Experimental & numerical investigation of heat transfer using twisted tapes with rectangular cuts

Nookaraju B Ch[1*], *Dhanuri* Bharath Yadav[1], *Kotholla* Raghavendar[1], *Puneeth* Varma[4], *Ravi* Kumar Gugulothu[2], *Aaluri* Suresh[3], *Hayidr* Muhamed[4]

[1]Department of Mechanical Engineering, GRIET, Bachupally, Hyderabad, Telangana, India.
[2]JNTUH College of Engineering, Kukatpally, Hyderbad, Telangana, India.
[3]KG Reddy College of Engineering and Technology, Hyderabad, Telangana, India
[4]Department of Refrigeration and air Conditioning Techniques engineering, College of technical engineering, The Islamic University, Najaf, Iraq.

Abstract. The current work focuses on using rectangular inserts with water as the working fluid to investigate heat transfer experimentally and numerically in a horizontal circular tube [10]. The study considers variations in the number of rectangular slots within the same strip. The tube has dimensions of 0.0266 m diameter. Twisted tapes, featuring rectangular cuts, are constructed from a 3 mm thick Stainless-steel strip with a length of 1035 mm. For experimentation, two different types of rectangular inserts were considered: one with nine cuts and the other with eighteen cuts. The dimensions of the cuts were as follows: length of 1000 mm, width of 13 mm, depth of cut 8 mm, and thickness 3 mm. The heat flux applied to the horizontal tube was steady and uniform. The range of the Reynolds number was 9,000–19,000. A plain tube without an insert was used to compare the results. The horizontal tube along with rectangular insert was modelled in Ansys Fluent software with fine meshing and analysed. Initially, CFD analysis was done for plain tube with and without insert, and results have been verified by comparison with experimental values. A comprehensive comparison is established, evaluating different heat transfer parameters, including convective heat transfer coefficient (h), heat transfer rate (q), and Nusselt number (Nu).

1 Introduction

A heat exchanger is a device designed to efficiently transfer heat from one medium to another. It is commonly used in various industrial processes and everyday applications to facilitate the exchange of thermal energy between fluids, gases, or solids. Heat exchangers play a crucial role in heating, cooling, and ventilation systems, as well as in chemical processing, power generation, and many other fields[1]. The Basic principle of a heat exchanger involves two fluids at different temperatures that flow through separate channels,

---

[*] Corresponding Author: bulipechinanookaraju@gmail.com

ensuring that they do not mix but still allow heat to transfer from the hotter fluid to the cooler one[3]. This process facilitates the control of temperature for the involved fluids.
The creation of various enhanced heat transfer surfaces and devices has received a lot of attention in recent years.

This is evident from the exponential rise in patents, There are hundreds of manufacturers that sell everything from upgraded tubes to full thermal systems with enhancement technology and the international technical literature on devices that enhance heat transfer [2]. Many techniques have been explored to increase the rates of heat transfer within circular tubes, and a variety of inserts have been used, especially when turbulent flow is taken into account. The Inserts that were examined included rectangular, quadrant, brush, mesh, coil wire, twisted tape, and strip inserts, among others. And the rectangular inserts have found portent applications in thermal energy systems at high temperatures, where the convection & radiation styles of heat transfer are both important.

The extensive contact surface enhances the internal heat exchange between the phases and consequently results in an increased thermal diffusivity. Due to the many possible engineering applications, including electric cooling, drying process, heat pipe etc.., Extensive research has been conducted on different varieties of twisted inserts in forced convection heat transfer; nevertheless, there is a scarcity of experimental work conducted in this domain.

2 Experimental Work

2.1 Experimental setup

A twisted tape with a cut was employed to improve the heat transfer rate. Convection is the movement of potential energy through a fluid's currents, such as heat[6]. This experimental study used twisted tape with cut inserts to measure the water's tube side heat transfer coefficient as shown in fig1 S.M. Peyghambarzadeh et al[16]

- The test section consisted of a 1035mm long copper tube with an external diameter of 30 mm and an internal diameter of 26.6 mm and 1000mm was used for test section.
- The bulk temperatures were measured using two thermometers at the tube's inlet and outlet sections.
- A manometer was used to determine the pressure drop at two different points in the test section.[11]
- The experiment included measuring two distinct temperature parameters: one related to the outer surface of the tube and the other to the inlet and outlet temperatures of the water.
- Data was took only for the plain copper tube and with inserts.

