International Journal of Applied Engineering Research
ISSN 0973-4562 Volume 10, Number 6 (2015) pp. 13863-13876

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A Comprehensive Review of Heat Transfer Enhancement By Passive Inserts

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Abstract

Heat transfer enhancement is a subject of interest because it has wide application in many industries such as heat exchanger, air conditioning, chemical reactor, and refrigeration system and space technology. Hence many heat transfer enhancement techniques are being investigated on energy saving as well as economical and compact devices. The experimental and numerical results show inserts such as twisted tapes, conical ring, and wire coil etc., adopted in heat exchanger improves overall thermal performance. Many researchers observed that newly developed twisted tape inserts increases heat transfer efficiency for heat exchangers. Other passive techniques such as conical ring, ribs, wire coil etc., are more efficient in turbulent flow than the laminar ones. Thus passive method of Heat transfer is economical and reliable.

Keywords: Heat transfer enhancement, Turbulent flow, Heat exchange

Introduction

Heat transfer enhancement techniques are widely used in many engineering applications like heat recovery process, shell-and-tube heat transfer exchanger, air conditioning and refrigeration systems, nuclear energy industry, chemical reactors, high power laser systems and chemical process plants, etc. One of the ways to enhance heat transfer rate is to increase the effective surface area, residence time of the heat transfer fluids. Whenever inserts technologies is used for enhancement of heat transfer, turbulators generate periodic vortices in the flow and heat transfer coefficient enhancement takes place due to boundary layer disruption [21]. Sumana Biswaenes [2] observed that the secondary flow (swirl flow) generated by twisted tape element provide greater mixing and higher heat transfer coefficient. Several enhancement of heat transfer devices have been introduced and improved for increasing the heat transfer rate and thermal performance in heat exchangers. In general, heat transfer augmentation methods are classified into three broad categories of active, passive methods and compound methods.

Active Method

This method involves some external power input for the enhancement of heat transfer. Some examples of active methods include reciprocating plungers and induce pulsation by cams, the use of magnetic field to disturb the seeded light particles in a flowing stream , mechanicals aids, surface vibration, fluid vibration, electro- static fields, suction or injection and jet impingement requires an external activator/power supply to bring about the heat transfer enhancement.

Passive Method

Passive heat transfer augmentation methods do not need any external power input. This method generally uses surface or geometrical modifications to the flow channel by incorporating inserts or additional devices. For example inserts, swirl flow devices, treated surface, rough surfaces, extended surfaces, displaced enhancement devices, coiled tubes, surface tension devices and additives for fluids are used.

Compound Method

It is a combination of the active and passive methods, such as rough surface with a twisted tape swirl flow device or rough surface with fluid vibration.

Important Definitions Commonly Used In Heat Transfer Augmentation

Thermal performance factor are 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 heat transfer coefficient, the friction factor and Reynolds number [1]. 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. Overall enhancement is defined as the ratio of the heat transfer enhancement ratio to the friction factor ratio. The overall enhancement ratio is expressed as:

$$\text{Overall Enhancement Ratio} = \frac{Nu/Nuo}{\left(\frac{f}{fo}\right)^{\wedge\left(\frac{1}{3}\right)}}$$

Where f, Nu, and f_o and Nu_o are the friction factors and Nusselt number for a duct configuration with and without inserts respectively. The friction factor is a measurement of head loss or pumping power.

Twisted Tape Inserts Devices

Twisted tapes are metallic strips twisted with some suitable techniques at desired shape and dimension and inserted in the flow. Twisted tape inserts are popular and widely used in heat exchangers for heat transfer augmentation besides twisted tape inserts promote heat transfer rates with less friction factor penalty on pumping power.

