# Numerical Investigation of Bowl Cut TT Inserts and $TiO_2$/CuO Hybrid Nano Fluids on the Augmentation of Heat Transfer in a Double Pipe Heat Exchanger

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**Abstract**

Double pipe heat exchangers (DPHE) are used for low heat duty applications. In this work, numerical research was performed on a U-shaped DPHE inserted with bowl cut twisted tape inserts and circulated with $TiO_2$/CuO Hybrid nanofluids (HNFs). The twisted tape insert has a constant twist ratio (H/D=3). But its scale ratio was varied from 25% to 75% of its width with the increments of 25%. The effect of the bowl cut twisted tape insert on the friction factor(ff), Nusselt number (Nu) and thermal performance factor (TPF) was analyzed in the regime of turbulent flow. K-ε RANS turbulence model was chosen to perform the simulations. The flow rate of the hot fluid inside the annulus was kept constant at 6LPM. But the flow rate of the cold fluid was adjusted from 3LPM to 15LPM. The Reynolds number ranged from 2000 to 12000. According to the numerical outcomes, at scale ratios of 75%, 50%, and 25%, respectively. The augmentation of Nu was around 65%, 63%, and 55% greater than base fluid with bowl cut twisted tape (H/D=3) with a moderate rise in the pressure drop. Along with the rise in the scale ratio, the TPF has also risen, with a scale ratio of 75% of the bowl cut twisted tape insert and 0.05% $TiO_2$/CuO hybrid NFs, the maximum value of TPF (ἠ=2.3) was attained with the proper increase in pressure drop.

**Keywords**: Hybrid nanofluids, Bowl-cut twisted tapes, Heat transmission, Finite volume method, Computational Fluid Dynamics, Thermal performance factor.

