A Review Study of Passive Methods for Enhancement of Heat Transfer by Twisted Tape and Wire Coil Turbulator

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***Abstract*—The different heat transfer enhancement techniques are used for the increasing the heat transfer without affecting much the overall performance of the thermal system. The development of the highly efficient thermal system with the high-performance has increased interest in the heat-transfer enhancement techniques. Different enhancement techniques are active, passive, and compound methods passive method is design and use for enhancement of heat transfer. The purpose of this review presents the effect of twisted tape and wire coil turbulator, which is part of passive methods on the heat transfer enhancement. The most widely employed in several industrial and engineering applications of heat exchanger are the solar collector, heat engine, thermal power plant, electronic cooling, refrigerators, chemical process industries etc. heat transfer enhancement using different type of the turbulators placed in the tube has extensively studied. The present review paper mainly focus on the twisted tape and wire-coil for heat transfer enhancement and its design modification towards the enhancement of heat transfer and saving pumping power.**

***Keyword*—heat transfer enhancement, heat exchanger, twisted tape, wire coil insert, turbulator, passive techniques for heat transfer enhancement.**

1.) INTRODUCTION

In many engineering applications the good thermal performance of the heat exchanger or thermal systems are needed and for that various types of methods are developed and extensively used to enhance the heat transfer in the system. There are many methods are available for enhancing the heat transfer from the fluid in conventional heat exchanger by using various augmentation techniques. These techniques enhance the heat transfer rate by creating the following conditions: 1) increased the heat transfer area, 2.) generating of the swirling and/or secondary flows, and 3.) interruption of boundary layer development and rising the degree of turbulence in the flowing fluid.

For the enhancement of heat transfer in heat exchanger mainly used three methods are:

1.) Active methods.
2.) Passive methods.
3.) Compound methods.

From the past, several studies focused on the passive heat-transfer enhancement methods. In the passive methods swirl flow devices or reverse flow devices like groove, wire coil, twisted tape, conical ring, winglet, rib, etc) form an important group of the passive augmentation techniques. The turbulators or the swirl flow device is widely used in the heat transfer engineering application. The swirl flow devices or the turbulators are inserted into the pipe through which the fluid is flowing to provide an interruption of the boundary layer development, to increase the heat transfer surface area and to cause enhancement of heat transfer by increasing the turbulence intensity or the fast and better mixing of the fluid.Therefore, more compact and economical heat exchanger with lower operation cost can be obtained.

Mechanistically, turbulator increases the composite velocity, increases the radial turbulent fluctuations which causes an efficient eruption of thermal boundary layer. Turbulators in the various shapes have proposed. There are many literature reviews are available on using the twisted tape (TT) and also for the wire coil turbulators, but from their conclusions is not so high, so that some researchers maybe cannot decide which kind of twisted tape or wire coil and/or combinations of these two turbulators can be used for the future work. But this problem can be solved in this analysis to decide which kind of the combination will be select for the achievement of high heat transfer co efficient and higher thermal performance of the heat exchanger. For the last some decades lot of researches with the twisted tape and wire coil devices employed for the augmentation of laminar and turbulent flow heat transfer and the results are discussed [1].

I.) Active methods:

These techniques are very complicated or say more complex from the use and design point of view, this is because the method requires some external power input to cause the desired flow modification and increase the heat transfer rate. These techniques find limited application because of the need of external power in many practical applications. In comparison of these active techniques with the passive techniques, these techniques have not shown much potential as it is difficult to provide external power input in many practical cases. Some of the active techniques are as give below:

- **Mechanical Aids:**Mechanical aids envolve the different devices, it includes rotating tube heat exchanger, scrapped surface heat, and mass exchangers. These devices stir the fluid by mechanical means or by rotating the surface.
- **Injection:**In this technique, same kind of fluids or the other fluid is injected into the main bulk fluid through a porous heat transfer interface or upstream of the heat transfer section. This technique has used for the single-phase heat transfer process.
- **Suction:**This technique has used for both two phase heat transfer and single-phase heat transfer process. Two phase nucleate boiling involves the vapour removal through a porous heated surface whereas in single-phase flows fluid has withdrawn through the porous heated surface.
- **Surface vibration:** They have used primarily in single-phase flows. A low or high frequency applied to facilitate the surface vibrations, which result in higher convective heat transfer coefficients.
- **Fluid vibration:** This is also one good techniques of the active method. In this method, instead of applying vibrations to the surface, pulsations created in the fluid itself. This kind of vibration enhancement technique employed for single-phase flows.
- **Jet impingement:** this technique is applicable for both two phase and single-phase heat transfer process. In this method, fluid heated or cooled perpendicularly or obliquely to the heat- transfer process.
- **Electrostatic fields:** Electrostatic field like electric or magnetic fields or a combination of the two from DC or Ac sources has applied in heat exchanger systems, which induces greater bulk mixing, force convection or electromagnetic pumping to enhance the heat-transfer. This technique is applicable in heat-transfer process involving dielectric fluids.

II.) Passive methods:

This technique is one of the heat-transfer enhancement technique generally use geometrical or surface modification to the flow channel by incorporating inserts or additional devices. They promote higher heat-transfer coefficients by distributing or alternating the existing flow behavior, which also leads to increase in the pressure drop. Passive techniques hold the advantage over the active techniques, as they do not require any direct input of external power. Heat-transfer augmentation by these techniques can be achieved by using:

- **Treated surfaces:**This technique involves using pits, cavities or scratches like alteration in the surfaces of the heat transfer area, which may be continuous or discontinuous. They primarily used for boiling and condensing duties.
- **Extended surfaces:** Plain fins are one of the earliest types of extended surfaces used extensively in many heat exchangers. Finned surfaces have become very popular now days owing to their ability to disturb the flow field apart from increasing heat transfer area.
- **Swirl flow devices:** They produce swirl flow or secondary circulation on the axial flow in a channel. Helical twisted tape, twisted ducts & various forms of altered (tangential to axial direction) are common examples of swirl flow devices. They can be used for both single phase and two-phase flows.
- **Surface tension devices:** These devices direct and improve the flow of liquid to boiling surfaces and from condensing surfaces. Examples include wicking or grooved surfaces.
- **Displaced enhancement devices:**These inserts has used primarily in confined forced convection. They improve heat transfer indirectly at the heat exchange surface by displacing the fluid from the heated or cooled surface of the duct with bulk fluid from the core flow.
- **Rough surfaces:**These surface modifications particularly create the disturbance in the viscous sub-layer region. These techniques are applicable primarily in single-phase turbulent flows.
- **Additives for liquids:** This technique involves addition of solid particles, soluble trace additives and gas bubbles added to the liquids to reduce the drag resistance in case of single-phase flows. In case of boiling systems, trace additives added to reduce the surface tension of the liquids.

