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Recent Advances in Heat Transfer Augmentation by using Twisted Tapes: A Review

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Abstract
In the past decade several studies on the passive techniques of heat transfer augmentation have been reported. The present paper is a review on progress with the passive augmentation techniques in the recent past and will be useful to designers implementing passive augmentation techniques in heat exchanger. In passive technique twisted tape insert is playing an important method to enhance the heat transfer characteristics of a heat exchanger without affecting much the overall performance of the system. The present review is organized in two different sections: augmentation of heat transfer in laminar flow and augmentation of heat transfer in turbulent flow.
Key words: Heat transfer augmentation, Passive methods, Twisted Tape inserts, Reynolds number, Friction factor

1. Introduction:

The process of improving the performance of a heat transfer system is referred as the Heat transfer enhancement technique (augmentation technique). Nowadays, a significant number of thermal engineering researchers are seeking for new enhancing heat transfer methods between surfaces and the surrounding fluid. This technique refers to different methods used to increase rate of heat transfer without affecting much the overall performance of the system. The subject of enhanced heat transfer has developed to the stage that it was of serious interest for heat exchanger design. Large numbers of attempts have been made to reduce the size and costs of the heat exchangers.

Classification of Augmentation Techniques

Existing enhancement techniques can be broadly classified into three different categories:

1. **Passive heat transfer augmentation methods** - Passive heat transfer augmentation methods do not require any direct input of external power; rather they use it from the system itself which ultimately leads to an increase in fluid pressure drop. They generally use surface or geometrical modifications to the flow channel by incorporating inserts or additional devices. The passive methods are based on the same principle. Use of this technique causes the swirl in the bulk of the fluids and disturbs the actual boundary layer so as to increase effective surface area, residence time and consequently heat transfer coefficient in existing system.

Following Methods are generally used,

1. Inserts
2. Extended surface
3. Surface modifications
4. Use of additives.

2. **Active heat transfer augmentation methods-** Active techniques involves some external power input for the enhancement of heat transfer, some examples of active techniques include induced pulsation by cams and reciprocating plungers, the use of a magnetic field to disturb the seeded light particles in a flowing stream, etc

3. **Compound heat transfer augmentation methods** – When any two or more of these techniques are employed simultaneously to obtain enhancement in heat transfer that is greater than that produced by either of them when used individually, is termed as compound enhancement. This technique involves complex design and hence has limited applications.

Method	Approach	Description
Passive	Surface Interruptions	Slits or offset fins interrupt the boundary layer, restarting it, creating secondary flows, and/or generating flow unsteadiness.
	Surface Roughness	Accelerates transition from laminar flow to turbulent; also increases turbulent flow heat transfer
	Surface Protuberances	Ridges or three-dimensional shapes (cube, pyramid, etc.) generate secondary or unsteady flows
Active	Forced Flow Unsteadiness	Surface vibration or sound waves thins or restarts boundary layer and/or induces secondary flows.
	Boundary Layer Injection	Enhancement primarily for multiphase flows.
	Boundary Layer Suction	Removal of boundary layer restarts boundary layer downstream.

2. IMPORTANT TERMS USED IN TWISTED TAPE

2.1 **Thermo Hydraulic Performance-** For a particular Reynolds number, the thermo hydraulic performance of an insert is said to be good if the heat transfer coefficient increases significantly with a minimum increase in friction factor Thermo hydraulic performance estimation is generally used to compare the performance of different inserts under a particular fluid flow condition.

2.2 **Overall Enhancement Ratio**- The overall enhancement ratio is defined as the ratio of the heat transfer enhancement ratio to the friction factor ratio.

2.3 **Nusselt Number**- The Nusselt number is a measure of the convective heat transfer occurring at the surface and is defined as hd/k, where h is the convective heat transfer coefficient, d is the diameter of the tube and k is the thermal conductivity.

2.4 **Prandtl Number**- The Prandtl number is defined as the ratio of the molecular diffusivity of momentum to the molecular diffusivity of heat.

2.5 **Twisted tape**- Twisted tapes are the metallic strips twisted with some suitable techniques with desired shape and dimension, inserted in the flow. Following are the main categories of twisted tape which are analyses earlier.

2.6 **Pitch**- The Pitch is defined as the distance between two points that are on the same plane, measured parallel to the axis of a Twisted Tape.

