# CFD ANALYSIS ON HEAT TRANSFER ENHANCEMENT IN HORIZONTAL TUBE EQUIPPED WITH MODIFIED CLASSIC TWISTED TAPE INSERTS

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***Abstract:*** This paper reports computational fluid dynamics analysis on the friction factor, Nusselt number and thermal-hydraulic performance of a tube equipped with the modified classic twisted tape inserts 1)Classic twisted tape with triangular holes 2) Classic twisted tape square holes 3) Classic twisted tape with nails. The results showed that the Nusselt number and performance of the modified classic twisted tape insert with nails were higher than other ones. A maximum increase of 12.5% and 10.6% were observed in the calculated Nusselt number and performance of the classic twisted tape insert with nails as compared with those obtained for the classic ones. The higher turbulence intensity of the fluid which is near to tube wall has been expressed as the main reason for observations.

***Index Terms*** **- Reynold's number, Friction factor, Nusselt number, Turbulent flow.**

## I. INTRODUCTION

Conventional resources are decreasing day by day with a high rate, which makes the utilization of conventional sources are difficult. As a result, more importance is given to the development of various heat transfer surfaces. Normally the augmentation heat flow techniques could be classified into three methods described as follows:

- Passive method
- Active method
- Compound method

These methods don't need the use of an external source. Many researchers prefer passive heat transfer improvement techniques for their application simplicity. For example, tube insertions show some advantages over other improvement techniques, because of easy installation on the heat exchanger tubes without modifying their mechanical properties like strength. Easy installation and low cost. It is relatively easier for cleaning operations. Treated surfaces, the main characteristic of this kind of surface are that they present a fine-scale change on their finish. The changes could be continuous or discontinuous, in this case, the roughness is smaller on the heat transfer process affecting only a single-phase, and they can be applied as a basics boiling and condensing conditions.

General modification on surfaces, these surfaces induce a turbulent flow or steam, Single-phase flows doesn't increase the heat transfer surface area. That is why the roughness is changed by using random sand-grain or discrete three-dimensional surface. Extended surfaces, this are called finned surfaces, this configuration provides an effective increase in the heat transfer process based on modifications. The principle for this is to use plain fins to insert randomly into the tubes of the heat exchangers. The upcoming development of technologies led to finned surfaces to improve the heat transfer coefficient by the increase of the surface area. Mechanism with displaced enhancement, this is basically insertions used in confined forced convection, the biggest contribution is the capacity of energy transportation at the surface of the heat exchanger "displacing" fluid from one surface (heated or cooled) on the duct with the main flow that comes from the core.