Insertion of twisted tapes in a tube provides a simple passive technique for enhancing convective heat transfer by introducing swirl into the bulk flow and disrupting the boundary layer at the tube surface due to repeated changes in the surface geometry. Such tapes induce turbulence and superimposed vortex motion (swirl flow) results in a better heat transfer coefficient and higher Nusselt number due to changes in the twisted tape geometry. However, the pressure drops inside the tube will be increased by introducing the twisted-tape. Hence a lot of research has been carried out experimentally and numerically to investigate optimal design and achieve the best thermal performance with less frication loss. The enhancement of heat transfer using twisted tapes depends on the Pitch and Twist ratio. The twist ratio is defined as the ratio of pitch to inside diameter of the tube y=H/d, Where H is the twist pitch length and d is the inside diameter of the tube.

Pitch is defined as the distance between two points that are on the same plane, measured parallel to the axis of a twisted tape.

Main Categories of Inserts

- Rectangular-cut twisted tape insert: Slots and holes of suitable dimensions made in the twisted tape in order to create more turbulence.
- Helical screw tape inserts: twisted tapes are shaped left–right helical and sometimes with screw element.
- Smooth and spiky twisted tapes: favorable types of twisted tapes which generate higher degrees of HTE.
- Perforated twisted–tapes: The holes existing along a core tube diminish pressure loss within the tube.
- Varying length, alternate-axes and pitches twisted tape: These are short length tapes with different pitches spaced or twist types connecting each other.
- Wire coil with twisted tape: Twisted tape is inserted into the wire coil to create a continuous impinging swirl flow along the tube wall.

Impact of Twisted Tapes on Heat Transfer

Large number of experimental work are carried out by researchers to investigate the thermo hydraulic performance of various twisted tapes including the traditional simple twisted tapes, regularly spaced twisted tapes, varying length twisted tapes, tapes with different cut shapes, tapes with baffles, tapes with different surface modifications and wire coil with twisted tape.

Pongjet Promvonge [6] experimentally investigated the influence of insertion of wire coils in conjunction with twisted tapes on heat transfer and turbulent flow friction. They inserted wire coils of different spring pitch ratios (CR = H/d = 4, 6 and 8) into the tube by wall-attached position. The twisted tapes made of 2 mm thick steel strip with 35 mm width (w) for two twist ratios (Y = P/w = 4 and 6) were fitted tightly into the wire coil placed in the test tube. The tube was heated by wrapping nichrome wire around test section. They found that Nusselt number ratio tends to decrease with the rise of Reynolds number from 3000 to 12,000.The Nusselt number ratio, Nu_a/Nu_0, defined as a ratio of augmented Nusselt number to Nusselt number of smooth tube. The use of wire coil and the twisted tape inserts results increase in pressure drop and also provides considerable heat transfer augmentations. The range of Nu_a / Nu_0 is 3to 6. Therefore, the combined wire coil and twisted tape provide highest heat transfer rate of about 200-350%.

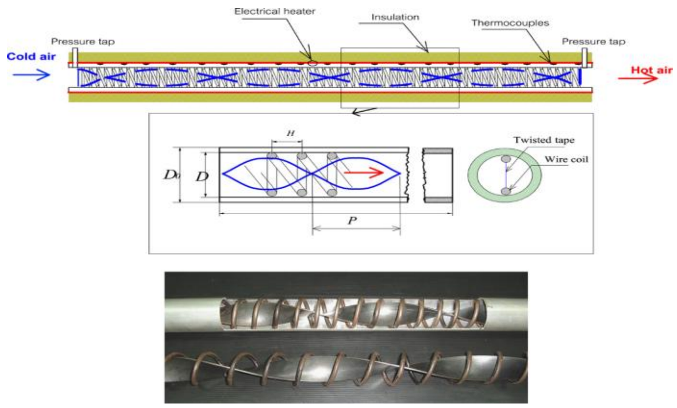

Figure 1: Tube With Wire Coil And Twisted Tape Inserts [6]

C. Thiangpong et al. [3] took forward research on enhancement of heat transfer by twisted tape. They carried out experiment with perforated twisted tape instead of normal twisted tape. They performed experimental investigation on heat transfer and pressure drop characteristics of turbulent flow in a tube equipped with perforated twisted tapes with parallel wings (PTT) for Reynolds number between 5500 and 20500.