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## 1 Introduction

In the progress of industrial and thermal applications, heat transmission improvement plays an increasingly important role. Numerous methods have been developed to improve the heat transmission and heat exchanger equipment design. Heat transfer improvement strategies fall into three categories: Passive, active and compound. In active technique external power sources such as a pulsating flow device, vibrating force, and magnetic field are exploited. On the other hand, the passive approach increases the heat transfer rate by including extra mechanisms such as fins, roughening the heat transfer surface, inserting twisted tape or coiled wires, nozzles and tabulators to locate them in the fluid path Moreover, a plenty of research has recently concentrated on nanoparticles suspension as an alternative to conventional heat transfer fluid for improving heat transmission Akhtari et al. [2013], explored the increase of double-pipe, shell as well as tube HEs utilizing $Al_2O_3$/water NFs fractions. According to the results, the heat exchanger's heat transmission coefficient has increased significantly in contrast to the accomplishment of heat transmission of 26.2%, which is more than the theoretical value. Beheshti el al. [2014], examined the comparison of the flows of $TiO_2$ and $Al_2O_3$ under a circular channel. They found that the rate of heat transmission increases with the NPs' increased volume loading. Blasius [1908], concentrating on several types of magnetic nanoparticles, cobalt ferrite (CoFe2O4) and magnetite (Fe3O4) are combined with water and kerosene as base fluids. A visual representation and discussion of the impacts of several physical factors, including the magnetic field, volume fraction, radiation, and slip conditions, on the flow and heat transfer characteristics are provided. Chandra and Vasudeva Rao, [2013] carried out exploratory analysis to ascertain the heat transmission as well as the ff of $TiO_2$/ethylene glycol water NFs. They discovered that when volume loadingof0.02% of the NFs, when compared with water, the ff as well as the heat transmission convective coefficient has increased significantly. Choi et al. [2012] performed numerical simulation under forced convection heat transmission. Their research has shown that the average Nu number rises when Re and nanoparticle concentration rise. As specific heat has increased, the NFs' heat transport properties have also improved. Demir et al.'s [2022] CFD study on the temperature and velocity contours of water-based $Al_2O_3$and $TiO_2$NFs in a DPHE. Moreover, return bend allows for the highest possible rate of heat transmission in a DPHE. Duan et al [2022] demonstrated on "Experimental and numerical study on heat transfer enhancement by Flow-induced vibration in pulsating flow." The PETB's vibration intensity was increased by the pulsing flow, which also caused the turbulence kinetic energy to rise and the vorticity patterns to change. Consequently, the flow-induced pulsing flow was used to boost passive heat transfer, resulting in a 28%, 25%, and 19.5% increase in the heat transfer coefficient for pulsating flow, coupled flow, and stable flow, respectively. In a DPHE with a return bend, Durga Prasad et al. [2015], investigated the heat transmission and ff of an $Al_2O_3$/water NFs flow and found a 25% gain in heat transmission at 0.03% volume loading and a Re of 22,000. When a pipe fixed with modified twisted tapes was subjected to exploratory as well as CFD investigations on heat transmission and ff characteristics. Esmaeilzadeh et al [2014], concentrated on Heat transmission and friction factor properties of γ-Al2O3/water nanofluid via circular tubes with twisted tape inserts of different thicknesses at constant heat flux were investigated experimentally. The working fluid in this experiment was γ-Al2O3/water nanofluids at two volume concentrations: 0.5% and 1%. Twisted tape maintained a steady twist ratio of 3.21. The average convective heat transfer coefficient was found to be improved by twisted tape inserts; the greatest improvement was attained at maximum volume concentration. Fiebig et al [1995], investigated the "Conjugate heat transfer of a finned tube Part B: heat transfer augmentation and avoidance of heat transfer reversal by longitudinal vortex generators." In the tube wake, there is a noticeable local heat transfer augmentation of several hundred percent when the span-averaged Nusselt numbers for the fin with and without DWP are compared. The global heat transfer augmentation by a DWP, which represents just 2.5 percent of the fin surface, is 31% for Re = 300 and Fi = 200. Ganesan Narendran et al. [2023] reported that in a micro channel heat sink utilized for applications of recovery of waste heat, flow rate and heat recovery efficiency increase by NFs volume loading. When conducting optimization multi-objective in a micro channel heat sink for waste heat recovery applications. Specifically, with GO-0.12% NFs, an utmost efficiency of 66% of heat recovery was achieved for micro channels with ribs. Ganguly et al. [2004] demonstrated on "Heat transfer augmentation using a magnetic fluid under the influence of a line dipole. The heat transfer augmentation using a magnetic fluid while a line dipole is present." They conclude that the equivalent flow is subject to localized magnetic effects. Colder fluid approaches the line dipole due to the local asymmetry in the thermal boundary layer around it and the ensuing spatial nonuniformity of the fluid susceptibility. Thus, a local vortex is created close to the cold wall as a result of the magnetic field. This modifies the flow's temperature distribution, improves heat transmission, and modifies advection energy transport. Gharebaghi et al. [2007] focussed on " enhancement of heat transfer in latent heat storage module with internal fin "On non uniform grids transient simulations have been run for varying fin and PCM layer thickness while maintaining PCM layer to fin thickness ratio. According to computational calculations, the module thermal and geometrical properties such as various wall temperature and fin parameters like spacing, thickness and height determine the phase change time and, in turn the rate of absorption. Gnielinski et al .[1976] carried out experiments on supercritical COR2R in reactors with square as well as triangular array tubes. They reported on the advancements using mesh configurations, turbulence models, and flow channel diameter when simulating supercritical COR2R. The results indicated that supercritical COR2R has a stronger heat transmission impact than the supercritical water when used as a chilled medium, indicating that the former is a better choice in terms of thermal efficiency. The use of porous fins for heat transfer augmentation in parallel plate channels was the main topic of Hamdan et al. [2010] This study primarily shows the how thermal performance of the current flow is affected by Reynolds number, thermal conductivity ratio, Darcy number, thickness of porous fin and microscopic internal coefficient. The finding demonstrates that raising microscopic internal coefficient, lower the darcy number, and using high thermal conductivity fins can all improve heat transmission. Masoud Rahimi et al. [2015] found that the thermal accomplishment of the jagged inserts was 22% and 31% better than that of the classic inserts. In a plate heat exchanger. Huang et al. [2015] investigation looked at the loss in pressure and rate of heat transmission augmentation of MWCNT and $Al_2O_3$/water NFs streams experimentally due to MWCNTNFs' more severe heat transmission rate than that of $Al_2O_3$/water NFs. The goal of Kanti et al. [2021] numerical study on fly ash–Cu hybrid nanofluid heat transfer characteristics was to use STAR CCM+ software to investigate the forced convection heat transfer of fly ash–Copper (80:20% by volume) in a horizontal circular copper tube under a constant heat flux of 7962W/m². The results demonstrate that, at a concentration of 1 vol.%, the hybrid nanofluid's heat transfer coefficient and Nusselt number are raised by roughly 66.0% and 36.67%, respectively, in comparison to water. Kim et al. [2006] studied "Numerical Analysis of Experimental Observations for Heat Transfer Augmentation by Ultrasonic" the experimental conditions inside the water pool with and without ultrasonic vibration were numerically analyzed. Based on these results, it is concluded that an ultrasonic vibration enhances fluid mixing around the heater and thus provides heated surface with fresh water. This has an effect of lowering liquid temperature adjacent to heater surface, and in turn, leads to a heat transfer augmentation. Khoshvaght and Aliabadi [2014] investigated the impact of Re varying from 6000 to 22,000 on different design parameters of sinusoidal corrugated channels in turbulent conditions. In comparison with water, the NFs reach the highest Nu values. The pressure drops for both the NFs and water displayed comparable patterns. Krishna Varma et al. [2018] the overall heat transmission is influenced by the of wall function in a STHE. In contrast to the CFD data with that of the exploratory data in a U-bent DPHE. Krishna Varma et al. [2017] explored the influence of different cut sections and twist ratios (H/D=3) on heat transmission coefficient and Nu. They reported that the cut sections in the twisted tapes enhance the Nu as well as the TPF in a DPHE. Using FLUENT. "Heat Transfer Enhancement of TiO2/Water Nanofluids Flowing Inside a Square Mini channel with a Micro fin Structure. A Numerical Investigation" was the main topic of Kristiawan et al. [2019] In this work, two passive heat transfer enhancement methods utilizing nanofluids and a micro fin structure were combined and numerically examined. Six micro fins (N=6) and TiO2/water nanofluids with different nanoparticle concentrations of 0.005, 0.01, and 0.1 vol.% were present in the SMM employed in this study. SMM was used as a passive heat transfer enhancer in conjunction with nanofluids as working fluids, resulting in a maximum PEC value of 1.2 at Re = 380 with a volume fraction of 0.01 vol.%. The features of the heat transmission investigation on rod-like water/ZnO NFs in regimes of turbulent flow were numerically examined by Lin et al. [2015] They discovered that the ff predominates more in NFs than in water, and that it decreases with the increasing aspect ratio and Re. Madhesh et al.[2014] focussed on "Experimental investigation on convective heat transfer and rheological characteristics of Cu–TiO2 hybrid nanofluids". The heat transfer and rheological characteristics of nanofluids containing Hybrid NC of an averaged size of 55 nm were experimentally investigated. The test results reveal that the convective heat transfer coefficient, Nusselt number and overall heat transfer coefficient were increased by 52%, 49% and 68% respectively, up to 1.0% volume concentration of Hybrid NC. Beyond the volume concentration of 1.0% and up to 2.0%. To enhance the effectiveness in HE's, mono NFs and hybrid NFs were utilized. Similarly, many combinations of the hybrid NFs were explored. According to Maghlany et al. (2016) Cu/water NFs were shown to increase the efficacy and number of transmission units of a twin pipe HE. Higher heat transmission rates were seen. The study "Experimental and CFD studies on heat transfer and friction factor characteristics of a tube equipped with modified twisted tape inserts" was conducted by Masoud Rahimi et al. [2009] They look into the friction factor and Nusselt number of a tube that has three modified TT inserts in addition to the traditional one. The findings demonstrated that the jagged insert outperformed the standard one by a maximum of 31% and 22%, respectively, in Nusselt and performance. Mohammed et al. [2013] analyzed the CFD research examined various equations based on the heat transmission of $Al_2O_3$, CuO, $SiO_2$ as well as ZnO NFs in a DPHE with strip inserts of louvered shape. considering various FVM based equations. Notter et. al. study [1972] used numerical validation in conjunction with empirical correlations that are found in the literature to provide results that were in good agreement. It also showed that the presence of inserts improved heat transmission accomplishment. Energy is the amount of work that a reversible system can perform in a given environment that can be measured. Energy analysis, sometimes referred to as second law analysis, is essential for understanding the thermodynamic behaviour of a heat exchanger thermal performance Most investigations in the literature focus solely on the energy performance of hybrid NFs with various vol. concentration. Petukov group [1970] investigated the turbulent heat transmission and found significant differences in the physical parameters throughout the flow cross section and diffusivity, as well as discrepancies between theoretical and experimental results. When Ravi Kumar et al. [2023] performed the experiments on the thermal properties of $TiO_2$/CuO hybrid NFs, they found that, at a volume loading of 0.05%, the NFs' thermal conductivity has raised by 65.8% compared to the base fluid water. They have found that their density and dynamic viscosity has increased. It was discovered that when the volume loading increased, their specific heat decreased. The work carried out by Ravi Kumar Mande et al. [2021] examined the synthesis, characterisation, and possible importance of thermal properties in heat transmission applications. They have proposed recommendations for the approaches that should be used when utilizing hybrid NFs in important heat transmission-related sectors. Ravi Kumar Mande et al. [2024] focussed on Augmentation of heat transfer in a DPHE with bowl cut twisted tape inserts and $TiO_2$/CuO hybrid nanofluids, the bowl-cut with hybrid NFs was found to be 83.35, 115.31, and 172% for hybrid NFs, Nu.no has been enhanced by 66.09%. Rao and Reddy [2014] used volume loading of 0.02%. 40:60% of ethylene glycol was combined with water and $TiO_2$NFs were developed. At a Reynolds number of 15,000, the flow in a twin pipe HEX was evaluated. Heat transmission and ff enhancement were seen to be increased by 10.73% and 8.73%, respectively. The investigation of turbulent convective heat transfer and pressure drop of TiO2/water nanofluid in circular tube" was the main focus of Sajadi et al. [2011] When the volume percentage of nanoparticles in the base fluid was less than 0.25%, the experimental investigation of the turbulent heat transfer behaviour of a titanium dioxide/water nanofluid in a circular pipe was conducted. The current correlations for the nanofluid convective heat transfer coefficient in the turbulent domain have been compared with the experimental data. Finally, using the findings of the tests with titanium dioxide nanoparticles dispersed in water, a novel correlation of the Nusselt number will be provided. According to Syam Sunder and Mesfin [2021] integrating nano diamond+ $Fe_3O_4$/water-EG hybrid NFs increased the Nusselt's number than the reference fluid, which raised the frictional entropy generation by 272.5% at 0.2% vol. concentration. Additionally, analyses evaluating the energy and entropy of NFs have been found, demonstrating that NFs have a higher energy efficiency than their base fluids. In an experiment on improving the thermal performance in a DPHE using $CeO_2$NFs, Sreenivasulu Reddy et al. [2023] found that there is a rise in Nu and ff at a particular Re in contrast to the water. According to Sreenivasulu Reddy et al.'s analysis [2023] of experimental and CFD investigation of thermal analysis of DPHE using $CeO_2$, they observed, a moderate increase in pressure. The average rise in Nu for 0.3% and 0.2% $CeO_2$ was 43.35% and 30.13%, respectively. Varun et al. [2016] noted that greater advancements in heat exchanger technology will result from ongoing research into twisted tapes. Xuan et al. [2003] focussed on "Investigation on convective heat transfer and flow features of nanofluids" both the convective heat transfer coefficient and friction factor of the sample nanofluids for the turbulent flow are measured. The effects of such factors as the volume fraction of suspended nanoparticles and the Reynolds number on the heat transfer and flow features are discussed in detail. A new type of convective heat transfer correlation is proposed to correlate experimental data of heat transfer for nanofluids. "Numerical and experimental investigations on the thermal performance of a borehole ground heat exchanger with PCM backfill" was presented by Yang et al. [2019]. Investigations of the BGHE's experimental performance in both summer and winter modes have been carried out. According to the findings, in the summer and winter modes, the soil thermal interference radius with PCM backfill is approximately 86.5% and 87.8% of that with soil backfill, respectively. When Yang et al. [2022] examined a CFD investigation on the heat transmission of supercritical $Co_2$ based NFs, they found that the optimal augmentation of heat transmission for these NFs was 51.4%. Convective heat transmission was also as a result of lower specific heat and improved thermal conductivity of the NFs. Increased wall function with field variable close to the wall is pivotal in heat transmission pattern analysis. In Zamzamian et al. [2011] they analysed the effect of $Al_2O_3$ and CuO NFs with ethylene glycol in a DPHE. They found that the heat transmission was enhanced by 26% and 37%, respectively, for a weight fraction of 1.0% of $Al_2O_3$ and a for a weight fraction of 1.0% of CuO in the DPHE and by 38% and 49%, for plate HEs. considering various FVM based equations. In an experimental study on flow characteristics.