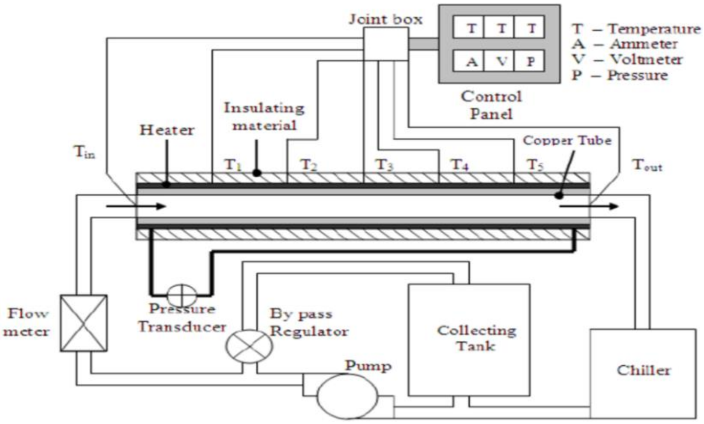

Fig. 1. Schematic diagram of Experimental Setup

Table 1. Data Collection

Parameter	**Value**
Test tube inner diameter	26.6 mm / 0.0266 m
Tube outer diameter	30 mm / 0.03 m
Tube test length	0.90 m
The Thermal conductivity of copper	379 W/m°C
Viscosity of the water	0.00087 Kg/m.sec (at 28°C)
Water Density, ρ	1000 kg/m3
Water Thermal Conductivity, k	0.62 W/m°C
Specific heat of the water (at 28 °C), Cp	4177 J/kg°C
Outer Surface area	0.0718 m^2
Inner Surface area	0.0702 m^2
Length of the Insert	1000mm
Depth of Rectangular Cut	8mm
Width of Rectangular Cut	13mm
Thickness	3mm

2.2 Procedure

The water in the system was pumped around, and the different flow rates were managed by a rotameter. Subsequently, a voltage regulator provided a constant voltage and a voltage regulator supplied current to the heater. A series of measurements were conducted to gauge the flow rate at which the temperature stabilized at both the inlet and outlet points. Initially, readings were obtained as the flow rate was varied from 192 ml/s to 334 ml/s for a plain copper tube without any additional inserts. Following this, the same procedure was repeated after inserting an aluminum component into the copper tube. The experiment encompassed trials with and without inserts, spanning various mass flow rates while keeping the heat input and flux constant throughout.

2.3 Order of Operation

Experiments are conducted first without inserts and then with inserts.

2.3.1 With-out Insert

Firstly, the experiment (plain tube experiment) was conducted with-out any inserts. Water is the working fluid, moves inside the pipe segment with the less amount of resistance15].

2.3.2 With Inserts

The inserts used for the experimentation is aluminium material as shown in fig. 2. (length of 1000 mm, width of 13 mm, depth of cut 8 mm, and thickness 3 mm). Firstly 9 number of cuts were inserted into the plain tube with same dimension as mention above[8]. After that the number cuts will be increased to 19 number of cuts are inserted in plain tube.

Fig. 2. Photography of Rectangular insert

Each insert is taken and positioned axially within the test section.The attendance of insert in the tube causes confrontation to flow and raises the turbulence. Turbulence is increased and flow resistance is created by the insert's presence in the pipe[5]. The mass-flow values of the water and heat input are equal as the plain tube experiment.

