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PREDICTION THE THERMAL AND HYDRODYNAMIC PERFORMANCE OF NANO FLUIDS FLOW IN A TUBE COUPLED WITH DOUBLE TWISTED TAPE

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ABSTRACT

In this study, the fluid flow of the Al_2O_3 nano fluid in a horizontal pipe equipped with twin twist tape insert has been numerically studied. Different values of twisting ratio (y/w) of 2, 4 and 6 with volume concentration (φ) of 0.5% and 4 % are investigated under Reynolds number range of 5000 to 35000. The object of this project is to augment the transfer of heat in a tube by employing the combined influence of double twisting tape with nano fluid. The Navier - Stockes and energy equations as well to the turbulence model are desired for modeling this physical problem. ANSYS Fluent code is utilized to gain the results. The numerical consequence explained that the Nusselt number (Nu), friction factor (f), and overall thermal performance factor raises as twisting ratio decreases. The results also display that the twin twisting tape more effective than a plain tube for heat transfer augmentation. This increase is improved with increasing volume concentration.

Keywords: twin twisted tape, CFD, nano fluids.

INTRODUCTION

Several heat transfer improvement techniques has been accomplished by re arranging of geometry, alteration fluid of cooling, inserting whirl producer etc. The techniques of heat transfer upgrade are strong tools to raise heat transfer rate (HTR) and thermal performance as well as to minimize of the size of heat transfer system in installing and working costs [1]. In general, the methods of heat transfer enhancing classified into active and passive techniques. The passive method greatly attracted the attention of the researchers and engineers due to its ease of installation and lower cost. A main and beneficial way of passively enhancing the amount of heat transfer in tubes is to utilize a nanofluid. A nanofluid refers to the fluids which containing solid, and mostly metallic, particles smaller than 100 nanometers. The nano sized particles raise the thermal conductivity of the mixture and thus increases the heat transfer rate. This property has be attracted to the attention of researchers. [2, 3, 4]. Furthermore, a significant collection of devices applied in passive method is eddy flow devices such as twisted tape. These equipments produce secondary flows on axial flow leading to an increase of turbulent fluctuations. This permits a better mixing of fluid inside a heat exchanger tube and subsequently reduces a thickness of the boundary layer. During the Last two decades, the use of the twisted-tapes inserts has be given a lot of importance for rise the heat transfer rate of the heat exchanger due to stable enforcement, simple establishment, and the tape can be inserted into the tube without a need for expertise. Likewise, its cost invention is low when contrasted with other heat exchange improvement methods that join blades, spring and so forth as supplements. Also, it's up keep cost is low contrasted with different systems [1, 5, 6]. Based on previous researches, the heat transfer augmentation has been receiving larger attention. Using nanofluid together with twisted taped for heat transfer enhancement is encouraging. Eiamsa -ard *et al.* [7] reported experimentally and numerically the influence of overlapped dual twisting-tapes with Tio_2/water on heat transfer improvement in a heat exchanger. They exposed that the lower value of overlapped twisting ratio with high volume concentricity provides a maximum gain in HTR inside a heat exchanger. coefficient of heat transported, friction factor index, the heat transfer augmentation efficiency in a circular tube fitted with rectangular-cut twisting tape, employ water as occupied fluid for turbulent flow were examined experimentally by Bodius Salam *et al.* [8] It was discovered that, the Nusselt number was enhanced by 2.3 to 2.9, friction factors index by 1.4 to 1.8 times compared to that of an ordinary tube. Heat transported enhancement effectiveness was found to be in the range of 1.9 to 2.3 at twisting ratio 5.25. Naik *et al.* [9] utilized copper oxide water /propylene glycol (70:30% by volume) as a working fluid flow inside a circular tube with twisting tape experimentally. It was observed that the coefficient of heat transport of Cuo nano fluid is (76.06%) times higher compared to flow of water in a tube fitted with twisting tape with twisting ratio of five. The friction factor index rises up to 26.57% at same term when compared to the base fluid. Determination the influence of the assorted geometrical progression ratio (GPR) of twists as the new modified twisting tapes and various concentrations of nanofluid on the friction factor index and transported of heat. Eiamsa-ard *et al* [11] investigated the influence of twisting tape with alternative axis at diverse alternate length on heat transported, friction factor and thermal enhancement. Two various length have been examined uniform alternative lengths and non-uniform alternative lengths. The experimental outcome revealed that all the uniform alternative lengths and non-uniform alternative lengths yielded higher Nusselt number and friction factor index than the typical twisting tape and the Nusselt number and friction factor index acquired were

