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Heat Transfer Enhancement in Heat Exchangers With Inserts: A Review

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***Abstract*— Heat transfer augmentation techniques are used to increase rate of heat transfer without affecting much the overall performance of the system. Heat transfer augmentation techniques are commonly used in areas such as heating and cooling in evaporators, air-conditioning equipment, thermal power plants, space vehicle, automobile etc. This paper contains literature survey of enhancement techniques in heat transfer using inserts with and without using nanofluid.**

Keywords*— Heat transfer enhancement, passive method, inserts.

I. INTRODUCTION

The heat exchangers have an important role in the energy storage and recovery. Due to the development of modern technology, the heat exchangers required in various industries for high heat-flux cooling to the level of megawatt per meter square. At this level, cooling with conventional fluids such as water and ethylene glycol and so forth, are challenging. Hence, it is necessary to increase the heat transfer performance of working fluids in the heat transfer devices. Heat transfer augmentation techniques (passive, active and compound) are commonly used in areas such as process industries, heating and cooling in evaporators, thermal power plants, air-conditioning equipment, refrigerators, radiators for space vehicles, automobiles, etc. The rate of heat transfer can be increased passively by increasing the surface area, roughness, and by changing the boundary conditions. The active method involves addition of nanosized, high thermal conductivity, and metallic powder to the base fluid, to increase the heat transfer rate. Such a fluid is termed as nanofluid. Passive techniques, where inserts are used in the flow passage to augment the heat transfer rate, are best suited compared to active techniques. Because the insert manufacturing process is simple and these techniques can be easily applied in an existing application.

In many literature gap shows the experimentation on perforated twisted insert like in experimental analysis of heat transfer characteristics using inserts in tubes. Heat transfer enhancement techniques refer to different methods used to increase rate of heat transfer without affecting much the overall performance of the system. Heat transfer augmentation techniques refer to different methods used to increase these techniques and broadly divided in two groups, passive and active. Active techniques involve some external power input for the enhancement of heat transfer. Passive heat transfer augmentation method does not use any external power input. One of the ways to enhance heat transfer performance in passive method is to increase the effective surface area and residence time of the heat transfer fluid. Use of this technique causes the swirl in the bulk of the fluids and disturbs the actual boundary layer so as to increase surface area, given time and similarly heat transfer coefficient in existing system. Inserts refer to the additional arrangements made as an obstacle to fluid flow so as to augment heat transfer rate.

II. DIFFERENT METHODS OF HEAT TRANSFER ENHANCEMENT

Heat transfer enhancement, augmentation deals with the improvement of thermo hydraulic performance of heat exchangers. Different enhancements techniques have been broadly classified as passive and active techniques.

A. *Active method*

The active method involves external power input for the enhancement in heat transfer; for examples it includes mechanical aids and the use of a magnetic field to disturb the light seeded particles in a flowing stream, etc**.**

B. *Passive method*

The Passive heat transfer augmentation methods does not need any external power input. In the convective heat transfer one of the ways to enhance heat transfer rate is to increase the effective surface area and residence time of the heat transfer fluids. By Using this technique causes the swirl in the bulk of the fluids and disturbs the actual boundary layers which increase effective surface area, residence time and simultaneously heat transfer coefficient increases in an existing system. Methods generally used are, extended surface, displaced enhancements devices, rough surfaces surface tension devices, Inserts

Inserts requires additional arrangements to make to fluid flow which enhance and augment the heat transfer. The types of inserts are: twisted tape, wire coils, ribs, baffles, plates, helical screw insert, mesh inserts, convergent – divergent conical rings, conical rings etc.

Twisted tapes are the metallic strips twisted using some of the suitable techniques as per the required shape and dimension, which are inserted in the flow to enhance the heat transfer. The twisted tape inserts are most suitable and widely used in heat exchangers to enhance the heat transfer. Twisted tape inserts increase heat transfer rates with less friction factor. The use of twisted tapes in a tube gives simple passive technique for enhancing the convective heat transfer by making swirl into the heavy flow which disrupting the boundary layer at the tube surface due to rapidly changes in the surface geometry. Which means to say that such type of tapes induce turbulence and swirl flow which induces inside the boundary layer and which gives better results of heat transfer coefficient and Nusselt number due to the changes in geometry of twisted tape inserts. Simultaneously, the pressure drop inside the tube will be increases when using twisted-tape as an insert. For this a many researchers have been done by experimentally and numerically to investigate the desired design to achieve the better thermal performance with less frictional losses. The heat transfer enhancement of twisted tapes inserts depends on the Pitch and Twist ratio.

