Also, heat transfer and pressure drop results obtained for the flow of nanofluid through tube equipped with twisted tapes of various twist ratios deviates from the values determined by using equations of single phase flow. New equation was developed to determine Nusselt number for the transition flow of nanofluid as well as water through a circular plain tube and tube equipped with twisted tape. The correlation was presented to predict the friction factor in transition region.

Wongcharee K and Eiamsa-ard (2011) [2]: Experimental study to analyse heat transfer enhancement of ofCuO/water nanofluids in micro-fin tube fitted with dual twisted tapes. The experiments were performed with CuO/water nanofluids having concentrations between 0.3% and 1.0% by volume and Reynolds number range 5650 – 17,000. The results found increase of heat transfer rate with increase of nanofluid concentration. Also microfin tube equipped with dual twisted tapes showed high thermal performance factor.

Raja Sekhar et al. (2013) [3]: Experimental investigation to study heat transfer and pressure drop characteristics for various volume concentrations of Al2O3 nanofluids through a pipe equipped with twisted tapes. The experiments were carried out at low Reynolds number (800-2200) with water and water based Al2O3 nanofluids. The results showed that the values of heat transfer coefficient for nanofluids were found higher than those for water. Also the highest value of friction factor was obtained with nanofluid of 0.5% particle concentration in comparison with water. The study concluded that enhancement of heat transfer takes place with the increase in Reynolds number and particle concentration.

Waghole et al. (2013) [4]: Experimental study on heat transfer and friction characteristics with different volume for flow through tube of absorber/receiver of parabolic trough collector having twisted tapes and no twisted tape inserts. Experiments were conducted using silver nanofluid and water. The range of Reynolds number considered was 500 – 6000 and twist ratios of the twisted tape was considered within the range of 0.577 – 1.732. The results revealed that use of twisted tapes inserts yields considerable heat transfer enhancement in absorber. Also, for volume concentration range 0 0.1% of silver nanofluid, the friction factor and heat transfer coefficient was found higher as compared to water flow through tubes of absorber/receiver. In addition to this, values of friction factor, Nusselt number and efficiency enhancement were found to be 1.0 1.75 times, 1.25 – 2.10 times and 135% 205% more compared to absorber/receiver with plain tube (without twisted tape).

Maddah et al. (2014) [5]: Carried out an experimental investigation on heat transfer enhancement of Al2O3/water nanofluid in a horizontal double pipe heat exchanger equipped with modified twisted tapes. The study was done under turbulent flow conditions (Reynolds no. range 5000–21,000) with different geometrical progression ratio (GPR: ratio of pitch length along the twist) of twists. It was found in the results that heat transfer rate and friction factor with twisted tape and nanofluids are respectively; 1.03 to 4 and 1.4 to 2.8 times those in the plain tube.

Esmaeilzadeh, et al. (2014) [6]: Experimentally studied the effect of Al2O3/water nanofluids and twisted tape inserts with various thicknesses at constant heat flux in a circular tube on heat transfer. The nanofluids with 0.5% and 1% volume fraction was taken. The insert had twist ratio of 3.21 with thickness 0.5 mm, 1 mm and 2 mm. The laminar regime with Reynolds numbers150 to 1600 was considered. The results showed that better enhancement with more thickness of tape and nanofluids with higher concentration.

Eiamsa-ard, et al. (2014) [7]: Investigated heat transfer in a tube with combination of multiple twisted tapes in different arrangements and TiO2 nanoparticles/water. It was concluded that multiple twisted tapes with nanofluids showed better results compared with plain tube or the tube inserted a single twisted tape. This was due to increased surface area, swirl intensity and fluid mixing with multi-longitudinal vortices flow. So more studies should be performed by using combination of nanofluids and different types of inserts with minimum friction factor and maximum heat transfer. Further correlations which could be used for wider range and predicting accurate results should be developed.