Perforated twisted tapes with parallel wings create an extra turbulence near tube wall and thus efficiently disrupt a thermal boundary layer and holes existing along a core tube to diminish pressure loss within the tube. They performed the experiment with perforated twisted tapes of three hole diameter ratio (d/W = 0.11, 0.33 and 0.55) and wing depth ratio (w/W = 0.11, 0.22 and 0.33). They found that Nusselt number increased with increasing wing depth ratio (w/W) and also the larger depth ratio causes higher turbulence intensity and thus better mixing fluid near the tube wall. For tape with the largest depth ratio (w/W = 0.33), the increase in heat transfer rate was up to 49% and 23% over the ones with w/W = 0.11 and w/W = 0.22, respectively. They found that the tape with the largest depth ratio (w/W = 0.33) yielded 40.8% and 18.3% higher mean friction factor than the ones with w/W = 0.11 and w/W = 0.22 respectively.

Figure 2: Perforated Twisted Tape with Parallel wings [3].

Impact of Helical Screw Tape Inserts on Heat Transfer

P. Sivashanmugam et al [4] investigated the heat transfer and friction factor characteristics of circular tube fitted with full length helical screw element of different twist ratio instead of perforated twisted tape with air as working fluid. They performed the experiment with different twist ratio inserts Y=1.95, 2.93, 3.91, 4.89. and also one inserts element by increasing twist ratio. Experiments were also held for other inserts element of decreasing twist ratio. They found that heat transfer coefficient is more for inserts having increasing twist ratio. It is also observed that inserts with decreasing twist ratio have higher Nusselt number than the plain tube.

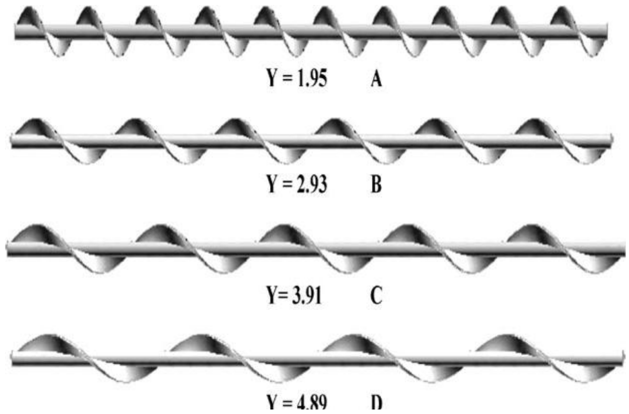

Figure 3: Helical screw inserts of different twist ratio [4]

Effect of Smooth and Spiky Twisted Tapes on Heat Transfer

Shyy Woei Chang et al [5] experimentally studied heat transfer properties over developing and developed flow regimes, the pressure drop coefficients and the thermal performance factors (TPF) of tubular flows with the continuous and spiky twist tapes enhanced by perforated, jagged and notched winglets. The Reynolds numbers (Re) of air varied from 500 to 40000 are comparatively examined for different types of twisted tapes with three twist ratios (y) of 1.875, 2.186 and 2.815. With the group of modified twist tapes by perforating or notching the spiral spikes, the laminar and turbulent Nu_{DE} /$Nu_{\infty}$are raised to 6.84–15.45 and 5.4–2.62; while the laminar and turbulent Nu_{FD}/Nu_{∞} are raised to 4.94–9.11 and 3.78–2.38 respectively.