III.) Compound methods: A compound augmentation technique is the one where more than one of the above-mentioned techniques has used in combination with the purpose of further improving the thermo-hydraulic performance of a heat exchanger.

1.1) TREATED SURFACES: [2,3]

Treated surfaces for the heat transfer enhancement is one of the passive method of heat-transfer enhancement technique. It consists of the different variety of structured surfaces like (continuous and/or discontinuous integral surface roughness) and coatings. The roughness created by this treatment do not causes any significant effect in the single-phase heat transfer. These are applicable in cases of two-phase heat-transfer only.

1.1.1) BOILING: Some of the treated surfaces are as follows:

- Machined or grooved surfaces.
- Formed or modified low-fin surfaces.
- Multilayered surfaces.
- Coated surfaces.

In enhanced boiling treated surfaces, provide a large number of stable vapour traps ornucleation sites on the surface for bubble formation. In case of highly wetting fluids likerefrigerants, organic liquids, cryogens and alkali liquid metals the normal cavities present onthe heated surfaces tend to experience sub-cooled liquid flooding.

1.1.2) CONDENSING: In condensation of vapour, treated surfaces promote drop wisecondensation which is ideal for preventing surface wetting and break up the condensate filminto droplets. This process provides better drainage and more effective vapour removal at cold heat transfer interface.This technique increases heat transfer by a factor of 10 to 100 indrop wise condensation when compared with that in film wise condensation as proposed byBergles.

1.2) ROUGH SURFACES:[2,3]

Surface modification or the small-scale roughness promotes turbulence in the flow field near the wall region by disturbing the viscous laminar sub-layer. This disturbance causes higher momentum and heat transfer. This small-scale roughness has little effect in laminar flows, but is very effective in turbulent single-phase flows. Structured roughness can be integral to the surface.

Wire-coil type inserts can inserted inside the tube to provide protuberances in the surface. In case of structured roughness, almost an infinite number of geometric variations can produced by machining, casting, or welding.

1.3) EXTENDED SURFACES:[2,3]

Extended or finned surfaces increases the heat-transfer area, which could be very effective in case of fluids with low heat transfer co-efficient. This technique includes finned tube for shell & tube heat exchangers, plate fins for compact heat exchanger and finned heat sinks for electronic cooling. Finned surfaces enhance the heat-transfer in natural or forced convection heat-transfer regime but also can used for forced convective heat-transfer. Figure 1 shows segmented or interrupted fins, promote boundary layer separation of the fluids and disturb the whole bulk flow filed inside circular tubes. Separation and restarting of the boundary layers increases heat transfer rate.

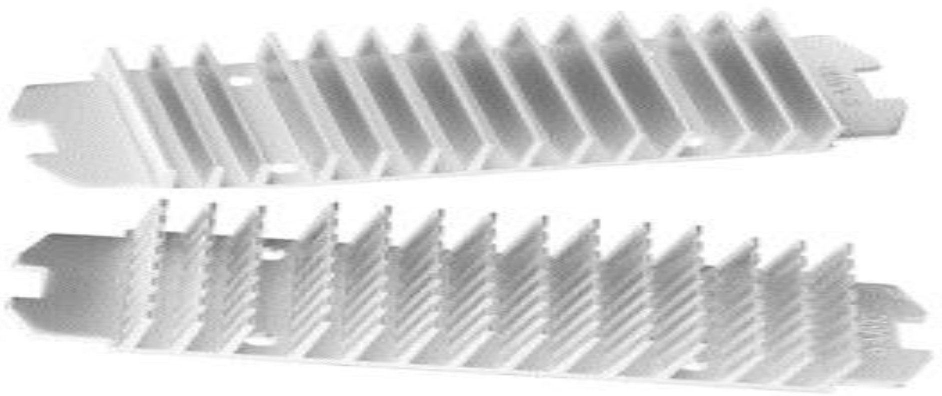


Figure 1: Extended surface [Segmented fin]

1.4) SWIRL FLOW DEVICES:[2,3]

Swirl flow devices causes swirl flow or secondary flow in the fluid.A variety of devices can employed to cause this effect, which includes tube inserts, altered tube flow arrangements, and tube geometry modifications. Dimple, ribs, helically twisted tubes are examples of duct geometry modifications. Tube inserts include twisted tape inserts, helical strips or cored screw-type inserts and wire-coils. Among the swirl-flow devices, twisted tape inserts had been very popular owing to their better thermal hydraulic performance in single-phase boiling and condensation force convection, as well as design and application issues. Figure 2 shows the typical twisted tape which used commonly.

Figure 2: Typical twisted tape

Twisted tape insert increases the heat transfer coefficients with relatively small increase in the pressure drop. They are the one of the easiest swirl flow devices employed in the single-phase heat transfer processes. Because of the design and application convenience hey have been widely used over the decades to generate the swirl flow in the fluid. Size of the new heat exchanger can reduced significantly by using twisted tapes in the new heatexchanger for a specified heat load.Inserts such as twisted tape, wire coils, ribs and dimples mainly obstruct the flow andseparate the primary flow from the secondary flows. This causes the enhancement of the heat-transfer in the tube flow. Inserts reduce the effective flow area thereby increasing the flowvelocity. This also leads to increase in the pressure drop and in some cases causes' significantsecondary flow.Secondary flow creates swirl and the mixing of the fluid elements and henceenhances the temperature gradient, which ultimately leads to a high heat transfer coefficient.

