# Heat Transfer Through Duct With Twisted Tape Inserts: A Review

**Anant Kumar**
M.Tech. Scholar, Mechanical Engineering Department, Sagar Institute of Research and Technology, Bhopal MP, India,kranant92@Yahoo.com

**Irshad Ahmad Khan**
Associate Professor, Mechanical Engineering Department, Sagar Institute of Research and Technology, Bhopal MP, India, irshadak85@gmail.com

***Abstract—Twisted tape is one of the most important passive techniques, which has been proved to disturb the flow fluid in tube and then strengthen the heat transfer efficiency. Inserts are used to enhance the heat transfer rates between the two fluids in heat exchanger tubes. A variety of tube inserts such as twisted tape, wire coil, swirl flow generator has been investigated for their effect on heat transfer rates and fluid friction. This paper reviews the works pertaining to the application of different class of tube inserts in order to comprehend the prevailing mechanism of fluid flow and heat transfer. An attempt has been made to elucidate the fluid flow behavior sustained by the particular class of insert that controls the heat transfer rates across the thermal boundary layer attached to the tube wall.***

***Keywords—Twisted Tap, Nusselt Number, Heat transfer, Pressure Drop***

## I. INTRODUCTION

The thermal performance of a heat exchanger depends on the thermal resistance between the heat exchanging fluids. It has been observed that the convective resistance at the solid-fluid interface offers a major impediment in the path of heat transfer. Several techniques have been employed so far to enhance the heat transfer rates by increasing turbulence near the tube wall. The passive methods of heat transfer enhancement include the artificially roughened inner tube surface, axially located fluid displacement promoters, and vortex generators. The application of different types of tube inserts is found useful in promoting turbulence by the way of swirl motion, secondary flows and vortices that leads to higher heat transfer coefficient at the tube wall. It has been reported in the literature that the twisted tape inserts bring out considerable heat transfer enhancements but usually preferred for the laminar flow as it incur severe frictional losses in turbulent flow. [1-5]

Need of high heat transfer in heat exchangers has promoted to develop the various techniques, which enhanced the convective heat transfer by reducing the thermal resistance at the heated surface. Generally, enhanced heat transfer rate is accompanied with increase in pressure drop, leading to high pumping power requirement. Researchers have been trying to develop such techniques, which enhance the heat transfer rate at a minimum possible pressure drop. These techniques include the forced flow of fluid such as air, water, mineral oil, ethylene glycol and other nanofluids on the heated surface. The heated surface may be smooth, rough, stationery or moving, which depend on the applications. Mainly, heat transfer enhancement methods are classified as active and passive method. In the active method, some external power input needs to enhance the heat transfer rate. The external power may be either given to heated surface or given to fluids, which depends on the system requirement. Active methods are complicated because analysis of flow structure is not easily accessible due to external effect. Passive methods do not need any external power and usually utilize the modified surfaces and/or insertion of elements (turbulence promoters) in the flow. This methodalters the flow treatment which causes to convective heat transfer coefficient to increase. Turbulence promoters create turbulence in the flow, which help to eliminate the thermal boundary layer and promote to fluid mixing, leading to high heat transfer rate. 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. Some reviews have been also reported on twisted tapes however it is still need to summarise all previous works and latest techniques and modification in geometries required to increase the performance of twisted tapes. In the present paper an attempt has been carried out to review various analytical, experimental and numerical studies done on twisted tapes. Almost all previous works carried out on different types of twisted tape geometries for heat transfer enhancement in all applications; are included in this paper. [6-9]

## II. LITERATURE REVIEW

Kaliakatsos et al. [10] have investigated the CFD analysis of pipe equipped with twisted tape inserts. Sarma et al. [11] have studied about the performance of heat transfer with laminar convective heat transfer with twisted tape inserts in a pipe. Manglik et al. [12] have analyzed with the heat transfer and pressure drop correlations for twisted tape inserts inisothermal tubes. Salman et al. [13] has investigated the CFD analysis of heat transfer and friction factor characteristics in a circular tube fitted with horizontal baffles twisted tape inserts. Ibrahim et al. [14] have discussed about the augmentation of laminar flow and heat transfer in flat tubes by means of helical screw tape inserts. Shabanian et al. [15] have investigated with the CFD and experimental studies on heat transfer enhancement in an air cooled equipped with different tube inserts. Sivashanmugam et al. [16] has been studied about the experimental analysis on heat


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transfer and friction factor characteristics in turbulent flow through a circular tube fitted with right left helical screws tape inserts. Krishna Varma et al. [17] has analysis the CFD analysis for the enhancement of heat transfer with cut twisted tape inserts.