2.4. Heat Transfer Calculations

$$\text{Velocity } (v) : m/ \rho * A \tag{1}$$

$$\text{Area}(A) = \pi d_i^{\,2} /4 \tag{2}$$

$$\text{Reynolds Number (Re)} : \rho\, v\, d/ \mu \tag{3}$$

$$\text{Heat transfer rate (Q)} : mc_p\,(T_o-T_i) \tag{4}$$

$$\text{Heat flux (q)} : Q/A \tag{5}$$

$$\text{Area (As)} : \pi dL \tag{6}$$

$$\text{Heat Transfer Coefficient (h)} : Q / \{As\,(T_{\text{inner surface}}-T_{\text{bulk}})\} \tag{7}$$

$$\text{Nusselt Number (Nu)} : hd_i/k \tag{8}$$

Eq. (8) provides the experimental Nusselt Number.

The Nusselt number obtained from experimental data of the plain tube was compared.

$$Nu = 0.023\, Re^{0.8}\, Pr^{\,0.4} \tag{9}$$

Eq. (9) gives the theoretical Nu

$$Pr : \mu\, c_p/k \tag{10}$$

3 Computational Fluid Dynamics Analysis

There are lot of devices & systems that are difficult to prototype. We can forecast a design's performance & test numerous iterations until we achieve the best outcome by using CFD analysis. It would take a great deal of time and work to accomplish these through physical prototyping and testing. Better and faster design is made possible by the insight that CFD analysis provides. Sharp edges enhance the recirculation zones and cause blockages in the complex flow field that characterises the flow inside tubes with various insert types. Here, the device is substituted with a separate set of points together show the total geometry of the cell containing the pressure, velocity, etc. distributions. Determining the mathematical formulas that control the physical process is necessary for the approach. Only at the discrete points that correspond to the geometry will these equations be solved. The overall performance & optimisation of the tubes with or with-out inserts is done using CFD techniques. FLUENT software was used to simulate the flow of fluid 1 and heat transfer inside the horizontal tube. The simulation takes into account the same physical parameters as the experimental setup, such as the tube's inner diameter of 26.6 mm, length of 0.90 m, and the material of the tube and insert is aluminium, which in the case of a plain tube .

The existing experimental data for tubes with or without rectangular inserts are utilized to confirm the outcomes of the simulated computational fluid dynamics (CFD) analysis, including values like the Nusselt number and heat transfer coefficient. Ansys Fluent is used to create the test section geometry for each insert. Two different kinds of rectangular inserts—one with nine cuts and the other with eighteen—were taken into consideration for CFD analysis. The cuts had the following measurements: 1000 mm in length, 13 mm in width, 8 mm in cut depth, and 3 mm in thickness.

Mesh is shaped in 3-D taking symmetrical model of test section. The problem is solved using a isolated solver with the following default settings: energy equation, steady (time-independent) calculation, turbulent (k-e model), and implicit formula. We employed the Second-Order Upwind scheme for the density and momentum equations, PRESTO for the pressure interpolation scheme, and SIMPLE for the pressure-velocity coupling method. The solution took about 500 iterations to reach convergence. Two post-processing features in FLUENT are used to produce the graphical results.

3.1 Heat Transfer Measurements

Both convective and conductive terms are present in the energy equivalence that FLUENT numerically solves for fluid side, the impact of the conductive relations on the surface wall temperature parameters may also be important. The conduction performances in parallel with convection. A steady wall heat flux is provided in order to observe temperature variations throughout the tube. The temperature differential between the axial fluid and wall at the tube's beginning and end is 301 K and 306 K, respectively.

Fig.3 Displays the model produced in FLUENT the horizontal tube without rectangular insert. Rectangular insert is created by taking symmetric model in FLUENT (2-D).

Fig.4 & 5 illustrations the model generated in FLUENT for horizontal tube with inserts of 13 mm in width, 8 mm in cut depth, and 3 mm in thickness respectively.

Fig.6 ,7 &8 show the contours of temperature distribution. The normal temperature of tube wall is noted to rise alongside an increased the number of cuts. This phenomenon arises from a greater volume of water flowing through the horizontal tube with larger Reynolds numbers, resulting in a decrease in the tube wall temperatures. This can be explained by the intense turbulence that the rectangular insert creates.

