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# CFD analysis on heat transfer enhancement and pressure drop reduction in tube fitted with rectangular cut twisted tapes

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***Abstract*** — Augmenting the rate of heat transfer is a major concern for the manufacturers of heat exchangers. There are basically two methods available for enhancing the rate of heat transfer like passive and active methods, among these methods passive methods are preferred for enhancing the heat transfer. This is because; passive method of heat transfer does not require any external source of energy input. In this paper, a circular pipe of 10 mm outer diameter, 9.2 mm inner diameter and a length of 2300 mm is considered for the analysis of heat transfer and pressure drop by placing a full length twisted tape (having rectangular cuts on both sides of the twists) along the flow passage. The circular pipe is subjected to constant heat flux of 15000 W/m$^2$. The heat transfer fluid (HTF) considered for the analysis is water and its inlet temperature was maintained constant as 288K. The outlet temperature of HTF is determined for various Reynolds numbers ranging from 4500 to 10,000. The drafting and modelling of the geometry was done using solid works 2013, meshing was done using ICEM-CFD 14.5. The analysis was carried out using FLUENT 14.5. The results obtained shows an increase in convective heat transfer coefficient and rate of heat transfer for the heat exchanger provided with rectangular cut twisted tapes than plain tube heat exchanger. The pressure drop across the heat exchanger for twisted tape with rectangular cut is higher than the plain tube heat exchanger. This increase in rate of heat transfer is due to the introduction of secondary swirl flow (due to twisted tape) along with the primary flow. The presence of twisted tape (TT) in the flow passage increases the flow length, residence time of the fluid in the flow passage, disturbance in the boundary layer and also the turbulence, all the above said factors cumulatively resulted in increased rate of heat transfer.

***Keywords***— Heat transfer augmentation, Twisted tapes, CFD analysis, Passive heat transfer enhancement.

## I. Introduction

Tubular heat exchangers (HX) are devices which transfer thermal energy from hotfluid to a cold fluid by means of conduction (within the pipe wall) and by convection on both sides of the heat exchanger pipeline. The enhancement of heat transfer in a thermal energy system can be achieved by increasing the effectiveness of the HX. Process industries concentrate on various ways of enhancing the rate of heat transfer in order to reduce the period of operation of the processes, cost involved and size of heat exchanger. Primarily there are three ways available,to augment the rate of heat transfer in a tubular heat exchanger viz., active method, passive methods and combined method. In an active method, the heat transfer augmentation is achieved using an external power source. This method uses devices like stirrer, vibrator, electrostatic field to the flowing fluids, and jet.Predominantly passive method of heat transfer enhancement is used, since it does not require any external power source. The various techniques used in this method are surface coating, surface roughness, special geometries, wire coil insert, swirl generators, serpentine heat exchanger, surface tension devices, additives etc., The advantages of providing twisted tapes (TT) in the flow path are ease of manufacturability, setting up, low cost and steady performance. The combined method of heat transfer enhancement uses both active and passive methods. The genesis of heat exchangers over the period of time with reference to heat transfer augmentation is provided in the Table 1.

Table 1 Heat Exchanger Generations

| **Generation** | **Geometry / Technique** |
|---|---|
| First Generation | Plain tube |
| Second Generation | Plain tubes with fins / roughness |
| Third Generation | Tubes with vortex generators |
| Fourth Generation | Tubes with fins and electrostatic fields<br>(or)<br>Tubes with vortex generators with electrostatic fields |

The generally used different types of twisted tapes used are Plain TT, Full length TT, Short length TT, Square cut TT, Rectangular cut TT, V cut TT, Single swirl flow TT, Co- swirl flow TT and Counter-swirl flow TT. However many profiles of the TT are possible and out imagination is the limit for this. According to L. Léal et al [1], the projection of a high speed fluid towards a surface increases the convective heat transfer coefficient by breaking the boundary layer and mixing the fluid near the surface.

A novel method was proposed to enhance the rate of heat transfer using the flow-induced vibration of a newly designed heat transfer device by L Cheng et al [2]. They developed a

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correlation for the shell-side convective heat transfer coefficient by studying the vibration and the heat transfer of these devices both numerically and experimentally.This newly designed heat exchanger significantly increased the convective heat transfer coefficient and decreased the fouling resistance.