From the literature, it was found that numerical investigations on various types of twisted tapes like full length twisted tape, short length twisted tape, twisted tapes with winglets, cut twisted tapes etc. These twisted tapes enhance the heat transfer by either interrupting the flow or by creating swirl or by creating turbulence inside the tubes of the heat exchanger. They also enhance the heat transfer by reducing the thermal boundary layer. But each modification in the twisted tape geometry either on the periphery on the axial areas or by creating perforations on the geometry of the twisted tapes. Some of the researchers tried to enhance the heat transfer using cuts on the periphery of the twisted tapes. Various types of shapes of cuts are used in the literature. Various cut shapes like rectangular, triangular, trapezoidal, semi-circular shapes of cut were utilized and considerable enhancement in the heat transfer has been achieved. But these shapes of cut are regular sections and provide considerable turbulence in the tubes of the heat exchangers. But in order to create more turbulence in addition to the swirl generation inside the tubes, variable cross sections of cut are required. In this work, bowl cut twisted tapes of variable cross section are considered to enhance the rate of transfer of heat in the double pipe heat exchanger. Hence the objective of this work is to determine the Nusselt number, friction factor and thermal performance factor of the double pipe heat exchanger fitted with bowl cut twisted tapes. Moreover, in the literature, various parameters of twist tapes like twist ratio, clearance ratio, width ratio are considered for the analysis. In this work, a new parameter called scale ratio is considered into account. In addition to this, compound methods enhance the rate of heat transfer in a better manner compared to other techniques of enhancement of heat transfer. Hence $TiO_2$/CuO Hybrid Nano Fluids are also circulated along with the bowl cut TT to enhance the heat transfer in a better manner with the combined effect of bowl cut TT and TiO2/CuO Hybrid Nano Fluids. Also, it is aimed to study the effect of the scale ratio of the bowl cut TT on the heat transfer and friction factor characteristics.

## 2 Physical Model

Using the commercial software ANSYS 2022r1, numerical analysis was performed on a DPHE equipped with bowl cut TT with constant twist ratio (H/D=3) and changing scale ratios 25%, 50%, and 75% of the width. The Re's' range varied from 2000–12000.The DPHE's three-dimensional geometrical model is shown in Fig.1. After being created in solid works, this model was imported into ANSYS. Tetrahedron elements were used for meshing. A randomly organized mesh was produced. The meshed model of the bowl cut TT inserted in the tubes of the heat exchanger is shown in Fig.2. At the heat exchanger's departure section, three-dimensional models of the bowl cut TT with varying scale ratios 25%, 50%, and 75% of the diameter are created and placed inside the DPHE tube. The aim of this is to intensify the heat exchanger's heat transmission rate. The geometrical parameters are as follows: material (Al), length (L), width (D) of the tube, thickness (t) of the tape, and twist ratio (H/D=3).

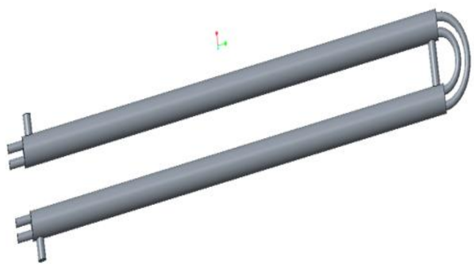


Fig. 1. Geometrical model of the DPHE

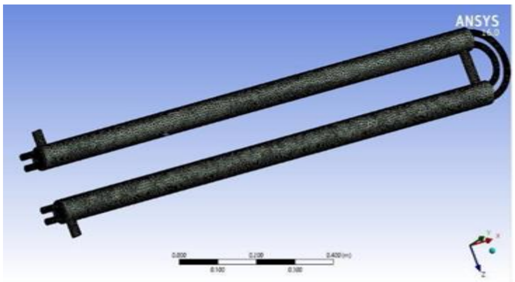



Fig. 2. Meshed model of the bowl cut TT

## 3 Bowl- cut geometry

Fig.3. illustrates the numerical model of the simple tube inserted with bowl cut TT with a twist ratio of 3. The TT is 1meter long and 15 mm wide. The detailed view of the numerical model of the bowl cut TT are displayed in Fig.4. Details of the DPHE are pivoted in Table.1. An essential component of energy conversion and storage is the thermal amplification of heat transmission. The method of passive technique i.e., introduced twisted tape, roughness elements; wire coil inserts etc. are the best method of thermal performance augmentation. In the present analysis, thermal performance augmentation using bowl- cut TT (H/D=3) insert has been carried out with varied scale ratios of 25%,50% and 75% of D numerically. Table.2 shows the input parameters used in the bowl cut geometry.