ARPN Journal of Engineering and Applied Sciences

considerably increased with reduction the alternate length. Experimentation were also accomplished by Sundar *et al.* [12] on Al2O3/water nanofluid in the turbulent flow in the domain of 3000 and 22,000 Reynolds number in a round tube with various aspect ratios of longitudinal strip inserts. The results indicated an increase in heat transported coefficients with nanofluid concentricity by volume and reduction with aspect ratio. A numerical model for turbulent stream of nanofluids in a tube with twisting tape embeds has been produced by Azmi *et al* [13]. The speculation of this model are reliant on van Driest swirl diffusivity condition which can be connected by considering the coefficient and the Prandtl index in momentum and heat individually as a variable. The outcome demonstrated that the heat exchange coefficient and friction factor has been improved. Hamed *et al*. [14] studied the heat transfer development by twin twisting tape in the same direction and twin twisting tape in different direction with nano fluid inside a flat tube for laminar flow. Their numerical result presented that the tubes twin twisting tape in different direction possessed highest HTR by an average of about 76% and maximum friction factor by an average of about 340% as compared with a plain tubes. Azmi *et al.* [15] assessed heat transported coefficient and friction factor index of Tio2 nano liquid for a maximum concentration to 3% with twisting tape. They reported a decreased heat transported coefficients to values minimize than water for flow in a tube and with twisted tape when an increased in the nanofluid concentration to 3.0%. At 1% nanofluid concentration for H/D = 5 and Re=23558, the heat transport coefficient increased by 81.1% and friction factor 1.5 times greater compared to values with flow of water in a tube. Prasad *et al.* [16] carried out the experimental analysis to study augment the rate of heat transfer in a double pipe U- tube heat exchangers with trapezoidal-cut twisting tape and Al2o3 nano fluid. They found that the increases in the volume concentration of Al_2O_3 nano fluid and reduce the trapezoidal-cut twist ratio lead to enhance the Nusselt number by 34.24% as compared to water. The friction factor is enhanced by 1.29 times at the highest volume concentration of Al2o3 nano fluid with low the trapezoidal-cut Twist ratio. Chokphoemphun *et al.* [17] examined the heat transfer and pressure drop features in a round tube taking a constant heat-fluxed wall fitted with single, double, triple, and quadruple twisting-tape append in heat exchanger. The experimental results indicated that when increasing the number of twisted tape leads to an increased nusselt number and pressure drop. Bhuiya *et al.* [18] addressed thermal performance factor, Nusselt number and friction factor of a circular tube equipped with perforated twisting tape inserts for experimental investigation under turbulent flow by using air as an occupied fluid. The experimental results for perforated twisted tape give higher HTR, friction factor and performance factor by 110 - 340, 110 - 360 and 28-59%, respectively compared to that of the plain tube.

In the literature explored above, different investigation works were offered on diverse types of inserts but only a little research works were reported on twin twisting tape with nano fluid. However, in the current work, two configurations of twin twisting tapes are tested. The typical twin twisted tape and alternate axis twin twisted tape, these two configurations are examined with Al2o3 - water nano fluid. To the knowledge of the authors, there is no study was documented on using the tube compound with alternate axis twin twisted tape and nano fluid.