1.5) ADDITIVES FOR LIQUIDS:[2,3]

Pressure drop in the flow is a consequence of the frictional loses with the solid surfaces. These frictional losses occurs because of the drag force of the fluid. This technique concerned with reducing the drag coefficient using some additives to the fluid in single-phase flows. Additives when added to the fluids found to have operational benefits by lowering the frictional losses. Polymeric additives induce a viscoelastic character to the solution, which promotes secondary circulation in the bulk flow. These secondary flows have significant effect on the transfer coefficient. Some of the additives used are polystyrene spheres suspension in oil and junction of gas bubbles.

2.) PERFORMANCE OBJECTIVE:

In most practical applications of the heat-transfer enhancement techniques, the following performance objectives, along with a set of operating conditions and constraint, are usually considered for optimizing the use of a heat exchanger:

1. Reduce the size or heat-transfer surface area requirements for a specified heat duty and pressure drop or pumping power.
2. Reduce the process stream's pumping power requirements for a given heat load and exchanger surface area.
3. Increase the heat duty of an existing heat exchanger without alternating the pumping power (or pressure drop) or flow rate requirements.
4. Reduce the approach temperature difference between the two heat-exchanging fluid streams for a specified heat load and size of exchanger.

3.) TWISTED TAPE (TT) DEVICES:

swirl flow devices which are used to create swirl or secondary flow, twisted tape inserts are very popular because of their good thermal performance in medium like single and two phase flow. Main parameters of the twisted tapes are the empty tube Reynolds number (Re), half-pitch (H), twist ratio (y). figure shows the typical twisted tape and configuration of TT.

Figure 3: Typical Twisted tape

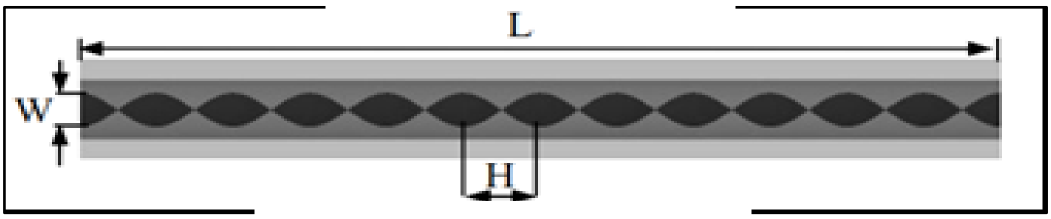


Figure 4: Twisted tape configuration

1.) Reynolds number:

Reynold number is defined respect to the empty tube. The Reynolds number is given by Re = 4m/πDμ, where m is the mass flow rate, μ is the viscosity, and D is the tube inside diameter.

2.) The half-pitch:

H defined as the distance between two points on the edge of a TT 97which lie down on the same plane or in other words the length of the 98 tube in which a TT completes 180° of revolution.

3.) The twist ratio:

Y is defined as the ratio of the half-pitch to the inside diameter of the tube, Y = H/D.

4.) The number of revolutions:

N is described as the number of 360° revolutions of a TT.

3.1) REVIEW OF WORK CARRIED OUT WITH TWISTED TAPE:

Different researches for the heat transfer enhancement by using twisted tape carried out by the different researchers and their outcomes are as follows:

Smith Eiamsa-ard et al [4] conducted experiments on a concentric tube heat exchanger. Hot air passed through inner tube while the cold water was flown through the annulus. A maximum percentage gain of 165% in heat transfer rate was obtained by using the helical insert in comparison with the plain tube.

Saha et al. [5] investigated the use of turbulences promoters with short length Twist tape, and regularly spaced Twist tape element. They achieved better thermodynamics performance with short length Twist tape, and regularly spaced Twist tape element instead of full-length Twist tape while working with twisted tape.

Anil Singh Yadav [6]has been studied theinfluences of the half-length twisted tape insertion on heat transfer and pressure drop characteristics in a U bend double pipe heat exchanger experimentally. In the experiments, the swirling flow introduced by using half-length twisted tape placed inside the inner test tube of the heat exchanger. The experimental results revealed that the increase in heat transfer rate of the twisted-tape inserts found to strongly influence by tape-induced swirl or vortex motion. The heat transfer coefficient found to increase by 40% with half-length twisted tape inserts when compared with plain heat exchanger. It also observed that the thermal performance of Plain heat exchanger was better than half-length twisted tape by 1.3-1.5 times.

Eiamsa-ard et al. [7] developed a twisted tape with serrated edges. Their experiment demonstrated that the heat transfer rate and thermal performance factor in the tube with this type of twisted tape insert were about 1.04-1.27 and 1.02-1.12 times those in the tube with smooth twisted tape insert, respectively.

Rahimia et al. [8] studied the heat transfer and friction factor characteristics of the tube fitted with perforated, notched and jagged twisted tapes. The results revealed that only the jagged insert was better than the conventional twisted tape in the heat transfer coefficient and thermal performance factor.

Chinaruk Thianpong et al. [9]The experiments were performed under uniform wall heat flux condition by using PTs with y/W = 3, 4 and 5, d/W = 0.11, 0.14 and 0.17 and s/W = 0.4, 0.6 and 0.8 where y is a twist length, d is a perforation hole diameter, s is a spacing between holes (pitch) and W is a tape width. The experimental results reveal that Nusselt number increased with decreasing s/W and y/W and increasing d/W. For the present range, the maximum heat transfer was obtained by utilizing the tape with s/W = 0.4, d/W = 0.17 and y/W = 3, which is higher than those obtained from the plain tube with and without typical twisted tape by around 27.4 and 86.7%, respectively.

Bodius Salam et al. [10] An experimental investigation was carried for measuring tube-side heat transfer coefficient, friction factor, heat transfer enhancement efficiency of water for turbulent flow in a circular tube fitted with rectangular-cut twisted tape insert.A stainless steel rectangular-cut twisted tape insert of 5.25 twist ratio was inserted into the smooth tube. The rectangular cut had 8 mm depth and 14 mm width.At comparable Reynolds number, Nusselt numbers in tube with rectangular-cut twisted tape insert were enhanced by 2.3 to 2.9 times at the cost of increase of friction factors by 1.4 to 1.8 times compared to that of smooth tube.