Masoud Rahimiet.al [1] done experimental work on tube type solar water heater attached with various types of inserts, in order to know the behaviour of thermal-hydraulic efficiency, friction factor and Nusselt number. From their work jagged one is best in terms of efficiency and Nusselt number. They concluded that fluid turbulence is more at tube wall portions. S JaiSankaret.al [2-3] worked on a thermo-syphon solar water heater fitted with a full length left-right twist insertion, fitted with a rod and spacer at the back end and compared with full length twist. Heat enhancement in twist fitted with rod at the trailing edge is maximum when compared with twist fitted with spacer because the swirl flow is maintained throughout the length of rod. Keguang Yao et.al [4] worked on heat transfer performances of solar water heaters for different initial temperatures with twist tape inserts and found the twist with twist ratio 3 will have high performance. S. JaiSankar et.al [5] worked on left-right twisted tape with various twist ratios have been studied and compared with a plain tube collector at the same operating conditions with Reynolds number varied from 3000 to 23000 and confirmed that the heat transfer augmentation in left-right twisted tape collector was better than plain tube collector Compared to various twist ratios, heat enhancement and pressure drop were higher with minimum twist ratio 3.Halit das et.al [6] investigated on helical twist at different twist ratios and clearance ratios in range of Re from 5132 to 24989 and compared with typical one. Concluded that heat transfer enhancement is uniform for Reynolds number over 15000 and at low Reynolds number it is best performance. Bhuiya et.al [7] performed experiment on perforated twisted tapes at different porosities over a Reynolds number range of 7200 to 49800 at uniform wall heat flux boundary condition and concluded that perforated twisted tape have shown a better performance than plain tube. A.S.M.Sayem et.al [8] conducted experiment on double counter twisted tape with four different twist ratios over a Reynolds number range of 6950 to50050. Stated that friction factor, Nusselt number and thermal enhancement were increasing with decrease in the twist ratio and obtained a maximum of 1.34 thermal enhancement efficiency at a constant blower power. Pankaj.N.Srirao [9] focuses on horizontal circular pipe with different internal threads of pitches 100mm,120mm,160mm in a transitional flow regime over a Reynolds number range of 7000 to 14000 at uniform and constant heat flux and compared with plain pipe at same pumping power. Finally concluded that pipe with internal threads have a better performance over plain horizontal pipe. Bodius Salam et.al [10] experimented on rectangular cut twisted tape insert in a circular tube at uniform heat flux and over a Reynolds number range of 10,000 to 19,000. Insulated the test section with nichrome and fibre glass and compared with plain tube. Results were shown that rectangular cut twisted tape got heat transfer enhancement efficiencies are found in a range 1.9 to 2.3 on comparison with plain tube. Paisarn Naphon [11] worked on pressure drop and heat transfer characteristics in a horizontal double pipe with and with-out twisted tapes with different relative pitches. Results of tube with twisted tape is compared with tube without and stated that tube with twisted tape has ideal results. P.K. Sarma et.al [12] in this work a generalised correlations were originated in finding heat transfer co-efficient and friction factor with twisted tapes in a tube over wide range of Prandtl numbers and Reynolds numbers. S.K.Saha et.al [13] investigated on regularly spaced twisted tape element by placing rod element in between twists and full length twist with a viscous fluid with intermediate Prandtl number range at uniform heat flux. Liao and Lin [14] studies about heat transfer enhancement inside the tubes with three dimensional internal extended surfaces and twisted tape inserts carried out at various ranges of Prandtl numbers Reynolds numbers and proposed a correlation for finding Stanton number and friction factor. P. Sivashanmugam, S. Suresh [15] experimented on full length helical screw element of different twist ratio, increasing and decreasing order of twist ratio set with uniform heat flux over a Reynolds number range of 2700 to 13500 and compared the experimentally obtained data with previously reported in the literature. They stated that higher performance is obtained for helical twisted tape on comparison with the twisted tape insert.

## II. MODELING OF TWISTED TAPES

CAD is the initials to Computer-Aided Design, it´s also called Computer-Aided Design and Drafting (CADD), this kind of tool allows to design and prepare different types of problems, case study for engineering investigation and their documentation using a computer. The versatility of using CAD software is that provides results based on the initial conditions and can process all the data more quickly than by hand, the output is obtained in digital format ready for printing. The CAD development software used in the industry for construction, manufacturing, etc., seeks to improve the design times with detailed reports, this software works with an environment based in vector (linear) at the same time that uses graphics fundamentals based in raster (pixilated).

### 2.1. Introduction to PRO/ENGINEER

Pro/ENGINEER Wildfire is software that allows to draw 2D forms and create 3D models design according to the standards established for the case of study. Pro/ENGINEER CAD/CAM software allows the designers to perform a technical evaluation of the model more quickly with technical reports which maximize the operation time and help to create and solve any issue before construction.

The software gives the engineers the capacity to adapt the model to any customer requires, Pro/ENGINEER is easy to use and provides solutions to designers.

**Models created in Pro/E**

Fig.1. classic twist with square holes

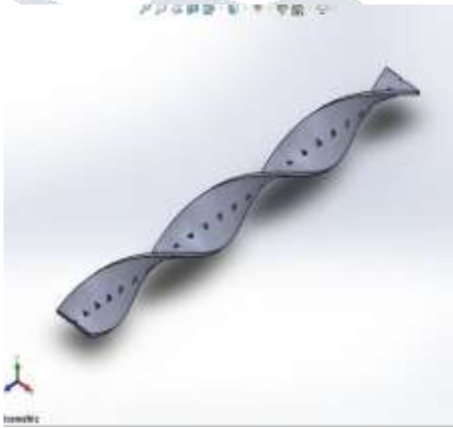


Fig.2. classic twist with triangular holes

Fig.3. classic twist with nails

## III. CFD ANALYSIS

CFD is the abbreviation of Computational Fluid Dynamics, it is a part that belongs to mechanics of fluids that is based in the use of algorithms numerical methods to find the solution in systems that involve fluid flows studies. In the same way that thermal analysis in CFD is needed the use of a computer to establish the condition of study and simulate the interaction that may exist between liquids and gases in a determinate environment. For turbulent flows simulation, CFD presents better precision as well less time to obtain the results. The initial validation of CFD is executed using a wind tunnel.

