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A Comprehensive Review onHeat Transfer and Fluid Flow Charactersticks of Heat Exchanger Tubes with Inserts

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Abstract—A Heat exchanger is a steady flow device in which two or more fluids flow through the same device and thermal energy is transferred from high temperature fluid to low temperature fluid by heat transfer.Heat transfer enhancement techniques are one of the most significant tools to deliver energy in different operations. In this paper a brief introduction is given about different techniques used to enhance the heat transfer in a heat exchanger, and some most effective insert geometries has been presented.

Index Terms—Friction factor,Heat exchanger, Heat transfer, Inserts,Nusselt number, Thermal performance.

1 Introduction

A Heat exchanger is a steady flow device in which two or more fluids flow through the same device and thermal energy (enthalpy) is transferred from high temperature fluid to low temperature fluid by heat transfer. In heat exchangers, there are usually no external heat and work interactions. The heat exchangers are popular and most commonly used thermal devices for different industrial and engineering applications such as petrochemical and oil organizations, power plant stations and even residential areas. The design procedure of heat exchangers is quite complicated, as it needs exact analysis of heat transfer rate, efficiency and pressure drop apart from issues such as long term performance and the economic aspect of the equipment.

Nowadays high prices of energy motivates industries to employ energy saving methods as much as possible in their installations. Heat transfer enhancement techniques are one of the most significant tools to deliver energy in different operations. By employing heat transfer enhancement techniques, one can achieve; high heat transfer rate by reducing losses, reduced cost of material, reduced weight and volume of heat exchanger, increased efficiency of system, increased heat transfer rate at same mass flow rate of flowing fluid.

2 Heat Transfer Enhancement Techniques

In general, heat transfer enhancement techniques are classified in three broad categories; active method, passive method and compound method:

2.1 Active Methods

In these methods, some external power input needs in order to reach augment in the rate of heat transfer. Because of the need of equipment, this method has limited application in many practical applications. Various active techniques are as follows:

i. Mechanical Aids: These devices stir the fluid by mechanical means or by rotating the surface. Examples of the mechan-cal aids include rotating tube exchangers and scrapped surface heat and mass exchangers.

ii. Surface Vibration: They have been used primarily in single phase flows. A low or high frequency is applied to facilitate the surface vibrations which results in higher convective heat transfer coefficients.

iii. Fluid Vibration: Instead of applying vibrations to the surface, pulsations are created in the fluid itself. This kind of vibration enhancement technique is employed for single phase flows.

iv. Electrostatic Fields: Electrostatic field like electric or magnetic fields or a combination of the two from DC or AC sources is applied in heat exchanger systems which induces greater bulk mixing, force convection or electromagnetic pumping to enhance heat transfer. This technique is applicable in heat transfer process involving dielectric fluids.

v. Injection: In this technique, same or other fluid is injected into the main bulk fluid through a porous heat transfer interface or upstream of the heat transfer section. This technique is used for single phase heat transfer process.

vi. Suction: This method is 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 is withdrawn through the porous heated surface.

2.2 Passive Methods

This method generally uses surface or geometrical modifications to the flow channel by incorporating inserts or additional devices. Although there are hundreds of passive methods to enhance the heat transfer performance, the following nine are most popular used in different aspects:

i. Treated Surfaces: They are heat transfer surfaces that have a fine-scale alteration to their finish or coating. The alteration could be continuous or discontinuous, where the roughness is much smaller than what affects single-phase heat transfer, and they are used primarily for boiling and condensing duties.

ii. Rough Surfaces: They are generally surface modifications that promote turbulence in the flow field, primarily in