Azmi, et al. (2014) [8]: Experimentally showed enhancement in heat transfer coefficients with of tape inserts in tube using TiO2/water nanofluid. The particle loading upto 3.0% at 30 C was taken in Reynolds range of 8000-30000. Results revealed a considerable heat transfer augmentation of 23.2% at 1.0% concentration. Further as in earlier cases the HTC increased with decrease in twist ratio. Observation showed increase in HTC by 81.1% at Reynolds number 23,558 at 1.0% concentration and twist ratio 5, in comparison to flow of water in a tube. Further with greater particle loading of 3% the decrease in An increase in decreased heat transfer was observed.

K. Aliabadi, et al. (2015) [9]: investigated heat transfer and overall performance in a plane tube with twisted-tape inserts (variable twist lengths) in the presence of Cu– water nanofluids. The weight concentration of nanofluids was 0, 0.1, and 0.3 wt.%. The tests were performed in turbulent regime

(7500 - 15,000). It was observed that all inserts having non-uniform twist lengths, performed better than the uniform one. Using short twist lengths at the beginning of inserts lead to increase in the heat transfer. By using Cu–water nanofluid (0.3 wt.% concentration) and twisted-tape insert (Low to High twist lengths) showed the overall enhancement ratio improvement of nearly 87%.

Wire Coil inserts with Nanofluid:

Chandrasekar, et al. (2010) [10]: Experimentally studied the heat transfer of Al2O3/water (0.1% Vol. conc.) nanofluid in a horizontal tube with and without wire coil inserts in laminar regime. Better heat transfer was observed with nanofluid combined with wire coil insert. This was interpreted due to dispersion or backmixing which flattens the temperature distribution and make the temperature gradient between the fluid and wall steeper.

S. S. Chougule et al (2015) [11]: Experimentally studied the fully developed laminar flow convective heat transfer and friction factor characteristics of MWCNT/water nanofluid (φ=0.15%) flowing through a uniformly heated horizontal tube with and without wire coil The stable nanofluid was prepared by dispersing CNTs of diameter 10 nm in distilled water. The experiments using the plain tube and with wire coil inserts were also carried out with distilled water as the working fluid for experimental setup validation and comparison. The experimental results reveal that the use of nanofluids increases the heat transfer rate with negligible increase in friction factor in the plain tube and the tube fitted with wire coil inserts.

Eda Feyza Akyurek et al (2018) [12]: Analysed Experimentally that Nanofluids are a novel class of heat transfer suspensions of metallic or nonmetallic nanopowders with a size of less than 100 nm in base fluids and they can increase heat transfer potential of the base fluids in various applications. For comparison, an experiment using water as the working fluid in the heat exchanger without wire coils was also performed. Turbulent forced convection heat transfer and pressure drop characteristics of Al2O3–water nanofluids in a concentric tube heat exchanger with and without wire coil turbulators were experimentally investigated in that research. Experiments effected particle volume concentrations of 0.4-0.8-1.2-1.6 vol.% in the Reynolds number range from 4,000 to 20,000. Two turbulators with the pitches of 25 mm and 39 mm were used. The average Nusselt number increased with increasing the Reynolds number and particle concentrations. Moreover, the pressure drop of the Al2O3–water nanofluid showed nearly equal to that of pure water at the same Reynolds number range. As a result, nanofluids with lower particle concentrations did not show an important influence on pressure drop change. Nonetheless, when the wire coils used in the heat exchanger, it increased pressure drop as well as the heat transfer coefficient.

Grooved or Corrugated tube with Inserts:

H. Usui et al. (1984) [13]: The combined use of an internally grooved rough tube and a twisted tape was proposed as a technique for enhancing heat transfer in single-phase turbulent heat transfer. A remarkable increase in heat transfer efficiency was obtained when the heat transfer promoters satisfied the following conditions. 1) The tape should be counter-twisted against the rotation of the grooves. Better performance was obtained when the cross angle between the twisted tape and the groove was near 90 degrees. 2) Relative roughness of groove should be considerably large. Typically, 2.2% of relative roughness to the tube diameter gave better enhancement of heat transfer than the case of 1.1 % of relative roughness. The best performance of the heat transfer promoter proposed in this work can be stated as follows : The heat transfer coefficient at the same pumping power consumption reached 3.0-3.5 times larger than that of a smooth tube, and a 70-75% reduction of heat transfer surface compared with a smooth tube was obtained under conditions of the same pumping power and the same heat duty.