The CFD modelling involves numerical solutions of the conservation equations for mass, momentum and energy. These equations for incompressible flows can be written as follows:

Mass conservation:

$$\frac{\partial \rho}{\partial t}+\nabla.(\rho\vec{u}) = 0 \qquad (1)$$

Momentum conservation:

$$\frac{\partial(\rho\vec{U})}{\partial t}+\nabla.\ (\rho\vec{u}\vec{u}) = \rho g-\nabla P+\nabla.\ (\bar{\bar{\tau}}) \qquad (2)$$

Energy conservation:

$$\frac{\partial \rho e}{\partial t}+\nabla.\ (\vec{u}(\rho e + P)) = \nabla.\ (K_{eff}\nabla T + (\bar{\bar{\tau}}_{eff}\ .\vec{u})) \qquad (3)$$

Where

$$\bar{\bar{\tau}}= \mu((\nabla\vec{u} + \nabla\vec{u}^{T}) -\frac{2}{3}\nabla.\vec{u}I)$$

## IV. RESULTS AND DISCUSSION

### Classic insert with Nails

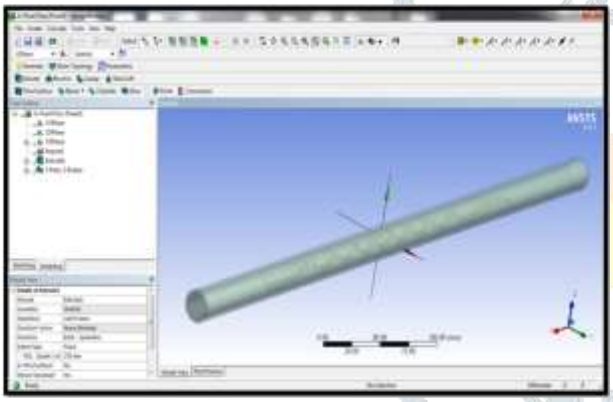


Fig.4. imported model

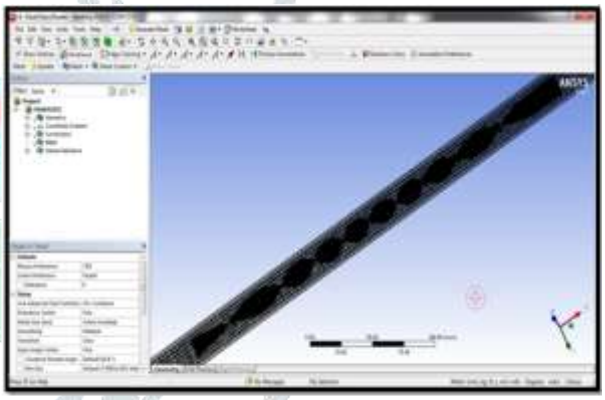


Fig.5. meshed model

### VELOCITY- 0.49m/s

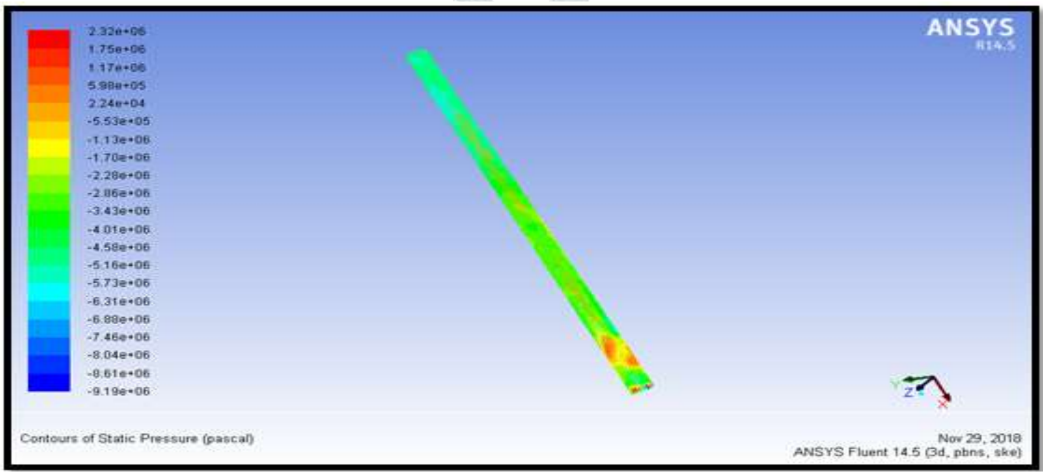



Fig.6.variations in pressure for a tube with classic insert with nail

