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Experimental Investigation in the Enhancement of Heat Transfer Rate Using Twisted Tape Turbulators in Heat Exchangers: A Review

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Abstract

Enhancing heat transfer surface are used in many engineering applications such as heat exchanger, air conditioning, chemical reactor and refrigeration systems, hence many techniques have been investigated on enhancement of heat transfer rate and decrease the size and cost of the involving equipment especially in heat exchangers. One of the most promising techniques used are passive heat transfer technique. These techniques when adopted in Heat exchanger proved that the overall thermal performance was improved significantly. One of the most acclaimed method to improve the heat transfer rate is to insert the twisted tape turbulators in the heat exchangers. When these turbulators are placed in the path of the flow of the liquid, creates a high degree of turbulence resulting in an increase in the heat transfer rate and the pressure drop. So as to elucidate the useful findings an attempt has been made to review various turbulators that are used to enhance the heat transfer rate. From the various researchers we observe that the twisted tape inserts give more heat transfer rate with reasonable friction factor as compared to the plain tube.

Keywords: *Heat Exchanger, Twisted Tape heat transfer rate, turbulators, pressure drop, friction factor.*

1. Introduction

Heat exchangers are devices that can be used to transfer heat from a fluid stream (liquid or gas) to another fluid at different temperatures. Heat Exchanger is a device in which the exchange of energy takes place between two fluids at different temperature. A heat exchanger utilizes the fact that, where ever there is a temperature difference, flow of energy occurs. So, that heat will flow from higher temperature heat reservoir to the lower temperature heat reservoir. The flowing fluids provide the necessary temperature difference and thus force the energy to flow between them. Heat exchangers are used in different processes ranging from conversion, utilization & recovery of thermal energy in various industrial, commercial & domestic applications. These include power production, process, chemical and food industries, electronics, environmental engineering, and waste heat recovery, manufacturing industries and air conditioning, refrigeration and space applications. Examples of heat exchangers that can be found in all homes are heating radiators, the coils on your refrigerator and room air conditioner and the hot water tank. The development of high performance thermal systems has stimulated interest in methods to improve heat transfer. The study of improved heat transfer is referred to as heat transfer enhancement, augmentation or intensification. The performance of conventional heat exchanger can be substantially improved by a number of enhancement techniques. A great deal of research effort has been devoted to developing apparatus and performing experiments to define the conditions under which an enhancement technique will improve heat transfer. Heat transfer enhancement technology has been widely applied to heat exchanger applications in refrigeration, automobile, process industries etc. The goal of enhanced heat transfer is to encourage or accommodate high heat fluxes. This result in reduction of heat exchanger size, which generally leads to less capital cost. Another advantage is the reduction of temperature driving force, which reduces the entropy generation and increases the second law efficiency. In addition, the heat transfer enhancement enables heat exchangers to operate at smaller velocity, but still achieve the same or even higher heat transfer coefficient. This means that a reduction of pressure drop, corresponding to less operating cost, may be achieved. All these advantages have made heat transfer enhancement technology attractive in heat exchanger applications. For shell and tube heat exchangers, the tube insert technology is one of the most common heat transfer enhancement technologies,

particularly for the retrofit situation. With tube insert technology, additional exchangers can often be avoided and thus significant cost saving becomes possible.
Furthermore as a heat exchanger becomes older, the resistance to heat transfer increases owing to fouling or scaling. These problems are more common for heat exchangers used in chemical industries and marine applications. In this case the heat transfer rate can be improved by introducing a disturbance in the fluid flow by different enhancement technologies (breaking the viscous and thermal boundary layer). In this projects, a review of heat transfer enhancement tool i.e. Inserting Twisted Tape Turbulaters is done, for laminar and turbulent flow. Since it is most commonly used enhancement tool.

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2. Augmentation Techniques of Heat Transfer: Twisted Tape Insert

The augmentation techniques of heat transfer are widely applied to improving the performance of heat exchangers in chemical industries and air conditioning systems to reduce the size and costs of the heat exchangers, these techniques are classified as active and passive techniques. The active techniques require external forces, e.g. electric field, surface vibration or Jet impingement. The passive techniques require special surface geometries or swirl/vortex flow devices. Many of experimental works on heat transfer augmentation using twisted tape as swirl/vortex flow devices have been reported in the literature.