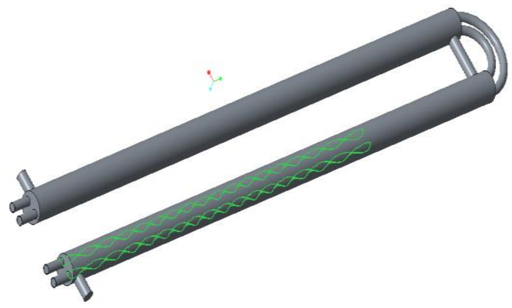


Fig. 3. Numerical model of the DPHE with bowl cut TT

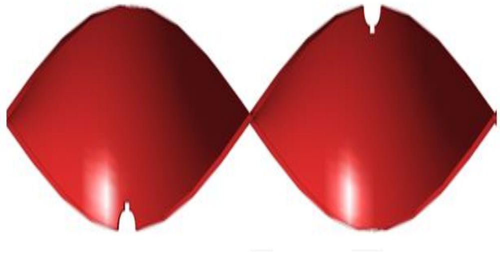


Fig. 4. Detailed view of the bowl cut TT

**Table 1 Details of double pipe heat exchanger**

| Specifications of the heat exchanger | Value/name |
|---|---|
| Material of Inner tube | Copper |
| Material of Outer tube | M.S |
| Inner tube ID in mm | 17 |
| Inner tube OD in mm | 19 |
| Outer tube ID in mm | 60 |
| Outer tube OD in mm | 63 |
| Cold water inlet temperature | $30^0$C |
| Hot water inlet temperature | $60^0$C |

**Table 2 Input parameters used in bowl-cut twisted tape**

| Constraints | Value/ name |
|---|---|
| Total Length of the twisted tape | 1000mm |
| Material of the Twisted tape | Al |
| Thickness of Twisted tape | 1.5mm |
| Width of Twisted tape (D) | 15 mm |
| Pitch of the Twisted tape (H) | 45mm |
| Twisted ratio (H/D) | 3 (25%,50% and 75% D) |

## 4 Mathematical Model

Numerical simulations were conducted utilizing ANSYS 2022r1. Table.1 depicts the specifications of the hot as well as the cold fluids at the outflow and the inlet. The shell's walls are thought to be adiabatic. For improved domain accuracy, the k-ε turbulence model and three conservation equations are used in the numerical simulation. Curvature correction was applied to improve performance and to prevent issues caused by low Reynolds numbers. The diameter of the tube determines the Re, which varies between 2000 and 12000. The Re is kept constant inside the heat exchanger's shell. The criterion of convergence was set at $10^{-6}$ for the energy equation and at $10^{-5}$ for the equations of continuity as well as the momentum. These standards are followed as per Yang et al. [42]. 3D geometry models were developed in ANSYS Work Bench for simulation. purpose. Grid selection was based on the steady state approach's pressure-based solver which is allowed for convergence. The turbulence in the pipe was modelled using the conventional k-ε model. It is a type of turbulence model which relies on the Reynolds averaged Navier Stokes (RANS) model, when the heat dissipation rate (ς) and turbulent kinetic energy (k) are given. Turbulence kinetics is associated with the heat dissipation rate. The heat dissipation rate is correlated with turbulence kinetic energy and is depicted in Eq. (1). This can be represented as

$$\varepsilon = K^{3/2} / L_t \quad (1)$$

where $L_t$= turbulent length. The temperature gradient of the pipe is determined by the simulation, and the quantity of loss of heat within the pipe system is computed based on the difference in the enthalpy between the hot as well as the cold fluid at the intake and outlet, respectively.

## 5 Boundary conditions and Governing equations

Boundary conditions are provided to the model at the entrance and outlet. Two tubes are designated as the inlets. Other two tubes are designated as the exits of the counter flow heat exchanger. Table.3 contains a tabulation of the boundary conditions. Except for the tube wall, no slip (q=0) is taken into account for all the walls. The governing equations of continuity and momentum, which are used to analyse heat transmission under turbulent flow field in a circular DPHE inserted with bowl cut TT, are established based on the mentioned hypotheses. The convergence criterion for the continuity and momentum governing equations is set at $10^{-5}$, whereas the equation of energy is fixed for 3D at $10^{-6}$. The flow is regarded as turbulent, steady state, and incompressible. The RANS (k-ε) turbulence model featuring wall functions is chosen to investigate DPHE integrated with bowl cut TT insert numerically. Eq. (2) shows the governing equations of continuity, Eq. (3) and Eq. (4) shows momentum and energy.

Continuity Equation (2)

$$\frac{\partial}{\partial x_s}(\rho U_s) = 0$$

Momentum Equation: (3)

$$\frac{\partial}{\partial x_s}(\rho U_s U_t) = \frac{\partial}{\partial x_s}\left(\mu \frac{\partial U_t}{\partial U_s}\right) - \frac{\partial P}{\partial x_t}$$

Energy Equation: (4)

$$\frac{\partial}{\partial x_s}(\rho U_s T) = \frac{\partial}{\partial x_s}\left(\frac{K}{C_p}\frac{\partial T}{\partial x_s}\right)$$

Where ρ is density of water, U is component of velocity, P is pressure, μ is dynamic viscosity, Cp is specific heat, K is thermal conductivity of the fluid and T indicate temperature of the fluid. Subscripts s and k indicate the direction towards s and k. The computational domain in the current analysis is chosen based on the flow rate as well as pressure drop at the boundary condition. It is assumed that a uniform mass flow rate at a temperature of $303^0$K enters the tube at the inlet, and that the wall temperature on the annulus side remains constant at $333^0$K. Heat transmission between the fluid and the bowl cut is minimal since the bowl cut TT is submerged with an adiabatic boundary condition. On the bowl cut TT insert, no slip velocity conditions are applied across the tube wall as well as surface. At the typical bulk temperature, the physical characteristics of water stay unchanged, and the effects of gravity and radiation are to be minimal.

**Table 3 Tabulation of boundary conditions**

| Boundary conditions | Annulus | Tube |
|---|---|---|
| Inlet mass flow rate | 6 LPM | 3-15 LPM |
| Temperature | $60^0$C | $30^0$C |
| Shell and tube | Adiabatic | Diathermic |
| At wall side | No slip | No slip |

## 6 Numerical methods

### 6.1 Grid Independency study

Independence study chooses five distinct grid sizes 8,90,200; 10,20,231; 16,31,399; 39,75,665; and 60,52,473 to determine the ideal size grid. Application of the grid sensitivity study is applied to the base fluid for a flow rate of 3LPM. The hot as well as cold liquid temperatures in a HE is displayed in Fig.5 in relation to the grid sizes. Analysis of the temperature deviation was done with a maximum of 60, 52,473 of grid size. According to a grid research, the cold and hot fluids have smaller deviations of 0.28% and 0.38%

when using a grid size of 39, 75,665. Hence this 39, 75, 665 grid size of is considered for the numerical analyses because of its reduced variances.