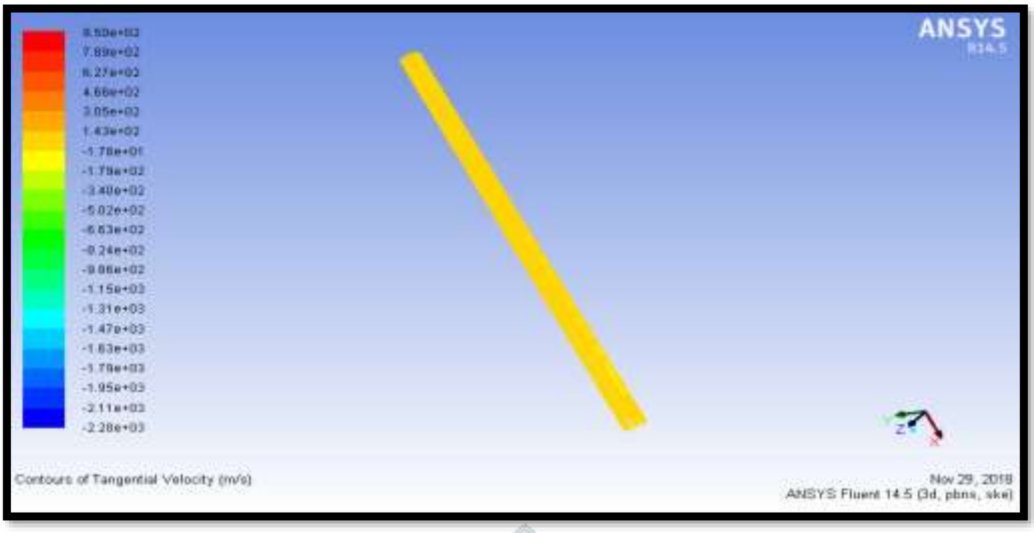



Fig.7.variations in tangential velocity for a tube with classic insert with nail

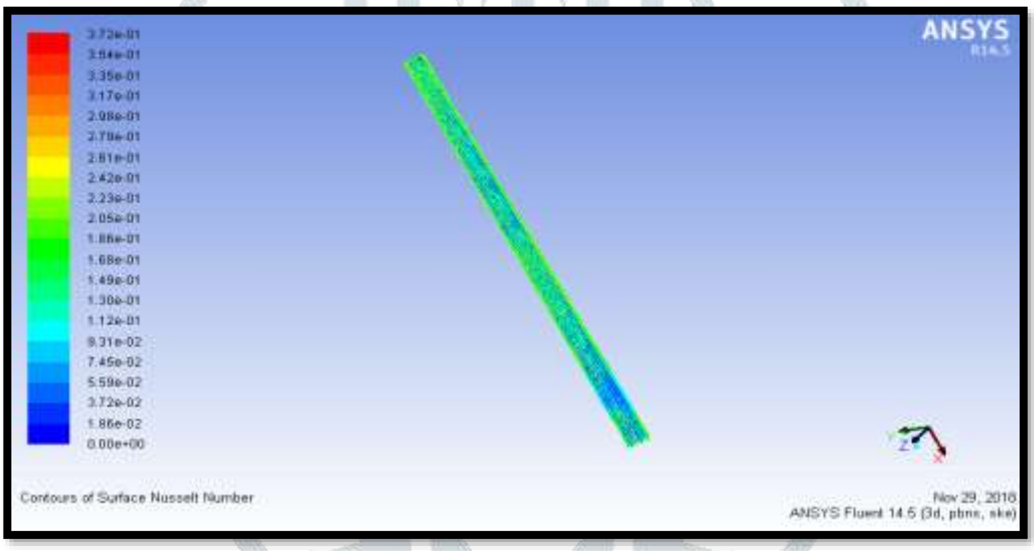



Fig.8.variations in Nusselt number for a tube with classic insert with nail

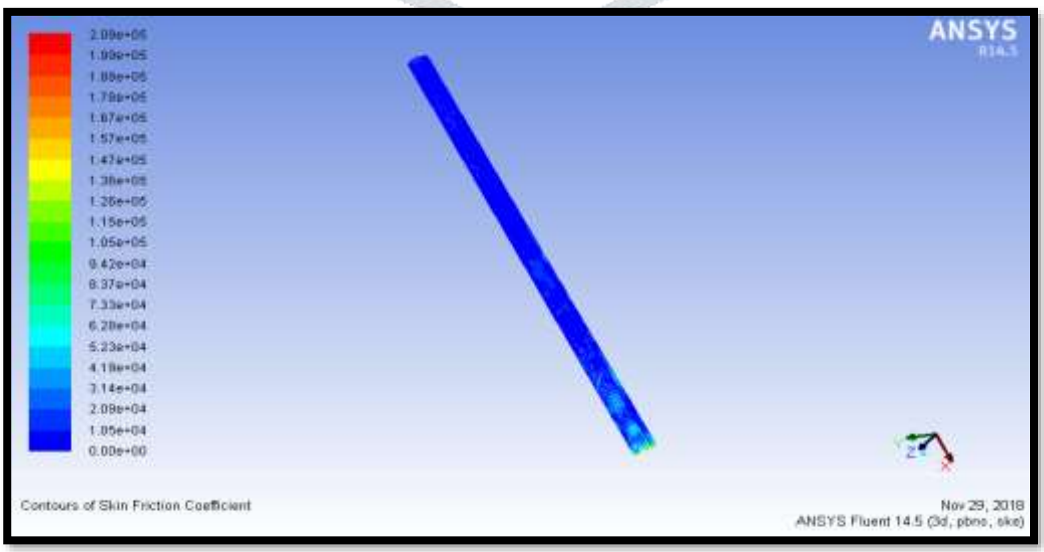



Fig.9.variations in friction co-efficient for tube with classic insert with Nail

Table.1.Pressure difference (mbar) across test tube for different inserts in the tube at different velocities

| Velocity *(m/s) | Plain Tube | Classic Insert with nails | Classical Insert | Classic insert with Triangular holes | Classic insert with Square holes | Perforated Insert |
|---|---|---|---|---|---|---|
| 0.12 | 2.28 | 10.11 | 9.28 | 8.83 | 7.84 | 6.37 |
| 0.24 | 8.67 | 29.28 | 25.34 | 24.20 | 21.64 | 18.68 |
| 0.37 | 17.34 | 56.78 | 42.56 | 41.32 | 38.32 | 32.16 |
| 0.49 | 28.02 | 89.32 | 67.17 | 63.48 | 59.27 | 51.38 |

Table.2. Variations in tangential velocity (m/s) in a vertical slice for different inserts at various Reynolds numbers