Problem statement

The adopted computational domain consisted of a circular tube with two configurations, the typical twisting tape and alternate axis twin tape. Figure-1 shows a schematic view of the suggested model. The considered specifications of the geometrical parameters of the twisted tape are listed in Table-1. The circular tube have a diameter of 50mm, length of 1000mm with constant wall heat flux .This configuration is studied with Al_2o3 /water nano fluid with two values of volume concentration as φ=0.5 and 4% respectively.

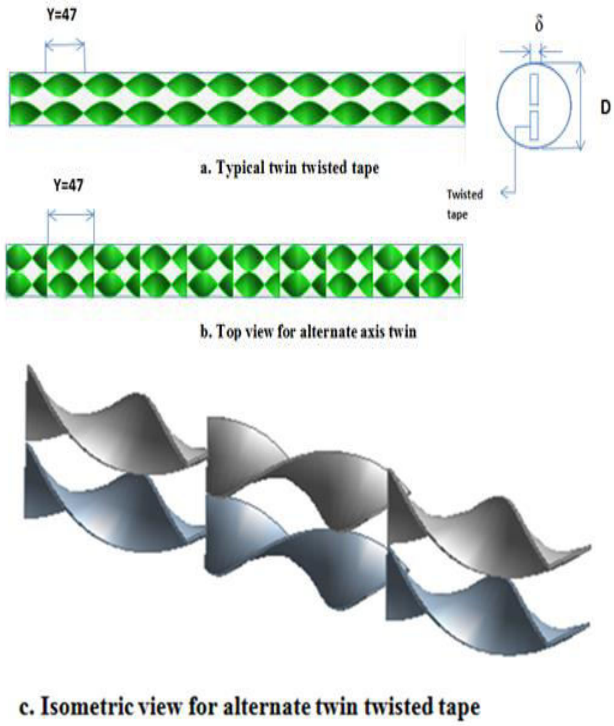

Figure-1. Schematic representing of the physical problem.

Table-1. Details of twisted tape insert.

Twisted tape	TT	ATT
Twisted width(w)	23.5mm	23.5 mm
Tape pitch length(y)	(47,94,141)mm	(47,94,141)mm
Twist ratio (y/w)	2,4and6	2,4and 6

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Mathematical model and numerical analysis

To evaluate the thermal and flow features of this model, the following assumptions are made:

a) The nano fluid is considered a single phase flow.

b) The impact of body force is neglected.

c) Incompressible turbulent flow.

The next formulation denotes the mathematical report of the governing equations based on the above assumptions

Continuity equation:

$$\frac{\partial}{\partial xi} = 0$$

Momentum conservation:

$$\frac{\partial}{\partial x_i}(\rho u_i u_j) = -\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_i}\left[(\mu+\mu_t)\frac{\partial u_j}{\partial x_i}\right] + \frac{\partial}{\partial x_i}\left[(\mu+\mu t)\frac{\partial u_i}{\partial x_i}\right]$$

Energy equation:

$$\frac{\partial}{\partial x_i}(\rho u_i T) = \frac{\partial}{\partial x_i}\left[\left(\frac{\lambda}{c_n} + \frac{\mu_t}{\sigma_T}\right)\frac{\partial T}{\partial x_i}\right]$$

RNG k-ε turbulence model

Renormalization Group "RNG" k- ε disturbance demonstrate incorporates two transport equations, one for the turbulence kinetic energy (k) and the second for the dissipation rate (ε) is adopted. Using this model in this study due to its ability to improve the turbulence remedy by adopting an additional term in its transport equation for turbulence dissipation rate [19]

$$\frac{\partial}{\partial xi}(\rho k ui) = \frac{\partial}{\partial xi}\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial xi}\right] + G_k - \rho\varepsilon$$

$$\frac{\partial}{\partial xi}(\rho\epsilon ui) = \frac{\partial}{\partial xi}\left[\left(\mu + \frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial \varepsilon}{\partial xi}\right] + \frac{\varepsilon}{k}\left(c_1 G_k - c_2\rho\varepsilon\right)$$

where G_k represents the generation of turbulent kinetic energy, which can be expressed as

$$G_k = -\rho\overline{u_i u_j}\frac{\partial u_j}{\partial x_i}$$

The turbulence viscosity μ_t is defined as

$$\mu_t = \frac{\rho c_\mu k^2}{\epsilon}$$

Where Cμ=0.09, C1=1.44, C2=1.92, Cμ=0.0845, σk= 1.0,σε=1.3.

