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A Review on Enhancement of Heat Transfer by using Passive Heat Transfer Techniques of Twisted Tape Inserts

Abhijit A Patil[1,a)], Dr. Uday C Kapale[2, b)]and Dr. P B Gangawati[3,c)]

[1]Department of Mechanical Engineering, Shivaji University, Sanjay Ghodawat group of Institutions, Atigre, Kolhapur, Maharashtra

[2]Department of Mechanical Engineering, S. G. Balekundri Institute of Technology, Belgaum, Karnataka

[3]Department of Mechanical Engineering,VTU, Basveshwar Engineering College, Bagalkot, Karnataka

Abstract: *Heat transfer is considered as a most promising criterion in the thermal performance analysis of any system. Enhancement of heat transfer gives result to high thermal performance of the system. Every component of the thermal system is restricted with its own thermal properties for the transition of heat energy. There are many heat transfer augmentation techniques which are used to increase the rate of heat transfer without affecting the performance of the system. These techniques are generally used in various application areas like heat exchangers in process industries, space vehicles, refrigeration and air conditioning, thermal power stations etc. Passive heat transfer enhancement techniques are more effective due to ease of manufacturing, operation and maintenance etc. The present paper reviews a detail study of the heat transfer enhancement by using different geometry twisted tape inserts and its effect on the thermal performance factors like heat transfer coefficient, frictional factor, pressure drop etc.*

Key words: Heat transfer enhancement, thermal performance, twisted tape inserts, twist ratio, Reynolds number.

1. INTRODUCTION

Heat transfer can be enhanced by creating the disturbance or turbulence in the flow pattern. According to Bergles heat transfer enhancement techniques are broadly classified into three different categories:

1.1. Active techniques:

Such techniques require an external power input to get a flow modification which will lead to increase the heat transfer rate. They are rarely used due to the complexity in design and manufacturing.

1.2. .Passive techniques:

These techniques use geometrical modifications to the flow channels by inserting additional devices in the flow stream or passage. These techniques have more advantages as it does not require external power input also the tape inserts are easy to design, manufacture and apply. The twisted tape insert acts as a turbulator disturbs and alters the flow behavior hence increases the heat transfer rate.

1.3. Compound techniques:

Such technique uses the combination of above techniques simultaneously to enhance the heat transfer rate. But due to the complexity of application they are rarely used.

In this paper a review of heat transfer enhancement by using passive method using twisted tape insert is done. The performance criteria are discussed with geometrical modification, fluids and type of flow.

TABLE 1: Nomenclature

h	Heat transfer coefficient	PT	Peripherally Cut Twisted Tape
F	Friction factor	PT-A	Peripherally Cut Twisted Tape with alternative axis
s	Free space ratio	VTT	V-cut Twisted Tape
θ/α	Twist angle/Rotated angle	ɳ	Heat transfer efficiency index
UHF	axially Uniform wall Heat Flux	CT/CoT	Twin counter/ co-twisted tapes
Nu	Nusselt number	C-CC TT	Counter Clockwise Twisted Tape
H	Thermohydraulic efficiency	ETT	Edgefold Twisted Tape
TT	Twisted Tape	STT	Spiral Twisted Tape
D coil	Decreasing coil	T-A	Twisted tape with Alternate axis
DI coil	Decreasing Increasing coil	WT	Twisted Tape with wings
S	Space between two twisted tapes	WT-A	Centre Wing and alternate axis Twisted tape
Y	Twist ratio	β	Angle of attack
Re	Reynolds number	DWT	Delta Winglet Twisted Tape
Sw	Swirl parameter	S-DWT/O-DWT	Straight/ Oblique – Delta winglet Twisted tape
MTVG	Multiple twisted vortex generator	DR	Depth Ratio
THE	Heat Transfer Enhancement	WR	Width Ratio
STT	Single Twisted Tape	BTT	Broken Twisted Tape
CCT	Center Cleared Twisted tape	TTWB	TT with baffles
TA	Twisted Tape with alternative axis	CTTT	Centre Trimmed Twisted Tape
g	Thermal enhancement index	MCHS	Micro Channel Heat Sink

