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A Detailed Review on Wavy-Tape Insert Configuration for Pipe Heat Transfer

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Abstract-Various techniques have been tested on heat transfer enhancement to upgrade the involving equipment, mainly in thermal transport devices. These techniques unveiled significant effects when utilized in heat exchangers. One of the most essential techniques used is the passive heat transfer technique. Corrugations represent a passive technique. In addition, it provides effective heat transfer enhancement because it combined the features of extended surfaces, turbulators and artificial roughness. The motivation behind this study is the desire to obtain more effective heat exchangers and other industrial applications, with the major objectives being to provide energy, material, and economic savings for the users of heat transfer enhancement technology.

Keywords- Wavy tape insert, heat transfer, performance, heat exchanger.

I. INTRODUCTION

In heat exchangers, corrugation and other surface modifications are commonly used because they are very effective in the heat transfer enhancement; also it is appearing very interesting for practical applications because it is a technique that promotes secondary recirculation flow, by inducing non-axial velocity components [1].

Recently, a swirl or helical flow pattern produced by employing surface modifications or any other passive technique for heat transfer enhancement is very interesting [2]. Also, Spiral corrugation increases heat transfer enhancement due to secondary flow swirls and surface curvatures pass by fluid layers, which also causes pressure losses [3].

The main reason for employing heat transfer enhanced techniques is for cutting costs as well as for practical purposes. The major roles of corrugations are for enhancing the secondary re-circulation flows, via induction of the component the radial velocities as well as the mixing of the flow layer. These techniques have been widely utilized in recent heat exchangers [4].

The outcome generated from the surface area modifications or the manipulations of heat transfers, which has been demonstrated to induce swirls or spirally flowing patterns has attracted increasing interests [5]. Additionally, corrugation enhances heat transfer owing to the existence of mixing fluids generated through separations and re-attachments [6].

II. HEAT TRANSFER ENHANCEMENT USING TWISTED TAPES

Heat transfer augmentation is always an important matter of concern since the enhancement of heat transfer rate leads to increase the performance of system which is quite important in various heat transfer applications. Twisted tapes are well known heat transfer enhancement devices and several correlations of heat transfer and pressure drop have been developed for different types of twisted tapes.

The enhancement of heat transfer is obtained by developing swirl flow of the tube side fluid, which gives high velocities near boundary and fluid mixing and consequently high heat transfer coefficient. In heat transfer systems equipped with twisted tapes, the heat transfer and pressure drop.

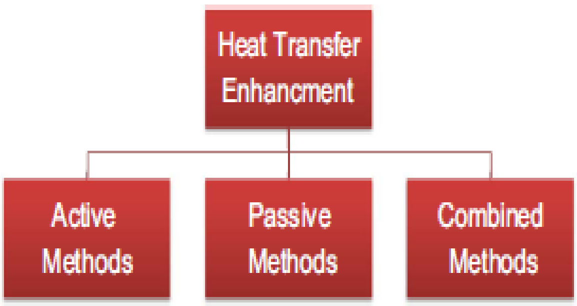

Fig 1. Methods of heat transfer enhancement.

III. LITERATURE REVIEW

Heat transfer enhancement is an important matter of concern for energy conservation and also beneficial from economic point of view. The use of passive devices like twisted tapes, roughness elements, wires inserts etc. are effective methods of heat transfer augmentation. Many research studies on different types of twisted tapes geometries to increase heat transfer rate have been carried out. Also, several correlations were developed to determine heat transfer and friction fact or for twisted tape inserts.

In the present study, a review on work done in the area of heat transfer augmentation using twisted tapes has been carried out. Previous experimental and numerical studies on various types of twisted tapes (based on the literature survey) were discussed.

1. Review on Effect of Enhancement Techniques:
A lot of studies have been done on the heat transfer enhancement and friction factor of heat exchangers in recent years. In addition, examining the effectiveness and NTU of heat exchangers has been an interesting topic for researchers [1–3].

Generally, methods to increase the heat transfer and effectiveness of heat exchangers are classified into three groups of active, passive and compound methods. In active methods such as using sound waves or magnetic fields [4], external power source is used to improve the heat transfer. To increase the heat transfer rate in passive approaches, external energy is no longer required. Some of the examples of passive methods include using different kind of turbulators.

Various heat transfer enhancement techniques have different advantages and limitations. They vary in geometrical configuration and construction complexity while operating under different flow and thermal conditions. On the basis of these parameters this review is classified as follows.