3. Different Techniques used for Heat Transfer Enhancement

Heat transfer enhancement or augmentation techniques refer to the improvement of thermo hydraulic performance of heat exchangers. Existing enhancement techniques can be broadly classified into three different categories:

3.1 Active Techniques: These techniques are more complex from the use and design point of view as the method requires some external power input to cause the desired flow modification and improvement in the rate of heat transfer. It finds limited application because of the need of external power in many practical applications.

3.2 Passive Techniques: These techniques do not require any direct input of external power; rather they use it from the system itself which ultimately leads to an increase in fluid pressure drop. They generally use surface or geometrical modifications to the flow channel by incorporating inserts or additional devices. They promote higher heat transfer coefficients by disturbing or altering the existing flow behavior except for extended surfaces.

3.3 Compound Techniques: When any two or more of these techniques are employed simultaneously to obtain enhancement in heat transfer that is greater than that produced by either of them when used individually, is termed as compound enhancement.

4. Design Consideration

4.1. Boundary layer effect

In order to increase the heat transfer, the techniques must affect the boundary layer (laminar and buffer layers) by reducing its thickness, or increasing its surface area, or increasing the turbulence. The boundary layer thickness may be reduced by fitting protuberances to the heat transfer surface. These interrupt the fluid flow so that a thick boundary layer cannot form. Alternatively a boundary layer thickness may be reduced by imparting a rotational motion to a fluid flowing inside a tube. The boundary layer surface area may be increased by extending the surface with fins, spines, coils and strips, etc. The turbulence may be increased on the internal and external surfaces by artificial roughening, or using special devices inside tubes known as turbulence promoters.

4.2. Relative thickness of the thermal and momentum boundary layers

The thickness of the momentum and thermal boundary layer are not necessarily the same. For many fluids the viscous boundary layer is thicker than the thermal boundary layer. Liquid metals are notable exceptions to this rule. The relationship is generally expressed in a dimensionless group called the pandtl number, after the great German physicist Ludwig Prandtl. The Prandtl Number Pr is defined simply as the ratio $Pr = \nu/ά$ where; ν = Kinematic viscosity of fluid $ά$ = Thermal diffusivity of fluid. The kinematic viscosity is indicative of the rate at which momentum diffuses through a fluid because of molecular motion. The thermal diffusivity is indicative of the rate of diffusion of heat in the fluid. The ratio of these quantities is therefore a measure of the relative magnitudes of diffusion of momentum and heat in the fluid. These diffusion rates are precisely the quantities that determine how the thick boundary layer will be for a given flow: large diffusivity means that viscous or temperature effects are expressed further out in the flow.

The Prandtl number is therefore correction between the velocity field and the temperature field. Now

$$\nu = \mu/\rho \text{ and } \acute{\alpha} = k/(\rho\, Cp)$$

Then $$P_r = \nu/\acute{\alpha} = Cp\,\mu / k$$

The common values of $0.7 < P_r < 1$ for many gases is striking. Also many liquids, apparently dissimilar have a P_r in range 2 to 4.

4.3. Heat transfer coefficient

The rate of heat transferred q can be calculated very simply from the equation

$$Q = h\,A\,(Tw - T\,\infty) \quad (1)$$

Where, q = rate of heat6 transferred

h = convective heat transfer coefficient

A = contact area for heat transfer between fluid and wall

T_w = wall temperature

T_∞ = Fluid free stream temperature.

It is both convenient and conventional to express the heat transfer in terms of yet another dimensionless group, the Nusselt number Nu, after Wilhelm Nusselt, another noted German engineer and scientist active in developing the science of heat transfer in the 1930s. The Nusselt number is composed of three elements:

$$Nu_x = h.x/k \quad (2)$$

For Laminar flow in tube

$$Nu_d = hd_o/k \quad (3)$$

For turbulent flow in smooth tube

$$Nu = 0.023\, Re^{0.8}\, P_r^{\,n} \quad (4)$$

4.4. Pressure drop

Pressure drop inside circular tube is given by fanning equation

$$\Delta p = 4fLV^2 \quad (5)$$

5. Experimental Procedure

It is essential to have calibrated instrument in order to get the good experimental results. The heat exchanger special designed for this work was calibrated and was tested for heat balance. It was found that approximate 2 to 5 % error was found in heat load of hot fluid and cold fluid side of heat exchanger.

The set-up consisted of:

1. An oil tank with heater of 0.64m^3 capacity placed on floor.
2. An overhead water tank (0.5m^3 capacity located at an elevation of 2.75 meters).
3. A double pipe u bend heat exchanger.
4. Measuring devices like Rotameter, temperature indicator, pressure gauge.