V. Zimparov (2001) [14]: Experimentally found Heat transfer and isothermal friction pressure drop for two three-start spirally corrugated tubes combined with five twisted tape inserts with different relative pitches in the range of Reynolds number 3×10^3–6×10^4. The characteristic parameters of the tubes are: height to diameter ratio, e/D_i= 0.0407 and 0.0569; and relative pitch, H/D_i= 15.3, 12.2, 7.7, 5.8, 4.7. Significantly, higher friction factor and inside heat-transfer coefficients than those of the smooth tube under the same operating conditions have been observed. And it found that water side heat transfer coefficient is high when a corrugated tube was combined with twisted tape.

V. Zimparov (2002) [15]: Experimentally found Heat transfer and isothermal friction pressure drop for two single-start spirally corrugated tubes combined with five twisted-tape inserts with different relative pitches in the range of Reynolds number 4×10^3– 6×10^4. The characteristic parameters of the tubes are: height-to-diameter ratio, e/D i= 0.0371 and 0.0441; and relative pitch, H/D i= 7.7, 6.25, 3.95, 2.95, 2.4. Significantly, higher friction factor and inside heat transfer coefficients than those of the smooth tube under the same operating conditions have been observed. It is concluded that the use of corrugated tube in conjuction with twisted tape is proposed as method of enhancing heat transfer in single-phase turbulent flow. It has been experimentally shows that the heat transfer is enhanced very considerably when the roughness of corrugated tube has a certain value (e/D_i=0.044) and relative pitch H/D_i decreases.

P. Bharadwaj et al. (2009) [16]: experimentally determined pressure drop and heat transfer characteristics of flow of water in a 75-start spirally grooved tube with twisted tape insert are presented. Laminar to fully turbulent ranges of Reynolds numbers have been considered. The grooves are clockwise with respect to the direction of flow. Compared to smooth tube, the heat transfer enhancement due to spiral grooves is further augmented by inserting twisted tapes having twist ratios $Y \simeq 10.15$, 7.95 and 3.4. It is found that the direction of twist (clockwise and anticlockwise) influences the thermo-hydraulic characteristics. Constant pumping power comparisons with smooth tube characteristics show that in spirally grooved tube *with and without* twisted tape, heat transfer increases considerably in laminar and moderately in turbulent range of Reynolds numbers. However, for the bare spiral tube and for spiral tube with anticlockwise twisted tape ($Y = 10.15$), reduction in heat transfer is noticed over a transition range of Reynolds numbers. It is found by experimentally that for spirally grooved tube with twisted tape shows maximum enhancement of 600% in the laminar range and 140% in the turbulent range.

Pranab Kumar Pal (2014) [17]: The experimental friction factor and Nusselt number data for laminar flow of viscous oil through a circular duct having integral spiral corrugation roughness and fitted with twisted tapes with oblique teeth have been presented. The thermohydraulic performance has been evaluated. The major findings of this experimental investigation are that the twisted tapes with oblique teeth in combination with integral spiral corrugation roughness perform significantly better than the individual enhancement technique acting alone for laminar flow through a circular duct up to a certain value of fin parameter.

Miao Gui et al. (2016) [18]; Experimentally studied the both transverse groove tube and twisted tape, as an alternative to traditional smooth tube in shell and tube heat exchanger, are useful techniques for the enhancement of heat transfer. In that experimental study for the combination of transverse groove tube and twisted tapes was carried out. The flow and heat transfer characteristics of heat transfer oil flowing in the transverse groove tube (TGT) fitted with continuous twisted tape (CT), discontinuous twisted tape (DT) and perforated twisted tape (PT) was investigated with the Reynolds numbers ranging from 600 to 8000, respectively. The effect of the geometrical parameters of twisted tapes on the heat transfer performance was considered. The comprehensive performance of heat transfer of the transverse groove tube fitted with twisted tapes was analyzed using traditional method and the some conclusions can be obtained that the modified heat transfer enhancement tubes, TGT-CT, DT and PT, all show better effects of heat transfer enhancement than ST and ST-CT.