2. Effect of swirl producing devices on heat transfer:
The twisted tape inserts have been used as a heat transfer enhancement device in last few decades and particular most widely used in heat exchangers to reduce their size and cost. Depending upon the application, twisted tapes are used with different twist ratio, with varying twist direction, fit and loose tape insert, full and short tape insert, perforated insert, insert with peripheral cuts, etc.

3. Effect of twisted tape dimensions:
Instead of full length twisted tape, **Saha et al. (2001)** used regularly spaced twisted tape. They investigated experimentally the effect of twist ratio, space ratio, tape width, phase angle on heat transfer and concluded that reduction in tape width gives poor heat transfer and higher than zero phase angle creates complexity in tape manufacturing rather than improving the heat transfer.

Eiamsa-ard et al. (2006) conducted experiments with a twisted tape with twist ratio of 6–8 for a full length tape and free space ratio of 1, 2 and 3 for a regularly spaced twisted tape insert. They concluded that the heat transfer coefficient increases with decrease in twist ratio and space ratio.

Eiamsa-ard et al. (2009) also investigated the effect of short length twisted tape insert. They used twisted tape with fix twist ratio and different length ratio. Short length inserts generated strong swirl at the tube entrance while the full length tape produced strong swirl flow over the entire length. Outcome of their research revealed that the maximum Thermal Performance Factor obtained for full length tape is 1.04 at Re = 4000 and decreases as the length ratio decreases.

Sarada et al. (2011) observed that the width of the twisted tape significantly affects the heat transfer rate. It was found that the heat transfer enhances as the width of insert increases.

Piriyarungrod et al. (2015) presented the effect of taper in the twisted tape to enhance the heat transfer performance. Their experiments for different taper angles revealed that the taper twisted tape does not achieve the thermal performance factor more than 1.05 but increases the heat transfer rate. Thus, taper tape is not a feasible method for heat transfer enhancement.

Esmaeilzadeh et al. (2014) also analyzed the effect of thickness of twisted tape with nanofluid and showed that the increase in thickness of the tape increases the heat transfer rate, friction factor and TPF.

Eiamsa and Promvonge (2010) assessed the performance of alternate clockwise and counter clockwise twisted tape inserts. They used tapes in experiments having twist ratios of 3, 4 and 5 each with three twist angles of 30°, 60° and 90° and conclude that the heat transfer rate and TPF of alternate twisted tapes are higher than typical twisted tapes at similar operating conditions. Heat transfer rate and TPF (1.3–1.4) increase with decrease in twist ratio and increase in phase angle.

Effect of twist ratio

Patil and Vijaybabu (2012, 2014) conducted experiments to understand the effect of the twist ratio on heat transfer augmentation. They concluded that the heat transfer increases with decreasewith twist ratio. Also the use of twisted tape in laminar flow can result in energy saving. Twisted tape with increasing–decreasing twist ratio has a TPF of 1.98–1.60 at low Re = 100 (Patil & Vijaybabu, 2014).

Eiamsa-ard et al. (2012) employed sequentially, repeatedly and intermittently twisted tape with increasing decreasing twist ratios. Among the tapes tested, the repeatedly increasing-decreasing twist ratios offered the maximum TPF of around 1.03.

Effect of helical insert

Helical twisted tapes have also been used to enhance the heat transfer rate (Sivashanmugam & Suresh, 2007; Sivashanmugam & Nagarajan, 2007). These authors used the full length helical inserts with different twist ratios (Fig. 2), with equal and unequal lengths with right and left turns. Their experiments showed that the helical tape insert improves the heat transfer compared to a plain tube and the TPF with right-left helical insert could be obtained an up to 3 for different configurations.

Moawed (2011) used the helical screw tape inserts in an elliptical tube. For low Re, it was foundthat the maximum TPF of 1.2 could be obtained with a combination of pitch ratio of 1 and twist ratio of 0.22. Multiple helical twisted tapes have been analyzed by Bhuiya et al. (2012) at different helix angles (9°, 13°, 17° and 21°). The power consumed by the blower increases 2–3 times with decrease in helix angle. TPF achieved is from 1.08 to 1.30.

Maakoul et al. (2017) numerically investigated TPF of a double pipe heat exchanger fitted with helical baffles in the annulus side. They used Fluent to solve three dimensional computational fluid dynamics model. From their analysis, it was found that in all cases TPF was less than one which was mainly due to higher pressure drop in entrance region effect.

4. Effect of modified twisted tape:

Research was carried out by **Rahimi et al. (2009)** to investigate the effect of modified twisted tape insert on heat transfer characteristics. They performed experiments using simple twisted tapes, perforated twisted tapes, notched twisted tapes and jagged twisted tapes in their investigation.