Heat transfer enhancement by passive method generally uses the inserts in the form of Twisted Tape to change the geometrical modification of the flow channel. The twisted tape is of different shapeand classified as,

i. **Full length TT:** Length equal to length of test section.
ii. **Varying length TT:** ½ length, ¾ length, ¼ length of test section.
iii. **Regularly spaced TT:** Short length tapes of different pitches spaced by regular interval.
iv. **Tape with attached baffles:** Baffles are attached on TT to achieve more enhancements.
v. **Slotted tape/ hole tape:** Slots or holes or slot and holes with suitable dimensions in the TT.
vi. **Tape with modified surface:** One of the surface modifications is to make the surface insulated to avoid fin effect.

2. COMMON TERMINOLOGY FOR TT

2.1 Pitch: the distance between two successive twists.

2.2 Twist ratio: ratio of pitch length to inside diameter of the tube (approx. o the width of the tube).

2.3 Fin effect: the effect of fin due to the absorption of heat till its saturation is called fin effect.

Heat transfer in Laminar mainly takes place by conduction and molecular diffusion. Therefore the use of TT is more effective for laminar flow as compared with turbulent flow.

Commonly used terminology and definitions for further discussions**:**

2.4 Reynolds number: It is a dimensionless quantity which is used to decide the flow pattern.

2.5 Nusselt Number: It is the ratio of convective heat transfer to the conductive heat transfer across the boundary.

2.6 Prandtl Number: It is the ratio of molecular diffusivity of the momentum to the molecular diffusivity of heat.

2.7 Hydraulic diameter: It is the ratio of cross-sectional area to the wetted perimeter of the cross section.

3. REVIEW OF TT

The present paper is a review of twisted tape inserts and its effect on the thermal performance. The review is carried out on plain TT, modified TT and modified TT geometry.

3.1 Plain TT:

L. Syam Sunder and K.V.Sharma [1] determined the thermophysical properties like thermal conductivity and viscosity of Al2O3 nanofluid through experiments for different volume concentrations and temperatures. The result shows that heat transfer coefficient and ‘f’ are higher as compared with water in a plain tube. They developed a generalized regression equation with the experimental data for the estimation of ‘f’ and ‘Nu’.

S. Eiamsa –ard et al. [2] investigated the ‘h’, ‘f’ and ‘η’ parameters experimentally in a tube with the combined devices between TT and wire coil. The experiment is carried with two forms of wire coils as D coil and DI coil by varying two different twist ratios. The result shows highest thermal performance by using DI coil with TT at lower Re. they developed an empirical co relation of ‘Nu’ and pressure drop.

Kapatkar V.N.et al [3] investigates the heat transfer rate and ‘f’ with full length TT by varying tape material, ‘Re’ and ‘y’. It was found that the average ‘Nu’ improves more for Aluminiuum material as compared with Stainless steel and insulated tape. The isothermal ‘f’ was higher as compared the plain tube.

Suhas V. Patil et al [4] investigated the heat transfer and ‘f’ characteristics with increasing and decreasing order of ‘y’. The tests were performed on square duct and water as a fluid. The result shows not much variation in ‘h’ with increasing or decreasing ‘y’. The value of ‘Nu’ increases as compared with plain duct.

NajimAbidJassim et al [5] investigated experimentally heat transfer and ‘f’ characteristics by using full length plain TT inserts. The experiment was carried by varying ‘y’ and water as a test fluid. It was found that the heat transfer rate decreases with the increase in ‘y’.

3.2 Modified TT:

P.Ferroni et al. [6] investigated the experimental dependence of the Darcy friction factor on the empty tube Re, y and TT spacing experimentally. Water is used as a working fluid t room temperature.fro experimental results a correlation for the Darcy friction factor in the form of f was developed with excellent accuracy.

Yangiun Wang et al [7] presented the work by using CFD modeling on optimization of regularly spaced short length twisted tape in a circular tube. Air is used a working fluid. The configuration parameters includes‘s’, ‘y’ and ‘a’. The conclusion is the larger value of ‘a’ gives higher heat transfer value where as smaller value of ‘s’ results in better heat transfer.