| Reynolds Number# | Plain Tube | Classic Insert with nails | Classical Insert | Classic insert with Triangular holes | Classic insert with Square holes | Perforated Insert |
|---|---|---|---|---|---|---|
| 2950 | 0.00068 | 0.023 | 0.030 | 0.021 | 0.017 | 0.015 |
| 5900 | 0.00116 | 0.030 | 0.031 | 0.024 | 0.019 | 0.016 |
| 8850 | 0.00125 | 0.127 | 0.160 | 0.118 | 0.106 | 0.101 |
| 11800 | 0.00241 | 0.178 | 0.278 | 0.146 | 0.112 | 0.106 |

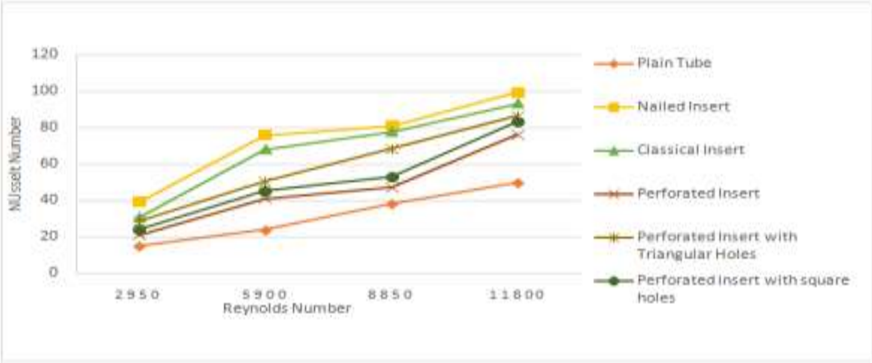
Table.3. Variations in Nusselt number for different inserts in tube at various Reynolds number

| Reynolds Number | Plain Tube | Classic Insert with nails | Classical Insert | Classic insert with Triangular holes | Classic insert with Square holes | Perforated Insert |
|---|---|---|---|---|---|---|
| 2950 | 15.02 | 38.90 | 30.72 | 28.3 | 23.82 | 21.12 |
| 5900 | 26.73 | 75.71 | 68.01 | 50.2 | 45.31 | 41.01 |
| 8850 | 38.12 | 80.82 | 77.73 | 68.01 | 52.84 | 47.36 |
| 11800 | 49.64 | 99.13 | 93.21 | 86.23 | 83.12 | 76.20 |