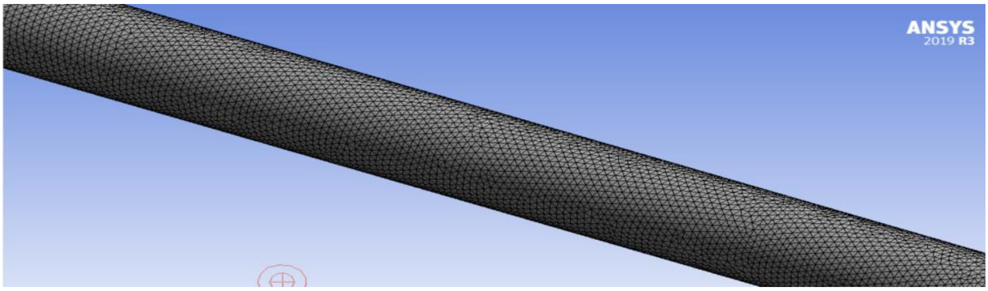

Fig. 3. Geometric model of the plain tube without insert

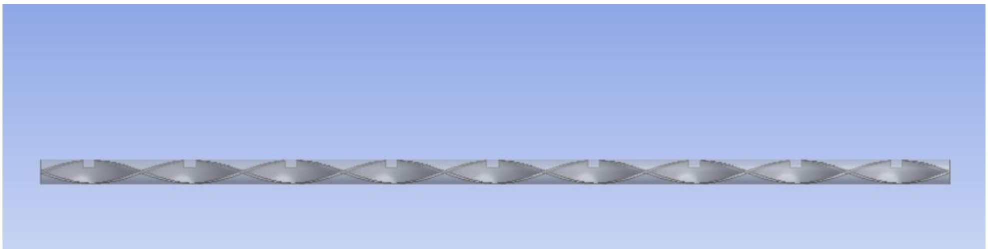

Fig. 4. Geometric model of the plain tube with primary insert placed inside it.

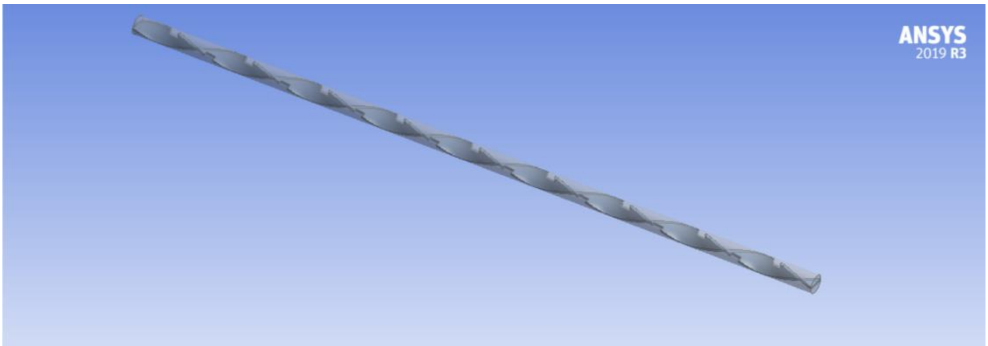

Fig. 5. Geometric model of the plain tube with secondary insert placed inside it.