C. Thianpong et al.[11] Heat transfer, friction factor and thermal performance characteristics in a tube equipped with twisted-rings (TRs) are experimentally investigated. The experiments were conducted using TRs with three different width ratios (W/D=0.05, 0.1 and 0.15) and three pitch ratios of (p/D=1, 1.5 and 2) for Reynolds numbers ranging from 6000 to 20,000 using air as a test fluid.Nusselt number and friction factor increase as width ratio increases and pitch ratio decreases.

S.N. SARDA et al. [12] studied the effect of varying width twisted tape inserts with air as the working fluid in horizontal tube.the reduction in tape width causes reduction in Nusselt numbers as well as reduction in pressure drop, the percentage increase in Nusselt numbers for reduced width tapes compared to plain tube are about 11–22%, 16–31%, 24–34% and 39–44% respectively for tape widths of 10, 14, 18 and 22 mm respectively for twist ratio =3. For full width tapes, the percentage increase is observed to be 58 to 70% compared to plain tube, the percentage increase in Nusselt numbers for reduced width tapes compared to plain tube are about 5–12%, 9–22%, 13–30% and 23–36% respectively for tape widths of 10, 14, 18 and 22 mm respectively for twist ratio=4.For full width tapes, the percentage increase is observed to be 36 to 42% compared to plain tube.

Chinaruk Thianpong et al. [13] The influences of the perforated twisted tapes (PTs) on the heat transfer, pressure loss and thermal performance characteristics were investigated experimentally. The experiments were performed under uniform wall heat flux condition by using PTs with y/W = 3, 4 and 5, d/W = 0.11, 0.14 and 0.17 and s/W = 0.4, 0.6 and 0.8 where y is a twist length, d is a perforation hole diameter, s is a spacing between holes (pitch) and W is a tape width.The experimental results reveal that Nusselt number increased with decreasing s/W and y/W and increasing d/W. For the present range, the maximum heat transfer was obtained by utilizing the tape with s/W = 0.4, d/W = 0.17 and y/W = 3, which is higher than those obtained from the plain tube with and without typical twisted tape by around 27.4 and 86.7%, respectively.

3.1.1) TWISTED TAPE IN LAMINAR FLOW:

A summary of the important investigation of twisted tape in a laminar flow represented in the table 1. Twisted tape increases the heat transfer coefficient with an increase in the pressure drop. Different configurations of the twisted taps, like full-length twisted tape, short-length twisted tape, full-length twisted tape with varying pitch, reduced width twisted tape, and regularly spaced twisted tapes have studied widely by many researchers.

Table 1: Summary of the Important Researches of Twisted Tape in Laminar Flow [14]

Sr. No	Authors	Fluid	Configuration of twisted tape	Type of investigation	Observation	Remarks
1.	Saha and dutta [15]	Waterwith (205< Pr< 518)	a) Short length (b) Full length (c)Smoothly varying pitch (d)Regularly Spaced	Experimentin a circulartube	1) Friction andNu low for shortlength tape (2) Short lengthtape requiressmall pumpingpower (3) Multiple twist and single twisthas no difference on thermo-hydraulicperformance.	1.) It was observedthat twisted tapeis effective inLaminar flow. 2.) Short length twisted tapeperform betterthan full-lengthtape.
2	BerglesandHong [16]	Water (3<Pr <7) (83< Re <2460) Ethylene Glycol(84<Pr< 192) (13 <Re<390)	Full-lengthtwisted tape	Experimentin circulartube	(1) Nu is function of twist ratio, Re and Pr (2) Friction isaffected by tapetwist only at highRe (3) Nu is 9 times that of emptytube	Twisted tape canbeen used as full-lengthtwisted dtape, half-lengthtwisted tape andvarying pitchtwisted tape.
3	Saha et al. [17]	Fluidswith 205 <Pr<518	Twistedtape(regularlyspaced	Experimentin circulartube	(1) Pinching oftwisted tape givesbetter results thanconnecting thinrod for thermo-hydraulicperformanc	

					e (2) Reducing tapewidth gives poorresults; largerthan zero phaseangle noteffective	
4	Lokanath [18]	Water (240 < Re< 2300) (2.6 < Pr <5.4)	Full-lengthand half-lengthtwistedtapes	Experimental inhorizontaltube	(1) On unitpressure dropbasis and on unitpumping powerbasis, half-lengthtwisted tape ismore effectivethan full-lengthtwisted tape	
5	ManglikandBergles[19]	Water (3.5< Pr < 6.5)Andethyleneglycol (68 < Pr <100)	ThreeDifferenttwist ratios:3, 4.5 and 6	ExperimentInisothermaltube	(1)Proposedcorrelation forfriction andNusselt number (2) Physicaldescription ofenhancementmechanisms	Pinching oftwisted tape givesbetter resultscompared withconnected thinrod.
6.	Ujhidy[20]	Water	Twistedtape	Experimentin channel	(1) Explainedflow structure (2) Provedexistence ofsecondary flow intubes with helicalstatic elements.	
7	Saha andBhunia[21]	Servotherm-Medium oil (205<Pr<512,45 <Re < 840)	Twistedtape (twistratio 2.5<y<10)	Experimentin circulartube	(1) Heat transferCharacteristicsdepend on twistratio, Re and Pr	Uniform pitchtwisted tapeperforms betterthan graduallyvarying pitchtwisted tape
8	Agarwaland Raja Rao [22]	Servothermoil	Twistedtape	Experimentin circulartube	Nusselt numberfor augmentedtube is more thanplain tube	

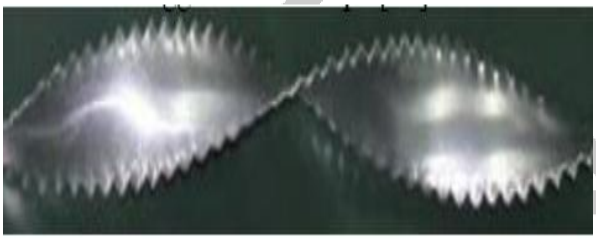
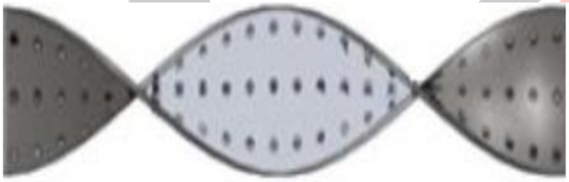
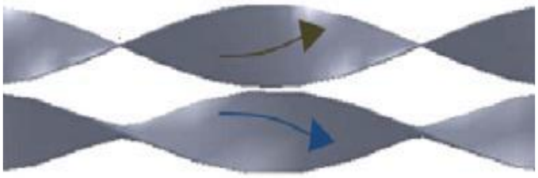
3.1.2) TWISTED TAPE IN TURBULENT FLOW:

Unlike the laminar flows where resistance exist entirely over the cross section, it is limited to the thin viscous sub-layer. Therefore, the main objective of the twisted tape in the turbulent region is to reduce that resistance near the wall to promote better heat-transfer. Besides, a tube inserted with a twisted tape produces swirl and causes intermixing of the fluid, which leads to better performance than plain tube. Heat-transfer rate has improved effectively with the increase of the frictional losses. A summary of the important investigations of twisted tape in turbulent flow listed in table 2.