Boundary conditions

The following boundary conditions are applied

1. At inlet: uniform inlet velocity is imposed.
v=0 and w=0,Tin= 298 k
2. At the pipe wall and twisted tape, no slip condition and constant heat flux is imposed,
u=v=w=0 .
3. At outlet: Gauge pressure =0.

Numerical simulation

The commercial CFD solver FLUENT 17.1 is used to carry out the numerical simulation. The finite volume formula is applied to solve the above-mentioned governing equations accompanied with boundary conditions. The SIMPLE "Semi-implicit Method for Pressure-Linked Equation" algorithm has been employed to evaluate the coupling between the velocity and pressure fields. A second order upwind process is exercised for the convective and diffusive terms, respectively. For the convective and diffusive terms, respectively. The convergence criteria for all the three velocity component, continuity and energy are set to 10 -6.

The numerical simulation was made for twin twisting tape inserts at three twist ratios (y/w=2,4and6). A grid independence steps was accomplished to estimate the most favorable mesh size. Topical grid refinement is utilized in the boundary layers. The detailed information of number of elements for the studied cases is as listed in the Table-2.

Table-2. Specified number of grid elements.

case	Twist ratio	Number of element
TT	2	2374811
TT	4	2455093
TT	6	2624116
ATT	2	2894201
ATT	4	2955419
ATT	6	2976599

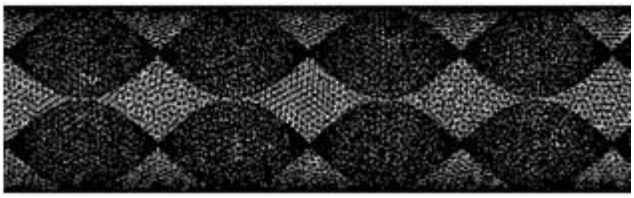

Figure-2. Tetrahedral mesh that generated for tube occupied with twin twisting tape.

Thermophysical properties of nanofluids

In current study, physical- properties of nano particle were taken from Karimipour [20]. The thermo-physical properties of the Al2O3/water nanofluid are calculated based on expressions cleared below:

The "density" of nanofluid can be gotten from the relation [21]

$$\rho_{nf} = \varphi\,\rho_n + (1-\varphi)\rho_{hf}$$

The "specific heat" of the nanofluid has been calculated as [21]

$$Cp_{nf} = \varphi(Cp)p + (1-\varphi)(Cp)bf$$

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The equation of Maïga *et al.* [22] is adopted for the estimation of "viscosity" for water based nano fluids.

$$\mu_{nf} = (123\varphi^2 + 7.3\varphi + 1)\mu_{hf}$$

Also the "thermal conductivity" are calculated from Maxwell model, as [23]

$$\frac{k_{nf}}{k_{hf}} = \frac{k_p + 2k_{bf} + 2\emptyset(k_p - k_{bf})}{k_n + 2k_{hf} + \emptyset(k_n - k_{hf})}$$

Calculation of thermal and hydrodynamic parameters

The Nusselt number is defined as follows:

$$Nu = \frac{h_{nf}D}{K_{nf}}$$

where h_{nf} is the average convective heat exchange coefficient, K_{nf} is the conductivity index of nano fluid, and D is the tube hydraulic diameter. The average convective heat exchange coefficient is estimated as flows:

$$h = \frac{q}{(Tw - Tb)}$$

where q is wall heat flux, Tw, Tb are the mean wall temperature and bulk temperature, respectively.