Smith Eiamsa-ard et al [8] investigated experimentally on enhancement of heat transfer and pressure drop in a round tube under UHF. The experiments were conducted using single TT’s, full length dual TT with three different ‘y’ and regularly spaced dual TT with three different space ratios. The result shows the heat transfer rate of the tube with dual TT was higher than that of plain tube. The value of ‘Nu’ and ‘f’ increased with decreased ‘y’.

K Hata et al [9] investigated the heat transfer and pressure drop for different mass velocities of water with different values of 'y'. The effect of 'y' and 'Re" based on swirl velocity on the TT induced swirl flow heat transfer were studied and a precise correlation is developed on the experiment data.

S. Eiamsa-ard [10] experimentally studied the heat transfer and 'f' characteristics of MT-VG with the different value of 'y' and 'Re' in a rectangular channel. The conclusion found was the smaller value of 'y' and free spacing ratio gives higher heat transfer rate and pressure loss as compared with larger values of 'y' and space ratios. A correlation of 'y' and 'f' was developed.

Suvanjan Bhattacharyya et al [11] experimentally studied the effect of CTTT on heat transfer rate, 'f' and thermal enhancement efficiency. A numerical analysis is done by finite volume base. The results concluded that the heat transfer and thermal enhancement efficiency get decreased by decreasing 'y'. The "Nu' also increased with 'Re'.

3.3 Modified Geometry TT:

JianGuo et al [12] computed results for good thermal performance with CC-TT and SW-TT. It was found that the heat transfer rate and thermal performance got enhanced for the tube with CC-TT as compared with conventional TT.

KhwanchitWongcharee and Smith Eiamsa-ard [13] experimentally investigated heat transfer, 'f' and thermal performance characteristics of copper oxide-water (CuO) nanofluids. The experiment was conducted with modified TT with TA fitted in a circular tube. The concentration of nanoflud was changed while the value of 'y' was kept constant. It was seen that the 'Nu' increases by increasing 'Re' and nanofluids concentration. The empirical correlation was developed for 'h', 'f' and thermal performance factor.

P. Murugesan et al [14] studied the effect of VTT inserts on 'h', 'f' and thermal performance factor characteristics in a circular tube for different twist ratios and different combinations of depth and width. From results the conclusion made the mean Nusselt number and the mean friction factor in the tube with VTT increases with decreasing 'y', width ratios and increasing depth ratios. An empirical correlation was also formulated.

S. Eiamsa-ard et al [15] studied experimentally the effect of CT and CoT TT on 'Nu', 'f' and 'g' by varying 'y'. The results shows that CT's are more efficient than CoT's for heat transfer enhancement. The values of 'Nu', 'f' and 'g' increase with decreasing 'y'. An empirical correlation was also developed between 'Nu', 'f' and 'g' from the experimental results.

Smith Eiamsa-ard and PongjetPromvonge [16] presented experimentally study of turbulent heat transfer and flow friction characteristics in a circular tube with two typical twisted tapes and C–CCTT and different values of 'y'. Water as used as a working fluid. From obtained result the C–CCTT shows higher heat transfer rate, 'f' and HTE index than the typical twisted-tapes at similar operating conditions. Also the heat transfer rate of the C–CCTT increases with the decrease of 'y' and the increase of 'α'.

CUI Yong-zhang [17] studied heat transfer characteristics and the pressure drop of air flow in a circular tube with ETT and with classic STT experimentally and numerically without varying 'y'. It was found that the Nusselt number of the tube with ETT is higher than that with STT, and the 'f' of the tube with ETT is higher than that of STT inserts.

Smith Eiamsa-ard and PongietPromvonge [18] investigated the effect of STT on heat transfer and pressure drop experimentally on air with constant 'y'. The result shows that the value of 'Nu' increases with increasing value of DR and decreases with increases in WR. An empirical relation was developed between SDR, SWR and Re from the experimental data.