B. Tajik et al [3] introduced sound waves along with the fluid stream and enhanced rate heat transfer in a closed cylindrical tube filled with water on a down-ward-facing horizontal heating surface and applied constant heat flux. The heat transfer enhancement was achieved due to vibrations of the flow passage by introducing the acoustic waves. The results showed that the enhancement of the heat transfer between the heating source and the bulk water near the vibrating plate was up to 390% with the acoustic streaming generated by the ultrasonic vibrations. Murugesan et al, [4] has studied on turbulent heat transfer and pressure drop in a tube fitted with square cut twisted tape. They found that, Nusselt number and friction factor values of TT with square cut are considerably more than that of plain tube HX and HX tube fitted with plain twisted tape. In an another study on heat transfer and pressure drop in a circular tube fitted with and without V-cut twisted tape insert, The results revealed that there was an improvement in friction factor, thermal performance, and heat transfer rate than plain twisted tape. In the case of V cut TT, the depth ratio was more dominant than breadth ratio for all cases of Reynolds number.

O. Zeitoun and A. S. Hegazy [5] analysed heat transfer in a circular pipe provided with internal longitudinal fins, when subjected toconstant wall temperature under laminar flow. The fins were arranged in two groups of different heights. The results obtained for different pipe-fins geometries showed that the fin heights affect greatly the flow and heat transfer characteristics. S K Saha et al [6] studied the laminar swirl flow generated inside a circular tube fitted with TT. They reported on friction factor and Nusselt number for a large Prandtl number (205<Pr>518). It was observed that, for constant pumping power, short-length TT are good choice because in that case the swirl generated by the TT deteriorated slowly along the downstream of the flow and increased the heat transfer coefficient with minimum pressure drop, as compared with a full-length TT. Tariq et al [7] found that in a laminar flow the introduction of turbulent generators like internal thread are not efficient compared to a TT insert.

Manglik and Bergles [8] considered flow rate and geometry of TT and found that the enhancement of heat transfer is due to the tube partitioning, flow blockage, the large flow path and secondary fluid circulation. They developed correlations for the friction factor and Nusselt number, including the swirl parameter for constant wall temperature. The heat transfer correlation as proposed by them is

$$Nu = 4.162[6.413\text{x}10^{-9}(SW\,\text{Pr}^{0.391})^{3.385}]^{0.2}\left(\frac{\mu}{\mu_w}\right)^{0.14}$$

where SW is the swirl parameter and is defined as $SW = \frac{\text{Re}}{\sqrt{Y}}$.

Considering the overall enhancement ratio, twisted tape is effective for small Prandtl number fluids and wire coil is effective for high Prandtl number fluids (Pr> 30), as discussed by Wang and Sunden [9].

Lokanath [10] represented experimental data on laminar flow of water through a horizontal tube under uniform heat flux condition and fitted with half-length TT. He found that, on the basis of unit pressure drop and unit pumping power, half-length tapes are more effective than full-length tapes. The creation of swirl in the flow due to the presence of TT decreases the ratio of maximum velocity to mean velocity in a tube compared to a straight flow (i.e. without a twisted tape). This creates a centrifugal force and aids convective heat transfer according to Kreith.F and Margolis,D [11].

Short-length twisted tapes (25 – 45 per cent of the tube length) performed better than full-length TT according to Klaczak A [12]. Chou Xie Tan et al [13] empirically investigated the heat transfer enhancement in a tube fitted with a square-cut circular ring insert in the transitional and the fully turbulent flow regimes. The findings show the incorporation of insert in the flow passage enhances the heat transfer rate, the characteristics of the flow in the transitional and the fully turbulent flow regimes induced by the effect of insert are distinct.

## II. MODELLING OF A TUBE FITTED WITH RECTANGULAR CUT TT.

The thermo-hydraulic analysis of fluid flow through a circular tube equipped with rectangular cut twisted tape was carried out by following the below mentioned methodology.


Figure 1 Flow Chart of Methodology

The circular pipe is of 10 mm outer diameter and 0.4 mm thick and of 2300 mm long. The twisted tape was placed in the flow passage in order to create swirl in the flow. The pitch of the twisted tape is of 25 mm and the width is 7.7 mm, and the twist ratio is 3.426. The drafting and assembly of the geometry under study was done using *Solidworks* 2013 software. The modelling of the geometry was also done in *Solidworks* software. The modelled geometry was exported to ICEM CFD 14.5 in parasolid (X_T) format. The dimensions of the geometry and its modelling are represented in Figures 2 and 3.