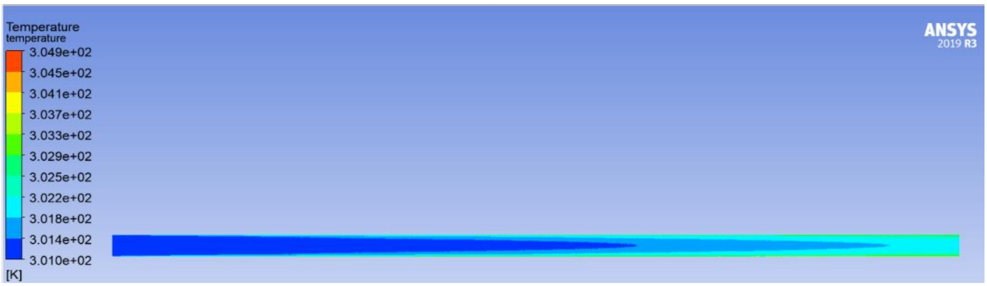

Fig. 6. Temperature distribution for plain tube

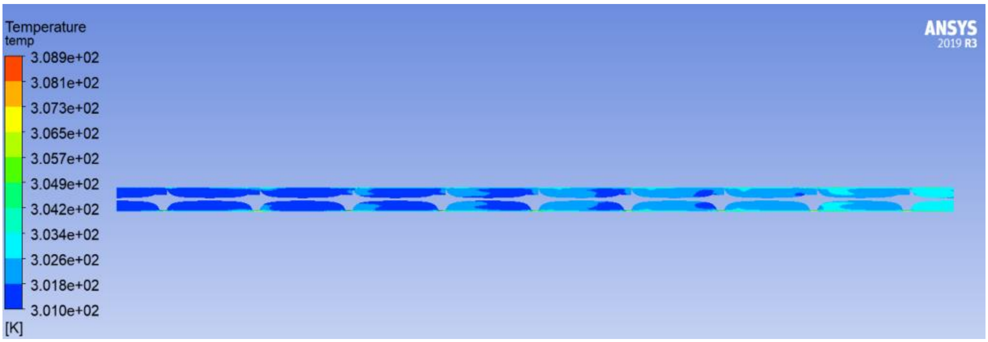

Fig. 7. Temperature distribution in the plain tube with primary insert

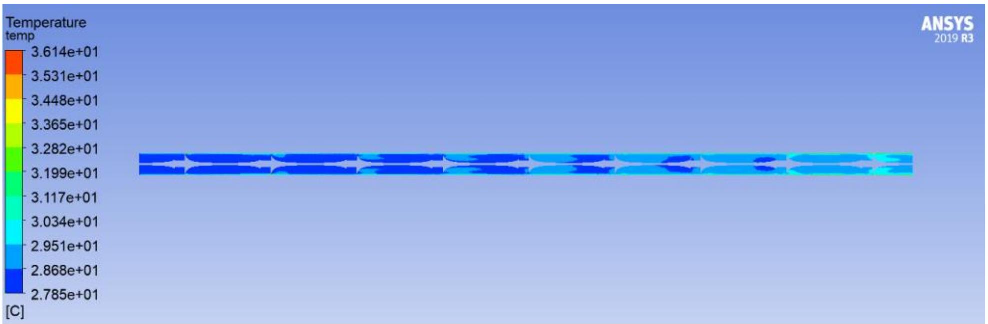

Fig. 8. Temperature distribution in the plain tube with secondary insert

4 Results and Discussion

Comparison is made between numerically and experimentally determined Nusselt Number values for plain tubes (without rectangular inserts).

Fig.9 illustrates a comparison between analytically obtained and experimentally determined Nusselt numbers for plain tubes. The Nusselt number achieved through computational fluid dynamics (CFD) analysis was found to be higher than the experimental Nusselt number.The total heat dissipated by the water as it flows through the test section is determined by the combined effects of convective and radiative heat transfers.

Figure 10 presents a comparison between numerical and experimental data showing the variation of the heat transfer coefficient with the Reynolds number. A portion of heat supplied to test section is attributed to radiation heat transfer. When determining the heat transfer coefficient using Equation 7, the heat loss induced by radiation is considered. In contrast to the numerical values, the experimentally obtained heat transfer coefficient values are relatively lower. As the flow rate in a plain tube escalates, the heat transfer rate likewise rises due to a greater volume of water gradually absorbing more heat as it traverses the tube. Concurrently, pressure drops amplify with the escalating flow rate in the plain tube. Notably, the numerical heat transfer coefficient values surpass the experimental values.

Fig.11 &12 show a comparison of the Nusselt number and heat transfer coefficient in relation to the Reynolds number for a plain tube fitted with a rectangular insert.