2.7 **Twist Ratio**- The twist ratio is defined as the ratio of pitch length to inside diameter of the tube.

3. REVIEW OF WORK CARRIED OUT:

The present paper is a review on progress with the passive augmentation techniques in the recent past and will be useful to designers implementing passive augmentation techniques in heat exchange. Twisted tapes, wire coils, ribs,

fins, dimples, etc., are the most commonly used passive heat transfer augmentation tools. An extensive literature review of heat transfer enhancement in laminar flow and turbulent flow using twisted tape insert is discussed in following sections.

3.1 Augmentation of Laminar Flow Heat Transfer

In the laminar flow, heat transfer takes place mainly by conduction and molecular diffusion as there is no cross mixing of the fluid. The heat transfer coefficients in laminar flow were generally low. So, for a given heat transfer rate, larger heat transfer whereas will have to be provided as compared with turbulent flow heat transfer situations.

LITERATURE SURVEY

Yadav [1] studied experimentally by insertion of half length twisted tape in a U-bend double pipe heat exchanger on heat transfer and pressure drop characteristics for a laminar flow. Comparative study of performance is obtained from heat exchanger with inserted twisted tape and plain heat exchanger i.e. without twisted tape. In a heat exchanger with twisted tape the heat transfer rate is greatly influence by tape induced swirl or vortex motion. On the basis of equal mass flow rate it was found that heat transfer performance of half length twisted tape is better and upto 40% more than plain heat exchanger.

Naphon et al. [2] investigated the heat transfer characteristics and the pressure drop in the horizontal double pipes with twisted tape insert. The results obtained from the tube with twisted insert are compared with those without twisted tape. This work predicts the variations in heat transfer coefficient and friction factor of the horizontal pipe with twisted taped insert.

Bharatdwaj et al. [3] determined experimentally heat transfer characteristics and pressure drop of water flow in a spirally grooved tube inserted with twisted tape. Reynolds numbers range is considered for a flow from laminar to fully turbulent. The grooves made inside a tube are clockwise with respect to the direction of flow which helps in enhancement of heat transfer rate. Compared to smooth tube, the heat transfer enhancement is further augmented by inserting twisted tapes having twist ratios Y= 10.15, 7.9 and 3.4.

Lin and Wang et al. [4] investigate experimentally convective heat transfer coefficient of a laminar flow in a circular tube fitted with twisted tape. To the thermal boundary condition the sensitivity of heat transfer enhancement and the Nusselt number are the effect on heat conduction in a circular tube fitted with tape. The results expose that for fully developed laminar heat convective transfer, different tube wall thermal boundaries show the way to different effects of conduction in the tape on heat transfer characteristics.

Saha et al. [5] determined experimentally the heat transfer enhancement and pressure drop characteristics in a tube fitted with regularly spaced twisted tape element. The obtained show that the heat transfer coefficient is improved as compared with plain heat exchanger i.e. without inserted tape.

Klaczak [6] investigate experimentally the heat transfer for laminar flow of water in an air cooled vertical copper pipe with TT inserts of various pitch value. The tests were executed for laminar flow within $110 \leq Re \leq 1500$, $8.1 \leq Gz \leq 82.0$ and $1.62 \leq y \leq 5.29$. Result shows that the heat transfer increases with increase in Twisted tape pitch value.

Suresh Kumar at al. [7] an experimental investigation was carried out to determine the pressure drop characteristics in a large diameter annular test section for the hydro-dynamically developed laminar flow under constant heat flux condition. The results obtained are compared under two conditions: with and without twisted tape inserts. The variations of friction factor with Reynolds number for various twist ratios along the circumference of the test section were investigated. The thermo hydraulic performance in laminar flow is better for twisted tape as compared to wire coil for the same helix angle and twist ratio.

Sivashanmugam et al. [8] Experimental investigation is carried out for a laminar flow through a circular pipe fitted with full length helical screw element of different twist ratio to analyses the heat transfer and friction factor characteristics. The experimental data obtained are compared with those obtained from plain tube. The empirical correlations developed in terms of twist ratio and Reynolds number, are appropriate the experimental data within plus or minus 15% and 13% for Nusselt number and friction factor, respectively.