C. Compound enhancement

When any two or more techniques i.e. passive and active may be employed simultaneously to enhance the heat transfer of any device, which is greater than that of produced by any of those techniques separately, the term known as Compound enhancement technique.

III. NANOFLUID

A. History

The nanotechnology is new, but it is existence of the functional devices and structure of nanosized devices are not new in this world. In 1905, experimental data on the diffusion theory showed that the molecule has nano meter diameter, which is considered as the notable landmark in the scientific history of nanotechnology. In 29 December 1959: Visionary statement by Prof. R.P. Feynman, "There is enough space at the bottom". A carbon nano tube is a tube shaped material, made of carbon, having a diameter measuring on the nano meter scale. Carbon nano tubes are Allotropes of carbon with a cylindrical nanostructure. The cylindrical carbon molecules have unusual properties which are valuable for nanotechnology. In particular owing to their extraordinary thermal conductivity and mechanical and electrical properties carbon nano tubes find application as additives to various structural materials.

B. Need of Nanofluids

- High specific surface area, therefore more heat transfer surface between particles and fluids.
- High dispersion stability with motion of particles.
- Reduces pumping power as compare to the pure liquid to achieve the better heat transfer enhancement.
- Reduces particle clogging as compare to conventional slurries and hence promoting the system miniaturization.
- Nanofluids are most reliable for continuous heating and cooling systems.
- With nano size particles, fluid is considered as integral fluid.

As per the heat transfer point of view, there are the most important challenge faced by the researcher to increase the heat flux and simultaneously reduce the size of the heat exchanger for the efficient applications in various fields.

C. Application

The concepts of nanofluids are used for the heat transfer characteristics which are applicable for many systems for better performance. There are many researches did on the heat transfer properties using nanofluids especially on thermal conductivity and convective heat transfer. Applications of nanofluids in many industries such as heat exchanging devices appear promising with these characteristics. Nanofluids can be used in following specific areas:

- Heat-transfer.
- Coating.
- Chemical.
- Engine cooling and Engine transmission oil nanofluids
- Process/extraction.
- Pollution cleaning.
- Nuclear system cooling.
- Solar water heating.
- Bio- and pharmaceutical etc.

IV. REVIEW OF WORK CARRIED OUT

S.S.Giri, V.M.Kriplani, [1] they did the review on heat Transfer Characteristics using inserts in Tubes. The overall conclusions which they found during the study the twisted type insets heat transfer rate increase in turbulence of the flow and also the pressure drop increases. For conical ring inserts, the heat transfer rate more than that of the plain surface tube simultaneously increases the frication factor. In a wire inserts, the friction factor increases in the fully laminar region and increased the heat transfer coefficient with respect to the smooth tube. In mesh insert, pressure drop increases by increasing the ratio of porous material and enhancement of heat transfer rate when compared with the plain tube. Similarly In a baffle insert, the rate of pressure drop increases with varying the Reynolds number for transient flow conditions.

Om Shankar Prajapati, A. K. Rajvanshi, [2] experimentally investigated on effect of AL_2O_3/water nanofluids in convective heat transfer. In this paper the work is carried out in turbulent flow forced convection heat transfer of Al_2O_3/water nanofluid inside an annular tube with variable wall temperature was investigated experimentally. Which we have review the Nusselt numbers of nanofluid they obtained for various heat fluxes which are in the range of 0 - 60 and Nusselt number increases with increase in heat flux. Reynolds numbers ranges from 3500-11500 and a nanoparticles concentration was to be taken in the ranges from 0.25%-1% at atmospheric pressure. They concluded that the use of nanoparticles in water heat transfer coefficient increases and increases with increase in the nanoparticles concentration with heat flux and flow rate.