Grooved or Corrugated Tube with Nanofluid:

M.A. Ahmed et al. (2015) [19]: Numerically and experimentally investigated the convective heat transfer of SiO_2-water nanofluid flow in channels with different shapes is numerically and experimentally studied over Reynolds number ranges of 400-4000. Three different channels such as trapezoidal, sinusoidal and straight were fabricated and tested. The SiO_2-water nanofluid with different volume fractions of 0%, 0.5% and 1.0% were prepared and examined. All physical properties of nanofluid which are required to evaluate the flow and thermal characteristics have been measured. In the numerical aspect of the current work, the governing equations are discretized by using the collocated finite volume method and solved iteratively by using the SIMPLE algorithm. In addition, the low Reynolds number k-ε model of Launder and Sharma is employed to compute the turbulent non-isothermal flow in the present study. The results showed that the average Nusselt number and the heat transfer enhancement increase as the nanoparticles volume fraction increases, however, at the expense of increasing pressure drop. Furthermore, the trapezoidal-corrugated channel has the highest heat transfer enhancement followed by the sinusoidal-corrugated channel and straight channel. The numerical results are compared with the corresponding experimental data, and the results are in a good agreement.

N. V. Sali et al. (2017) [20]: Experimentally investigated the tube in tube heat exchanger in which four different heat exchanger test sections are compared for different thermal characteristics. Tubes of heat exchanger test section are made up with single start internal/external and combined grooves. Overall heat transfer coefficient is compared with increase in inlet temperature by keeping flow rate constant. Variation of Reynolds number with Nusselt number and friction factor are checked by varying flow rate. Water, Al_2O_3 Nanofluid of 0.25%, 0.50%, 0.75% has been studied. The results are compared with Open Literature. It has been observed that overall heat transfer coefficient increases with increase in concentration of nano-fluid. Increase in surface irregularities leads to increase in pressure drop. For plain pipe heat exchanger 48% increase in overall heat transfer coefficient is observed for 0.75% concentrated Al_2O_3 nanofluid as compared to distilled water. Same was 27%, 25% and 16% for section 2, 3 and 4 respectively. Nusselt number varies as 10.25, 11.89, 4.75, 7.5% respectively for test section 1,2,3,4 respectively. Pressure drop of 37% is observed in grooved tubes as compared to plain tubes.

Twisted tape and Wire coil inserts:

Pongjet Promvonge (2008) [21]: Experimentally investigated Influences of insertion of wire coils in conjunction with twisted tapes on heat transfer and turbulent flow friction characteristics in a uniform heat-flux, circular tube using air as the test fluid. The wire coil used as a turbulator is placed inside the test tube while the twisted tape is inserted into the wire coil to create a continuous impinging swirl flow along the tube wall. The effects of insertion of the two turbulators with different coil pitch and twist ratios on heat transfer and friction loss in the tube are examined for Reynolds number ranging from 3000 to 18,000. The experimental results are compared with those obtained from using wire coil/twisted tape alone, apart from the smooth tube. The results indicate that the presence of wire coils together with twisted tapes leads to a double increase in heat transfer over the use of wire coil/twisted tape alone. The combined twisted tape and wire coil with smaller twist and coil pitch ratios provides higher heat transfer rate than those with larger twist and coil pitch ratios under the same conditions.

S. Eiamsa-ard et al. (2010) [22]: Heat transfer, friction factor and thermal performance behaviors in a tube equipped with the combined devices between the twisted tape (TT) and constant/periodically varying wire coil pitch ratio are experimentally investigated. The periodically varying three coil pitch ratios were arranged into two different forms: (1) D-coil (decreasing coil pitch ratio arrangement) and (2) DI-coil (decreasing/increasing coil pitch ratio arrangement) while the twisted tapes were prepared with two different twist ratios. Each device alone is also tested and the results are subjected for comparison with those from the combined devices. The experiments were conducted in a turbulent flow regime with Reynolds numbers ranging from 4600 to 20,000 using air as the test fluid. Compared to each enhancement device, the heat transfer rate is further augmented by the compound devices. Over the range investigated, the highest thermal performance factor of around 1.25 is found by using DI-coil in common with the TT at lower Reynolds number.