Sujoy Kumar Saha [19] experimentally studied the heat transfer and the pressure drop characteristics of turbulent flow for different types of ducts and tape inserts. The axial corrugations in combination with oblique teeth TT performs better than without oblique teeth TT.

S.Eiamsa-ard et al [20] experimentally studied the thermohydraulic properties in a round tube by using modified TT. For experimental purpose three different types of TT were considered as: WT, T-A and typical TT. Different trials were conducted at constant twist ratio. Water was considered as working fluid. The wings

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were generated along the centre line of the tape with three different angles of attack. It was found that the heat transfer rate in the tube fitted with the WT-A was higher than WT, T-A and plain tube. The heat transfer rate increased with increasing angle of attack. The experimental correlations of Nu, f and thermal performance factor were also developed.

PanidaSeemawute et al [21] investigated experimentally the effect of PT-A with a uniform heat flux on the heat transfer enhancement characteristics. The tests were conducted with water as a working fluid. The correlations of the Nu, f and thermal performance were developed for the tube equipped with the PT-A, Re and Pr.

S Eiamsa-ard et al [22] investigated heat transfer, f and thermal performance factor characteristics by using water a test fluid. The experiments were conducted on different types of DWT. The effect of O-DWT and S-DWT were studied by varying the values of 'y'. It was found that the O-DWT gives higher 'h' as compared with S-DWT.

S Eiamsa-ardet.al. [23] investigated effect of PT on heat transfer, f and thermal performance factor characteristics in a tube. Experiments were performed by varying DR and WR and by keeping 'y' constant. It was found that heat transfer increases as the DR increases and WR decreases. A predictive correlation of 'f' and 'Nu' was also developed.

Pratap Kumar Raut et al [24] investigated 'f' and 'Nu' data for laminar flow with wire coil and helical screw TT in a circular duct. A correlation was developed for 'f' and 'Nu'. It was found that helical screw insert TT with wire coil inserts performs better than individual enhancement methods.

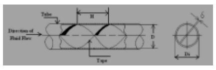
A. M. Mulla et al [25] studied the heat transfer and pressure drop by applying typical TT and TTWB, keeping uniform heat flux, fixed 'y' and constant flow rate. The experiment was carried with water as a working fluid and flow as laminar. From results it was found that the values of heat transfer and pressure drop increases as compared with plain tube.

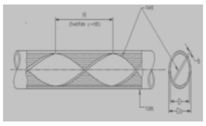
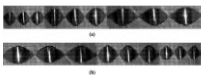
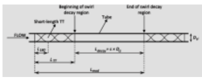
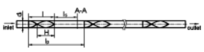
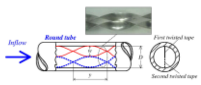
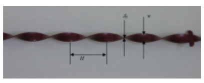
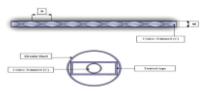
DurgeshV.Ahire et al [26] investigated 'f' and 'h' for different conical rings of different pitches. It was observed that the value of 'h' increases with increase in 'Re' and decrease in 'f' for a conical ring.

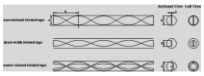
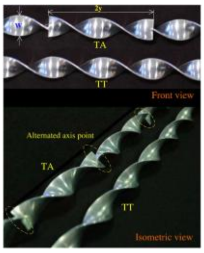
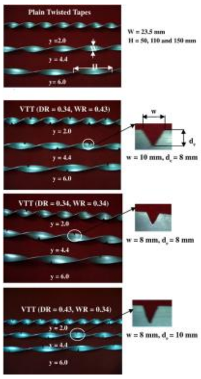
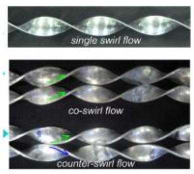
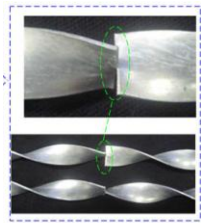
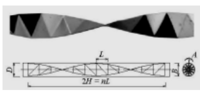
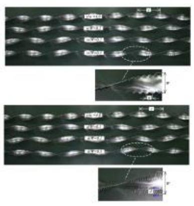
SibelGinus et al [27] numerically investigated the heat transfer enhancement with hexagonal cross section wire coiled inserts by varying the pitch ratios. It was found that the heat transfer rate increased with wire coiled tape inserts as compared with plain tube.