Their results obtained from CFD analysis and experiments revealed that a jagged twisted tape has best TPF of 1.21 due to higher turbulence developed close to the tube wall.

Shubanian et al. (2011) analyzed heat transfer enhancement in an air cooler equipped with three types of tube inserts namely the butterfly, classic and jagged twisted tape. Their results indicated that the increase in Nu is accompanied by the rise in Re.

Ratio of Nu/Nu0 is higher in a butterfly insert compared to jagged and classic twisted tape insert in the range of Re considered. It was also observed that the tube fitted with tube inserts showed a substantial increase in the friction factor compared to the plain tube. Friction factor is high at low Re and tends to decrease with increase in Re.

Heat transfer enhancement can also be obtained at the expense of increase in pressure drop. TPF varies between 1.28–1.62, 1–1.23 and 0.88–1.03 for butterfly, jagged and classic inserts respectively.

TPF depends on Re, inclination angle and twist ratio. Results obtained from CFD analysis using the k-e turbulence model was shown to be in good agreement with the experimental results.

5. Effect of wings and winglet twisted tape:

Smith Eiamsa-ard et al. (2010, 2013) and Eiamsa-ard et al. (2013) investigated the effect of delta winglet twisted tape inserts on heat transfer and pressure drop characteristics. The investigation was made for straight and oblique delta winglet (S. Eiamsaard et al., 2010) along with twin delta winged twisted tape insert (Smith Eiamsa-ard et al., 2013). They analyzed twisted tapes for different twist ratios and depth of wing cut ratios. From results, it was concluded that oblique delta-winglet is more efficient than straight delta winglet. Over the range of Re studied, TPF for oblique delta winglet twisted tape and straight delta winglet twisted tape were found to be 0.92–1.24 and 0.88–1.21 respectively.

The twin delta winged twisted tape wings were cut in three different positions: up, down and opposite (Smith Eiamsa-ard et al., 2013). Wings were inclined at an angle of 15° with the tape surface. The effect was examined for three different wing tip angles of 20°, 40° and 60°. The result revealed that upside position performs well compared to down and opposite side wings; heat transfer rate increases with wing tip angle; twin tape wing up with 20° wing tip angle gives the highest TPF of 1.26.

Instead of using twisted tape inserts, Deshmukh and Vedula (2014) used curved delta type vortex generator to analyze the heat transfer and friction factor characteristics of flow through a circular tube. The insert was constructed with a central rod on which curved delta wings were attached at specific locations. Local heat transfer coefficient and average pressure drop were examined for different pitch to projected length ratio, height to tube inner diameter and angle of attack. Nu/Nu0 ratio was found to be in the range of 1.3–5.0 and TPF from 1.0 to 1.8.

Behfard and Sohankar (2016) conducted a numerical study of delta winglet vortex generator used in a rectangular duct. They found a TPF of 1.49. Augmentation of heat transfer by using wire-rod bundles was investigated by Nanan et al. (2013). Analysis was done for 4, 6 and 8 wire bundles with three different pitch ratios. Heat transfer rate increased compared to the plain tube. But TPF was less than one in most of the combinations. The combined effect of the twisted tape and vortex generator was experimentally investigated by Promvonge et al. (2014). Experiments were conducted in a square duct with simple, two V winglets and four V winglets with a fixed angle of attack of 30°. Highest TPF of 1.62 was obtained which was 17% more than that of twisted tape.

Arulprakasajothi et al. (2015) investigated the effect of staggered and non-staggered conical strip inserts in a circular tube under laminar flow condition. The conical strip of forward and backward direction was used as turbulators which led to enhanced heat transfer coefficient. Numerical simulation was carried out by Zheng et al. (2017) to investigate the effect of vortex rod in heat exchanger tube. Their results revealed that the vortex rod inclination angle, diameter ratio and Re affects heat transfer and friction factor considerably. Also by using Artificial Neural Network they concluded that the vortex rod with diameter ratio 0.058 and inclination angle 57.05 at Re = 426.767 gives the best TPF.

Wongcharee and Eiamsa (2011) used a twisted tape with alternate axis and triangular, rectangular and trapezoidal wings for heat transfer enhancement. Performance was evaluated for three different wing chord ratios of 0.1, 0.2 and 0.3 with constant twist ratio of 4. Wings were fabricated at an angle 60° relative to the adjacent plane. For the same operating conditions, Nu ratio, friction factor ratio and TPF were higher in trapezoidal cut compared to the other two. Maximum TPF was 1.43 with trapezoidal wings with wing-chord ratio of 0.3.