Sujoy Kumar Saha et al. (2012) [23]: Experimentally found friction factor and Nusselt number data for laminar flow through a circular duct having wire coil inserts and fitted with center-cleared twisted tape have been presented. Predictive friction factor and Nusselt number correlations have also been presented. The thermohydraulic performance has been evaluated.The major findings of this experimental investigation are that the center-cleared twisted tapes in combination with wire coil inserts perform better than the individual enhancement technique acting alone for laminar flow through a circular duct up to a certain amount of center-clearance.

Seyed Sharifodin Hosseini et al (2017) [24]: Studied in which carried out in a mild and wet region, designed and fabricated an indirect solar desalination system (double loops), to investigate effect of employing separate and combined insertion of twisted tape and wire coil turbulators in a spiral heat exchanger at diffrent mass rate of salty water on productivity of desalination in this system. In comparison to simple spiral tube heat exchanger, the insertion of the turbulators in a circular tube heat exchanger would enhance discharge rate between 2% to 14% in using Twisted Tape, and combined Twisted Tape & Wire Coil, respectively. In addition, simultaneous insertion of twisted tape and wire coil could increase the output to its maximum discharge. The best working conditions of this system was to put 1 lit/s mass rate of salty water. Productivity system increased up to 9.7% too.

Conclusion

In this review paper very recent experimental and numerical studies of various combined heat transfer enhancement techniques. There are lot of works which emphasize the increased heat transfer rate and on the other hand which stress the decreased pressure drop or minimized friction factor.
From the of study of various techniques to enhanced heat transfer it is concluded that the heat transfer enhancement by using combined techniques (more than one techniques) is always more than the single enhancement techniques. In every techniques heat transfer rate increases also the pressure drop is increases.

References:

1. Sharma KV, Syam Sundar L, Sarma PK. "Estimation of heat transfer coefficient and friction factor in the transition flow with low volume concentration of Al2O3 nanofluid flowing in a circular tube and with twisted tape insert". IntCommun Heat Mass Transf 2009;36:503–7.
2. Wongcharee K, Eiamsa-ard S. "Enhancement of heat transfer using CuO/water nanofluid and twisted tape with alternate axis". Int. Commun. Heat Mass Transfer 2011; 38:742–8.
3. Raja Sekhar Y, Sharma KV, Thundil Karupparaj R, Chiranjeevi C. "Heat transfer enhancement with Al2O3 nanofluids and twisted tapes in a pipe for solarthermal applications", International Conference on Design and Manufacturing (IConDM 2013). ProcediaEng 2013;64:1474–84.
4. Dnyaneshwar R, Waghole, R. M. Warkhedkar, V. S. Kulkarni, R. K. Srivastava, "Experimental investigations on heat transfer and friction factor of silver nanofluid in absorber/receiver of parabolic trough collector with twisted tape inserts", 68th Conference of the Italian Thermal Machines Engineering Association, ATI2013, Energy Procedia 45; 2014. p. 558–567.
5. Maddah H, Alizadeh M, Ghasemi N, Alwi SRW. "Experimental study of Al2O3/ water nanofluid turbulent heat transfer enhancement in the horizontal double pipes fitted with modified twisted tapes". Int J. Heat Mass Transfer 2014;78:1042–54.
6. Esmaeilzadeh, E., Almohammadi, H., Nokhosteen, A., Motezaker, A., & Omrani, A. N. (2014). "Study on heat transfer and friction factor characteristics of γ-Al 2 O 3/water through circular tube with twisted tape inserts with different thicknesses". International Journal of Thermal Sciences, 82, 72-83.
7. Eiamsa-ard, S., & Kiatkittipong, K. (2014). "Heat transfer enhancement by multiple twisted tape inserts and TiO2/water nanofluid. Applied Thermal Engineering", 70(1), 896-924.
8. Azmi, W. H., Sharma, K. V., Sarma, P. K., Mamat, R., & Anuar, S. (2014). "Comparison of convective heat transfer coefficient and friction factor of TiO 2 nanofluid flow in a tube with twisted tape inserts". International Journal of Thermal Sciences, 81, 84-93.
9. Khoshvaght-Aliabadi, M., & Eskandari, M. (2015). "Influence of twist length variations on thermal– hydraulic specifications of twisted-tape inserts in presence of Cu–water nanofluid". Experimental Thermal and Fluid Science, 61, 230-240.
10. Chandrasekar, M., Suresh, S., & Bose, A. C. (2010). "Experimental studies on heat transfer and friction factor characteristics of Al 2 O 3/water nanofluid in a circular pipe under laminar flow with wire coil inserts". Experimental Thermal and Fluid Science, 34(2), 122-130.
11. S. S. Chougule, Vishal V. Nirgude, Prajakta D. Gharge, Mayank Modak, S. K. Sahu "Heat Transfer Enhancements of Low Volume Concentration CNT/water Nanofluid and Wire Coil Inserts in a Circular Tube" 5th International Conference on Advances in Energy Research, ICAER 2015, 15-17 December 2015, / Energy Procedia 90 (2016) 552 – 558.