Nevertheless, as depicted in fig.11 & Fig.12, compared to a plain tube lacking an insert, both the heat transfer rate and Nusselt Number exhibited an increase upon insertion of a twisted tape with cuts into the copper tube. Moreover, with an escalation in the number of cuts, the heat flux and heat transfer rate also saw an increase. The increase in the heat transfer rate resulted from the formation of two flow components—axial and radial— as water flowed through the tube. These components disrupt the water, enabling the flowing of water to absorb more amount of heat from its surroundings. The rate of flow escalates due to a secondary flow generated through the hole in the twisted tape with cuts. In contrast to a plain tube, pressure drop steadily rises with increasing flow rate. In terms of experimental error margins, it was determined that the numerical predictions closely aligned with the experimental findings.The difference between the numerical results and the experimental data for the Nusselt number and the heat transfer coefficient was approximately 10.2% and 12%, respectively.

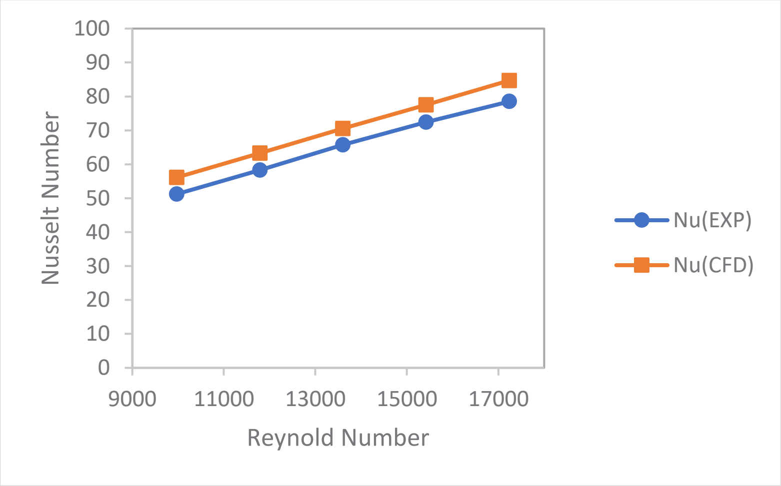

Fig. 9. A Comparison of Nusselt Number & Reynolds Number for Plain Tube

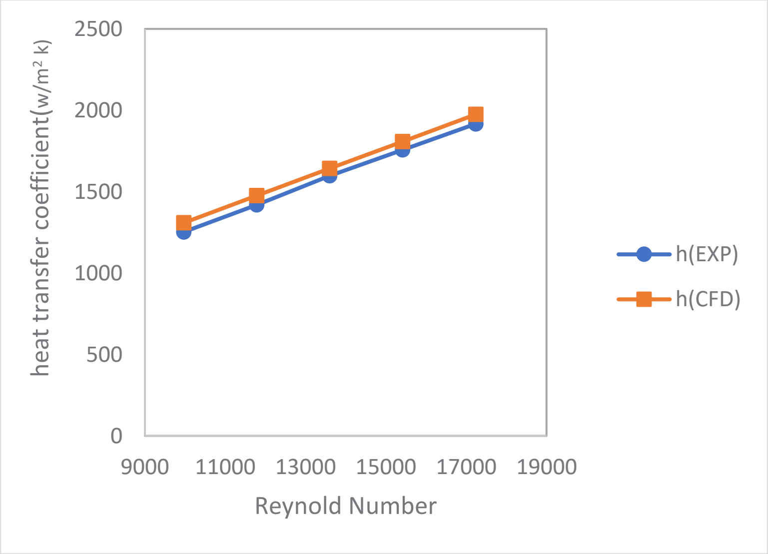

Fig. 10 A comparison of the heat transfer coefficient with the Reynolds number for a plain tube.