Bali and Sarac (2014) investigated the effect of propeller type vortex generator. They used two propeller vortex generators as the swirling flow decayed after some distance. They examined the effect of joint angle and number of joint vanes for a range of Re. Murugesan et al. (2010, 2011, 2011) analyzed the effect on heat transfer characteristics due to square (Murugesan et al., 2010), triangular (Murugesan et al., 2011) and trapezoidal (Murugesan et al., 2011) cut on the periphery of a plain twisted tape. They carried out experiments for twist ratio 2, 4.4 and 6. Their results revealed that Nu and friction factor increased simultaneously. TPF of 1.02–1.22, 1.07–1.27 and 1.02–1.27 was achieved for trapezoidal, triangular and square cut respectively.

Smith Eiamsaard et al. (2010) performed experiments for peripherally cut twisted tape with constant twist ratio of 3. Experiments were performed for different tape width and depth ratios in the range of Re 1000–20,000. They concluded that the peripherally cut twisted tape had better performance compared to a plain tube. TPF achieved was 2.28–4.88 in laminar regime and 0.88–1.29 in turbulent regime.

Smith Eiamsaard et al. (2010) conducted experiments for center cut wings in twisted tape. The wings were constructed along the centerline with three different angles of attack (43°, 53° and 74°). Center cut twisted tape with 74° inclined wings were found most effective giving TPF up to 1.4.

Lei et al. (2012) made a hole in the center of the twisted tape and observed that it performed well compared to the plain twisted tape. Another advantage of it was the material saving due to the material removal from the hole. TPF achieved was in the range 1.0–1.4 for different combinations of parameters.

Anvari et al. (2014) used the convergent and divergent type ring inserts. They placed the ring inserts in the tube at equal distance and uniform heat flux was applied from the outer surface. They concluded that the divergent type ring insert was more efficient than the convergent type ring. This approach is different since the fluid moves from periphery to the center where as in twisted tape fluid moves from center to the periphery.

Numerical study of heat transfer characteristics in laminar flow have been carried out by Lin et al. (2017) using twisted tape having parallelogram winglet vortex generator. This newly designed twisted tape has two ways to generate secondary flow which includes secondary flow generated by base tape and secondary flow generated by the parallelogram winglet. They observed improvement in TPF ranges from 1.25 to 1.85 for the studied range of Re.

IV. CONCLUSION

From the present review, it can be concluded that the heat transfer enhancement occurs in all cases due to reduction in the flow cross section area, an increase in turbulence intensity and an increase in tangential flow established by various types of inserts. Geometrical parameters of inserts like width, length, twist ratio, etc. affect the heat transfer enhancement considerably.

Twist direction is also an important parameter in case of multiple twisted tapes since the counter-swirl performs better than the co-swirl. The role of inserts in increasing the turbulence intensity is more significant in laminar regime than in turbulent regime. Therefore to enhance the heat transfer in turbulent flow, wire coil inserts are used.

In recent years, second generation enhancement techniques that combine the twisted tape inserts and wire coil have been used to get better heat transfer performance in laminar as well as turbulent flows.

Some researchers have also used regularly spaced and perforated twisted tape for the purpose of material saving; the results have shown that the perforation can lead to TPF of more than one. Since perforation results in less obstruction.

The regularly spaced twisted tape does not generate turbulence in non-twisted tape area. Therefore, it is better to use full length twisted tape instead of regularly spaced twisted tape. In large Prandtl number flow, roughness performs better than the twisted tape and the maximum heat transfer occurs due to roughness when the roughness height is three times the viscous sublayer thickness.

The artificially corrugated rough surface can be developed to significantly improve the heat transfer characteristics by breaking and destabilizing the thermal boundary layer on the surface. Passive techniques are widely used in various industries for their cost saving, low maintenance requirements and easy set up.

The TPF reduces with increase in Reynolds Number. Twisted tape does not perform well where air is used as a working fluid. It performs well where water and nano-fluid are used as working fluid because of larger density of liquid. Therefore for air heating applications vortex generators, ribs or deflectors are more helpful in increasing the TPF. In case of liquids swirl producing devices are more helpful in increasing the TPF.

Exhaustive research has been done by many investigators on the use of twisted tape, artificial roughness or vortex generators to enhance the heat transfer characteristics in tube heat exchangers as discussed in this review; however the areas related to outer tube geometries like conical, parabolic, frustum, etc. have not yet been explored and could be the focus of new research.

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