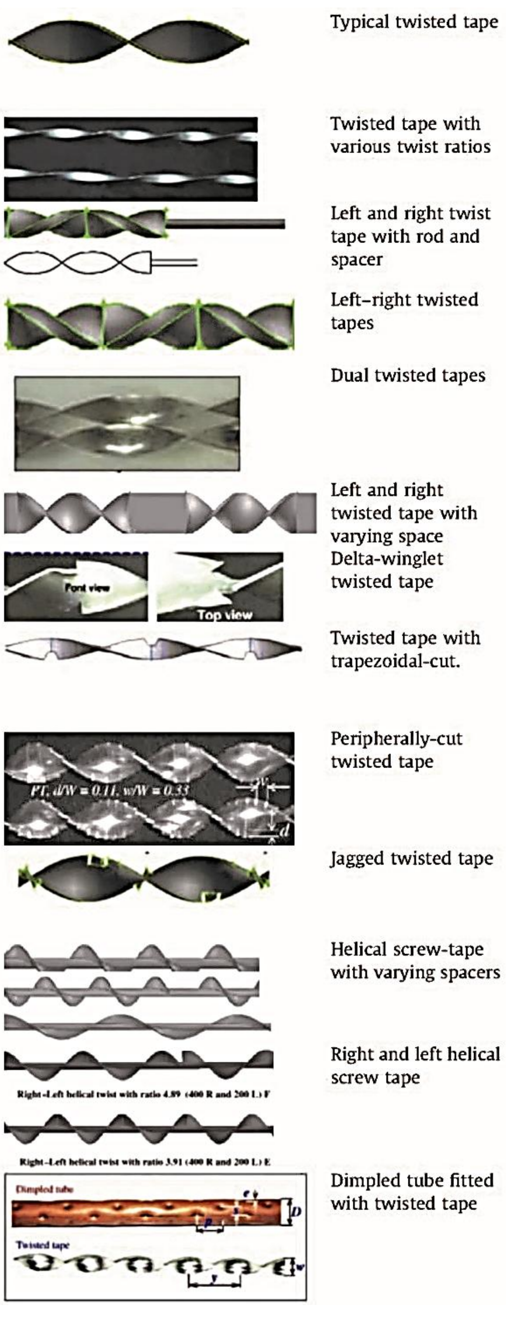


**Fig.1. Different type of twisted tape insets**

Kanade Rahul et al. [18] has conducted experiment on the heat transfer enhancement in a double pipe heat exchanger using CFD. Bhanuchandrarao et al. [19] explicated cfd analysis and performance of parallel counter flow in concentric flow heat exchangers. Salman et al. [20] have investigated the cfd analysis of heattransfer and friction factor characteristics in a circular tube fitted quadrant cut twisted tape inserts. Sharma et al. [21] has studied the friction coefficient and convective heat transfer characteristics in a combined approach with twisted tape inserts. Eiamsa et al. [22] has been discussed with the heat transfer and flow friction characteristics investigation of twisted tape elements. Sundar et al. [23] have investigated experimental heat transfer enhancement with nano fluids and twisted tape inserts. Nagarajan et al. [24] conducted numerical investigation fluid dynamics with heat transfer enhancement. Avineshsavekar et al. [25] has studied the analysis of heat transfer in pipe with twisted tape inserts.

Ray et al. [26] analysed the laminar flow and heat transfer through square duct with twisted tape inserts. Hejazi et al. [27] experimental investigation of twisted tape inserts and performance of heat transfer enhancement and pressure drop characteristics. Salman et al. [28] have investigated the numerical analysis of heat transfer and friction factor characteristics in a circular tube fitted with V cut twisted tape inserts. Jayakumar et al. [29] conducted the experimental and numerical simulation of heat transfer helical coiled heat exchanger. Salman et al. [30] have analysed the CFD simulation of heat transfer and friction factor augmentation in a circular tube twisted tape inserts. Dewan et al [31] was discussed as the passive techniques augmentation of heat transfer characteristics with twisted tape inserts. Sadman Hassan et al [32] has been presented as the heat transfer enhancement characteristics with passive techniques and twisted tape inserts of tubular heat exchanger. Elton et al [33] was examined with the heat transfer enhancement techniques in a parabolic concentrator with twisted tape inserts.