M. Raja, R. M. Arunachalam and S. Suresh, [3] studied heat transfer characteristics of Alumina/water nanofluid in a shell and tube heat exchanger with the aid of coil insert. They studied effects of Peclet number and the effect of the Al2O3/water nanofluid concentration on the heat transfer and pumping power characteristics. The concentrations were taken 0.5%, 1% and 1.5% was prepared and made solution with base fluid namely water. An increase in the volume concentration of the nanoparticles in the base fluid caused a significant enhancement in the overall heat transfer coefficient compared to that of water. When a wire coil insert was used, further increase in overall heat transfer coefficient was found for a particular Peclet number. The overall heat transfer coefficient was increased by 12.6%, 20% and 25% for Alumina/water nanofluid when the percentage of volume concentrations were 0.5, 1 and 1.5 respectively at a Peclet of 3000, compared to those of distilled water. There was significant increase of about 13% in the pumping power for wire coil insert, when compared to that of the pumping power obtained with distilled water. The superior thermal characteristics of nanofluid obtained with the aid of coil insert may be attributed to the thermal dispersion effect, which caused the temperature distribution to flatten and as a result the temperature difference between the fluid and tube wall steepened resulting in the increase of heat transfer.

Panida Seemawute, Smith Eiamsa-Ard, [4] studied visualization of flow characteristics induced by twisted tape consisting of alternate-axis has been comparatively investigated to that induced by typical twisted tape. The visualization was carried out via a dye injection technique. They studied the effects of twist ratios on heat transfer and fluid friction. They conclude that the visualization results shows that the twist axis give better mixing of fluid with higher heat transfer rate than that of twisted tape. In addition of swirl number and thus residence time of a fluid flow is increases as tape twist ratio decreases. This visualization results is consistent with the superior heat transfer at smaller twist ratio.

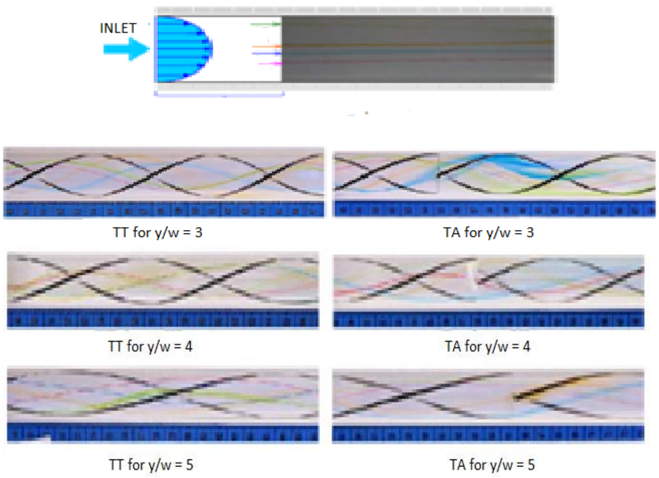

Figure [1] Axial and swirl flow patterns by dye injection techniques [4]

Shyy Woei Chang, Ming Hui Guo, [5] experimentally studied to investigate the heat transfer properties over developing and developed flow regimes. They concluded that the pressure drop and the thermal performance factors during tubular flows with the continuous and spiky twist tapes increases by perforated, jagged and notched winglets. The axial distributions of Nusselt number and the mean Fanning friction factors of the tubular flows at Reynolds numbers (Re) ranging from 500 to 40000 comparatively examined by them for five different types of twisted tapes with three twist ratios of 1.875, 2.186 and 2.815 for each type of twisted tapes.

C. Thianponga, et al., [6] studied experimental investigation on heat transfer and pressure drop characteristics of turbulent flow in a heating tube equipped with perforated twisted tapes with parallel wings for Reynolds number range from 5500 to 20500. They did the design of perforated twisted tape with the following concepts:
- The wings induced an extra turbulence near tube wall which caused to disrupt the thermal boundary layer efficiently.
- The existing holes along a core tube reduce the pressure losses of the tube.

The various parameters investigated by them i.e. the hole diameter ratio and wing depth ratio. And also typical twisted tape was also tested for the assessment. They compare the results with the plain tube, the result shows that the tubes with perforated twisted tape heat transfer rate increases up to 208 % and also with the twisted tape the heat transfer enhance up to 190%. They evaluate the overall performance during experimentation under the same pumping power with that of perforated twisted tape with ratio of *d/W* and *w/W* which are equal to 0.11and 0.33 respectively, gives the maximum thermal performance factor of 1.32, in the Reynolds number range of 5500.