Tariq et al. [9] found that in a laminar flow the introduction of turbulent promoters, such as an internally threaded tube, is not efficient compared with a twisted tape insert on the basis of the overall efficiency. Heat transfer coefficient in internally threaded tube is approximately 20 per cent higher than that in smooth tube.

Jian Guo et al. [10] investigate experimentally comparative results between center-cleared twisted tape and the short width twisted tape for a laminar flow in a tube. The computation results show that the thermal behavior is very different from each other in both methods. The thermal performance factor of the tube with centre cleared twisted tube can be improved by 7-20 % as compared with plain tube.

S. Jaishankar et al. [11] experimentally determine friction factor and heat transfer characteristics of thermosyphon solar water heater system with full length twisted tape with rod and spacer fitted at the trailing edge. Results obtained conclude that the heat transfer enhancement in twisted tape collector is higher than the plain tube collector.

A.V. N. Kapatkar et al. [12] An experimental investigation of heat transfer and friction factor of a smooth tube fitted with full length twisted tape inserts for laminar flow have been studied under uniform wall heat flux condition. The experiments has been carried out to study the tape fin effect by using full length tape inserts of different materials namely Aluminum, Stainless steel and insulated tape. The tapes have twist ratios from 5.2 to 3.4. It is found that, for the flow in smooth tubes, full length twisted tapes yield improvement in average Nusselt number, for Reynolds number range of 200 to 2000.For Aluminum tapes, the maximum improvement in Nusselt number range from 50% to 100%; for Stainless steel tapes, maximum improvement in Nusselt number range from 40% to 94% and for insulated tapes, maximum improvement in Nusselt number range from 40% to 67%.

Suhas V. Patil et al. [13] investigate experimentally heat transfer and friction factor characteristics in a concentric double pipe heat exchanger (square duct inner and circular tube outer) using full length twisted tapes of different twist ratios. The data were taken for Reynolds number well in the laminar region (Re =30-1100) with twisted tapes of twist ratios (y=2.66 and y=3.55). Experiments were carried out for constant wall temperature boundary condition using Ethylene glycol as working fluid. The results obtain show that as twist ratio decreases, the twisted tape gives better heat transfer enhancement. Isothermal friction factors were found to be 6 to13 times the plain duct values. Mean Nusselt number for the twisted tapes are higher than those for the plain duct around

6.0 and 5.30 times for y=2.55 and y=3.66 respectively.

Augmentation of Turbulent Flow Heat Transfer

Eiamsa-ard et al. [14] an experimental study on the mean 'Nu'; 'f' and 'g' in a round tube with short-length TT insert. The full-length twisted tape is inserted into the tested tube at a single y = 4.0 while the short-length tapes mounted at the entry test section. The experimental result indicates that the presence of the tube with short-length twisted tape insert yields higher heat transfer rate.

Behabadi et al. [15] experimental investigated the heat transfer coefficients and pressure drop during condensation of HFC-134a in a horizontal tube fitted with TT. The refrigerant flows in the inner copper and the cooling water flows in annulus. Also empirical correlations were developed to predict smooth tube and swirl flow pressure drop.

Murugesan et al. [16] investigated experimentally the 'HTE', 'f' and 'g' characteristics of tube fitted with VTT. The obtained results show that the mean Nusselt number and the mean 'f' in the tube with 'VTT' increases with in decrease 'y'.

S. Eiamsa-ard et al. [17] investigate experimentally heat transfer, flow friction and thermal performance factor characteristics in a tube fitted with delta winglet twisted tape, using water as working fluid. The experiments are conducted using the tapes having contour oblique delta-winglet twisted tape (O-DWT) and straight delta-winglet twisted tape (S-DWT) with three twist ratios (y/w = 3, 4 and 5) and three depth of wing cut ratios (DR = d/w = 0.11, 0.21 and 0.32) over a Reynolds number range of 3000–27,000 in a uniform wall heat flux tube. The obtained results show that mean Nusselt number and mean friction factor in the tube with the delta-winglet twisted tape increase with decreasing twisted ratio (y/w) and increasing depth of wing cut ratio (DR). It is also observed that the O-DWT is more effective turbulator giving higher heat transfer coefficient than the S-DWT. Over the range considered, Nusselt number, friction factor and thermal performance factor in a tube with the O-DWT are, respectively, 1.04–1.64, 1.09–1.95, and 1.05–1.13 times of those in the tube with typical twisted tape (TT).