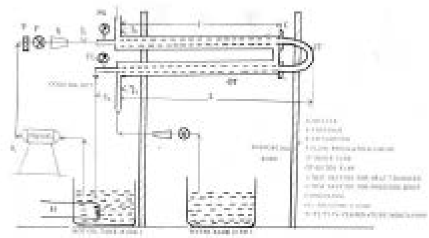

Fig.1. Experimental setup for Double pipe Heat Exchanger.

First the plain tube double pipe heat exchanger (i.e. without tabulator) was tested. At the beginning of series of tests, the hot oil was circulated through inner tube and cooling water through annulus tube in counter flow configuration. The air was bled at various locations. The flow rate of water was fixed to 15 lit/min. The cooling water coming in heat exchanger is at room temperature. First the oil flow rate was fixed to 2 lit/min. a prescribed heat input was given to the oil in tank and steady state was allow. Once the steady state was reached the flow rate of hot and cold fluid, temperature reading at inlet and outlet section of hot and cold fluid and bourdon pressure tube readings were taken. The series of readings up to steady state are shown in table. The flow rate of cold water was kept constant and above procedure was repeated for different flow rate of hot fluid viz. 4,8,12,18,24,30 (lit/min) one after other.

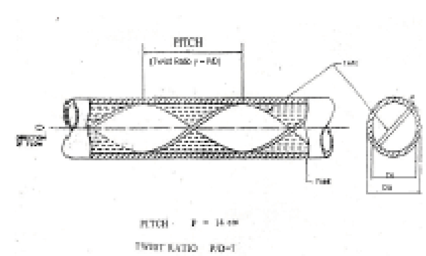

Fig.2 Twisted tape inside a circular tube.

After completing the test with plain heat exchanger (i.e. without turbulator), the u bend double pipe heat exchanger was removed from loop. Then twisted tape-1 of pitch = 15 cm was inserted into the both straight legs (4m each) of the u – tube. The tape was inserted from one side and pulled from other end by thread or thin wire. Then the heat exchanger was connected in loop. The same experimental procedure was repeated with two sets of twisted tape inserts. Throughout the experimental work the hot transformer oil was circulated inside tube and cold oil through annulus in counter flow arrangement.

6. Literature Review

S. Naga Sarada, A.V. Sita Rama Raju1, K. Kalyani Radha L. Shyam Sunder [1] experimental investigated the augmentation of turbulent flow heat transfer in a horizontal tube by means of varying width twisted tape inserts with air as the working fluid. In order to reduce excessive pressure drops associated with full width twisted tape inserts, with less corresponding reduction in heat transfer coefficients, reduced width twisted tapes of widths ranging from 10 mm to 22 mm, which are lower than the tube inside diameter of 27.5 mm are used. Experiments were carried out for plain tube with/without twisted tape insert at constant wall heat flux and different mass flow rates. The twisted tapes are of three different twist ratios (3, 4 and 5) each with five different widths (26-full width, 22, 18, 14 and 10 mm) respectively. The Reynolds number varied from 6000 to 13500. Both heat transfer coefficient and pressure drop are calculated and the results are compared with those of plain tube. The following conclusion can be drawn from their work:

The enhancement of heat transfer with twisted tape inserts as compared to plain tube varied from 36 to 48% for full width and 33 to 39% for reduced width-22 mm inserts. This enhancement is mainly due to the centrifugal forces resulting from the spiral motion of the fluid. Reduction in tape width causes reduction in Nusselt numbers as well as friction factors. The maximum friction factor rise was about 18% for 26mm and only 17.3% for reduced width inserts compared to plain tube.

The over all enhancement ratio of the tubes with full width twisted tape inserts is 1.62 for full width–26mm and 1.39 for reduced width-22mm twisted tape insert. 61% material savings could be obtained for reduced width-22 mm and the performance is 1.32–1.39 times compared to plain tube. Nusselt numbers decreased by a maximum of 8% and 29%, for tape widths of 22 and 10 mm, respectively compared to full width twisted tape inserts. The present work is comparable with the experimental results obtained by (Patil, 2000) on laminar flow heat transfer enhancement using reduced width twisted tape inserts Correlations for the heat transfer coefficient and friction factor are proposed based on the present experimental data. The agreement between the results obtained from the experimental and those obtained from the proposed correlations is reasonable.