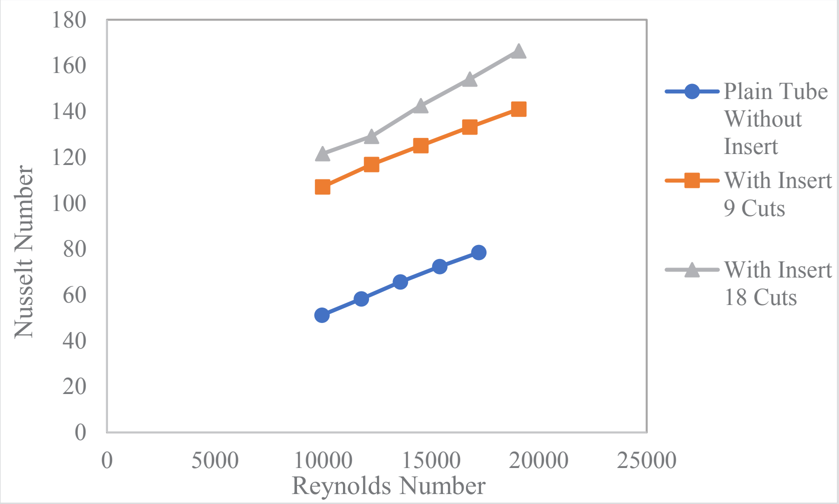

Fig. 11. A Comparison of Experimental Nusselt Numbers & Reynolds Number

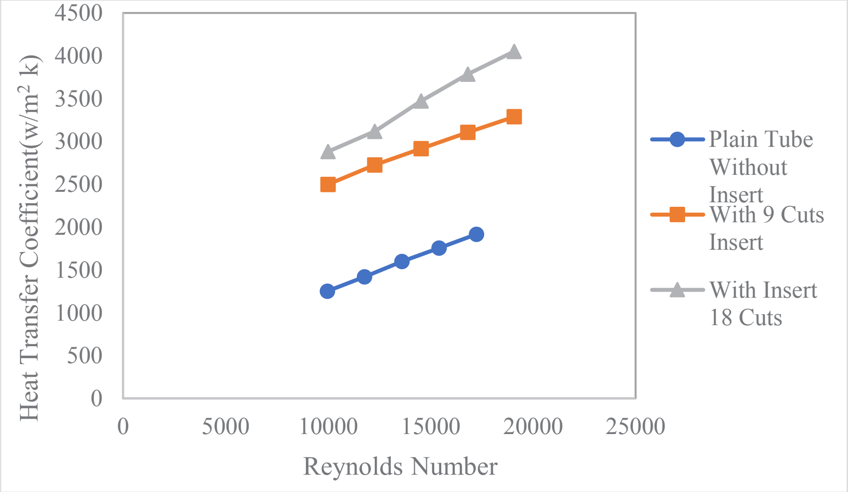

Fig.12. Comparison of the Experimental Heat transfer coefficient & Reynolds Number

5 Conclusion

The characteristics of the water-flow heat transfer coefficient [8] are performed experimentally and numerically in a horizontal tube that is heated externally and fitted with different inserts. The tested inserts facilitated improved mixing and increased heat transfer rates by inducing flow separation and secondary flow, consequently generating turbulence. Nusselt Number also affected due to the presence of inserts. The investigation involved studying the temperature, Nusselt number, and heat transfer coefficient variations in a horizontal tube equipped with rectangular cut geometry across Reynolds numbers ranging from 9000 to 19000. It was observed that as the Reynolds number increased, there was a corresponding increase in the Nusselt number, Reynolds number, and heat transfer coefficient.

- The Reynolds number for a simple tube without an insert is between 9,000 and 19,000. Heat transfer rates and the Nusselt number both rise in parallel with an increase in the Reynolds number. The study revealed a reasonable agreement between numerical predictions and experimental results. However, the numerical values obtained were higher than the experimental values. The plain tube's highest experimentally recorded values for the heat transfer coefficient and Nusselt number were 1916.4 (W/m²K) and 78.5, respectively.
- In the case of a plain tube with a rectangular insert, both the heat transfer rate and Nusselt Number showed an increase upon insertion of a twisted tape with cuts into the copper tube. Additionally, with an increase in the number of cuts, there was a corresponding rise in heat flux and heat transfer rate.In the plain tube with insert, the greatest experimental values for the heat transfer coefficient and Nusselt number were 4051.74 (W/m²K) and 166.5, respectively.