For the fluid flow, the friction factor index is computed by

$$C_f = \frac{\tau_w}{\frac{1}{2\rho}U^2}$$

in which U is the mean velocity in the test tube.

RESULTS AND DISCUSSIONS

The results obtained from this study including the impact of the twisting tape and Al2o3/water nano fluids on the heat transported, friction factor and overall thermal enhancement factor characteristics are listed as follows:

Validation

Plain tube

To achieve the accuracy of the present numerical result, data validation was done during comparing the gained Nusselt number(Nu) of plain tube with that of Dittuse-Boelter [24] and Gnielinski equation [25]. Also, the friction results of the present plain tube are validated with standard correlations of Petukhov correlation [26] and Blasius correlation, as shown in Figure-1 and Figure-2. As is clear from these figures the present simulations come to an agreement well with available corresponding correlations.

Dittuse-Boelter correlation

Nu=0.023 Re 0.8Pr 0.4

Gnielinski equation

$Nu = 0.012(Re^{0.87} - 280)Pr^{0.4}$

Petukhov correlation

$f = (0.79\ln Re - 1.64)^{-2}$

Blasius correlation

$f = 0.316Re^{-0.25}$

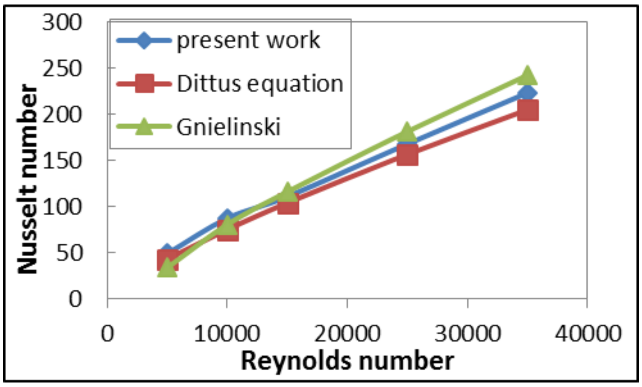

Figure-3. Validation of Nusselt number for the empty tube.

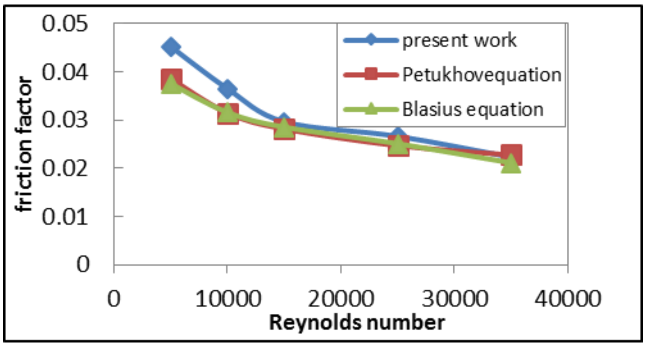

Figure-4. Validation of friction factor index for the empty tube.

Plain tube with twisted tapes

In this simulation, the numerical results obtained in terms of Nusselt number for a tube with a twisting tape and Al_2O_3-water nano fluid is validated with equations of Sundar and Sharma [27]. As shown in Figure-5, it is observed that an acceptable agreement is obtained between the results with deviation does not exceeds 9%.

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ARPN Journal of Engineering and Applied Sciences

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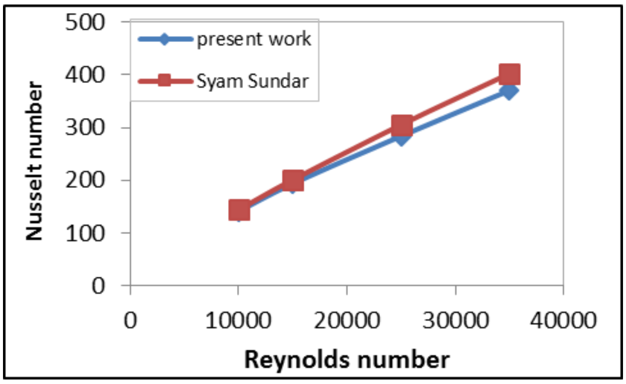


Figure-5. Validation for Nusselt number for the tube with twisting tape insert and Al_2O_3- water.