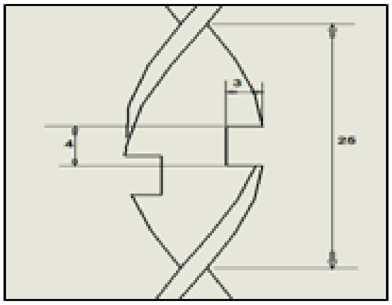


Figure 2 Dimensions of the twist

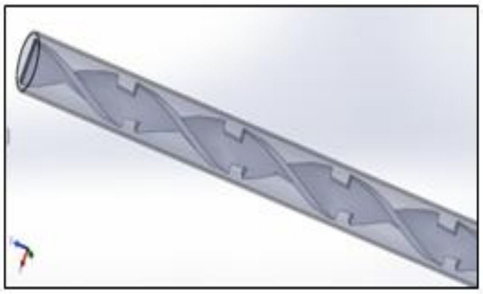


Figure 3 Modelling of the geometry

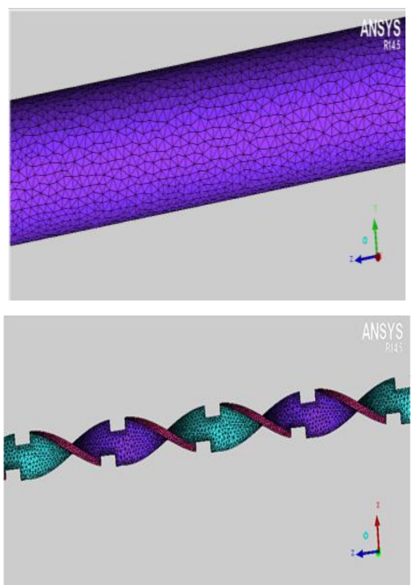


Figure 4 Meshing of the tube twisted tape

The meshing of the geometry was done using ICEM CFD software, tetrahedral volume mesh was used for the liquid and solid geometries. The fluid near the tube wall was meshed using prism mesh. The total number of elements of the geometry was 5086490. The meshed file was the imported using MSH formatinto the FLUENT 14.5 software for performing the analysis. The computational analysis was initially carried out for the heat exchange tube without any inserts in its flow passage. The heat exchange tube containing water as the working fluid was subjected to constant heat flux of 15000 W/m$^2$ on its outer surface for different flow rates. The parameters like outlet water temperature, outlet pressure, and convective heat transfer coefficient were determined. Similar analysis was also done for the heat exchange tube provided with twisted tape containing rectangular cut. The rectangular cut was made on both sides of the twist. The dimension of the rectangular cut is 4 mm X 3 mm and the thickness of the TT is 1.5 mm. The boundary conditions applied for the analysis are,

Heat flux on outer surface = 15000 W/m2
Inlet Temperature = 288K
Type of surface = Smooth
Density of fluid = 1000 kg/m$^3$
Reynolds number = 4800, 5900, 7000,8100 and 9200
Coefficient of friction = 0.00114
Tube material = Steel
Twisted tape material = Aluminium
Fluid = Water (liquid)

## III. COMPUTATIONAL ANALYSIS

The modelled and meshed geometry was analysed for the following different cases of flow.

Table 2 Different cases of computational analysis

| | | Reynolds Number | | | | |
|---|---|---|---|---|---|---|
| | | 4800 | 5900 | 7000 | 8100 | 9200 |
| Geometry | Plain Tube | √ | √ | √ | √ | √ |
| | Rectangular Cut TT | √ | √ | √ | √ | √ |

The sample outputs obtained from the computational analysis are listed below in the Figures 7 – 14.