Table 2: Summary of the Important Researches of Twisted Tape in Turbulent Flow [14]

Sr.no	Author	Configuration of tape	Observations	Comments
1	Zimparov et. al.[23]	Angled spiraling tape inserts,Spiraled tube.	Enhancement in the annulus side.	Angled spiraling tape inserts more efficient than spiralled tube.
2	Watcharin et.al [24]	Twisted tape insert.	Effect on heat transfer and frictionfactor.	Nusselt number and friction factorincreases with decrease in twist ratio.
3	Al-Fahed and Chakroun [25]	Loose fit tapes andtight –fit tape.	For same twist ratio effect of loosefit and tight fit twisted tape aresame.	
4	Klepper [26]	Short-lengthtwisted tape.	Usefulness of tape in gas-coolednuclear reactor.	
5	BlackwelderAndKreith[27]	Twisted tape.	Recommended that optimumdesign of heat exchanger withtape-induced swirl flow mustconsider combination ofcontinuous and decaying swirlflow.	
6	Zozulya and Shkuratov [28]	Twisted tape.	Smooth decrease in pitch oftwisted tape has significantinfluence on heat transfer.	
7	Cresswell [29]	Full length twistedtape.	Ratio of maximum velocity tomean velocity is smaller in swirl flow compared with straight flow.	Heat transfer coefficient has enhanced bytwisted tape.
8	Kreith and Margolis [30]	Full length twistedtape.	Centrifugal force aids convection when fluid heated up.	All configurations of twisted tape leadto high friction factor, which is due tofact that twisted tape disturbs entireflow field
9	Seymour [31]	Short-lengthtwisted tape	Short-length twisted tapes moreeffective than full-length twistedtapes	
10	Kreith and Sonju [32]	Short-lengthtwisted tape	Short-length (25–45 per cent oftube length) tapes perform betterthan full-length tapes	

3.2) Different Twisted Tape Geometries:

 Perforated twisted tape with Teflon ring	 Twisted tape with alternate axis and trapezoidal wings
 Twisted tape with U-cut	 Twisted tape with alternate axis and rectangular wings
 Serrated twisted tape	 Vertical wing-cut twisted tape
 Perforated twisted tape	 Twin twisted tape

4.) WIRE COIL TURBULATOR:

Wire coil turbulator are the another type of the turbulator which are used in the heat transfer devices for the enhancement of the heat transfer from the fluid.

AComparison of the thermal and hydraulic performances of twisted tape or wire coil inserts was introduced by Wang and Sunden [33] for both laminar and turbulent flow regions. They found that the coiled wire performs effectively in enhancing heat transfer in a higher turbulent flow region whereas the twisted tape yields a poorer overall efficiency.

Fig.5. Wire coil turbulators

4.1) REVIEW OF WORK CARRIED OUT WITH WIRE-COIL:

Garcia et al. [34] experimentally studied the thermo-hydraulic behavior of a round tube with helical-wire coil inserts in laminar, transition and turbulent regimes at different Prandtl numbers. In the investigation, they used water and water-propylene glycol mixtures (R3) as the test fluid at different temperatures. The authors tested six wire coils within a geometrical range of helical pitch 1.17 < p/d <2.68 and wire diameter 0.07 < e/d <0.10. They showed that within the transition region, by fitting the wire coils inside a smooth tube heat exchanger, the heat transfer rate increased up to 200%.

S. Biswas et al.[35]An experimental investigation was carried for measuring tube-side heat transfer coefficient, friction factor, heat transfer enhancement efficiency of air for turbulent flow in a circular tube fitted with wire coil insert. A copper tube having 27 mm inside diameter, 30 mm outside diameter and of which length of 285 mm was used as the test section. A stainless steel coil was used as an insert where the wire diameter (e) was 2.8 mm and coil diameter (d) was 24 mm. In the experiment, the dimensionless pitch (pl/di) was considered to be 0.71 and the dimensionless wire diameter (e/di) was considered to be 0.11.At comparable Reynolds number, Nusselt numbers in tube with wire coil insert were enhanced by 1.5 to 2.3 times at the cost of increase of friction factors by 3 to 3.5 times compared to that of smooth tube. Heat transfer enhancement efficiencies were found to be in the range of 1.3 to 2.6 and increased with the increase of Reynolds number.

Prof.Shashank S. Choudhari et al. [36] In the present study heat transfer characteristics and friction factor of horizontal double pipe heat exchanger with coil wire inserts made up of different materials are investigated. The Reynolds numbers are in the range of 4000-13000. The inner and outer diameters of tubes are 17 mm and 21.4 mm respectively. Hot water and cold water are used as working fluid on tube side and annulus side, respectively.The hot water and cold water flow rates are maintained same and in range of .033 to .1 kg/s.Coil wire has significant effect on heat transfer and friction factor. Cu insert has higher heat transfer enhancement of 1.58 times as compared to plane tube. On other hand Aluminum and stainless steel insert has heat transfer enhancement of 1.41 and 1.31as compared to plane tube respectively. The friction factor found to be increasing with decreasing coil wire pitch.