Morris and Rahmat-Abadi [34] investigated convective heat transfer experimentally in rotating circular pipe having internal ribs. Three different geometries of ribs had been investigated and tube was rotated in orthogonal mode. An enhancement in heat transfer on the trailing edge on the tube was found due to secondary flow. The secondary flow was induced due to cariolis force. Wright et al. [35] investigated the rectangular duct in rotating mode. The duct equipped with six different types of ribs, namely, angled, discrete angled, V-shaped ribs, discrete V-shaped ribs, W-shaped ribs and discrete W-shaped ribs. Rib parameters were considered as rib height to hydraulic diameter ratio (e/D) of 0.078 and rib pitch to height ratio (p/e) of 10. Discrete V-shape ribs and discrete W-shape ribs were found better in both rotating and non-rotating mode of duct, although the friction factor of these ribs were high, as reported. Li et al. [36] performed the experimental study which was based onthe heat transfer enhancement in rotating U-turn smooth channel. Shape of inlet pass and outlet pass were used as irregular (d = 24.5 mm) and rectangular (d = 19.6 mm), respectively. The ranges of rotation number for inlet and outlet pass were considered as 0–0.72 and 0–0.37, respectively. The results indicated that the maximum enhancement in Nusselt number on trailing edge to that of leading edge were found for rotating and stationery conditions as 4.3 and 1.5, respectively. Qui et al. [37] experimentally investigated the effect of rotation of smooth square duct in U shape on heat transfer and pressure drop. It was reported that rotation had more dominant effect on the enhancement in Nusselt number mainly in the turn region. The Nusselt number ratio increased linearly due to increase in rotation, but variation in the friction factor was oscillating with the values of rotation number. Tao et al. [38] experimentally investigated the heat transfer in wedge shape channel in rotation mode with lateral fluid extraction. The effect of two different outlet boundary conditions and five different channel orientation had also been investigated. The results indicated that rotation effect on the flow and heat characteristics had been influenced by channel orientation. Critical values of rotation number was found around 0.3.

Jeng et al. [39] investigated the effect of rotating cylinder on heat transfer characteristics under lateral air impingement jet. Ratio of the cylinder diameter to nozzle width (D/w) and the relative jet-impingement distance (L/w), were varied from 2 to 16 and 1 to 16, respectively by keeping fixed diameter and height of cylinder. Average Nusselt number was increased due to increase in the values of the jet Reynolds number (Rej) and the rotational Reynolds number (Rer) and average Nusselt number was decreased with increase in the values of D/w. Critical value of the relative jet-impingement distance (L/w)was exist, which gave highest Nusselt number, as reported