Table.4. Variations in friction factor for different inserts in tube at various velocities

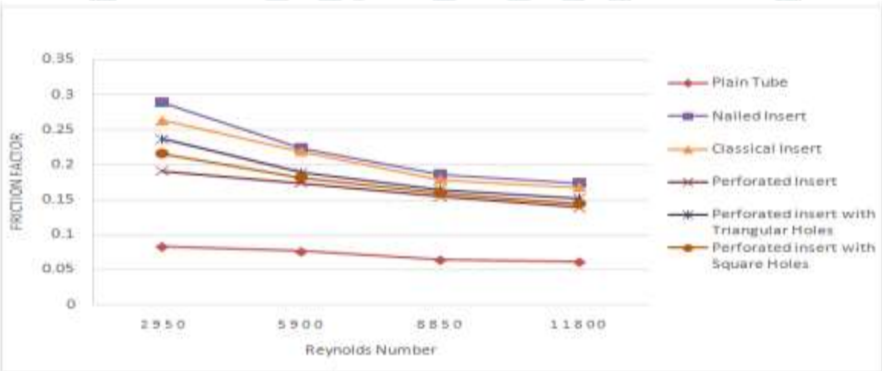
| Velocity (m/s) | Plain Tube | Classic Insert with nails | Classical Insert | Classic insert with Triangular holes | Classic insert with Square holes | Perforated Insert |
|---|---|---|---|---|---|---|
| 0.12 | 0.083 | 0.289 | 0.263 | 0.237 | 0.216 | 0.191 |
| 0.24 | 0.076 | 0.224 | 0.219 | 0.189 | 0.181 | 0.174 |
| 0.37 | 0.064 | 0.186 | 0.179 | 0.164 | 0.159 | 0.154 |
| 0.49 | 0.061 | 0.174 | 0.168 | 0.152 | 0.144 | 0.139 |

### 4.1 GRAPHICAL REPRESENTATIONOF ANALYSIS RESULTS



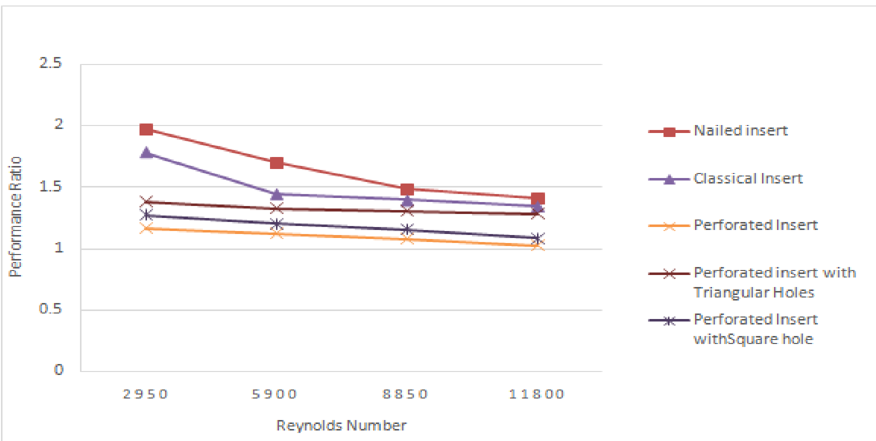

Graph.1. variations in Nusselt number for different inserts at various Reynolds numbers

The analysis of heat transfer for tubes fitted with different twisted tape inserts were calculated and shown above. By reducing the data from results, the variation of Nusselt Number with Reynolds for the tubes with different inserts are shown in Graph.1. By referring to Graph.1. It is observed that with an increase in Reynolds Number leads to increase in Nusselt Number. It shows that an enhancement in heat transfer co-efficient due to increase in convection. From the results it is seen that Nusselt Number for Insert with nails was higher than that of others at all Reynolds numbers and followed by classic, perforated with triangular holes, perforated with square holes, perforated and plain tube.