Thus the same performance can be achieved using reduced width tapes with 15% material saving at higher Reynolds number and/or lower twist ratios. Even for 61% material savings twisted tapes (of width 10.0 mm) the performance is 1.08–1.18 times better than for a smooth tube. Thus, from the considerations of enhanced heat transfer and savings in pumping power and in tape material cost, reduced-width tape inserts are seen to be attractive for enhancing turbulent flow heat transfer in a horizontal circular tube.

Jagpreet Singh, Ashwani Kumar, Satbir Singh Sehgal [2] investigated experimentally Convective heat transfer characteristics within a heat exchanger with twisted tapes of different cuts and materials. Effect of twisted tape of different cuts (square, circular and triangular) 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. The results obtained from the twisted inserts of GI, Al and Cu materials are compared and the experimental results reveal that the among the three different materials of inserts, Copper inserts performs better and too with square cuts. The following conclusions can be drawn from this study:

The maximum inlet and outlet minimum temperature difference is obtained in the pipe having Cu insert. This indicates that for a given constant heat input, the average Nusselt number becomes higher for pipe having Cu as insert followed by that for Al and without insert. There is a gradual change in the pressure drop variation with Reynolds number. This is attributed to the temperature dependence of fluid viscosity, and the increasing contraction and expansion pressure losses at the inlet and outlet of the pipe, respectively. It was observed that as the Reynolds number increases from 930.74 to 2792.19, the drop in hot water outlet temperature w.r.t. inlet temperature decreases due to less retention time of the fluid within the pipe.

P.K.Nagarajan, Nitesh Mittal, Rohit Chechani [3] Experimental investigated the heat transfer and friction factor characteristics of solar parabolic trough collector fitted with full length twisted tapes inserts of twist ratio 6, 8 and 10. The transitional flow regime is selected for this study with the Reynolds number range 1192 to 2534. The experimental data obtained were compared with those obtained from plain tube published data. The effects of full length twisted tape inserts on heat transfer and friction factor were presented. The heat transfer coefficient enhancement for twisted inserts is higher than that for plain

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tube for a given Reynolds number. The use of twisted inserts improved the performance of solar trough collector.

The heat transfer enhancement increases with decrease in twist ratio due to increased turbulence of water. It is due to the swirl flow motion provided by twisted tapes. The friction factor increases with the decrease of twist ratio again due to swirl flow exerted by the twisted tape. The lower the twist ratio performs much better than the higher twist ratio inserts. The enhancement of Nusselt number is much higher than that of enhancement in friction factor for the same twist ratio that justifies the usage of twisted tape in the solar parabolic trough collector. The performance of conventional solar parabolic trough collector can be improved by the use of twisted tape. The cost involved for manufacturing and inserting twisted tape is very minimal compared to energy efficiency improvement provided by these inserts.

Anil Singh Yadav [4] studied experimentally the influences of the half length twisted tape insertion on heat transfer and pressure drop characteristics in a U-bend double pipe heat exchanger. In the experiments, the swirling flow was introduced by using half-length twisted tape placed inside the inner test tube of the heat exchanger. The results obtained from the heat exchangers with twisted tape insert are compared with those without twisted tape i.e. Plain heat exchanger. The experimental results revealed that the increase in heat transfer rate of the twisted-tape inserts is found to be strongly influenced by tape-induced swirl or vortex motion. The heat transfer coefficient is found to increase by 40% with half-length twisted tape inserts when compared with plain heat exchanger. It was found that on the basis of equal mass flow rate, the heat transfer performance of half-length twisted tape is better than plain heat exchanger, and on the basis of unit pressure drop the heat transfer performance of smooth tube is better than half-length twisted tape. It is also observed that the thermal performance of Plain heat exchanger is better than half length twisted tape by 1.3-1.5 times.

From the present investigation on double pipe heat exchanger with and without twisted tapes inserts at different mass flow rate of oil, it was found that:

As compared to conventional heat exchanger, the augmented (with turbulator) heat exchanger has shown a significant improvement in heat transfer coefficient by 40% for half-length twisted tape.

MaheshkumarJ.Patel, K.S.Parmar, U. R. Soni [5] carried out the experiment in order to Improve the Performance of Heat Exchanger: Twisted Tape Insert With Metallic Wiry Sponge. They worked on Double tube type Heat Exchanger and resulting in it has been observed that the twisted tape insert with metallic wiry sponge gives more heat transfer as compared to the plain tube and twisted tape insert in the counter flow heat exchanger. And they got the results From the experiment they observed that Nu and overall heat transfer coefficient U was increase with respect to increase in Reynolds Number and friction factor was decreased with respect to Reynolds Number. Maximum Nusselt Number has been observed in the experiment by twisted tape insert with metallic wiry sponge. Large difference in Nusselt Number has been observed in between plain tube and with twisted tape insert in heat exchanger. Nu for twisted tape insert with metallic wiry sponge and twisted tape was high respectively as compared to plain tube. Also very small difference of friction factor has been observed between twisted tape and twisted tape with sponge inserts at higher Reynolds number. So that, from this experiment it has been observed that the twisted tape insert with metallic wiry sponge gives more heat transfer as compared to the plain tube and twisted tape insert in the counter flow heat exchanger.