12. Akyürek, E.F., Geliş, K., Şahin, B., Manay, E., "Experimental Analysis for Heat Transfer of Nanofluid with Wire Coil Turbulators in a Concentric Tube Heat Exchanger" Results in Physics (2018).
13. H. Usui, K. Sano, K. Iwashhita, A. Isozaki, Heat transfer enhancement effects by a combined use of internally grooved rough surfaces and twisted tape, Heat Transfer Jpn. Res. 13 (4) (1984) 19–32.
14. V. Zimparov, "Enhancement of heat transfer by combination of three start corrugated tubes with a twisted tape", Int. J. Heat Mass Transfer 44 (2001) 551– 574.
15. V. Zimparov, "Enhancement of heat transfer by combination of single-start spirally corrugated tubes with a twisted tape", Experimental Thermal and Fluid Science 25 (2002) 535-546.
16. P.Bharadwaj, A.D.Khondge, A.W.Date "Heat transfer and pressure drop in a spirally grooved tube with twisted tape insert' International Journal of Heat and Mass Transfer Volume 52, Issues 7–8, March 2009, Pages 1938-1944.
17. Pal PK, Saha SK . "Experimental investigation of laminar flow of viscous oil through a circular tube having integral spiral corrugation roughness and fitted with twisted tapes with oblique teeth" Experimental Thermal and Fluid Science, 2014, 57: 301-309.
18. Miao Gui, Qincheng Bi and Yajun Guo "Experimental Study on the Heat Transfer Enhancement by the Combination of Transverse Groove Tube and Twisted Tape Inserts" ASME 2016 Power Conference ISBN: 978-0-7918-5021-3.
19. M.A. Ahmed, M.Z. Yusoff, K.C., N.H. Shuaib, "Numerical and experimental investigation on the heat transfer enhancement in corrugated channels using SiO_2-water nanofluid" 2015, case study in thermal engineering.
20. N. V. Sali, et al. "Experimental Investigation of grooved tube in tube heat exchanger with and without Nano-fluid" International Journal of Scientific & Engineering Research, Vol. 8, Issue 4, April-2017.
21. P. Promvonge, "Thermal augmentation in circular tube with twisted tape and wire coil tabulators", Energy Convers. Manag. 49 (2008) 2949–2955. [41
22. S. Eiamsa-ard, P. Nivesrangsan, S. Chokphoemphun, P. Promvonge, "Influence of combined non-uniform wire coil and twisted tape inserts on thermal performance characteristics", Int. Commun. Heat Mass Transf. 37 (2010) 850–856.
23. Sujoy Kumar Saha, bikash kumar Barman, Soumitra Banerjee "Heat transfer enhancement of laminar flow through a circular tube having wire coil inserts and fitted with center-cleared twisted tape" Journal of thermal science and Engineering Applications, Sept 2012, Vol. 4.
24. Seyed Sharifodin Hosseini__ et al. "Experimental investigation of a solar desalination system using twisted tape and wire coil inside of spiral heat exchanger" Desalination 420 (2017) 34-44.