A. E. Zohir et al. [37] An experimental investigation has been carried out to study the enhancement in heat transfer coefficient by inserting coiled wire around the outer surface of the inner tube of the double-pipe heat exchanger. Insulated wires, with a circular cross-section of 2mm diameter, forming a coil of different pitches (p 5 6, 12, and 20 mm), were used as turbulators. The investigation is performed for turbulent water flow in a double-pipe heat exchanger with cold water in the annulus space for both parallel and counter flows.The experimental results reveal that the use of coiled circular wires leads to a considerable increase in heat transfer coefficients compared with a smooth wall tube for both parallel and counter water flows. The convective heat transfer coefficient for a turbulent water flow increases for all coiled wire pitches, with the highest enhancement of about 450% for counter flow and 400% for the parallel flow.

Behabadi et al. [38] An experimental investigation had been carried out to study the heat transfer augmentation and pressure drop by wire coil inserts at the time of heating the engine oil inside a horizontal tube. They developed two empirical correlations within an error band of ± 20%.

Gunes et al.[39] An experimental study in a coiled wire inserted tube in turbulent flow regime was carried out They used equilateral triangle cross sectioned wire coil inserts and showed that low Reynolds number regime were the best operating regime for wire coil insert.

C.Nithiyesh Kumar et al. [40] Heat transfer augmentation techniques refer to different method used to increase rate of heat transfer without affecting much the overall performance of the system. These techniques are used in heat exchangers. Some of the applications of heat exchangers are in process industries, thermal power plant, air conditioning equipment, refrigerators, radars for space vehicles, automobiles etc. In the past decade, several studies on the passive techniques of heat transfer augmentation have reported. The present paper review mainly focuses on the twisted tape heat transfer enhancement and its design modification towards the enhancement of heat transfer and saving pumping power.

V. Kongkaitpaiboon et al. [41] performed an experimental investigation of convective heat transfer and pressure loss in a round tube fitted with circular ring turbulators. They studied the effect of the circular-ring turbulator (CRT) on the heat transfer and fluid friction characteristics in a heat exchanger tube. The experiments were conducted by insertion of CRTs with various geometries, including three different diameter ratios (DR=d/D=0.5, 0.6 and 0.7) and three different pitch ratios (PR=p/D=6, 8 and 12). Experimental result reveled that heat transfer rates in the tube fitted with CRTs were augmented around 57% to 195% compared to that in the plain tube, depending upon operating conditions.

Table 3: Summary of the Important Researches of Wire-Coil in Laminar Flow:

Sr.No	Authors	Fluid	Configuration of wire coil	Type of investigation	Observation	Remarks
1	Inaba and Ozaki [42]	Water	Wire- coil	Experiment in Circular pipe flow.	High heat transfer and low Pressure loss obtained by leading edge effect near tube inlet and turbulent flow downstream of wire coil.	Performance of wire coil in laminar flow depends on Prandtl number. If Pr ¼ 0.7, performance is not good based on overall enhancement ratio. Overall enhancement ratio increases with Prandtl number
2	Ujhidy et al[43].	Water	Wire coil	Experiment in Channel flow	Explained flow structure (helical static element produces secondary flow)	
3	Wang and Sunden [44].	Water	Wire coil	Experiment in circular tube	Both inserts are effective in enhancing heat transfer rate in region other than turbulent flow and tape has poor overall efficiency if pressure drop is considered	
4	Oliver and Shoji [45]	Non Newtonian fluid 30<Pr<90, 20<Re<2000	Wire coil	Experiment in round tube	Heat transfer enhancement by factor of 4	
5	Inaba and Haruki [46]	Water	Wire coil	Experiment in circular pipe	Effect of wire coils on pipe friction and heat transfer coefficients elucidated under various values of flow velocity, wire coil diameter, pitch and length.	

Table 4: Summary of the Important Researches of Wire-Coil in Turbulent Flow:

Sr.No	Authors	Fluid	Configuration of wire coil	Type of investigation	Observation	Remarks
1	Raviguruarajan andBergles [47]	Water	Wire coil	Experimental study	Developed correlations for friction and heat transfer	Wire coil in turbulent flow performs better than any other insert
2	Rahai and Wong [48]	Air	Coil insert	Experiment in round tube	Coil with large pitch spacing increases mixing, turbulent kinetic energy and half width but reduces maximum mean velocity	
3	Rahai et al.[49]	Air	Wire coil	Experiment in round tube	Investigated effect of various coil spacings on mixing process	
4	Sams [50]	Air	Wire coil	Experiment in tube	Vortex flow can be created through coiled wire. Developed correlation for friction factor and Nusselt number	
5	Arici and Asn [51]	Water	Wire coil	Experiment in tube flow	Increase in pitch of wire coil increases heat transfer.	
6	Kumar and Judd [52]	Water 4<Pr<5	Wire coil	Experiment in tube	Proposed correlations for heat-transfer. Correlations under predicts by 50 per cent	
7	Kim et al.[53]	Gas and liquid	Wire coils	Experiment in Vertical round tube	Flow pattern, slug rise velocityand void fraction are higherfor wire coil insert thansmooth tube	

5.) CONCLUSION:

Enhancement of the hat transfer is subject of many interests t research in focusing on the techniques of how to increase heat transfer rate and achieve higher thermal performance of the system. Turbulator is device that turns the laminar flow into turbulent flow.

1.) Twisted tape in laminar flow, insert of twisted tape mixes the bulk flow well and therefore performs the better in a laminar flow than any other inserts, because in laminar flow the thermal resistance is not limited to the thin region. However, twisted tape performance also depends on the fluid properties such as the Prandtl number is high. On the basis of constant pumping power, short-length twisted tape is better than full-length twisted tape. For the design of compact heat exchanger, twisted tape can be used effectively to enhance the heat-transfer.

2.) Twisted tape in turbulent flow is effective up to a certain Reynolds number range but not over the wide range of Reynolds number. Compare the twisted tape with wire-coil, twisted tape is not so much effective in turbulent flow because it blocks the flow and therefore the pressure drop is large. Therefore, it may be concluded that for design of compact heat exchanger wire coil is good choice in turbulent flow.

3.) Wire-coil in turbulent flow, it enhances the heat-transfer in turbulent flow effectively. It performs better in turbulent flow than in laminar flow. The thermo hydraulic performance of wire-coil has good compared with twisted tape in turbulent flow.

4.) Wire-coil in laminar flow enhances the heat transfer rate significantly. However, the performance depends on the Prandtl number is high, the performance of the wire-coil is good because for the high Prandtl number the thickness of the thermal boundary layer is small compared with hydrodynamic boundary layer and wire coil breaks this boundary layer easily.