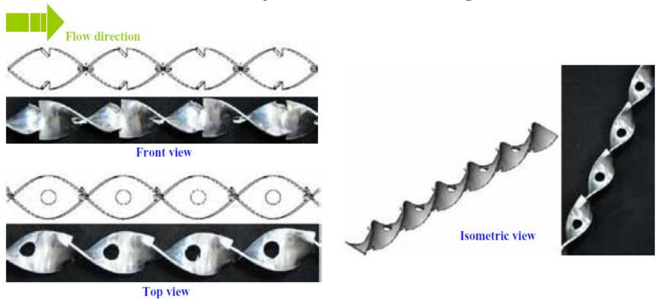

Figure [2] Photograph and sketch of Perforated twisted tape with parallel Wings [6]

Jaafar Albadr,Satinder Tayal, Mushtaq Alasadi,[7] had experimental study on the forced convective heat transfer and flow characteristics of a nanofluid consisting of water and different volume concentrations of Al_2O_3 nanofluid in between 0.3–2% which are flows in the horizontal shell and tube heat exchanger counter flow under turbulent flow conditions are investigated. The Al2O3 nanoparticles of about 30 nm diameter were used in the study. The results show that the convective heat transfer coefficient to nanofluid is slightly higher than that of the base liquid at same mass flow rate and at same inlet temperature. The heat transfer coefficient of the nanofluid increases with an increase in the mass flow rate, also the heat transfer coefficient, increases with the increase of the volume concentration of the Al_2O_3 nanofluid, however increasing the volume concentration cause increase in the viscosity of the nanofluid leading to increase in friction factor. It was found that at a particle volume concentration of 2% the use of Al_2O_3/water nanofluid gives significantly higher heat transfer characteristics.

Watcharin Noothong, et al., [8] they performed the experimental investigation and study on twisted tape inserts on heat transfer and flow friction characteristics in a concentric double pipe heat exchanger. In their experimental study, the swirling flow was introduced using twisted tape placed inside the inner test tube of the heat exchanger having the different twist ratios, (y = 5.0 and 7.0). During the experimental study the results show that, increase in heat transfer rate of the twisted-tape inserts strongly influenced by the tape-induced swirl or vortex motion. The range was for investigations i.e. the maximum Nusselt numbers for using for the enhancement devices with the twist ratio of y = 5.0 and 7.0 are increases the heat transfer rate up to 188% and 159%, respectively, which are higher than that of the plain tube. In addition of this the effects of the twisted tape are also investigated on the heat transfer enhancement efficiency.

Figure [3] twisted tape at different twist ratios [8]

S. Liu, M.Sakr, [9] they did the experimental study on passive heat transfer enhancements in pipe exchangers. This paper reviews shows the experimental and numerical works taken by researchers on passive technique since 2004 i.e. are twisted tape, wire coil, swirl flow generator, etc. for enhancing the thermal efficiency in heat exchangers and useful for designers to implement the passive augmentation techniques for heat exchanging devices. The authors found that various type of developed twisted tape inserts are popular researched and used for various heat exchanging devices for to get best heat transfer efficiency with appropriate applications. And also the other techniques used for specific work environments are studied in this paper. They conclude that the twisted tape inserts gives better performance in laminar flow than turbulent flow. Similarly, the other several passive techniques i.e. ribs, conical nozzle, and conical ring, etc. are generally perform better in the turbulent flow than the laminar flow.

Bodius Salam, Sumana Biswas and Muhammad Mostafa Kamal Bhuiya, [10] they studied the experimental investigation for measuring tube side heat transfer coefficient of water for turbulent flow in a circular tube fitted with twisted tape insert. They take a 914 mm long Copper tube of 26.6 mm inner diameter and 30 mm outer diameter was used and test section length is equal to 860 mm. the twisted tape made of stainless steel with 5.3 twist ratio was inserted into the smooth tube. The Reynolds numbers was varied in the range 9500-20000 with heat flux variation are 9 to 18 kW/m^2 for smooth tube and for 15 to 31 kW/m2 for insert inside the tube. The obtained Nusselt numbers for smooth tube was compared with Dittus and Boelter correlation and they found the error in the range of -13% to 18% with R.M.S. value of 12%. They conclude that the Reynolds numbers, Nusselt number in tube with twisted tape insert was enhanced with 2.9 to 4 times as compare with smooth tube.