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single-phase flows, and do not increase the heat transfer surface area. Their geometric features range from random sand-grain roughness to discrete three-dimensional surface protuberances

iii. Extended Surfaces: They provide effective heat transfer enlargement. The newer developments have led to modified fin surfaces that also tend to improve the heat transfer coefficients by disturbing the flow field in addition to increasing the surface area

iv. Displaced Enhancement Devices: These are the insert techniques that are used primarily in confined force convection. These devices improve the energy transfer indirectly at the heat exchange surface by displacing the fluid from the heated or cooled surface of the duct/pipe with bulk fluid to the core flow

v. Swirl Flow Devices: They produce and superimpose swirl flow or secondary recirculation on the axial flow in a channel. These devices include helical strip or cored screw type tube inserts, twisted tapes. They can be used for single phase or two-phase flows heat exchanger.

vi. Coiled Tubes: These techniques are suitable for relatively more compact heat exchangers. Coiled tubes produce secondary flows and vortices which promote higher heat transfer coeffi- cient in single phase flow as well as in most boiling regions

vii. Surface Tension Devices: These consist of wicking or grooved surfaces, which directly improve the boiling and condensing surface. These devices are most used for heat exchanger occurring phase transformation

viii. Additives for Liquids: These include the addition of solid particles, soluble trace additives and gas bubbles into single phase flows and trace additives which usually depress the surface tension of the liquid for boiling systems

ix. Additives for Gases: These include liquid droplets or solid particles, which are introduced in single-phase gas flows either as dilute phase (gas–solid suspensions) or as dense phase (fluidized beds).

2.3 Compound Methods

Compound methods is a combination of the above two methods, i.e. active and passive method, such as rough surface with a twisted tape swirl flow device, or rough surface with fluid vibration, rough surface with twisted tapes.

3 Terms and Parameters commonly used in Heat Exchanger

A few significant terms and parameters usually used in heat exchangers and heat transfer enhancement work are introduced as follows:

i. Nusselt Number : Convective heat transfer to conductive heat transfer ratio is called Nusselt number. It can be expressed as:

$$Nu = \frac{hD}{k} \quad (1)$$

where h, D and k are convective heat transfer coefficient, diameter of tube and conductive heat transfer coefficient respectively.

ii. Friction Factor: It is used to calculate the pumping power of heat exchanger, and expressed as

$$f = \frac{\Delta P}{(\rho u^2/2)(L/d_H)} \quad (2)$$

where ΔP is the pressure drop across the tube, ρ is the density of fluid, dH is the hydraulic diameter of the tube, u is the velocity of fluid and L is the length of the tube.

iii. Thermal Performance Factor: Thermal performance factor is generally used to evaluate the performance of different inserts such as twisted tape, wire coil, etc., under a particular fluid flow condition. It is a function of the heat transfer coefficient, the friction factor and Reynolds number. For a particular Reynolds number, if an insert device can achieve significant increase of heat transfer coefficient with minimum raise of friction factor, the thermal performance factor of this device is good. This parameter is also used to compare different passive techniques for the same pressure drop. It can be expressed as:

$$\eta = \frac{(Nu)/(Nu_0)}{(f/f_0)^{1/3}} \quad (3)$$

where Nu, f, Nu_o and f_o are the Nusselt number and Friction factor for a tube with and without inserts respectively.

4 Different Insert Geometries

According to **Wen-Tao Ji [1]**, the first survey on the techniques to enhance single phase forced convection heat transfer was made by **Bergles and Morton [2]**. In their paper, the enhancement techniques were classified into passive and active methods. The passive enhanced techniques includes: Artificial surface roughness, including protrusions, sand grains, and knurling; Displaced promoters, such as flow disturbers located away from the heat transfer surface; Vortex generators, like twisted tape insert, coiled wires inserts, threads, internally coiled tubes. According to this review, the heat transfer enhanced ratio of rough surface was around 2-fold compared with smooth surface. For the displaced promoters, the highest heat transfer enhanced ratio in the survey was 1.4. Turbulence promoters had generally higher enhanced ratio than those encountered with surface roughness elements and displaced turbulence promoters. The best enhancement ratio in the survey was 2.1–2.8.