Some more conclusions are, In case of the twisted tape with modified geometry more turbulence has created during the swirl of fluid and gives higher heat-transfer rate compared to plain twisted-tape.

References

[1] Dewan A, Mahanta P, Raju KS, Kumar PS. Review of passive heat transfer augmentation techniques. J Power Energy 2004; 218:509–25.

[2] B.Adrian and K. Allan D. Heat transfer enhancement. In Heat Transfer Handbook,Chapter 14, pg.1033, -1101, Wiley-interscience, 2003.

[3] Bergles, A.E. ―Techniques to augment heat transfer.‖ In Handbook of Heat TransferApplications (Ed.M. Rosenhow), 1985, Ch.3 (McGraw-Hill, New York).

[4] E. Smith, P. Yuttana, "An Experimental study of heat transfer and friction factor characteristics in a circular tube fitted with a helical tape".18th Conference of Mechanical Engineering network of Thailand, Khon Kaen, Thailand, 2004.

[5] S.K. Saha, A. Dutta, "Thermodynamic study of laminar swirl flow through a circular tube fitted with twisted tape elements". Journal of Heat Transfer, ASME, Vol. 123, No.3, 2001, 417-427.

[6] Anil Singh Yadav, "Effect of Half Length Twisted-Tape Turbulators on Heat Transfer and Pressure Drop Characteristics inside a Double Pipe U-Bend Heat Exchanger," Jordan Journal of Mechanical and Industrial Engineering, vol. 3, March. 2009, pp.17- 22.

[7] S. Eiamsa-ard, P. Promvonge, Thermal characteristics in round tube fitted with serrated twisted tape, J. Appl. Therm. Eng., 2010.

[8] M. Rahimia, S.R. Shabaniana, A.A. Alsairafib, Experimental and CFD studies on heat transfer and friction factor characteristics of a tube equipped with modified twisted tape inserts, Chem. Eng. Process 48, 2009.

[9] Chinaruk Thianpong, Petpices Eiamsa-ard, Smith Eiamsa-ard (2015) "Heat transfer and thermal performance characteristics of heat exchanger tube fitted with perforated twisted-tapes."

[10] Bodius Salam, Sumana Biswas, Shuvra Saha, Muhammad Mostafa K Bhuiya (2013) "Heat transfer enhancement in a tube using rectangular-cut twisted tape insert." Procedia Engineering 56 (2013) 96 – 103.

[11] C. Thianpong, K. Yongsiri, K. Nanan, S. Eiamsa-ard (2012) "Thermal performance evaluation of heat exchangers fitted with twisted-ring turbulators." International Communications in Heat and Mass Transfer 39 (2012) 861–868.

[12] S. Naga Sarada, A.V. Sita Rama Raju1, K. Kalyani Radha L. Shyam Sunder, Enhancement of heat transfer using varying width twisted tape inserts, International Journal of Engineering, Science and Technology, 2010.

[13] Chinaruk Thianpong, Petpices Eiamsa-ard, Smith Eiamsa-ard (2015) "Heat transfer and thermal performance characteristics of heat exchanger tube fitted with perforated twisted-tapes.

[14] A. Dewan, P. Mahanta, K Sumithraju, P. Suresh kumar ―Review of passive heat-transfer augmentation techniques‖. Proc. Institution of Mechanical Engineers Vol. 218Part A (2004): Journal of Power and Energy.

[15] Saha, S. K. and Dutta, A. ―Thermo-hydraulic study of laminar swirl flow through acircular tube fitted with twisted tapes.‖ Trans. ASME, J. Heat Transfer, 2001, 123, 417–421.

[16] Hong, S. W. and Bergles, A. E. Augmentation of laminar flow heat transfer in tubes bymeans of twisted-tape inserts. Trans. ASME J. Heat Transfer, 1976, 98, 251–256.

[17] Saha, S. K., Dutta, A. and Dhal, S. K. Friction and heat transfer characteristics oflaminar swirl flow through a circular tube fitted with regularly spaced twisted-tape elements. Int.J. Heat and Mass Transfer, 2001, 44, 4211–4223.

[18] Lokanath, M. S. and Misal, R. D. An experimental study on the performance of plateheat exchanger and an augmented shell and tube heat exchanger for different types of fluids for marine applications. In Proceedings of 5th ISHMT– ASME Heat and Mass Transfer Conference, India, 2002, pp. 863–868 (Tata McGraw-Hill, New Delhi).

[19] Manglik, R. M. and Bergles, A. E. ―Heat transfer and pressure drop correlations fortwisted tape insert in isothermal tubes.‖ Part 1: laminar flows. Trans. ASME, J. Heat Transfer, 1993, 116, 881–889.

[20] Ujhidy et. al, Fluid flow in tubes with helical elements, Chemical Engineering andProcessing 42 (2003), pp. 1–7.

[21] Saha, S. K. and Bhunia, K. ―Heat transfer and pressure drop characteristics of varyingpitch twisted-tape-generated laminar smooth swirl flow.‖ 4th ISHMT–ASME Heat and Mass Transfer Conference, India, 2000, pp. 423–428 (Tata McGraw-Hill, New Delhi).

[22] Agarwal, S. K. and Raja Rao, M. Heat transfer augmentation for flow of viscous liquidin circular tubes using twisted tape inserts. Int. J. Heat Mass Transfer, 1996, 99, 3547– 3557.

[23] V. D.Zimparov, P. J.Penchev, and J. P. Meyer. • \Performance evaluation of tube-intubeheat exchangers with heat transfer enhancement in the annulus.. Thermal Science, vol. 10. (2006), No.1, pp.45-56.

[24] Watcharin Noothong, Smith Eiamsa-ard and Pongjet Promvonge "Effect of TwistedtapeInserts on Heat Transfer in a Tube". The 2nd Joint International Conference on"Sustainable Energy and Environment (SEE 2006)", 21-23 November 2006, Bangkok, Thailand.

[25] Al-Fahed and Chakroun. Effect of tube- tape clearance on heat transfer for fullydeveloped turbulent flow in a horizontal isothermal tube‖.Int. J Heat and fluid flow: 17, 173-178, 1996.