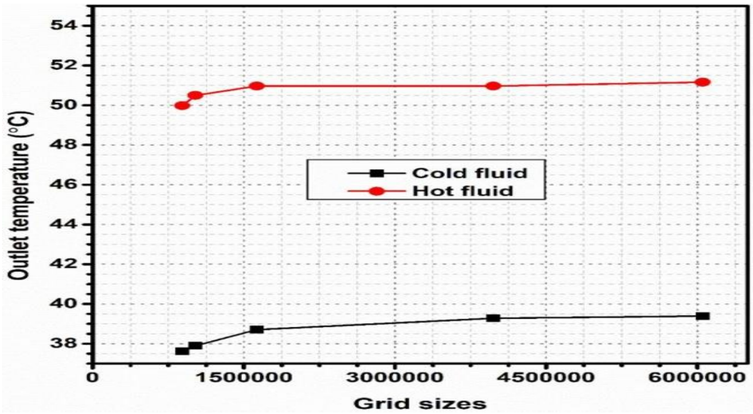



Fig.5. Grid independency study

6.2 Fluid flow phenomenon through bowl-cut twisted tape insert

Fig.6 displays the flow direction schematic produced by bowl-cut TT insert at Re ranging from 2000 to 12000. Additionally, the swirl flow produced by the bowl cut TT, the bowl cut TT creates vortex flow. At the tube wall, the fluid from the core region is pushed outward to combine with the cold liquid. Between the wall and the centre sections, the fluid is mixed by this extra flow turbulence. In contrast to a plain wall, the bowl cut TT insert increases the heat exchanger's thermal performance and rate of heat transmission. The various flow phenomenon to be considered into account are the viscous nature of the hybrid NFs when compared to the base fluid. Other aspect to be considered is the modification in the geometry of the bowl cut TT for the generation of the turbulence. Moreover, the combined effect of the hybrid NFs and the bowl cut TT is the utmost priority to attained thermal performance. Due to the increase in the concentration of the hybrid NFs, the thermal conductivity has increased. But this will also enhance the viscosity. This in turn increases the shear stresses at the wall regions and fluid molecules. But this in turn increases the chaotic motion and thus also increases the Brownian motion in the hybrid NFs. This tends to increase the overall heat transfer coefficient. But also tends to increase the pressure drop and thus in turn increases the friction factor. On the other hand, the TT obstructs the fluid flow and thus increases the retention time. Moreover, in addition they create the swirl flow and turbulence in the tubes of the heat exchangers. This turbulence and swirl flow enhances the rate of heat transfer in the tubes. Also, the bend in the heat exchanger also creates some pressure drop in the tubes of the heat exchanger. The bowl cut in the TT generates more turbulence because of the variable section and curvatures in the section. These TT also reduce the centreline velocity and the thermal boundary layer.

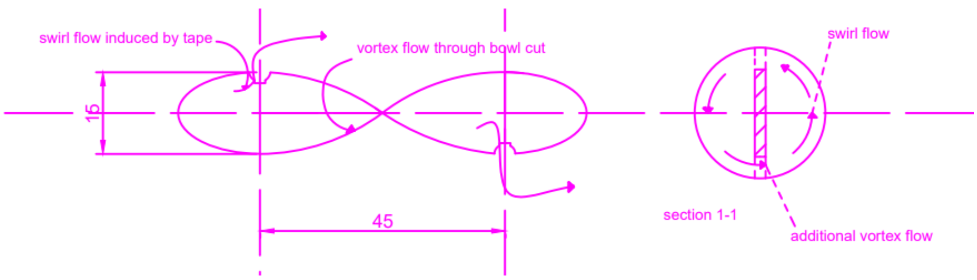



Fig. 6. Fluid flow phenomenon in the bowl-cut twisted insert tape

6.3 Validation study

Fig.7 depicts the Nusselt number validation of the numerical data of the plain tube. Additionally, the current findings are contrasted with the classical Gnielinski [14] and Notter Rouse [29] correlations. In contrast to Gnielinski [14] and Notter Rouse [29]. The average deviation of Nu of water derived from the numerical is around 9.97%, and 5.75% respectively with that of the Gnielinski [14] and Notter Rouse [29].

Fig.8 depicts the comparison of Numerical friction factor with that of the correlations of Petukhov [30] and Blasius [3]. It was found that the Numerical friction factor of water has a deviation of 7.85%and 11% respectively with that of the data of Petukhov [30] and Blasius [3] Similarly, the numerical Nusselt number and friction factors of the hybrid nanofluids data was compared with the data of Sajadi and Kajemi [35] and Madesh et al. [25].

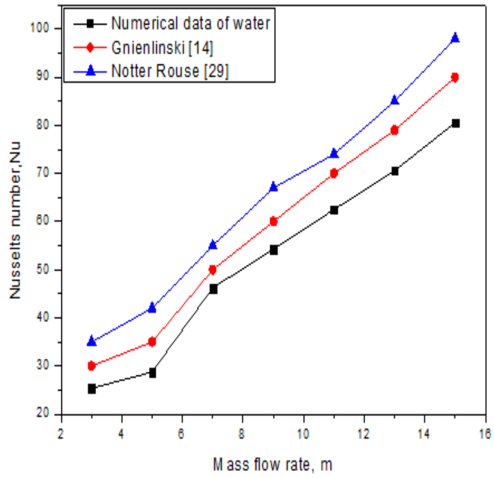



Fig 7 Validation of Numerical Nusselt number correlations of Gnielinski [14] & Notter Rouse [ 29]

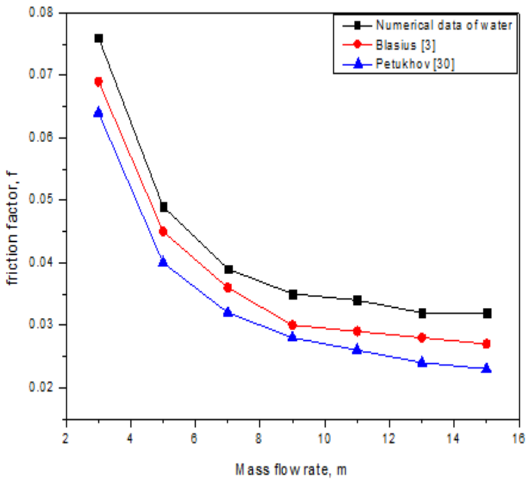


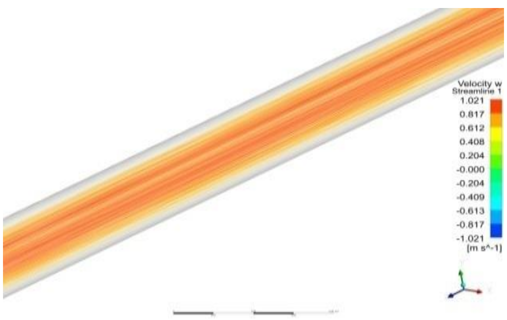

Fig.8 Validation of Numerical ff with correlations of Blasius [3] & Petukhov[30]

## 7 Results and Discussion

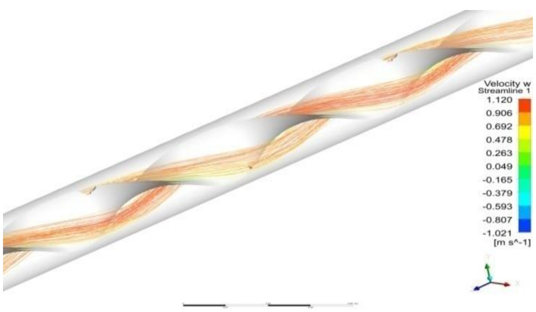
7.1 CFD Contours in plain wall as well as bowl cut TT (H/D=3) with 15LPM

7.1.1 Stream line fluid flow in a tube

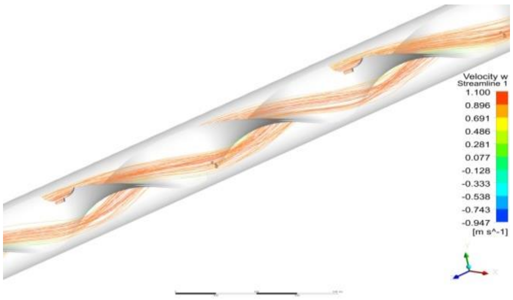
Stream lines of the fluid flow for were depicted using the contours in a U-bent DPHE of plain tube as well as the bowl cut TT at varying scale ratios of 25%, 50%, and 75% of width (D) from the centre of the bowl cut under turbulent flow condition, when Re ranged from 2000 to 12000. It demonstrates that the simple tube only creates axial flow throughout the pipe's length. The swirl flow produced by the bowl cut TT enhances the re-circulating flow between the heat exchanger's centre and walls. Additionally, it creates a turbulent flow in the pipe that transmissions heat in radial direction. It was observed that the swirl creation increased at the bowl cuts and it grew as the scale ratio increased. In the case of the plain tube, it was also noted that the stream lines are almost appear parallel to the tube's axis. But in the case of the bowl cut TT insert, the stream lines follow to the path of TT and also the peripheries of the bowl cuts at the cut regions as shown in Fig. 9.