Since the pioneering work of **Bergles and Morton [2]**, several insert geometries were used by different researchers in order to investigate the effect of different insert geometry and parameters on single phase heat transfer, friction factor and thermal performance factor.

It is found that different researchers have used different insert geometry and parameters in order to perform their experimental work. The effect of these insert geometries and their parameters showed different effects on the heat transfer, friction factor and thermal performance factor. Also it was seen, and is a well-known fact that any enhancement technique will introduce additional fluid pressure drop, and often the ratio of pressure drop increase is larger than that of heat transfer enhancement. Hence it is very important on how to quantitatively evaluate the thermo-hydraulic performance improvement for a given enhancement technique

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The most effective inserts geometries presented by different investigators is mentioned in Table 1 with their flow parameter and observations.

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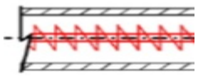
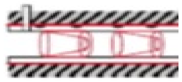
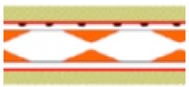
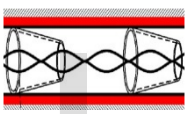
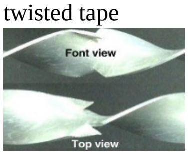
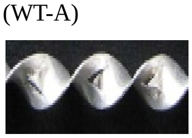
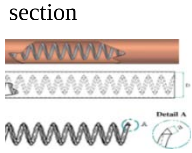
Table 1: Different Insert Geometries with their flow parameter and observations

S.No.	Author	Insert Geometry	Working fluid	Flow Parameters	Observations
1.	Smith Eiamsa-ard and Pongjet Promvonge[3]	Helical screw-tape with or without core-rod 	Water	2000<Re< 12000	➢ Increase in average Nusselt number of using the loose-fit, helical tape with and without core-rod are found to be 230% and 340%, respectively, over the corresponding plain tube. ➢ Without core rod friction factor is 50% less, and Nusselt number is 50% higher than with core rod.
2.	Pongjet Promvonge and Smith Eiamsa-ard [4]	Conical-nozzle turbulator (C and D Types) 	Air	8000<Re< 18000	➢ D nozzle arrangements provides higher heat transfer rate and friction factor. ➢ By using conical nozzle turbulator, heat transfer rate increased by 236-344% than plain tube.
3.	Pongjet Promvonge and Smith Eiamsa-ard [5]	V-nozzle turbulator 	Air	8000<Re< 18000	➢ The Nusselt number and friction factor utilizing the V-nozzle are found to be considerably higher than that for using the plain tube. ➢ The use of PR = 2.0 leads to higher Nusselt number and friction factor values than that of PR = 4.0 or 7.0
4.	P. Promvonge et al. [6]	Twisted tape with conical turbulators 	Air	6000<Re< 26000	➢ 367% improvement in heat transfer with respect to plain tube. ➢ Thermal Performance factor improves up to 1.95 times as compared to plain tube
5.	P. Promvonge [7]	Twisted tape with uniform coiled wire 	Air	3000<Re< 18,000	➢ Nusselt umber improves up to 7 times with respect to plain tube. ➢ Thermal Performance factor improves up to 1.5 times as compared to plain tube
6.	S. Eiamsa-ard et al. [8]	Delta winglet twisted tape 	Water	3000<Re< 27000	➢ 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
7.	S. Eiamsa-ard et al. [9]	Twisted tapes consisting of centre wings and alternate-axes (WT-A) 	Water	5200<Re< 22000	➢ Heat transfer rate in the tube fitted with the WT-A was consistently higher than those in the tube equipped the WT, T-A and plain tube. ➢ The use of WT-A at β = 74° was found to be the most effective for heat transfer enhancement
8.	Sibel Gunes et al. [10]	Coiled wire of triangular cross section 	Air	3500<Re< 27000	➢ The maximum thermal enhancement efficiency of 36.5% is seen with respect to plane tube

