Heat Transfer Enhancement in Heat Exchanger using Twisted Tape Inserts: A Review

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Abstract**—**Heat transfer enhancement plays an important role in many industries. Their applications include heat exchanger, air conditioning, heating and cooling in evaporators, chemical reactors and refrigeration systems. There are different techniques to enhance heat transfer such as active, passive or a combination of both. Several techniques are used to increase heat transfer and decrease cost and size of equipment. During design of compact heat exchangers, proper selection of passive insert is done according to heat exchanger working conditions. This paper contains a review of the use of passive enhancement techniques in the past and will help the designers to implement these techniques in heat exchange. Most commonly used passive heat transfer enhancement techniques considers use of Twisted tapes, wire coils, rough surfaces, ribs, fins, etc. This paper focuses on the use of Twisted tapes in heat transfer enhancement.

Keywords*-Twisted tapes, Passive technique, Twist ratio, Heat transfer enhancement, Pressure drop etc.*

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I. INTRODUCTION

Heat exchangers play an important role in many industries as an energy storage and recovery. Use of conventional fluids such as water and ethylene glycol for increasing heat transfer are challenging and therefore various techniques are develop to enhance heat transfer. These techniques plays major role in improvement of thermo hydraulic performance of heat exchangers. Heat transfer enhancement techniques such as active, passive and compound are used in various fields such as process industries, heating and cooling in evaporators, thermal power plants, air-conditioning equipment, refrigerators, radiators for space vehicles, automobiles, etc. [1]. Heat transfer enhancement techniques can be classified into three different categories:

1. Active Techniques: The active method involves the use of external power input for the enhancement in heat transfer. This external power input leads to modification in flow pattern and thus leads to increase in heat transfer. Examples of active methods include use of mechanical aids such as surface vibration, suction or injection and the use of a magnetic or electrostatic field to disturb the light particles inserted in a flowing stream, etc**.**
2. Passive Techniques: The passive method does not require use of external power input; they use it from within the system which leads to an increase in fluid pressure drop. They generally make use of inserts such as twisted tape, wire coils, ribs, baffles, plates, helical screw insert, mesh inserts, convergent – divergent conical rings, etc. This leads to surface or geometrical modifications to the flow through pipe. This technique causes the swirl in the fluids and disturbs the actual boundary layers. This leads to increase in effective surface area, residence time and also heat transfer coefficient in an existing system. Twisted tapes are the metallic strips which are twisted as per the required shape and dimension according to the application where it is used and are inserted in the flow to increase the heat transfer. Twisted tape inserts leads to increase in heat transfer rates with less friction factor. The manufacturing process for twisted tape insert is simple and these techniques can be applied easily in an existing application. The enhancement of heat transfer due to the use of twisted tapes inserts depends on the Pitch and Twist ratio. [2]
3. Compound Techniques: This involves the use of two or more of these techniques simultaneously for enhancement in heat transfer and enhancement in heat transfer obtained is greater than that produced by either of them when we use them individually, is known as compound enhancement.

II. DEFINITIONS

1. Thermohydraulic performance

The thermohydraulic performance of an insert for a particular Reynolds number is said to be good if the heat transfer coefficient increases significantly with a minimum increase in friction factor. Thermohydraulic performance calculation is used to compare the performance of different inserts such as twisted tape, wire coil, etc., 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. This parameter is also used to compare different passive techniques and enables a comparison of two different methods for the same pressure drop.
3. Nusselt number
   The Nusselt number is ratio of the convective heat transfer to conductive heat transfer occurring at the surface and is defined as $\frac{hd}{k}$, where h is the convective heat transfer coefficient, d is the diameter of the tube and k is the thermal conductivity.
4. Prandtl number
   The Prandtl number is a dimensionless number and is defined as the ratio of momentum diffusivity to thermal diffusivity.
5. Pitch
   Pitch is defined as the distance between two points that are on the same plane, measured parallel to the axis of a twisted tape.
6. Twist ratio, y
   The twist ratio is defined as the ratio of pitch to inside diameter of the tube $y = \frac{H}{d_i}$, where H is the twist pitch length and d_i is the inside diameter of the tube.

III. REVIEW

Twisted tape leads to increase in heat transfer coefficient but it also gives rise to pressure drop. Several researchers have studied different configuration of twisted tape inserts and did experimentation. Several configurations of twisted tape inserts are full-length twisted tape, short-length twisted tape, full-length twisted tape with varying pitchand regularly spaced twisted tape. The following section discusses work carried out by different researchers:

Behabadi et al. [3] did experimental investigation on the heat transfer coefficients and pressure drop during condensation of HFC-134a in a horizontal tube fitted with different twisted tape inserts. The cooling water flows in the annulus and the refrigerant flows in the inner copper tube. The experiments were carried out for a plain tube and four tubes with twisted tapes inserts consisting of 6, 9, 12 and 15 twist ratios. From the experiments it is observed that the twisted tape with twist ratio of 6 results in the highest enhancement in the heat transfer coefficient and the maximum pressure drop compared to the plain tube on a nominal area basis. The enhancement obtained in heat transfer and the pressure drop is increased by 40 and 240% when compared with the plain tube. Also it is seen that the twisted tape with the twist ratio of 9 has the minimum pressure drop and it has the best performance in enhancing the heat transfer. Empirical correlations are developed to predict smooth tube and swirl flow pressure drop.