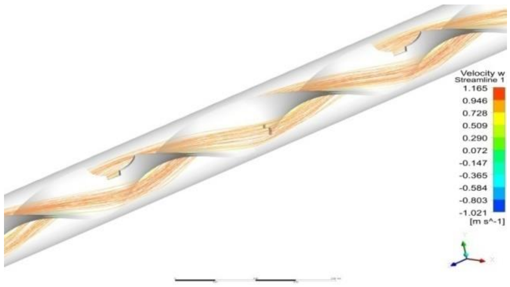

a. Plain tube




b. Bowl cut TT (25% of D)




c. Bowl cut TT (50 % of D)

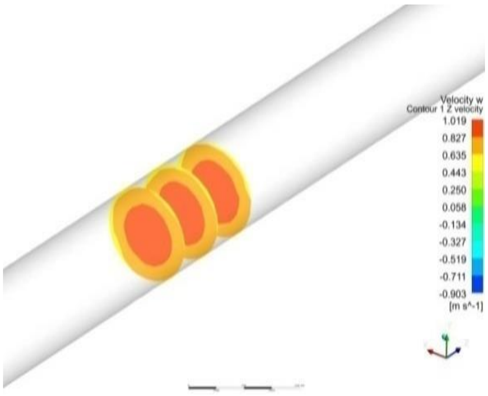



d. Bowl cut TT (75 % of D)

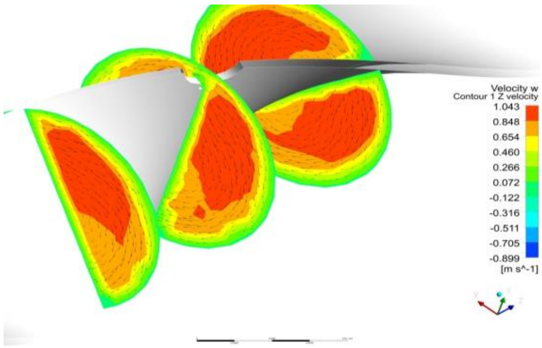
Fig. 9. (a-d) Steam line fluid flow in a tube

7.1.2 Velocity contours in a tube

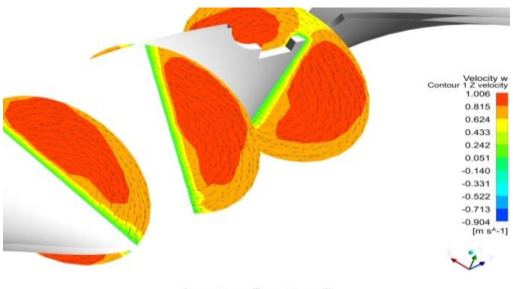
The velocity contour plots, which are displayed in Figure 10. were created in plain tubes and scale ratios of 25%, 50%, and 75% of bowl cut TT with (H/D=3) at 15LPM. It is evident that the swirl flow is being produced by an axial velocity that mixing. The enhancement of heat transport is the outcome of this. The retention duration is lengthened by the bowl cut TT because it lowers the fluid's velocity. The centre line velocity is likewise decreased by the bowl cut TT. Consequently, the fluid flow is reduced and its heat transfer coefficient increases. The bowl cut TT (H/D=3) and the plain tube's velocity contours make this quite visible. It was observed that the decrease in the fluid flow 's velocity of the results in the rise in the turbulence is greater in the core region.



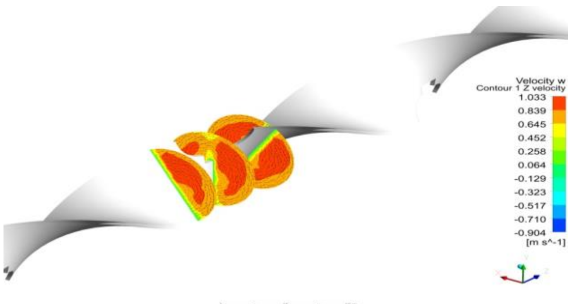

a. Plain tube




b. Bowl cut TT (25% of D)




c. Bowl cut TT (50% of D)

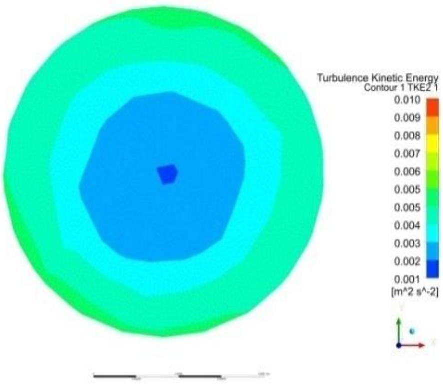



d. Bowl cut TT (50% of D)

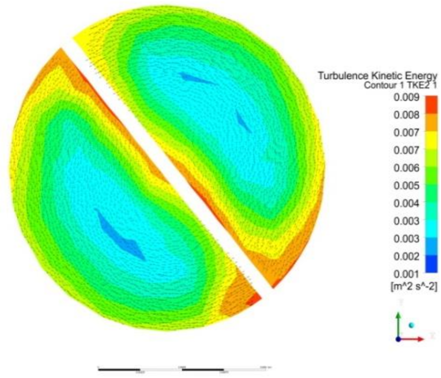
Fig. 10. (a-d) Velocity contours in a tube

7.1.3 Turbulent kinetic energy

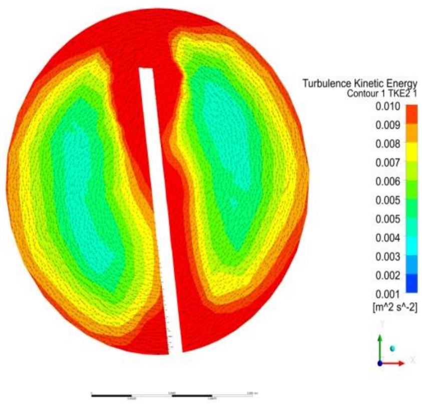
Fig. 11. displays the contour plots of the turbulent kinetic energy of plain tube as well as bowl cut TT (25%, 50%, and 75%) of width (D) from the centre of bowl-cut with a twist ratio (H/D=3) at a mass flow rate of 15LPM. The TKE contours aid in comprehending the flow pattern for varying bowl cut and twist ratios, because the size of the bowl cut contributes to turbulence. It is evident that the swirl flow resulting in the existence of a thermal boundary layer causes the TKE near the wall pipe to be significantly bigger than the insert tape wall. However, by varying the bowl cut TT, scale ratios, the turbulence creation is enhanced, leading to improvement of heat transmission. This is clearly evident from the contours of the plain tube as well as for different scale ratios of bowl cut TT.