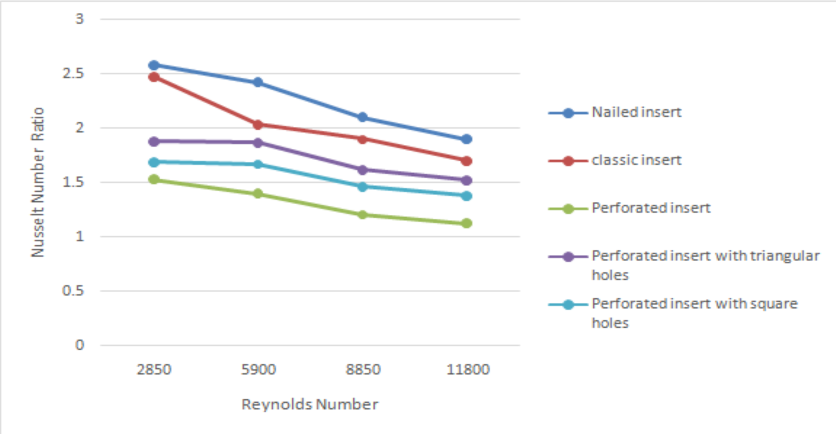

Graph.2. variations in friction factor in tube with different inserts for various Reynolds numbers

In Graph.2. Variation of friction factor with Reynolds Number for the tubes fitted with different types of twisted tape inserts is shown. From the graph Friction factors for the tube fitted with any insert is higher than the plain tube. For all the tube with different insert setups it is found that friction factor values are higher at lower Reynolds Number. Decreasing trend of friction factor is sharper for any of the insert placed inside the tube in comparison with plain tube. Decrease of blocking effect at the insert wall as well as decrease of the swirling flow are responsible for the above result. Friction factor curve for three types perforated inserts are lower on comparison with classic insert and Insert with nails have higher friction factor values than classic insert.




Graph.3. variations in performance ratio for different inserts at various Reynolds number

In Graph.3. Performance ratios of different setups are compared. Performance ratio is also called as Thermo-hydraulic Performance = $\frac{Nu/NU_0}{\sqrt[3]{f/f_0}}$.From the graph highest values were obtained for the insert with nails and it is followed by classic insert and three types of perforated inserts. On comparison with classic insert, insert with nails got a maximum increase of 10.6% and a minimum difference of 5.15% is achieved. The performance ratio decreased by increasing Reynolds Number. This indicates that at lower velocities the role of inserts in increasing the turbulence intensity is more significant than at higher velocities.




Graph.4. variations in Nusselt number Ratio for different inserts at various Reynolds number

In Graph.4.The effectiveness of heat transfer rate in the tube fitted with different inserts which are relative to the plain tube for various cases was compared. Effectiveness is termed by the ratio of Nusselt Number of the tube with an insert to that of plain tube i.e. Nusselt Number Ratio = $\frac{Nu}{NU_0}$ From the graph it evident that the effectiveness ratio is lower for three types of perforated inserts when compare with classic insert. Only tube fitted with nailed insert has significantly higher effectiveness ratio over classic insert. From the results it can be obtained that the ratio of [Nu/(Nu_0)] for tube fitted with different inserts decreased as the Reynolds number increased. This indicates that the role of inserts in increasing turbulence intensity is more significant in lower velocities than compared to fluid flow high velocity.

## V. CONCLUSION

In the present work three different types of inserts were used 1) Classic insert with triangular holes 2) Classic insert with square holes 3) Classic insert with Nails. The analysis is carried out at velocities 0.12m/s,0.24m/s,0.37m/s,0.49m/s on all the three new modified geometries for classic twisted tape inserts. Their results are compared with classic insert, perforated insert and plain tube from the previous author results. Using the analysis reports Nusselt Number, Friction factor, Nusselt Number ratio and Thermal-hydraulic performance ratio are obtained. From the analysis and calculations, results are evident that Higher Nusselt number and Thermal-hydraulic performance were obtained for classic insert with nails on comparison with other inserts at considered range of Reynolds number. A maximum increase of 12.5% and 10.6% were observed with those obtained for classic twisted tape insert. The higher amount of turbulence intensity of the fluid near the wall is one of the reasons for getting higher performance obtained by the insert with nails at low Reynolds Numbers.

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