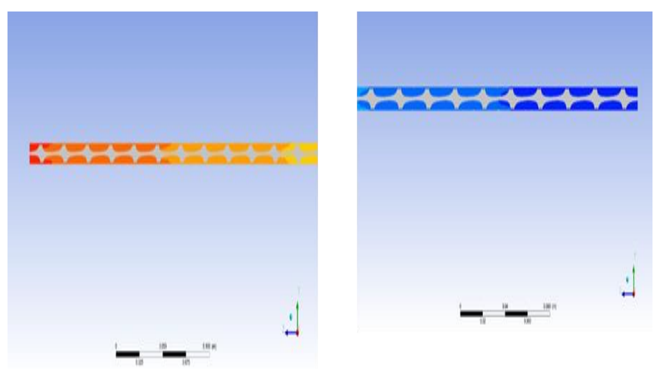


Figure 7 Pressure at the inlet section

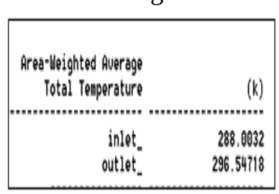



Figure 13 Sample output – Outlet temperature (with TT)

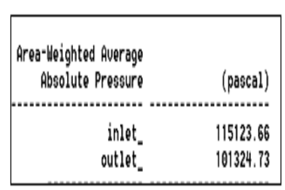



Figure 14 Sample output – Outlet pressure (with TT)

## IV. RESULTS AND DISCUSSIONS

The results obtained from the computational analysis for the different cases of turbulent fluid flow through the tube fitted with and without twisted tapes are plotted. The computational results obtained for the Nusselt was validated with the analytical Nusselt number suggested by Bodius Salam et al[14]. The variations of Nusselt number, heat transfer coefficient, pressure drop with 'Re' are depicted in the figures 15 -17. The comparison between computational and analytical Nusselt numbers is illustrated in Figure 18.From Figures 15 and 16, it is inferred that, the rate of heat transfer for the tube fitted with rectangular cut TT is more than the plain tube, since the heat transfer coefficient and Nusselt number are higher for the tube fitted with rectangular cut TT. The pressure drop for the tube fitted with rectangular cut TT is relatively more than the plain heat exchange tube, this is evident from the fact that, in the passive method of heat transfer enhancement pressure energy is sacrificed for augmenting the heat transfer.

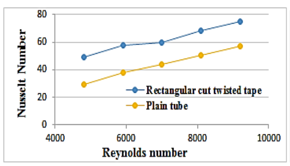



Figure 15 Variation of Nu with Re

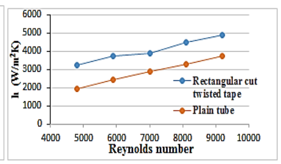



Figure 16 Variation of 'h' with Re

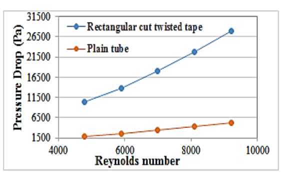



Figure 17 Variation of ΔP with Re

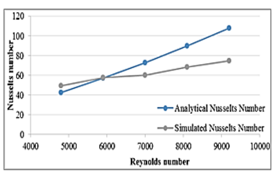
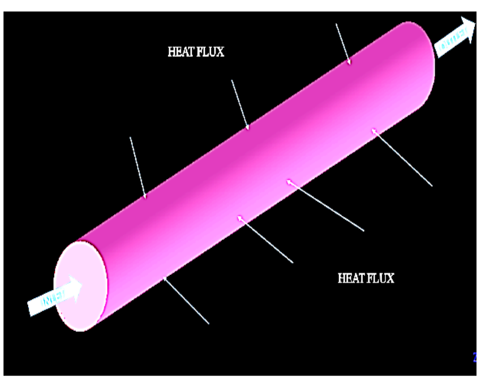



Figure 18 Comparison of computational and analytical Nu




From Figure 17, the pressure drop along the flow passage increases as the Reynolds number increases for both the cases of heat exchange tube. The comparison between the analytical and computational Nusselt numbers shows the computational results obtained are in good agreement with the analytical results for low Reynolds number flows. The computational results are deviating with the analytical results at high Reynolds number flow. The purpose of providing cut in the profile of the TT is to reduce the pressure drop, this reduction in pressure can be seen, if the comparison is made between tubes having TT with and without cut.

## V. CONCLUSION

Thus the computational results obtained indicate that the rate of heat transfer along and the pressure drop along tube fitted with rectangular cut twisted tape is higher than plain tube. The insertion of the TT in the flow passage results in creation of swirl along with normal flow. This swirl created increased the turbulence, flow length of the fluid flow, time of exposure of the fluid to the heat flux, resulting augmented rate of heat transfer. The laminar sub layer in the turbulent flow is considered as a barrier for the heat transfer, this has been disturbed due to the insertion of TT, and thermal barrier was overcome.

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