[26] Klepper, O. H. Heat transfer performance of short twisted tapes. AIChE J., 1972, 35,1–24.

[27] Blackwelder, R. and Kreith, F. Experimental investigation of heat transfer and pressuredrop in a decaying swirl flow. Trans. ASME Augmentation of Convective Heat and Mass Transfer, 1970, 102–108

[28] Zozulya, N. V. and Shkuratov, I. Y. Effect of length of twisted tape turbulencepromoter and its initial twisting pitch on augmentation of heat transfer inside a tube. Heat Transfer Sov. Res., 1974, 6, 98–100.

[29] Cresswell, J. D. Mechanism of swirling turbulent flow. MS thesis, Lehigh University,USA, 1958.

[30] Kreith, F. and Margolis, D. Heat transfer and friction in turbulent vortex flow. Appl.Sci. Res., 1959, 8, 457–473.

[31] Seymour, E. V. A note on the improvement in performance obtainable from fittingtwisted-tape turbulence promoters to tubular heat exchangers. J. IChE, 1963, 41, 159–162.

[32] Kreith, F. and Sonju, O. K. The decay of a turbulent swirl flow in a pipe. J. FluidMechanics, 1965, 22, 257–271.

[33] Wang L, Sunden B. Performance comparison of some tube inserts. International Communication Heat Mass Transfer 2002; 29(1):45–56.

[34] A. Garcia, P. G. Vicente and A. Viedma, "Experimental study of heat transfer enhancement with wire coil inserts in laminar-transition-turbulent regimes at different Prandtl numbers", Int. J. of Heat and Mass Transfer, Vol. 48, pp. 4640-4651, 2005.

[35] S. Biswas and B. Salam (2015) "Experimental Investigation of Tube Side Heat Transfer Enhancement Using Wire Coil Insert." Mechanical Engineering Research Journal Vol. 9, pp. 18.23, 2013, ISSN: 1990-5491.

[36] Prof.Shashank S. Choudhari, Prof.Taji S.G (2013) "Experimental Studies on Effect of Coil Wire Insert On Heat Transfer Enhancement and Friction Factor of Double Pipe Heat Exchanger."

[37] A. E. Zohir, M. A. Habib, and M. A. Nemitallah (2015) "Heat Transfer Characteristics in a Double-Pipe Heat Exchanger Equipped with Coiled Circular Wires." A Journal of Thermal Energy Generation, Transport, Storage, and Conversion, 28:6, 531-545, ISSN: 0891-6152.

[38] M. A. Akhavan Behabadi, R. Kumar, M. R. Salimpour and R. Azimi, "Pressure drop and heat transfer augmentation due to coiled wire inserts during laminar flow of oil inside horizontal tube", Int. J. of Thermal Sciences, Vol. 49, pp. 373-379, 2010.

[39] S. Gunes, V. Ozceyhan and O. Buyukalaca, “The experimental investigation of heat transfers and pressure drop in a tube with coiled wire inserts placed separately from tube wall”, Applied Thermal Engineering, Vol. 30, pp. 1719-1725, 2010.

[40] C.Nithiyesh Kumar, P. Murugesan “Review on Twisted Tapes Heat Transfer Enhancement” International Journal of Scientific & Engineering Research, Volume 3, Issue 4, April-2012, ISSN 2229-5518.

[41] V. Kongkaitpaiboon, K. Nanan, and S. Eiamsa-ard, “Experimental investigation of convective heat transfer and pressure loss in a round tube fitted with circular-ring turbulators,” International Communications in Heat and Mass Transfer, vol. 37, Feb. 2010, pp. 568–574, doi: 10.1016/j.icheatmasstransfer.2009.12.016.

[42] Inaba, H. and Ozaki, K. Heat Transfer enhancement andflow drag reduction of forced convection in circular tubes by means of wire coil insert. In Handbook of Compact Heat -Exchanger (Eds R. K. Saha, K. J. Bell, S. Mochizuki, and V. V. Wadekar) 2001, pp. 445–452 (Begell House, Inc. New York).

[43] Ujhidy, A., Nemeth, J. and Szepvolgyi, J. Fluid flow in tubeswith helical elements. Chem. Engng and Processing, 2003, 42, 1–7.

[44] Wang, L. and Sunden, B. Performance comparison of sometube inserts. Int. Commun. Heat Transfer, 2002, 29, 45–56.

[45] Oliver, D. R. and Shoji, Y. Heat transfer enhancement in around tubes using different tube inserts: non-newtonian fluids. J. Chem. Engng. Res. and Des., 1992, 70, 558–564.

[46] Inaba, H. and Haruki, N. Heat transfer enhancement ofwater flow in a straight pipe with drag reduction surfactant by using wire coil. Trans. Jap. Soc. Mech. Engrs, Part B, 2002, 68, 481–488.

[47] Ravigururajan, T. S. and Bergles, A. E. Development andverification of general correlations for pressure drop and heat transfer in single-phase turbulent flow in enhanced tubes. Exp. Thermal and Fluid Sci., 1996, 13, 55–70.

[48] Rahai, H. R. and Wong, T. W. Velocity field characteristicsof turbulent jets from round tubes with coil inserts. Appl. Thermal Engng, 2002, 22, 1037–1045.

[49] Rahai, H. R., Vu, H. T. and Shojaeefard, M. H. Mixingenhancement using a coil insert. Appl. Thermal Engng, 2001, 21, 303–309.

[50] Sams, E. W. Heat transfer and pressure drop characteristics ofwire coil type turbulence promoters. TID-7529 Part 1, Book 2, 1957, pp. 390–415.

[51] Arici, M. E. and Asan, H. Enhancement of turbulent flowheat transfer in tubes by means of wire coil inserts. ASME PD Adv. in Heat Transfer, 1994, 64, 113–117.

[52] Kumar, P. and Judd, R. L. Heat transfer with coiled wireturbulence promoters. Canadian J. Chem. Engng., 1970, 48, 378–383.

[53] Kim, H. Y., Koyama, S. and Matsumoto, W. Flow patternand flow characteristics for counter-current two-phase flow in a vertical round tube with wire coil insert. Int. J. Multiphase Flow, 2001, 27, 2063–2081.