References

1. Sami D. Salman, Abdul Amir H. Kadhum, CFD Analysis of Heat Transfer and Friction Factor Characteristics in a Circular Tube Fitted with Quadrant-Cut Twisted Tape Inserts, Volume 2013, Article ID 273764, 8 pages.
2. Simul Acherjee, M. Shahriar, Enhancement of Heat Transfer In A U-Loop Circular Tube With Axial Perforated Inserts, 2017, Vol. 5, No. 2 (2017) pp. 126-136.
3. A. H. Dhumal , G. M. Kerkal , K.T. Pawale, Heat Transfer Enhancement for Tube in Tube Heat Exchanger Using Twisted Tape Inserts, [Vol-4, Issue-5, May- 2017].
4. K.P.V. Krishna varma#1, P.S. Kishore*2, TulasiTirupathi#3 CFD Analysis for the Enhancement of HeatTransfer in a Heat Exchanger with Cut TwistedTape Inserts, [ISSN: 2348 – 8360, Special Issue May – 2017].
5. Muhammad Azmain Abdullah, M. Ruhul Amin, A Numerical Analysis Of Heat Transfer Enhancement By turbulence Generated From Swirl Flow By Twisted Tape, [IMECE2018-86616, November 9-15, 2018].
6. K. Sivakumar, Dr. K. Rajan, S. Murali, S. Prakash, V. Thanigaivel, T.Suryakumar, Experimental Analysis Of Heat Transfer And Friction Factor For Counter Flow Heat Exchanger, VOL 3, ISSUE 04 ISSN 2347-4289.
7. F Bozzoli1,2, L Cattani3, A Mocerino1, S Rainieri1,2 and G Pagliarini1,3, Experimental investigation on the convective heat transfer enhancement in tubes with twisted-tape inserts, Conf. Series 1224 (2019) 012046, doi:10.1088/1742-6596/1224/1/012046.
8. K.Sivakumar, Dr.K.Rajan and T.Mohankumar, Analysis of Heat Transfer Characteristics with Triangular Cut Twisted Tape (TCTT) and Circular Cut Twisted Tape (CCTT) Inserts, 2019.
9. K.P.V. Krishna Varma, P.S. Kishore, Effect of Shape of Cut in Twisted Tape Tabulators on Enhancement of Heat Transfer Characteristics, 2016, ISBN: 978-93-85100- 57-4.
10. Sajid Hussein Ali Al – Abbasi, CFD Analysis of Enhancement of Turbulent Flow Heat Transfer in A Horizontal Circular Tube with Different Inserts, 2014, vol.10, No.15 ISSN: 1857 – 7881.
11. Anuprita Bhosale, K. Karunamurthy conducted a study titled "Computational Fluid Dynamics Analysis on Improving Heat Transfer and Reducing Pressure Drop in a Tube Equipped with Rectangular Cut Twisted Tapes, Volume 1, in 2015.
12. Umana Nileen Dewanjee, Moham Ed Abdur Razzaq conducted an experiment titled "Exploring Heat Transfer Enhancement of TiO2 Nanofluid in Mineral Oil-Water

Mixture Using Diamond-Cut Single and Separated Tape Inserts, (ICMERE2019-PI-204) in 2019.

13. L. Syam Sundar, K. V. Sharma, Exploration of Heat Transfer and Friction Factor Characteristics in a Circular Tube with Longitudinal Strip Inserts, Volume 15, Issue 4, in 2008,spanning pages 325-333.
14. S. Naga Sarada, A.V. Sita Rama Raju, Improvement of Heat Transfer with Twisted Tape Inserts of Varying Widths, Volume 2, Issue 6, in 2010, spanning pages 107-118.
15. Sahira H. Ibrahim, Zainab H, Enhanced Heat Transfer in a Circular Tube Utilizing Twisted-Tape Inserts, (Volume 27, Issue 04, July 2023).
16. S.M. Peyghambarzadeh, S.M. Hoseini et.al Experimental study of heattransfer enhancement using water/ethylene glycol based nanofluids as a new coolant for carradiators. International Communications in Heat and Mass Transfer, 2011. 38: p. 1283-1290