Smith Eiamsa-ard, Pongjet Promvonge [19] experimentally investigated the influence of twisted tape with serrated-edge insert on heat transfer and pressure loss behaviors in a constant heat-fluxed tube. They inserted the serrated twisted tape (STT) into a tube with a constant twist ratio in order to generate a continuous swirling air flow with air as working fluid having Reynolds no 4000 to 20,000. They found that Nu increases with the rise in depth ratio but decreases by raising the width ratio. The heat transfer rate found up to 72.2% and 27% relative to the plain tube and the TT inserted tube, respectively. They found that the smaller width ratio w/W= 0.1yields higher heat transfer rate than the larger ones (w/W =0.2 and 0.3).

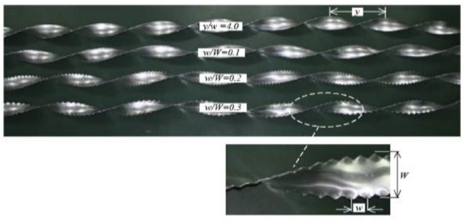

Figure 4: Twisted tape with serrated-edge (STT) [19]

Impact of Rectangular Cut Twisted Tape Inserts on Heat Transfer

Bodius Salam et al [2] investigated the influence of rectangular- cut insert on heat transfer coefficient, friction factor, and heat transfer enhancement efficiency of water for turbulent flow in a circular tube. They created a uniform heat flux condition by wrapping nichrome wire around the test section and fiber glass over the wire. A stainless steel rectangular-cut twisted tape insert of 5.25 twist ratio was inserted into the smooth tube. The rectangular cut 8 mm depth and 14 mm width. They found that heat transfer enhancement efficiencies were found to be in the range of 1.9 to 2.3 and increased with the increase of Reynolds number. An average of 68% enhancement of heat flux was observed for tube with rectangular-cut twisted tape insert (qe) than that of smooth tube (qs). The experimental frictional values with inserts were found to be 39% to 80% higher than the ones without inserts values. The heat transfer enhancement efficiency was found to be increased with Re, and values ranged between1.9 to 2.3.

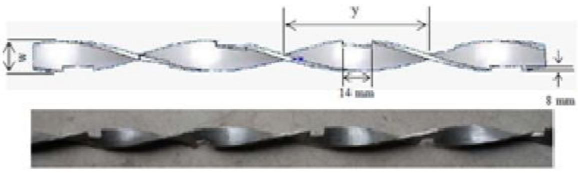

Figure5: Twisted Tapes with rectangular cut [2]

Impact of Coiled Wire Inserts on Heat Transfer

Sibel Gunes [11] experimentally studied the heat transfer enhancement and pressure drop in a tube with coil wire inserts placed separately from the tube wall in turbulent flow regime. They were performed experiment with a constant wire thickness of a = 6 mm, three different pitch ratios (P/D = 1, P/D = 2 and P/D = 3) and two different distances (s =1mm, s=2 mm) at which the coiled wire inserts were placed separately from the tube wall. Uniform heat was provided to external surface of tube by wrapping nichrome wire around the test section. Air was used as working fluid with Reynolds numbers varied from 4105 to 26400. They found that use of coiled wire inserts leads to a considerable increase in heat transfer and pressure drop over the smooth tube. They found that Nusselt number and friction factor increase with decreasing pitch ratio (P/D) and distance(s) for coiled wire inserts. The experimental results show that the Nusselt number and friction factor increase with decreasing of pitch ratio (P/D) and distance(s). The highest overall enhancement efficiency of 50% was achieved for the coiled wire with P/D = 1 and s =1 mm at Reynolds number of 4220. It is also found that using these coiled wire inserts separately from the tube wall is advantageous in order to provide higher thermal performance especially at low Reynolds numbers.