Bodius Salam et al., [11] they studied the experimental investigation the heat transfer enhancement efficiency of water for turbulent flow in a circular tube fitted with rectangular-cut twisted tape insert. The rectangular-cut twisted tape insert made of stainless steel with 5.25 twist ratio which was inserted into the smooth tube. They take the Reynolds number range from 10000 to 19000. They concluded that the Nusselt number increased with the increase of Reynolds number, an average percentage of 68, the result shows the enhancements of heat flux for tube with rectangular-cut twisted tape insert than that of smooth tube. They conclude that the experimental Friction factors with inserts are found to be 39% - 80% higher than that of Friction factor for smooth tube. They found the heat transfer enhancement efficiencies in the range of 1.9 to 2.3 and which increases with the varying Reynolds number.

Figure [4] Rectangular cut twisted tape inserts [11]

P. Promvonge [12] did the investigation on effects of the conical ring turbulator inserts. He did the investigations on heat transfer rate and friction factor on conical rings which are used as turbulators, which are mounted over the test tube. The Conical rings with three different diameter ratios of the ring to tube diameter (i.e. d/D = 0.5, 0.6, 0.7) was introduced for the tests. For each ratio, the rings placed with three different arrangements i.e. converging conical ring, referred to as CR array, diverging conical ring, DR array and converging–diverging conical ring, CDR array. It was used as cold air at ambient condition for Reynolds numbers in the range of 6000–26,000. It was concluded that conical ring inserts to a higher heat transfer rate than that of the plain surface tube. And the DR array founds the better heat transfer than the others. The heat transfer enhancement efficiency increases with decreasing the Reynolds number and ratios of diameter for the test. It was concluded that the effects of using the conical ring cause a substantial increase in friction factor.

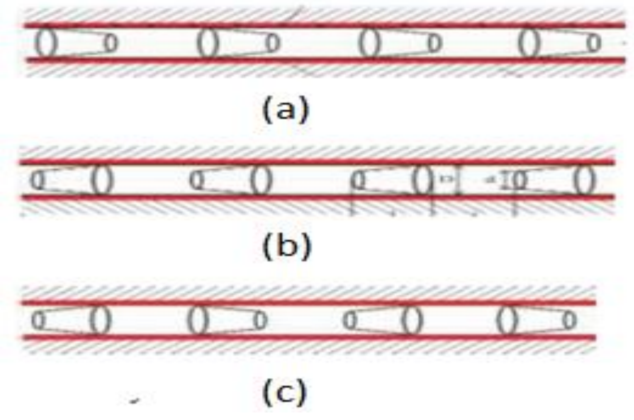

Figure [5] Test tube fitted with various conical ring arrays, (a) DR array, (b) CR array and (c) CDR array [12]

P. Sivashanmugam, S. Suresh [13] they did the study and experimental investigation of heat transfer of water for laminar flow in circular tube, the full-length helical screw element are fitted with tube at different twist ratio in increasing and decreasing order of twist ratio and the result was compared with the plain tube. They concluded that the heat transfer coefficient increases with increasing the twist ratio and friction factor with the twist ratio. The magnitude of heat transfer coefficient was not so much change with decreasing twist ratio and with increasing twist ratio. They take the Reynolds number range in between 1-10000 for flow. Reynolds number, are fitted in experimental data within ±15% and ±13% for Nusselt number and friction factor.

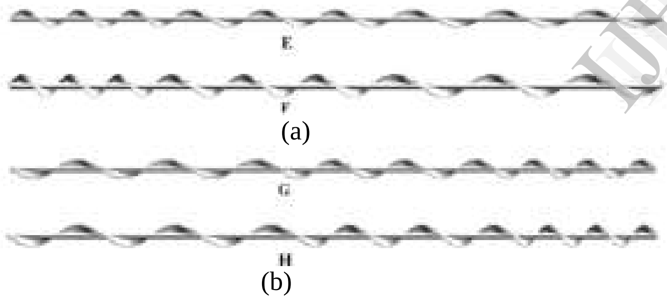

Figure [6]: (a) Helical screw inserts of increasing twist ratio. (b) Helical screw inserts decreasing twist ratio [13]

Alberto Garcia et al., [14] they did the experimental study on three wire coils which was the different pitch are inserted in the smooth tube in laminar and transition flows. The experimental study was performed for Heat transfer in the flow ranges of, Re=10–2500 and Pr = 200–700.They concluded that at below Re= 200, the insert wire coils was not enhanced the heat transfer. Vice versa for the Reynolds numbers range between 200-1000 wire coils insert increases the heat transfer. Similarly for the Reynolds number around 1000, wire inserts increased the heat transfer coefficient up to eight times as compare to the smooth tube. The friction factor increases in the fully laminar flow up to 5% to 40%.