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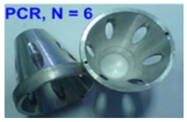
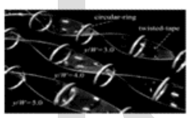
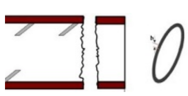
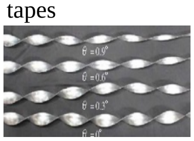
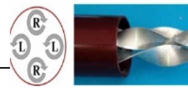
9.	V. Kongkaitpaiboon et al. [11]	Perforated conical ring  	Air	4000<Re<20,000	➢ 185% improvement in heat transfer is found with respect to plain tube. ➢ The thermal performance factor goes up to 0.92 times as compared to plain tube
10.	V. Kongkaitpaiboon et al. [12]	Circular disk 	Air	4000<Re<20,000	➢ 195% improvement in heat transfer can be noticed. ➢ Thermal performance factor improves up to 1.07 times as compared to plain tube
11.	Chinaruk Thianpong et al. [13]	Perforated twisted tapes 	Water	5300<Re<16700	➢ Perforated twisted tape gives higher heat transfer enhancement than plain tube with or without simple twisted tape. ➢ Nusselt number increased with decreasing s/W and y/W and increasing d/W
12.	Bodius Salam et al. [14]	Rectangular-cut twisted tape insert 	Water	10000<Re<19000	➢ 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
13.	Smith Eiamsa-ard et al. [15]	Twisted tape with ring 	Water	6000<Re<20000	➢ Heat transfer is 4.47 times the plain tube ➢ Thermal Performance factor improves upto 1.42 times as compared to plain tube.
14.	Prashant W. Deshmukh and Rajendra P. Vedula [16]	Vortex generator insert 	Air	10,000<Re<45,000	➢ The average Nusselt number ratio with and without the insert (Nu_a/Nu_s), at constant Reynolds number (Re) is found to be in the range of 1.3–5.0 ➢ The Nusselt number ratio (Nu_a/Nu_c), based on equal pumping power is found to be in the range of 1.0–1.8
15.	Pongjet Promvonge et al. [17]	Inclined vortex rings (VR) 	Air	5000<Re<26000	➢ The experimental results show a significant effect of the presence of the VRs on the heat transfer and pressure loss over the smooth tube. ➢ The VR at BR = 0.1 and PR =0.5 yields the best thermal performance
16.	N. Piriyarungroda et al. [18]	Tapered twisted tapes 	Air	6000<Re<20000	➢ Heat transfer enhancement and friction loss increased with decreasing taper angle and twist ratio. ➢ Thermal performance factor tended to increase with increasing taper angle and decreasing tape twist ratio
17.	Pongjet Promvonge et al. [19]	Inclined horseshoes baffles 	Air	5300<Re<24000	➢ Inclined horseshoes baffles provides considerable improvement of the heat transfer rate over the plain tube around 92-208% while the friction factor is increased at about 1.76-6.37 times. ➢ Thermal performance factor is examined and found to be in the range of 1.34-1.92
18.	Suriya Chokphoem-	Single, double,	Air	5300<Re<	➢ The Nusselt number increases with the increment of Re

phun et al. [20]	triple, and quadruple twisted-tape inserts 	24000	and of twisted-tape number. ➢ The values of Nu for the inserted tube are in a range of 1.15–2.12 times that for the plain tube while f is 1.9–4.1 times. ➢ The quadruple counter-twisted tape insert provides the maximum thermal performance

5 Conclusion

Some of the most effective insert geometries were shown in this paper, and their effects on heat transfer, friction factor, and thermal performance were seen.

Twisted tape is one of the most effective inserts to increase the heat transfer in a heat exchanger tube. Different modifications were made in the simple twisted tape, such as perforations, cuts, winglets, to enhance the heat transfer with minimum friction loss as main goal.

In addition to twisted tape, other inserts such as conical turbulators, v shape turbulators, wire coils, etc. were shown which can also enhance heat transfer effectively. Sometimes conjuction of two techniques were also employed to increase themal performance of the heat exchangers.

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