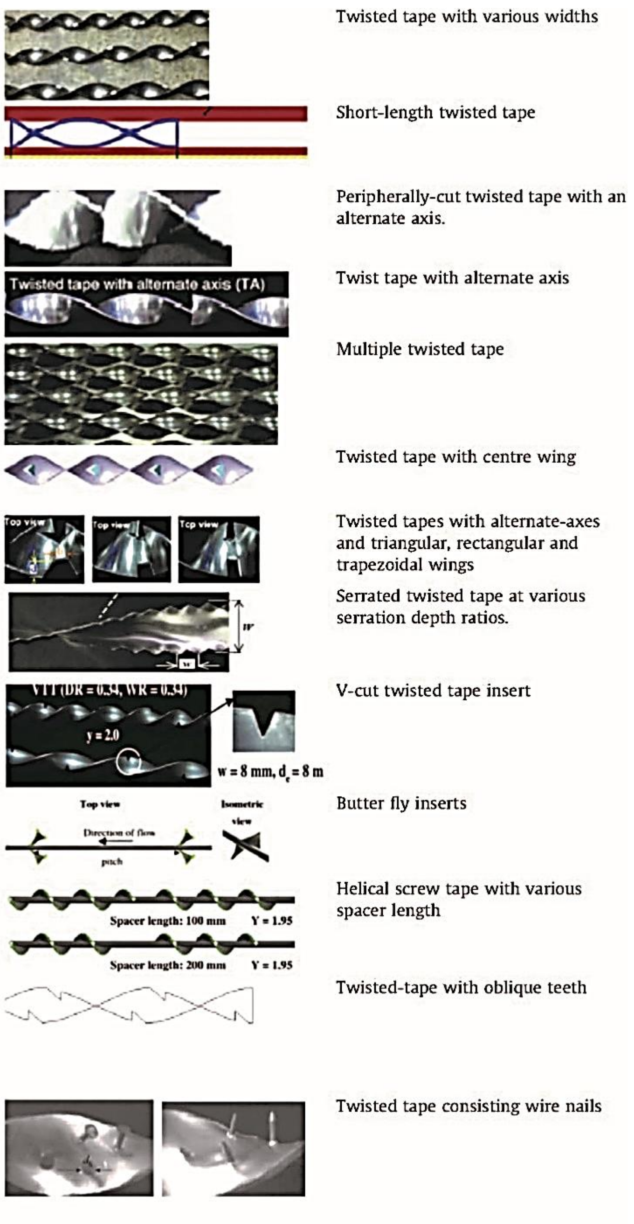


**Fig.2. Different type of twisted tape insets**

.Murugesan et al. [41] performed an experimental analysis to study heat transfer, thermal performance factor and friction factor characteristics in a plain circular tube and circular tube equipped with V-cut twisted tape inserts. Three twisted tapes of different twist ratios 2.0, 4.4 and 6.0 were considered. Also, three different combinations of depth ratio (ratio of depth of V-cut to tape width) and width ratio (ratio of width of V-cut to tape width) 0.34 and 0.43, 0.34 and 0.34, 0.43 and 0.34 were selected in the study. The results showed that both mean Nusselt number and mean friction factor increases with increase in depth ratio and decrease in width ratio and twist ratio. New correlations were obtained for Nusselt number and friction factor for plain tubes equipped with V-cut twisted tapes. The data from the developed correlations for tubes equipped with V-Cut twisted tapes fitted with theinvestigate heat transfer, pressure drop characteristics and thermal performance factors for tubular flows using continuous and spiky twisted tapes. The twisted tapes were tested at seven different flow conditions with Reynolds number ranges from 1000 to 40,000. Suitable type of twisted tape which gives high heat transfer enhancement over developing and developed flow was identified. The study revealed that V-notched spiky twisted tape provides highest heat transfer enhancement among all twisted tapes. In addition to this, empirical correlations to determine Nusselt number and friction factor for the enhanced tubular flows using all types of twisted tapes were discussed. Saha et al. [43] carried out an experimental investigation tostudy thermohydraulics performance for laminar flow through a circular duct equipped with centre-cleared twisted-tape and having integral axial rib roughness. The centre-cleared twistedtapes of twist ratio 2.5 were selected in the study. The results showed that the performance of duct with and without center-cleared twisted tapes and integral axial rib for laminar flow found better than duct only having a single enhancement technique. New correlations were also developed for Nusselt number and friction factor for both centre cleared centrecleared twisted-tape and having integral axial rib roughness. Saha [44] carried out an experimental study on laminar flowthrough a circular duct having axial corrugation and equipped with centre-cleared twisted tape. The twist ratio of twisted tape was 2.5 and the working fluid used was Servotherm medium oil of Indian Oil Corporation limited.. The study concluded that the usage of both centrecleared twisted tape and axial corrugation gives better performance than the single heat transfer enhancement technique for laminar flow through a circular duct. Also heat transfer was increased by 15-30% at constant pumping power. Karami et al. [45] performed an experimental and optimization study of heat transfer in an air cooled heat exchanger fitted with classic twisted tape inserts using Imperialist Competitive Algorithm (ICA) method. The classic twisted tape was having width of 15 mm and thickness of 1 mm. Four twisted tapes of different twist ratio 1.76, 2.35, 2.94 and 3.53 were selected for the experiments and the range of Reynolds number was 4021 to 16,118. The developed correlation was optimised using ICA method and the optimisation results shows that the maximum value of Nusselt number is obtained with twist ratio of 1.76. Tan et al. [46] carried out an analysis to study heat transfer enhancement in transitional and fully turbulent flow regimes for a tube equipped with a square-cut circular ring inserts. The study introduced a new non-dimensionless group from the analysis of experimental results to quantify the role of insert on heat transfer enhancement.Bhattacharyya et al. [47] carried out an experimental study onheat transfer characteristics for laminar flow through a circular tube having roughness of integral transfer rib and equipped with centre-cleared twisted tapes. The centre-cleared twisted-tapes of twist ratio 2.5 and servotherm medium oil for obtaining wide Prandtl number ranges from 235-537; were selected in the study. The results showed that combination of integral transfer rib and centre-cleared twisted tapes is much more effective than the individual heat transfer enhancement technique for laminar flow through a circular pipe up to a certain extent of centre clearance. New correlations were also developed for Nusselt number and friction factor for both integral transfer rib and centre-cleared twisted tapes, only centre cleared twisted tape and transverse rib only. The values from developed correlations support the experimental data within 710.58%. Salam et al. [48] carried out an experimental study to analyseheat transfer coefficient, friction factor and enhancement efficiency for turbulent flow through a circular tube equipped with rectangular cut twisted tape inserts under uniform heat flux condition. Rectangular cut twisted tape considered in the study. The working fluid used in the