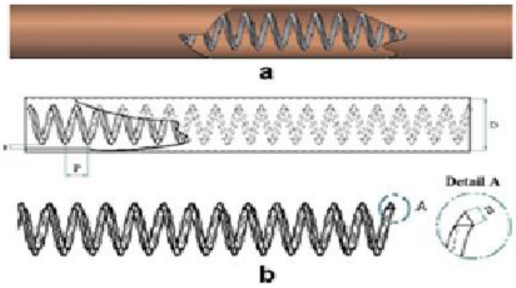

Figure 6: (a) Coil wire inserts placed separately from tube wall (b) detail of coiled wire [11]

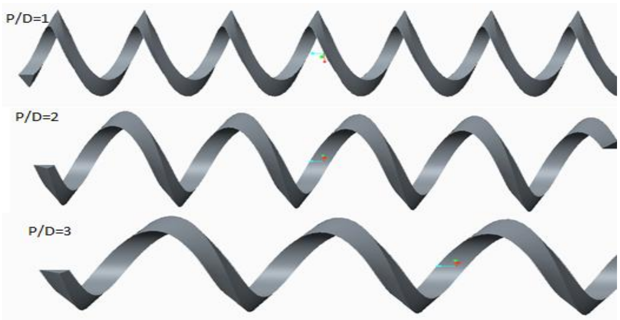

Figure 7: Coil wire with Teflon rings (s=2mm) [11]

Alberto Garcia et al [13] studied the effect of three wire coils of different pitch inserted in a smooth tube in laminar and transition regimes. Experiments have been performed with air as working fluid with Reynolds number ranging from 10-2500. Air was provided as working fluid. They found that at Reynolds numbers between 200 and 1000, wire coils significantly disturb the flow and heat transfer increases remarkably. At Reynolds numbers above Re =1000–1300, wire coil inserts promote the transition from laminar to turbulent flow. The heat transfer increase in this low Reynolds number region is very remarkable. When air provided at Re = 1000 and Pr = 360.The Nusselt number Nu is eight times the one of smooth tube. In turbulent flow, friction factor increases are much higher than in laminar flow. They reach up to 400% as it was analyzed by Garcia.

Pongjet Promvonge [20] studied the heat transfer enhancement in a circular tube fitted with coiled square wires. They carried out the experiment with a coiled wire of circular cross section and square cross section along with spring pitches of 15 and 20 mm. The Reynolds number of air varied from 5000 to 25,000 with wire thickness of 2 and 3 mm used during experiment. The result shows that 3 mm square wire provides both higher heat transfer and friction factor than the 2 mm one for all Reynolds number values. The Nusselt number increases for the 3 mm wire found to be about 10–20% over that of 2mm. The heat transfer rate at lower spring pitch is more than high pitch because turbulence intensity obtained from lower pitch is more than the other one.

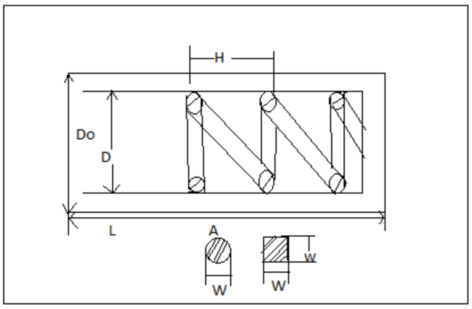

Figure 8: Test tube with coiled wire inserts [20].

Impact of Conical Ring on Heat Transfer

P. Promvonge [7] investigated the influence of the conical ring turbulator inserts on the heat transfer rate and friction factor. In this three different (converging conical ring, referred to as CR array, diverging conical ring, DR array and converging–diverging conical ring, CDR array) are studied in the experiment. Conical rings with three different diameter ratios of the ring to tube diameter (d/D = 0.5, 0.6, 0.7) are introduced in the tests for each ratio. The rings are placed with three different arrangements (CR array, DR array and CDR array). Air at Reynolds numbers in a range of 6000–26,000 is passed through the tube. They found that the ring to tube diameter ratio and the ring arrays provide a significant effect on the thermal performance of the test tube. It is found that heat transfer rate at Diverging conical ring array gives a better heat transfer rate than other array. The heat transfer rates obtained from using the conical rings of DR, CDR and CR arrays with d/D = 0.7–0.5 are found to be around 197–333%, 138–234% and 91–175%, more than the plain tube, respectively.