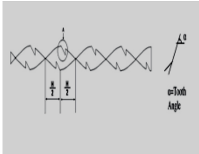
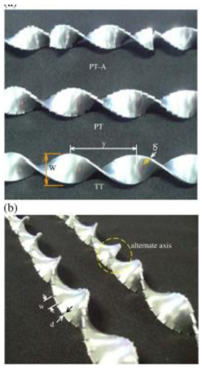
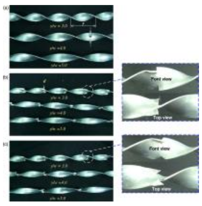
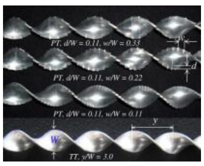
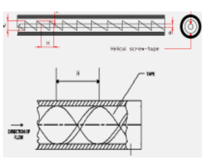
ZhenfeiFeng et al [28] numerically investigated the heat transfer performance with wire coil inserts. The effect of length and arrangement of wire coil is studied with distilled water as attest fluid. The microchannel heat sink with long wire coil placed at the center line resulted into higher heat transfer performance.

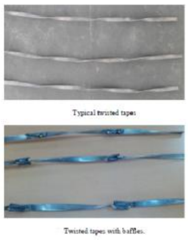
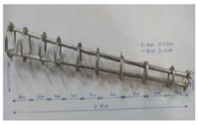
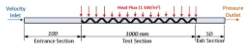
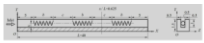
TABLE 2. Summary of important investigation.

Sr. No.	Author name	Fluid used	Type of flow	Tape configuration	Observation	Comment
1	L. Syam Sunder and K.V.Sharma	Al2O3 Nanofluid/ water	Turbulent		'h' and 'f' for y=5 are 33.51% and 1.096 times higher as compared with water.	No significant increase in pressure drop or 'f' as compared to the water at same 'y'. Better results for y=5.
2	S. Eiamsa –ard et al.	Air	Turbulent		At low 'Re' and y=3 and DI coil the highest thermal performance for the wire coil alone, TT alone, TT with uniform coil and TT with D coil is 6.3%, 13.7%,2.4% and 3.7% respectively.	Thermal performance for 'y'=3 is high for TT alone.

3	Kapatkar V.N.et al	Water	Laminar		Maximum improvement in 'Nu' for y=4.2 and Re=2000.	Maximum improvement in 'f' ranging from 50% o 100% by Aluminum tapes as compared with S.S. and insulated tapes.
4	Suhas V. Patil et al	Water	Laminar		The values for Nu were found 1.33 to 4.27 and 0.9 to 3.46 times plain square duct.	The increasing and decreasing values of y enhances heat transfer as well as increases 'f'.
5	NajimAbidJassim et al	Water	Laminar		The enhancement in heat transfer is higher for a TT with =3.5 and lower for y=5	Heat transfer enhancement increases by TT than a plain tube. 'Nu' increases with decrease in 'y'.
6	P.Ferroni et al.	Tap water at room temperature.	Turbulent		Multiple short length TT lowers the pressure drop by 50% as compared with full length TT.	Multiple short length results in high heat transfer coefficient as compared with full length TT.
7	Yangiun Wang et al	Air	Turbulent		For maximum heat transfer rate the values of y=4.25 to 4.75, α= 270° and Re= 10000 to 20200.	Larger α gives a higher heat transfer performance.
8	Smith Eiamsa-ard et al	Air	Turbulent		The value of 'f' increases 23% by dual TT than that of regular TT. The heat transfer rate increased by 12% to 29% as that of single TT for y= 3 to 5.	The value of 'f' decreases with the increases in 'Re' and 'y' values.
9	K Hata et al	Water	Turbulent		The value of pressure drop increases with an increase in 'Re'.	Heat transfer enhancement is high for lower 'y'. Overall heat transfer enhancement decreases with increase in 'Re'.
10	S. Eiamsa-ard	Air	Turbulent		Heat transfer rate is 1.4 times that of plain tube. 'f' in the range of 1.45 to 5.7 and 'Nu' increases with the range of 170%.	Heat transfer and pressure loss is higher for smaller 'y' and 's'
11	Suvanjan Bhattacharyya et al	Air	Laminar		The improved parameter is observed in the range of Re below 800 and above 4000.	CCTT gives more heat transfer enhancement than plain TT.
12	JianGuo et al	Water	Laminar		CCT gives the value 'g' more than TT in the	The heat transfer and thermohydraulic performance were