M.J.Patel, et al., [15] they did the review on the Enhancement in Heat Exchanger using twisted tape Insert. They concluded that, if twisted tape insert made of Metallic wiry Sponge than it was helpful to increase the Rate of Heat transfer in tube. Similarly if twisted Tape with Spiral Section which had the largest surface and contact Area with fluid so it was increases the heat transfer rate.

Prabhakar Ray, Dr. Pradeep Kumar Jhinge [16] they did the review on heat transfer rate enhancement using wire coil inserts in tube. They concluded that by using Wire coiled tube it the increases the pressure drop compare with empty tube. If wire coil insert in transition and turbulent region flows it gives better results. In the transition flow region if wire coils are fitted in the smooth tube heat exchanger, than heat transfer rate can increased up to 200% if pumping power is constant. Similarly in turbulent flow region, wire coils causing a high pressure drop increase which are mainly depends on the pitch to wire diameter ratio. Vice versa if pressure drop is not taken under consideration; wire coil inserts are suitable for both laminar and turbulent regions. The wire coil inserts depends on the shapes of the inserts, the Wire coil inserts gives better overall performance when it are compared with a smooth tube maintained constant pumping power, especially at low Reynolds number range.

A. M. Mulla, et al., [17] they did the experimental study on heat transfer and friction factor characteristics flowing through laminar flow in tubes of shell and tube heat exchanger fitted with twisted tapes with baffles. They concluded that during the experimentations if heat exchangers operate under laminar flow condition at low flow rate, the twisted tapes with baffles are goes to increase the heat transfer coefficient and pressure drop. For the experimentation the twisted tapes inclination with baffles in are at 450 which is at normal axis of twisted tape. Which is fitted in heat exchanger, for the Reynolds number range from 200 -600. During the experimentation the result shows that the Nusselt number is increased for same flow rate in tubes with twisted tape with baffle as compared to plain tubes as well as tubes with typical twisted tapes. They obtained highest heat transfer coefficient for tubes fitted with twisted tape with baffle compared to the plain tubes as well as tubes with typical twisted tapes for same Reynolds number and for same flow rate. They also found that for higher Pressure drop value in twisted tape with baffle as compared to in plain tubes with typical twisted tapes for same flow rate and Reynolds number. And they finally conclude that using twisted tapes with baffles on tubes, the thermal performance of the shell and tube heat exchanger under the laminar conditions it can increased up to 150% - 160% as compare to plain tube.

Figure [7] shows twisted tapes with baffles [17]

A.V.Gawandare, et al., [18] they did the experimental investigation on heat transfer and friction factor characteristics of circular tube fitted with full-length square jagged twisted tape inserts having different twist ratios. The Reynolds number ranges from 5000 - 16000.they shows the result in variation of twisted ratios in Nusselt number v/s Reynolds number. They concluded that increase in Nusselt number in plain twisted tape inserts with the twist ratio of 5.2 was found to be 44 % and similarly for twist ratio 4.2, 3.2 it was found to be 82% and 154% respectively. The friction factor was increased for twist ratios 5.2 in square jagged twisted tape was found to be 12%, 27% and 51% respectively. They also concluded that the heat transfer increased up to 154% for 51% increase in friction factor, for less pumping power heat transfer rate can increase.