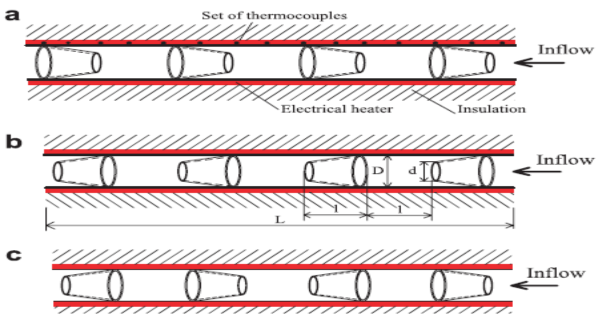

Figure 9: Test Tube fitted with Conial ring array a) DR array, b) CR array C) CDR array [7].

Veysel Ozceyhan et al [9] experimentally studied heat transfer enhancement in a tube with the circular cross sectional rings inserted near the tube wall. They carried out experiment at five different spacing between the rings p= d/2, p=3d/2, p=2d and p=3d with air as working fluid. They found that Nusselt number increases and friction factor decreases with increasing Reynolds number. The highest Nusselt number and friction factor are obtained in the case of p = d/2. As ring spacing decreased, they found that the Nusselt number and friction factor increase, with p=d/2 type insert introducing more pressure drop than other types. The overall enhancement ratio increases with increasing ring spacing. Therefore, the best overall enhancement of 18% was achieved for Re = 15,600 in which the spacing between ring is 3d. The overall performance also efficient for the case of p=d, 3d/2 and 2d.

Hakan Karakaya, Aydin Durmus [8] studied the effect of various Conical Spring Turbulators (CST) angle θ on heat transfer and pressure drop provided in a pipe. They performed the experiment with conical spring turbulators (CST) angle of 30^{θ}, 45^{θ}, and 60^{θ} along with three different arrangement of (DR, CDR, CR). Diverging ring array, Conical Diverging ring array and conical ring array with the air flowing through the inner pipe with Reynolds numbers in the range of 10,000–34,000.

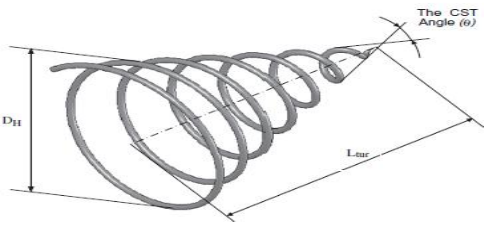

Figure 10: Conical Spring Turbulator [8]

They observed heat transfer rate of the DR array was found to be higher than that of the CR and CDR arrays by around 35–44% and 18–27%, respectively. The average Nusselt number for the DR array at all rings to tube angle ratio was found to be about 133–333% more than that of the plain tube.

Selahaddin Orhan Akansu [10] experimentally studied heat transfer enhancement and pressure drop by porous ring. The porous –ring height is taken as H=1 or 2mm. The distance between two porous rings is 0.5D, D or 2D where D is the inside diameter of the pipe. They found that, heat transfer decreases as the L/D ratio increases and friction factor reduces with increasing Reynolds number and blockage ratio. The maximum friction factor obtained is 3 for L/D =1/2, H/D = 0.4 and Re = 5000. They also found that friction factor increases due to decrease in distance between two turbulators. The Nusselt number for H/D = 0.4 is higher than for H/D = 0.2 until Re = 25,000. If the Reynolds number is higher than 25,000, the Nusselt numbers are almost the same for H/D = 0.2 and 0.4, the higher heat-transfer enhancement was obtained in the case of L/D and H/D being 0.5 and 0.2 respectively.