					range of 7% to 20 %	weakened by cutting off the tape edge.
13	KhwanchitWongcharee and Smith Eiamsa-ard	CuO/water Nanofluid	Laminar		The simultaneous use of nanofluid and TA increases Nu upto 13.8 times of the plain tube.	With increase in concentration and 'Re' the value of 'Nu' increases. T-A increases more efficiency by generating more swirl in the flow.
14	P. Murugesan et al	Water	Laminar/Turbulent. (2000-12000)		The effect of DR is more as compared with WR.	The V-cut twisted tape offered a higher heat transfer rate, 'f' and 'g' as compared to the plain TT.
15	S. Eiamsa-ard et al	Water	Turbulent		Heat transfer rates for the CT's are 12.5 to 44.5% than those for CoT's around 17.8 to 50% higher than those for the ST.	Decreases in 'y' increases 'f', 'Nu' and 'g'. CT's gives high heat transfer than CoT's and ST.
16	Smith Eiamsa-ard et al	Water	Turbulent		The maximum heat transfer rate of the C-CCTT with θ=90° for y= 3, 4, and 5 are 1.4, 1.34 and 1.3.	The value of η increases with decrease in Re and or y and decreases with reducing θ.
17	CUI Yong-zhang	Air	Turbulent		The thermo hydraulic performance increases by average 124% and 140% when the gap width reduced by 1.5 mm to 1.00 mm and 0.5 mm	The thermo hydraulic performance decreases as the value of y increases. The major factor affecting the heat transfer by ETT inserts are the value of y and the gap width between the tube and inserts.
18	Smith Eiamsa-ard and PongietPromvonge	Air	Turbulent		Nu increases with increases in DR and decreased with increase in WR. The heat transfer rate is 72.2% and 27% relative to the plain tube and TT tube.	STT tube is more significant over the plain tube.

19	Sujoy Kumar Saha	Air	Turbulent		The pumping power reduced upto 47% for the TT with oblique teeth.	Full length and short length TT with oblique teeth improves heat transfer than TT without oblique teeth.
20	S Eiamsa-ard et al	Water	Turbulent		The use of WT-A with β= 74° gives highest thermal performance factor upto 1.4.	Heat transfer rate increases with increase of β. WT-A performs more effective on thermohydraulic properties than WT and typical TT.
21	PanidaSeemawute et al	Water	Turbulent		For a turbulent flow the maximum thermal performances at constant pumping power of 1.25, 1.11 and 1.02 respectively.	The heat transfer rate by PT-A is maximum as compared with PT and TT.
22	S Eiamsa-ard et al	Water	Turbulent		The values of Nu, f and thermal performance factor in a tube with O-DWT are 1.04 to 1.64, 1.09 to 1.95 and 1.05 to 1.13 times as compared with typical TT.	O-DWT is more effective as compared with S-DWT.
23	S Eiamsa-ard et al	Water	Laminar and turbulent		The heat transfer enhancement by PT was 2.6 times (for Turbulent regime) and 12.5 times (Laminar regime) as compared with plain tube.	The heat transfer rate and f with PT are high as compared than typical TT and plain tube.
24	Pratap Kumar Raut et al	Servotherm medium oil	Laminar		The value of f increases by 50% to 100% with combination of wire coil and helical screw tape.	Nu and f increases with increase in the coil wire diameter and coil helix angle.