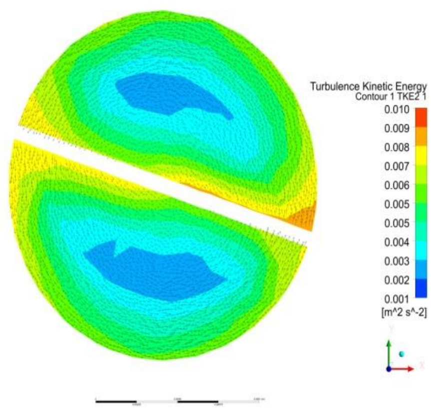

a. Plain tube




b. Bowl cut TT (25% of D)




c. Bowl cut TT (50% of D)




d. Bowl cut TT (75% of D)

Fig. 11. (a-d) Turbulent kinetic energy in a tube

7.1.4 Out let temperature of cold and hot fluid

In a DPHE, the heated liquid exits at the outlet of the shell and the cold fluid exits at the tube's outlet. While the cold fluid's flow rate is adjusted between 3LPM and 15 LPM, the hot fluid's flow rate is kept steadily at 6LPM. The effects of mixing of $TiO_2$/CuO hybrid NFs with cold liquid at volume loading of 0.01%, 0.03%, and 0.05% have been investigated. Due to an increase in the temperature of the base fluid, it was observed that heat carrying capacity of hybrid NFs increases with the augmentation in volume loading. The hybrid NFs thermal conductivity rises with increasing vol. concentration. It has also been observed that when the cold liquid's flow rate increases, the outflow of the liquid reduces. As a result, the time needed to extract the hot liquid's heat is minimal at greater flow rates. When the concentration of hybrid NFs flows in the heat exchanger shell increased, the hot liquid's temperature at the shell side's outlet decreased noticeably.

7.1.5 Overall heat transmission coefficient ($U_i$)

The numerical analysis of Ui vs Re for different volume loadings of $TiO_2$/CuO hybrid NFs using water as the base fluid was investigated and is shown in Fig. 12. According to Ui's numerical data, the lowest value for water is greater for $TiO_2$/CuO hybrid NFs at 0.05%, whereas the lowest value is found in 0.01% and 0.03% $TiO_2$/CuO hybrid NFs. Ui value increases as Re and volume loading of hybrid NFs climb at a certain mass flow rate of hot as well as cold fluids. In comparison to plain walls, the average augmentation of Ui for $TiO_2$/CuO hybrid NFs with bowl cut TT for CFD numerical analysis was determined to be 38.94%, 36.37%, and 33.50% for 0.05%, 0.03%, and 0.01%. The Overall heat transmission coefficient, $U_i$ is assessed using Eq. (5). The reason for the increase in the overall heat transmission coefficient is attributed to the increase in the thermal conductivity of the base fluid with TiO2/CuO hybrid NFs. This increase in the thermal conductivity tended to a more absorption of the heat by the hybrid NFs. This greater absorption capacity of the $TiO_2$/CuO hybrid NFs resulted in the reduction of heat from the hot fluid and thus resulted in the enhancement of the heat transfer and thus enhancement in the overall heat transfer coefficient. This phenomenon is also due to the combined effect of the increase in the thermal conductivity and viscosity with the increase in the vol. concentration of the hybrid NFs [43]. Since the analysis was carried out in a DPHE fitted with a U bend, the mixing of the hybrid NFs was not that efficient at the inlet and exit of the tubes. But before entering, in the bend region and at the exit of the bend region, the chaotic mixing of the hybrid NFs takes place which results in the Brownian motion. Because of this also, the heat transfer performance has increased with the increase in the overall heat transmission coefficient. The Nusselt number (Nu) is analysed using by the Eq. (6).

$$Ui = \frac{Qavg}{Ai.(\Delta T)LMTD} \tag{5}$$

$$Nu = \frac{hi.di}{khnf} \tag{6}$$

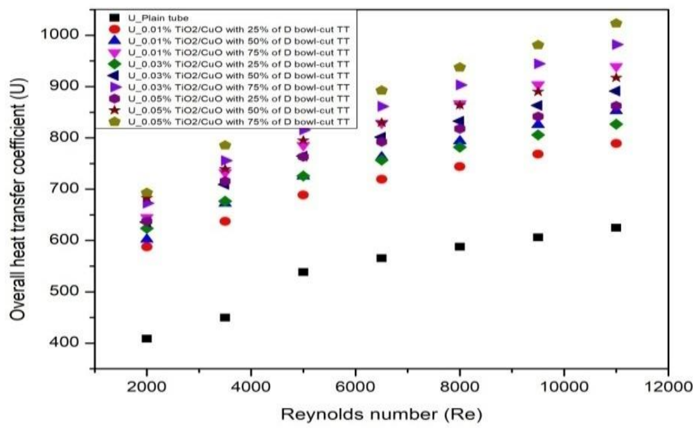



Fig. 12 Numerical Overall heat transmission coefficient for various $TiO_2$/CuO hybrid NFs with TT and base fluid

7.1.6 Nusselt number

The results (numerical) of Nu for base fluid and different vol. concentration of hybrid NFs with different Re are displayed in Fig. 13. It is noted that when Re rises, Nu also has increases, when compared to the base fluid and 0.01% and 0.03% 0.05% vol. concentrations of hybrid NFs. The highest value of Nu was attained by 0.05% of $TiO_2$/CuO hybrid NFs in numerical simulation. Due to the enhanced thermal conductivity that results from increasing the vol. concentration of NFs, more heat is absorbed on the shell side of the DPHE. According to the data, the improvement in Nu with bowl cut TT for 0.05%, 0.03%, and 0.01% of $TiO_2$/CuO was 65%, 63% and 55% in comparison to base fluid water. This was found to be 12%, 9%, 7% higher than the work carried out by Krishna Varma et al. [22], where they have used ferric Oxide nanofluids. The reason for the enhancement in the Nusselt number for the above cases is the thermal conductivity of the $TiO_2/CuO$ hybrid NFs is greater than the base fluid. Moreover, the micro convention and the increase surface area of the $TiO_2/CuO$ hybrid NFs results in the increase in the thermal conductivity and thus the enhancement in the Nusselt number

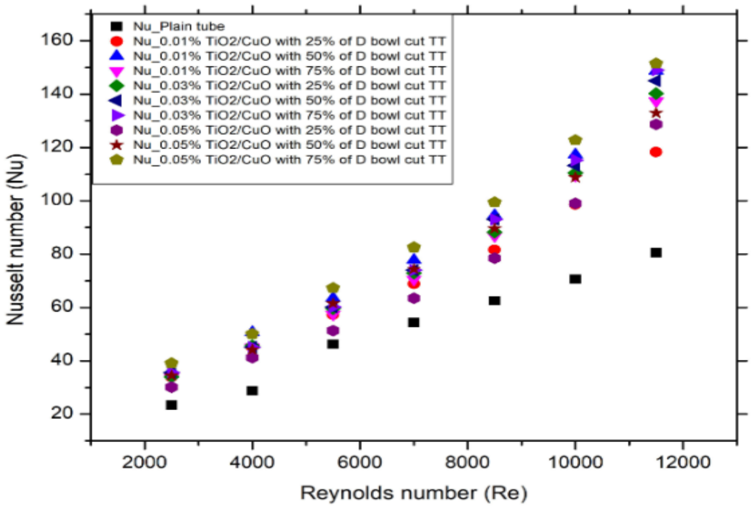



Fig.13 Numerical Nusselt number for various $TiO_2/CuO$ hybrid NFs with TT and base fluid