K. Kalyani Radha et al. [18] experimental investigations is carried out for the augmentation of turbulent flow heat transfer in a horizontal tube by means of varying width twisted tape inserts with air as the working fluid. To reduce excessive pressure drops associated with full width twisted tape inserts, with less corresponding reduction in heat transfer coefficients, introduce a varying width twisted tapes having range from 10 mm to 22 mm. Experiments were carried out for plain tube with/without twisted tape insert at constant wall heat flux and different mass flow rates. The twisted tapes use are of three different twist ratios (3, 4 and 5) each with five different widths (26-full width, 22, 18, 14 and 10 mm) respectively. The Reynolds number varied from 6000 to 13500. Both pressure drop and heat transfer coefficient are calculated and the results are compared with those of plain tube. It was found that the enhancement of heat transfer with twisted tape inserts as compared to plain tube varied from 36 to 48% for full width (26mm) and 33 to 39% for reduced width (22 mm) inserts.

P. K. Nagarajan et al. [19] experimentally investigate the heat transfer and friction factor characteristics of a circular tube fitted with right–left helical screw inserts of equal and unequal length of different twist ratios is studied. The experimental data obtained were compared with those obtained from plain tube published data. The heat transfer enhancement for right–left helical screw inserts is higher than that for straight helical twist for a given twist ratio. On performance evaluation the results obtained, indicating that the proposed twist inserts can be used effectively for heat transfer augmentation without any loss in pumping power.

Naga Sarada S. et al. [20] experimental investigations of the augmentation of turbulent flow heat transfer in a horizontal tube by insert of mesh with air as the working fluid. Sixteen types of mesh inserts with screen diameters of 22mm, 18mm, 14mm and 10mm for varying distance between the screens of 50mm, 100mm, 150mm and 200mm in the porosity range of 99.73 to 99.98 are used for experimentation. The Reynolds number is varied from 7000 to 14000. On comparing the result obtained It is observed that the enhancement of heat transfer by using mesh is more by a factor of 2 times where as the pressure drop is only about a factor of 1.45 times at the same mass flow rate.

Veeresh fuskele et al. [21] Experimental investigation of heat transfer and friction factor characteristics of double pipe heat exchanger fitted with twisted wire mesh for a twist ratio y=7.0 and y=5.0 is carried out for turbulent flow. The result obtained by using twisted wire mesh with different twist ratio has been compared with the plain tube heat exchanger. Heat transfer coefficient and friction factor increases with the decrease in twist ratio compared with plain tube. Twisted wire mesh insert in a tube augment the heat transfer rate 2.09 and 1.69 times and friction factor increases to 4.0 and 4.3 times than that of plain tube.

Jin Shuen Liou et al. [22]An experimental study measuring the axial heat transfer distributions and the pressure drop coefficients of the tube fitted with a broken twisted tape of twist ratio 1, 1.5, 2, 2.5 is performed in the Re range of 1000–40,000. This type of broken twisted tape is newly invented without previous investigations available. Local Nusselt numbers and mean Fanning friction factors in the tube fitted with the broken twisted tape increase as the twist ratio decreases. Heat transfer coefficients, mean Fanning friction factors and thermal performance factors in the tube fitted with the broken twisted tape are, respectively, augmented to 1.28–2.4, 2–4.7 and 0.99–1.8 times of those in the tube fitted with the smooth twisted tape

Conclusion:

This paper review the technique of augmenting the performance of heat transfer in a heat exchanger for laminar and turbulent flow by insert of plain and modified twisted tape. The vast literature is available on twisted tape insert in a flow to improve the performance of heat exchanger. In this paper review has considered mainly for heat transfer and pressure drop characteristics experimentally investigated for various geometry of twisted tape.

It has been observed that the twisted tape insert in the flow mix the fluid well, create turbulence during swirl of fluid and therefore improve the heat transfer rate. It performs better in laminar flow because in laminar flow thermal resistance is not limited to thin region. If pressure drop consideration is neglected the result of twisted tape insert is more effective. Also for less number of turn i.e. lower twist ratio performance achieved is better compare to higher twist ratio. Modified twisted tape insert in turbulent flow improved heat transfer characteristics for certain range of Reynolds number.

The summary after review show that for modified twisted tape geometry the heat transfer rate is higher with reasonable pressure loss and friction factor for both laminar and turbulent flow.

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