P. Naphon [4] carried out an experimental investigation on heat transfer coefficient and pressure drop in horizontal double pipe with twisted tape insert. Cold water is used as working fluid in shell side and hot water in tube side. Two test sections having different relative pitches were tested. The twisted tape is made from the aluminium strip with thickness of 1 mm and the length of 2000 mm. The results obtained from the tube with twisted insert were compared with tube without twisted tape and it was observed that heat transfer coefficient was higher for tube with twisted tape insert but pressure drop also increases significantly. Correlations were proposed for calculation of heat transfer coefficient and friction factor.

Date et. al. [5] carried out numerical investigation on heat transfer enhancement in laminar, viscous liquid flows in a tube with a uniform heat flux boundary condition. Flow conditions were idealized by assuming zero tape thickness, but the analysis included the twist and fin effects of the twisted tape.

Neshumayevet. al. [6] experimentally investigated the heat transfer enhancement by various turbulator inserts in gas heated channels. Twisted tape insert, the straight tape insert, and the combined turbulator insert were tested. The combustion products of light oil fuel and wood pellets were used as working fluid. The experiments were also conducted in the two fire tube boiler without any inserts. It was observed that heat transfer coefficient for twisted tape insert is higher than the straight tape insert. Also the mean heat transfer of the combined turbulator is high as compared to the mean heat transfer for the twisted tape and the helical wire coil insert.

Date et. al. [7] numerically predicted characteristics of laminar, turbulent flow and heat transfer in a square sectioned duct inserted with a twisted tape. Correlation for the friction factor and Nusselt number for a square duct was derived from the predicted data. Axially and peripherally constant wall heat flux conditions were considered and heat transfer characteristics were calculated for these conditions. Laminar flow friction factor data for $40 \leq Re \leq 1100$ and $1.5 \leq Y \leq 10$ are correlated by

$$f \times Re = 36\left[1 + 0.15 S_{w_e}\right]^{1/1.3}$$

Where, $S_{w_e} = \left(\frac{Re}{Y}\right)^{\frac{3}{4}} \left[\frac{1+0.01Y^4}{Y^6}\right]^{1/4}$

Y = twist ratio

The pitch-averaged laminar flow Nusselt number for $Re \leq 1100$, $1.5 \leq Y \leq 10$ and $0.1 \leq Pr \leq 500$ with nonconducting tape are correlated by

ISSN: 2321-8169
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$$Nu = 3.96\,[1 + 0.016Pr^{1.05}(\frac{Re}{Y})^{1.25}]^{1/2.6}$$

Promvongeet. al. [8] experimentally investigated influence of helical tapes inserted in a tube on heat transfer enhancement. To increase the heat transfer in a tube, swirl flow is generated by inserting a helical tape in the tube. Reynolds number range is in between 2300 and 8800. The swirling flow is generated by: 1. the full-length helical tape with or without a centered rod, and 2. the regularly spaced helical tape. These tapes are inserted in the inner tube of a concentric tube heat exchanger. Hot air enters the inner tube and cold water flows through the annulus. It was observed from experimental results that the use of helical tapes leads to higher heat transfer coefficients as compared to the plain tube. The heat transfer rate in full length helical tape with rod is highest and is better than that without rod but it leads to increase in pressure drop. To overcome pressure drop, different free spacing ratio were examined. Visualization technique was used to examine the flow pattern of the flow through the helical tape in the tube. It was found that there are strong swirling flows in the tube fitted with the helical tape. Also it was seen that there were weak swirling flows in the free spacing when regularly spaced helical tape without a rod were used.

Sahaet. al. [9] experimentally investigated the heat transfer and pressure drop characteristics in a circular tube fitted with regularly spaced twisted tape elements. Flow inside the tube was considered as laminar. Uniform wall heat flux condition was assumed for analysis. Regularly spaced twisted tape elements connected by thin circular rods were responsible for swirling inside the tube. The tape width and rod diameter both were varied. It was found that pinching (placing of a twisted tape exactly at the centre of the tube) of twisted tape in a tube gives better performance than a twisted tape inserted by a loose fit.