study was water and the range of Reynolds number was 10,000 – 19,000. Also, twist ratio of 5.25 is selected for the experiments. The results showed that values of Nusselt number and friction factor for tube equipped with rectangular cut twisted tape were found respectively 2.3 – 2.9 times and 1.4 – 1.8 times more than those of smooth tube. In addition to this, it was found that heat transfer enhancement efficiency increased with increase in Reynolds number within the range of 1.9 – 2.3. Bhuiya et al. [49] carried out an experimental study to analysethe heat transfer characteristics and flow friction for a turbulent flow through a circular tube provided with perforated twisted tapes. Four different twisted tapes were used of different porosities 'Rp' (1.6%, 4.5%, 8.9% and 14.7%) having corresponding pore diameters 3, 5, 7, 9 mm respectively. The length, width and thickness of the tapes were 1500 mm, 65 mm and 3 mm respectively and twist ratio was 1.92. The results showed a considerable increase in heat transfer rate and friction factor when compared to the results of plain tube (without twisted tapes). The Nusselt number, friction factor and thermal performance factor of the tube fitted with perforated twisted tape was 340%, 360% and 59% higher than the values obtained with plain tube. The results also showed that effect of 4.5% porosity was more prominent among all porosities. New correlations were proposed for Nusselt number and friction factor listed in the results from the developed correlations were validatedwith the results obtained from experiments within 74% for Nusselt Number and friction factor and 72% for thermal performance factor values. Saha and Saha [50] performed an experimental investigationon heat transfer and friction characteristics for laminar flow of viscous oil through a circular duct. The duct was having integral helical rib roughness and equipped with helical screw-tape inserts. The results showed that the use of both integral helical rib roughness and helical screw-tape inserts is better than the individual technique for heat transfer enhancement acting alone. New correlations were also developed for Nusselt number and friction factor. The developed correlations were fitted with experimental data within 7 13.15%. Bharadwaj et al. [51] carried out an experimental study on 75start spirally grooved tube equipped with twisted tapes inserts. Twisted tapes of twist ratios 10.15, 7.95 and 3.4 were selected for the study and the experiments were conducted with both clockwise and anti-clockwise direction of twisted tapes with Reynolds number ranges in all laminar to fully turbulent flow. The results showed 400% and 140% of heat transfer augmentation in laminar and turbulent flow respectively for spirally grooved tube without twisted tapes inert. In addition to this, heat transfer enhancement of 600% and 140% was found in laminar and turbulent region respectively when the spirally grooved tube was equipped with twisted tapes. Also, it was found that the thermo-hydraulic performance is affected by the direction of twisted used. Another important result obtained in the study was reduction in heat transfer for Reynolds number range 2500 o Re o 9000. The clockwise twisted tape having twist ratio of 7.95 gave high heat transfer enhancement among all three types of twisted tapes. Nusselt number and friction factor correlations were developed for grooved tube with twisted tapes. The data obtained from developed correlations supports the experimental data within 715% and 7 10% for Nusselt number and friction factor respectively.

## III. CONCLUSION

It is observed from the previous studies that use of twisted tapes in heat exchanger systems is quite effective method of heat transfer augmentation. Increase of Nusselt number, friction factor and thermal performance is reported by using twisted tapes inserts but accompanied with some pressure drop. A lot of experimental and numerical research studies have been performed on heat transfer augmentation using twisted tape inserts. Different types of geometries have been tested to check the heat transfer augmentation and many useful correlations to determine heat transfer and friction characteristics were developed. Geometry of pipe/duct and twisted tapes, flow characteristics are the major factors to control the thermohydraulic performance. Some new techniques like pinching of twisted tapes, broken twisted tapes, introduction of nanofluids etc. are also being introduced by the researchers and scientists to develop and promote the twisted tape techniques. Studies have also been reported the use of twisted tapes in areas like refrigeration, solar thermal technologies etc. Twisted tapes are also found useful in microfiltration of milk where they found as low-pressure loss turbulence promoter. In addition to this, the use of twisted tapes with nanofluids and other geometries is also found very useful. However, more future work in this area will be very effective to develop this technology and more generalized useful correlations will be obtained.

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