Pongjet et al [12] investigated the influence of inclined vortex rings (VR) on heat transfer augmentation in a uniform heat-fluxed tube. The experiment performed with three relative ring width ratios or (Blockage Ratio BR =b/ D = 0.1, 0.15 and 0.2) and four relative ring pitch ratios (PR =P/D = 0.5, 1.0, 1.5 and 2.0). Air was employed as the test fluid in the tube for the Reynolds number from 5000 to 26,000. The position of vortex ring placed at 30^{θ} inclinations repeatedly in the tube. They found that Nusselt number of the VR inserted in tube shows an increasing trend with the rise in BR and Re values but with the reduction of Pitch Ratio. They found that with the presence of the VRs at Blockage Ratio =0.2, PR =0.5 causes a much high pressure drop increase, f/f_0 = 35.1-36.5 but also provides a considerable heat transfer augmentation in the tube, Nu/Nu_0 = 3.6- 4.3.

Bogdan I. Pavel, Abdulmajeed A. Mohamad [16] investigated the effect of metallic porous materials inserted in a pipe on the heat transfer rate provided with the uniform heat flux over the pipe. They manufactured porous media for experiments from aluminum screen (wire diameter 0.8 mm, density 2770 kg/m^3, thermal conductivity 177 W/m^2K) cut out at various diameters Dp and then inserted on steel rods.

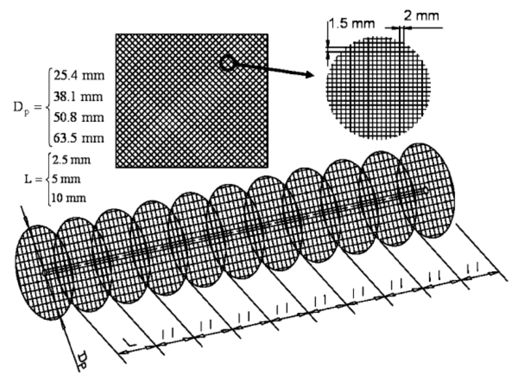

Figure 11: Porous Media [16]

They observed that Rp has a strong effect on heat transfer rate. Where (Rp = rp/r0 i.e. porous material radius ratio, Where rp=Radius of porous material and r0 =internal radius of pipe). Nu average increases with increasing order of Reynolds number and Rp = 0.4, 0.6, 0.8, and 1.0. and porosity is 98.1%. The pressure drop raise with increase in Reynolds number and at highest porosity of 98.1 %.The best result obtained at Rp=1.0.

J.M. Wu. [14] experimentally investigated the effect of longitudinal vortex generator on heat transfer in rectangular channels. They studied average convective heat transfer on the top and bottom surfaces of a plain plate and four plates with a pair of delta winglet longitudinal vortex generator punched directly from the plates at attack angles of 15^{θ},30^{θ}, $45^{\theta}$and 60^{θ} respectively,. They fixed plate horizontally in the center of the tested channel. Experimental results show that the average Nusselt number on the surfaces of plate increases with the increase of the attack angle of delta winglet pair compared with that of plain plate without delta winglet pair. The average Nusselt number of the plate with attack angle of 60^{θ} is slightly higher than that of plate with attack angle of 45^{θ}.

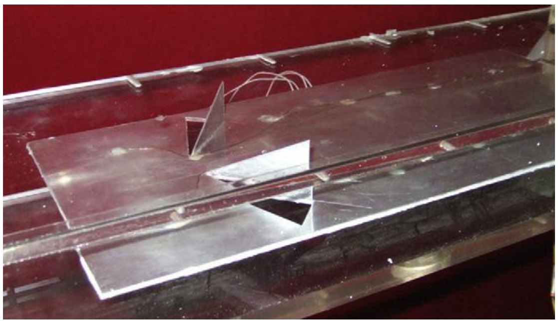

Figure 12: Aluminium Tested Plate [14]

A.W. Fan [17] studied the characteristics of heat transfer, flow resistance and overall thermo-hydraulic performance of turbulent air flow in a circular tube fitted with louvered strip inserts were investigated numerically. They found that Nusselt number is augmented by 2.75-4.05 times as that of smooth tube. Larger slant angle and smooth pitch can be effectively enhancing the heat transfer rate, but also increase the flow resistance. Nusselt number and friction factor are more sensitive to the slant angle than the inserts pitch, because a larger slant angle can produce a larger radial flow velocity. The louvered strip is also easy to fabricate. Thus, it is a promising tube insert which can be widely used in heat transfer enhancement of turbulent flow.