Watcharin Noothong, Smith Eiamsa-ard [6] Influences of the twisted tape insertion on heat transfer and flow friction characteristics in a concentric double pipe heat exchanger have been studied experimentally with different twist ratios, y = 5.0 and 7.0. The enhancement efficiency and Nusselt number increases with decreasing the twist ratio and friction factor also increases with decreasing the twist ratio. The partitioning and blockage of the tube flow cross-section by the tape, resulting in higher flow velocities. Secondary fluid motion swirl is generated by the tape twist, and the resulting twist mixing improves the convection heat transfer.

Kumbhar D.G. Dr. Sane N.K. presented [4] a review paper on Heat Transfer Enhancement in a Circular Tube Twisted with Swirl Generator**.**The authors stated that a twisted tape insert mixes the bulk flow well and therefore performs better in laminar flow, because in laminar flow the thermal resistant is not limited to a thin region. The result also shows twisted tape insert is more effective, if no pressure drop penalty is considered. Twisted tape in turbulent flow is effective up to a certain Reynolds number range. It is also concluded that twisted tape insert is not effective in turbulent flow, because it blocks the flow and therefore pressure drop increases. Hence the thermo hydraulic performance of a twisted tape is not good in turbulent flow. These conclusions are very useful for the application of heat transfer enhancement in heat exchanger networks.

C.Nithiyesh Kumar, P.Murugesan [7] has a review paper on Review on Twisted Tapes Heat Transfer Enhancement

This review has considered heat transfer and pressure drop investigations of the various twisted tape placed in heat exchangers. A twisted tape and modified twisted tape inserts mixes the bulk flow well and therefore performs better in laminar flow, because in laminar flow the thermal resistant is not limited to a thin region. The result also shows twisted tape insert is more effective in laminar flow, and pressure drop penalty is created during turbulent flow.

S.D.Patil [8] refers different methods of Heat transfer augmentation techniques used to increase rate of heat transfer without affecting much the overall performance of the system. These techniques broadly are of three types viz. passive, active and compound techniques. In this review they work on the passive augmentation techniques used in the recent past. From this review they found that twisted tape insert mixes the bulk flow well and therefore performs better in laminar flow. Because of laminar flow Thermal resistant was not limited to a thin region. The result also shows twisted tape insert is more effective, if no pressure drop penalty is considered. They also concluded that twisted tape insert is not effective in turbulent flow, because it blocks the flow and therefore pressure drop increases. Hence the thermo hydraulic performance of a twisted tape is not good in turbulent flow.

Bodius Salam [9] Work on Heat Transfer Improvement in Tube with Twisted Tape Insert. An Experimental investigation was carried for measuring tube side heat transfer coefficient of water for turbulent flow in a circular tube fitted with twisted tape insert. A stainless steel twisted tape insert of 5.3 twist ratio was inserted into the smooth tube. A uniform heat flux condition was maintained by wrapping Nichrome wire around the test section and fibre glass over the wire. Outer surface temperatures of the tube were measured at 5 different points of the test section by T-type thermocouples. At the outlet section the thermometer was placed in a mixing chamber. The Reynolds numbers were varied in the range 9500-20000 with heat flux variation 9 to 18 kW/m^2 for smooth tube, and 15 to 31kW/m^2 for tube with insert. Nusselt numbers obtained from smooth tube were compared with Dittus and Boelter correlation and error were found to be in the range of -13% to 18% with r.m.s. value of 12%. At comparable Reynolds number, Nusselt number in tube with twisted tape insert was enhanced by 2.9 to 4 times compared to that of smooth tube.

7. Conclusions

- This paper reviews the investigation carried out by various investigators in order to enhance the heat transfer by use of different types of turbulators.
- Use of turbulators of different types is found to be the most effective technique to enhance the heat transfer rate in the double pipe heat exchangers.
- The conclusions of above investigations are very useful for the application of heat transfer enhancement in heat exchangers.

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