### 7.1.7 Friction factor

Fig.14 depicts the numerical study of the ff in a DPHE for water and various vol. concentration of hybrid NFs under varied mass flow rate. It is noticed that the ff rises as the vol. concentration of $TiO_2/CuO$ hybrid NFs grows. But it decreases while the mass flow rate increases because the vol. concentration of hybrid NFs has a higher viscosity, which increases the frictional resistance. At 0.05% $TiO_2/CuO$ hybrid NFs and inserted with 75% of d bowl cut TT, the ff is 1.58 times greater than the plain tube. The ff is computed with the Eq. (7). This value is 0.39 times less than the work carried out by Sreenivasulu Reddy et al. [38]. The reason for the increase in the friction factor is vol. concentration of the $TiO_2/CuO$ hybrid NFs increases, the pressure drops increases and this in turn increases the friction factor. Also, the increase in the vol. concentration of the $TiO_2/CuO$ hybrid NFs increases the fluid friction with walls of tubes of the heat exchanger. This increases the fluid friction as well as the friction between the hybrid NFs and the walls. This could be attributed to higher velocity boundary layer of the bulk fluid.

$$f = \frac{\Delta p}{L/di(\rho v2/2)} \tag{7}$$

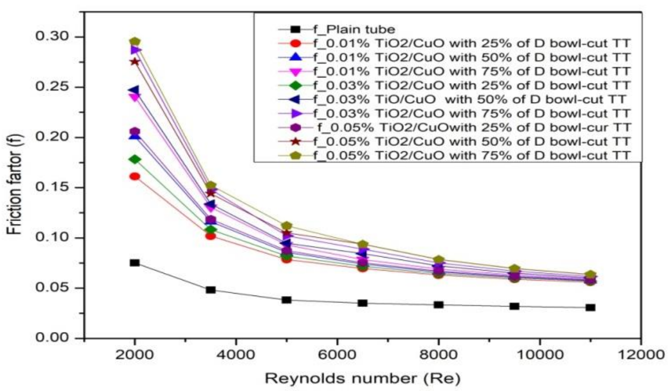



Fig. 14 Numerical friction factor for various $TiO_2/CuO$ hybrid NFs with TT and base fluid.

7.1.8 Thermal Performance factor (TPF)

The expression for the TPF is given by Eq. (8). The outcomes of TPF with Re for various vol. concentration of hybrid NFs with water in Fig.15. It is noted that for every fluid vol. concentration taken into account, the performance factor values are determined to be more than 1. The CFD analysis of 0.05% TiO2/CuO with bowl cut TT (H/D=3) yielded a maximum TPF value of 2.3 at a flow rate of 15LPM within the 2000–12000 range of Re, which is higher than that of Srinivasulu Reddy et al. [38]. The Figure.15 for all $TiO_2$/CuO hybrid NFs with bowl-cut (H/D=3) TT insert is more than unity, indicating that $TiO_2$ /CuO+ water are advantages in improving the overall performance regardless of increasing friction factor in the range of turbulent flow. The maximum TPF values for 0.05% ,0.03% and 0.01% $TiO_2$/CuO hybrid NFs are 2.3, 1.7 and 1.2 respectively for the Reynolds number of 11000 respectively. Furthermore, the total relative average error between experimental and numerical results is 15.21% in that Re range.

$$\text{TPF} = \frac{(Nui/Nubf)}{(fi/fbf)1/3} \tag{8}$$

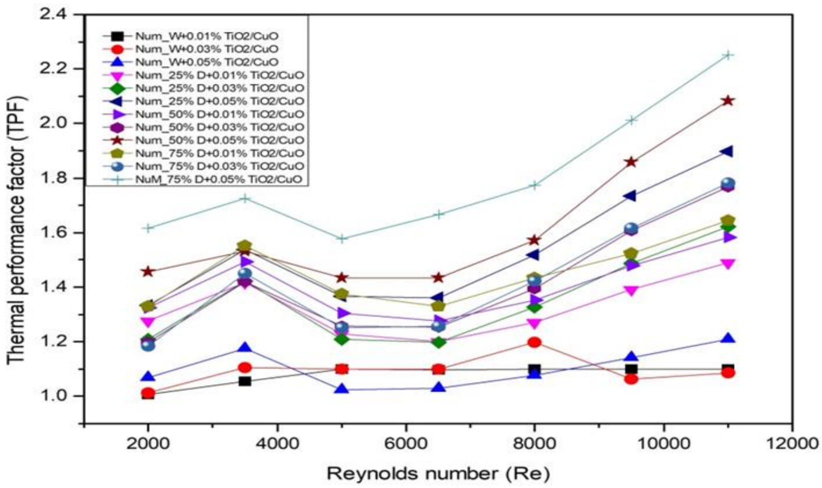



Fig.15. Numerical thermal performance factor for various $TiO_2$/CuO hybrid NFs with TT and base fluid

## 8.Entropy generation and Bejan number

The thermal and frictional entropy generation is mainly responsible for the total entropy generation of hybrid NFs/ base fluid and can be characterized by Eq. (9) and Eq. (10) and Eq. (11) respectively

$$S_g = S_{g,th} + S_{g,f} \tag{9}$$

$$S_{g,th} = \frac{Q^2{}_{avg}}{Nu \times \prod \times k \times T_{in} \times T_{out} \times L} \tag{10}$$

$$S_{g,f} = \frac{8 \times f \times m^3 \times L}{\rho^2 \times \prod^2 \times d^5{}_i \times (T_{out} - T_{in})} \times \ln(\frac{T_{out}}{T_{in}}) \tag{11}$$

Where $S_g$, $S_{g,th}$ , $S_{g,f}$ entropy generation, total entropy generation due to thermal and frictional factors. The heat transfer and fluid friction significantly contribute to the entropy generation inside the tube. The Bejan number (Be) measures the relationship between the irreversible heat transfer in thermal entropy generation and the overall entropy generation and is given by Eq. (12).

$$Be = \frac{S_{g,th}}{S_{g,th} + S_{g,f}} \tag{12}$$

## 9 Conclusions

Numerical analysis was carried out on a DPHE with $TiO_2/CuO$ hybrid NFs of different vol. concentrations (0.01 to 0.05%) with bowl cut TT of different scale ratios (25% to 75%). The mass flow rates of the cold fluid were varied from 3LPM to 15 LPM. The entire analysis was carried out in the turbulent flow regime. The following conclusions are drawn from the analysis and is presented below:

- The Overall heat transmission coefficient ($U_i$) has drastically increased when compared to the water. In this contrast, the improvement of $U_i$ were found to be 38.94%, 36.77% and 33.50% higher for concentration of hybrid NFs 0.05%,0.03% and 0.01% $TiO_2/CuO$ with bowl cut TT respectively.
- Nusselt number has increased with higher value of Re for $TiO_2/CuO$ hybrid NFs. However, the improvement of Nusselt number of 0.05%, 0.03% and 0.01% $TiO_2/CuO$ with 75% of D bowl cut TT is found to be 65%, 63% and 55% more comparatively to base fluid at Re= 2000 to 12000 respectively.
- Hybrid NFs achieved a notable improvement in heat transmission in contrast to the base fluid with the help of $TiO_2/CuO$. Although the thermal conductivity of hybrid NFs improves with a rise in volume, the heat transmission is found to be 32.9%, 30.87%, and 28.58% higher than that of water, with a corresponding pressure drop.
- While, analysing the thermal performance factor (TPF) increases abruptly with $TiO_2/CuO$ hybrid NFs volume loading. However, the maximum value of TPF is 2.3 achieved with flow rate at 15 LPM through 0.05% $TiO_2/CuO$ hybrid NFs with bowl cut TT(H/D=3) insert in CFD numerical computation.

### Authors' Contributions

M. Ravi Kumar: From Planning to correspondence. A. V. Sita Rama Raju: Planning, review of work, proof reading.

### Disclosure statement

The authors declare no conflict of interest

.

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