Henk Huisseune et al [15] experimentally studied the effect of punching delta winglet vortex generators into the louvered fin surface near the wake region of each tube. They observed that delta winglet give important mechanisms of heat transfer enhancement. Thus, due to swirling motion of the generated vortices, hot air is removed from the tube wake to the mainstream regions. Delta winglet induced wall-normal flow locally thins the boundary layer, which results in enhancement of the heat transfer. The generated vortices due to delta winglet reduce the size of the wake regions, but they do not propagate far downstream as they are destroyed by the louvers and the deflected flow in the downstream louver bank. It gives heat transfer enhancement mechanism of better fluid mixing, boundary layer thinning and flow separation delay from the tube surface. The delta winglet increases pressure drop, flow blockage and increased in friction results in higher heat transfer than the one without delta winglet.

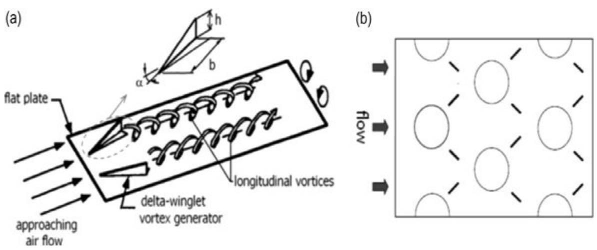

Figure 13: Delta winglet [15].

Effect of Rib on Heat Transfer

Ting Ma et al [18] studied the effect of inlet temperature and rib height on fluid flow and heat transfer performance of the ribbed channel inside high temperature heat exchanger. They performed the experiment by varying the ratio of rib height to channel height from 0.083 to 0.333 and also inlet temperature varies from 850K to 1250K.They found that, more heat can be transferred by increasing the rib height. The inlet temperature variation has little effect on the basic structure of fluid flow, but the velocity value and turbulence kinetic energy at higher temperature are larger so that heat transfer in most surfaces is enhanced.

Conclusion

This review paper focused on heat transfer augmentation by passive methods and influences of different inserts on heat transfer enhancement. It was found that twisted tape inserts give better heat transfer than smooth tube. The shape of inserts is important for the heat transfer. It is observed that heat transfer and friction factor were significantly influenced by the presence of wings and holes on perforated twisted tape.

The helical screw tape inserts are family of inserts in which the swirl moves in one direction along the helical and induce swirl in the flow, which increase the retention time of the flow and consequently provide better heat transfer performance over twisted tape inserts because shorter pitch length leads to stronger swirling flow. The helical tapes are used in solar water heating applications to carry heat transfer benefit. However inserts of different configuration are being used to meet the needs of higher heat dissipation rates.

This paper also focused on some circular tube with twisted tape and wire coil turbulators which lead to a double increase in heat transfer over the use of wire coil/ twisted tape alone. The combined wire coil and twisted tape provide better heat transfer rate than the single twisted tapes. The use of coiled square wire caused high pressure drop increase, which depends mainly on spring pitches and wire thickness also provides considerable heat transfer augmentations. Wire coil inserts are currently used in the applications such as oil cooling devices, pre heaters or fire boilers. They showed several advantages in relation to other enhancement techniques. These are given below

- Simple manufacturing process with low cost.
- Easy installation and removal.
- Possibility of installation in an existing smooth tube heat exchanger.
- Fouling mitigation (in refineries, chemical industries and marine application).

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