Figure [8.1] Copper square jagged twisted tape y=5.2 [18]

Figure [8.2] Copper square jagged twisted tape y=4.2 [18]

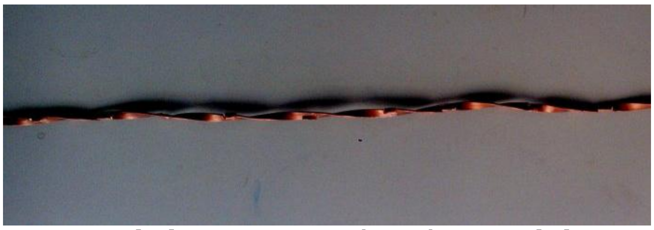

Figure [8.3] Copper square jagged twisted tape y=3.2 [18]

Jagpreet Singh, et al., [19] they did the experimental study on cconvective heat transfer characteristics on heat exchanger using twisted tapes different cuts shapes i.e. square, circular and triangular respectively and of different materials i.e. GI, Al and Cu are inside the inner tube of single unit on heat transfer and friction factor for heating of water for Reynolds number range 500-3000 was studied experimentally. They conclude that with maximum inlet and outlet, minimum temperature difference is observed in the pipe with Cu insert. This indicates that the average Nusselt number becomes higher for pipe with Cu insert as that of Al insert and without insert. They observed that with gradual change in the pressure drop in changes with Reynolds number. It was shows that dependency on temperature of fluid viscosity, and increasing contraction and expansion pressure losses in inlet and outlet of the pipe.

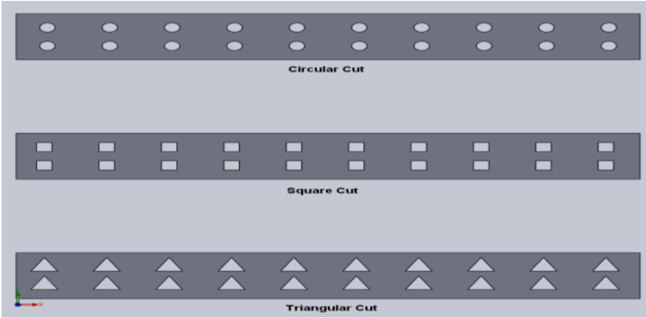

Figure [9] Different cuts on the inserts [19]

Prof. Rahul A. Lekurwale, et al., [20] had performs an assessment on heat exchanger tubes for improving the heat transfer rate in turbulent flows Using different Types of Twisted Tapes Inserts i.e. clock wise, counter clock wise and serrated twisted tapes and with three twist angles, θ=30°, 60° and 90° in a tube. They conducted the measurement on water with the Reynolds number from 4000-20000. After experimentations they conclude that or the results shows that the heat transfer rate as per Nusselt number increases with increase in depth ratio and decreases with raising the width ratio. The heat transfer rate is goes up to 72.2% and 27% relative to the plain tube. And the thermal performance factor of the serrated twisted tapes under constant pumping power was examine and found above unity which indicates that using serrated twisted tapes in tube was advantageous as compare to twisted tapes in tube or in plain tube. Similarly in clockwise and counter clockwise twisted tape performed during experimentation for over the range of Reynolds number under uniform heat flux condition, using water as flowing fluid. They also concluded that in the presence of novel an alternate clockwise and counter clockwise twisted, serrated twisted tape which shows the periodic change in swirl direction give a superior chaotic mixing to high turbulence flow for increasing the heat transfer rate compared with plane tube. And heat transfer enhancement performance factor for serrated twisted tape inserts which tends to increase with decreasing Reynolds number for types of tapes inserts.

Figure [10] Serrated twisted tape insert [20]

CONCLUSION

From this review, various ways of enhance the heat transfer rate by generating the swirl flow by passive method can be observed by using various types of inserts. In perforated twisted tape inserts, heat transfer rate increases hence, heat transfer coefficient increases with decreases in pressure drop. In a perforated twisted tape inserts, the friction factor increases in the laminar region and increase the heat transfer coefficient as compares to without perforated twisted tape inserts. In most of the review, nanofluid are not used for examine the heat transfer rate in heat exchanging device. The examination was done in perforated twisted tape insert either in thermal analyses, flow visualization, in heat exchangers, etc... The comprehensive study had been done on heat transfer in heat exchanger using various types of twisted tape inserts. They concluded the twisted tape inserts perform better in laminar flow than turbulent flow. The review shows that in future the inserts are most desirable function for heat transfer enhancement in various applications. We conclude that from the review if we use nanofluid for heat transfer enhancement with inserts heat transfer rate increases up to four times than that of without using nanofluid.

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