25	A.M.Mulla et al	Water	Laminar		The heat transfer and pressure drop for TTWB increased by 130% to 140% as compared with TT by 110% to 120%.	The values of Nu, h and pressure drop found higher for tubes fitted with TTWB as compared with plain tubes.
26	DurgeshV.Ahire et al	Air	Turbulent		The conical inserts with 3 mm thick and 30 mm pitch enhance Nu 50% to 58% and f as 36% as compared with tube without insert.	The heat transfer coefficient increases for conical ring insert as compared with plain tube without insert.
27	SibelGinus et al	Air	Turbulent		The maximum value of g is 43% for the wire with edge length ratio of 0.12 and pitch ratio of 1 for Re of 17000.	The value of Nu and f factorize with the decrease of pitch ratio. And increase in hexagon edge length ratio.
28	ZhenfeiFeng et. al.	Distilled water.	Laminar		The MCHS with long wire coil shows enhancement factor of 1.4 to 1.8at a heat flux 400 KW/m^2	Wire coil inserts enhances the heat transfer in MCHS.

4. CONCLUSIONS

The review of thermal performance, effect on friction factor and pressure drop has done with passive heat transfer techniques. Various TT are studied for different types of flow, tape geometries, types of twists and twist direction, etc. The effect of heat transfer enhancement due to the tape inserts is more important than the effect of rising friction. Many useful correlations to determine heat transfer, pressure drop and friction factor were developed.

Following are some conclusions after reviewing the articles:

4.1 Effect of type of flow:

- The effect of tape insert was studied for Laminar flow as well as for turbulent flow.
- The insertion of any geometrical TT generates swirling flow and increase turbulence intensity.
- A twisted tape insert mixes the bulk flow and performs better in laminar flow because of the thin thermal resistance.
- The TT insert in turbulent flow increases the pressure drop because of the blockage of the flow. It decreases the thermohydraulic performance of the system. Therefore the use of TT effectively results good upto certain Reynolds number range.
- Nusselt number increases with increase in Reynolds number which results into increase in heat transfer and swirl intensity.

4.2 Type of geometry:

- The TTs are categorized as plain TT, modified TT and geometry modified TT according to the geometry.

- The Nu, Re, Pr, pressure drop and friction factor depends on the geometrics of the twisted tape like different twist ratio, angle of rotation, spacers, pitch ratio, tape width, wire diameter etc .
- A plain TT and modified TT perform better in Laminar flow region because the thermal resistance is not limited to the thin region.
- Modified geometry TT shows higher thermal performance as compared to the plain TT and modified TT. It gives high heat transfer as more turbulence is created during the swirling of the fluid.
- The use of TT with artificial roughness enhances the heat transfer characteristics.
- In large Prandtl number flow, roughness performs better than the twisted tape. Therefore for high Prandtl number (Pr › 30) twisted tape inserts are not found to be useful.
- Full length TT performs better than regularly spaced TT because the turbulence is not getting created in non twisted tape area.

4.3 Type of fluid:

- Different types of fluids like tap water, distilled water, ethylene glycol, nanofluids with different concentrations, air etc. were reviewed.
- Use of TT performs better for larger density fluids like water and nanofluids.
- TT performs better for air in the turbulence region.

4.4 Type of twist and twist direction:

- Twist direction is important consideration for multiple TT.
- Counter swirl direction performs better than the co swirl direction as it tends to generate more swirling.
- The tape inserts reduces the flow cross section area results into increase in turbulence intensity and tangential flow.
- Wire coil tape inserts shows better heat transfer performance for turbulent region as compared to laminar region.
- The heat transfer coefficient increases with decrease in twist ratio.
- The heat transfer, thermal efficiency and friction factor increases with decrease in twist ratio.

4.5 Tape material:

- Twisted tape with low thermal conductivity performs better in enhancing heat transfer.

4.6 Effect of pressure drop:

- Enhancement of heat transfer, thermal efficiency, and friction factor takes place on account of small pressure drop.

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