AI-Fahedet. al. [10] carried out experiments to compare pressure drop and heat transfer coefficients for a plain, microfin, and twisted tape insert tubes. Laminar flow was considered. Steam was used as heat source for uniform wall temperature condition in Single shell and tube heat exchanger and Oil flows inside the tube. It was observed that as the twist ratio decreases, the twisted tape gives better heat transfer enhancement. Also it was seen that the tight fit tape performs better than the loose fit tape. It is recommended that for a low twist ratio and high pressure drop, a loose fit is to be used for design of the heat exchanger as it is easy to install and to remove for cleaning.

Liao et. al. [11] carried out experiments to study the heat transfer and friction characteristics for water, ethylene glycol, and ISO VG46 turbine oil flowing inside four tubes with three dimensional internal extended surfaces and copper continuous or segmented twisted tape inserts. Ranges of Prandtl numbers are from 5.5 to 590 and Reynolds number from 80 to 50,000. It was seen from the results that this compound enhanced heat transfer technique, a tube with three dimensional internal extended surfaces and twisted tape inserts, is highly advantageous to enhance the convective heat transfer coefficient for the laminar tube side flow. It was reported that inside the tubes with three dimensional internal extended surfaces, when the continuous twisted tape inserts were replaced with the segmented twisted tape inserts, a greater decrease in the friction factor was observed, decrease in the Stanton number was very small. Also it was found that in case of turbulent and transitional flow regions, the heat transfer is increased only a little, but there is significant rise in friction factor for liquid flow inside the 3 DIEST tube by means of twisted tape inserts.

Chang et. al. [12] experimentally investigated the turbulent heat transfer in a swinging tube with a Serrated Twist Tape insert under seagoing conditions to examine the effects of swinging oscillations on heat transfer. This swirl tube swings about two orthogonal axes under single and compound rolling and pitching oscillations. It was found that synergistic effects of compound rolling and pitching oscillations with either harmonic or non-harmonic rhythms leads to improvement in heat transfer performance. Buoyancy effects existing in the swinging swirl tube are found to increase the local Nusselt number but as the swinging force increases Nu gets weakened. Nusselt number correlations were developed.

Murugesan.et. al. [13] carried out an experimental investigation on the heat transfer and friction factor characteristics of trapezoidal cut full length twisted tape inserted inside circular tube with y = 4.0 and 6.0. From the experiment it was observed that there was a significant increase in heat transfer coefficient and friction factor for tape with trapezoidal cut as compared to plain tube. Correlations were developed based on experimental data.

Chang et. al. [14] carried out experimental investigation on compound heat transfer enhancement in a tube fitted with Serrated Twisted Tape. The serrations are on two sides of the twisted tape with twist ratio y = 1.56, 1.88, 2.81, ∞. They are basically the square-sectioned ribs with identical rib pitch and rib height. Reynolds number range is 5000-25000. As the twist ratio decreases the local Nusselt number and Fanning friction factor increase in the tube fitted with smooth or serrated twisted tape. Increase observed in serrated twisted tape is about1.25–1.67 times the heat transfer level in the tube fitted with smooth twisted tape. As

Re increases Fanning friction factors were found to be decreased in the tubes fitted with smooth twisted tapes and increased in serrated twisted tapes. From the experiment it is revealed that the friction factor and heat transfer rate for tube containing serrated twisted tape is comparatively higher than plain tube. Correlations were developed for Nusselt number and Fanning friction factor.

Chang et. al. [15] made an experimental study in measuring the axial heat transfer distributions and the pressure drop coefficients of the tube fitted with Broken Twisted Tape. Twist ratio for the experiments are 1, 1.5, 2, 2.5 or ∞. Reynolds number range is 1000-40000. As the twist ratio decreases Local Nusselt numbers and mean Fanning friction factors in the tube fitted with the broken twisted tape increase. As compared to tube fitted with the smooth twisted tape Heat transfer coefficients, mean Fanning friction factors and thermal performance factors in the tube fitted with the broken twisted tape are, respectively, increased to 1.28–2.4, 2–4.7 and 0.99–1.8 times. Nusselt number and Fanning friction factor correlations for tube with broken twisted tapes were developed.

IV. CONCLUSION

This paper consists of review of work done in enhancement of heat transfer by using different twisted tapes in heat exchangers. Also investigation on pressure drop is done. A twisted tape and modified twisted tape configurations creates swirl and mixes flow inside the tube very well and it leads to better performance in laminar flow region. Results also show that there is greater increase in pressure drop in turbulent flows. Twisted tape with modified geometry gives better heat transfer rate as compared to plain tube. But if the Prandtl number is high (Pr> 30) twisted tape inserts are not found to be useful. Also enhancement of heat transfer due to twisted tape is found to be economical and easy to install.

The literature review also shows that limited work is carried in case of minimum twist ratio for obtaining better heat transfer. Also use of twisted tapes in different geometries such as helical, spiral coils are to be investigated and effects on heat transfer and pressure drop is to be evaluated.

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