Figure-4 demonstrates the difference of Nusselt number with Reynolds number for the two kinds of twisting tape insert, typical twin twisting tape and alternate axis twin twisting tape with the twisting ratio equal to 2 and 4, respectively. This figure shows that the Nusselt number for the alternate twin twisting tape is greater than that of typical twisting tape and plain tube. Also, the Nusselt number increased as twisting ratio decrease.

Figure-5. shows the variation in Nusselt number versus Reynolds number for the two types of twisting tape insert, typical twin twisting tape and alternate axis twin twisting tape at different twisting ratio. In general, the Nusselt number rises as the Reynolds number increase for all types of twisted tape. The smallest twisted ratio gives the higher Nusselt number for the considered twisted tapes, because of the growth of whirl intensity transported to the stream at tube wall. The HTR of the embedded tube is observed to be impressively higher than that of plain tube with no insert. This can be ascribed to more whirl upgrading turbulence force, prompting higher convection heat transfer than axial flow in plain tube. Also from this figure, it can be observable that, the ATT gives the highest Nusselt number as comparison with TT, for the studied twist ratios. This can be referred to higher confirmed flow turbulence at each alternate point by the twin twisting tape as Reynolds number increases. Hence, the residence time of the flow growing with rising whirl flow intensity. In addition, These streams are conceivably coordinated to interfere into different flow which stream along the typical twisting direction, prompting the preferable efficient fluid blending produce by the altering flow modality. Build upon uses of twin twisted alternate axis and Al2o3 /water nanofluid, results in further enhancement number than the TT with nanofluid by around (2.145). As noted in Figure-6(a and b) the Nusselt number ratio will increasing by decreasing of twisted ratio. In addition, this ratio reduce as the Reynolds number increases.

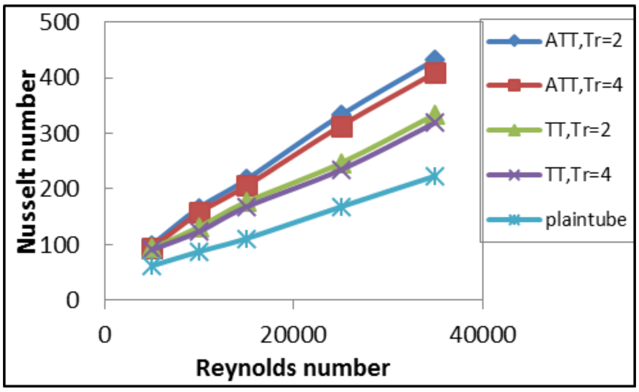


Figure-6. Variations of Nusselt number with Reynolds number for twin twist tape inserts with base fluid at different twist ratio.

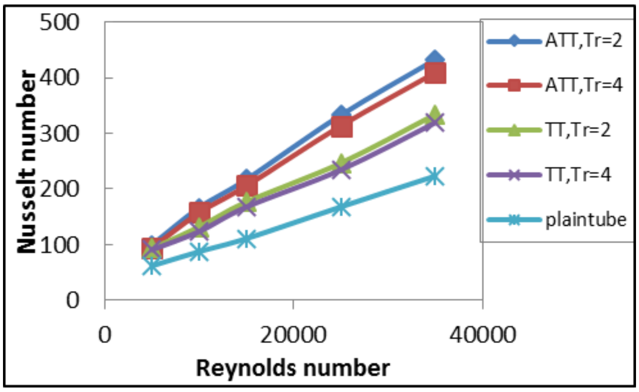
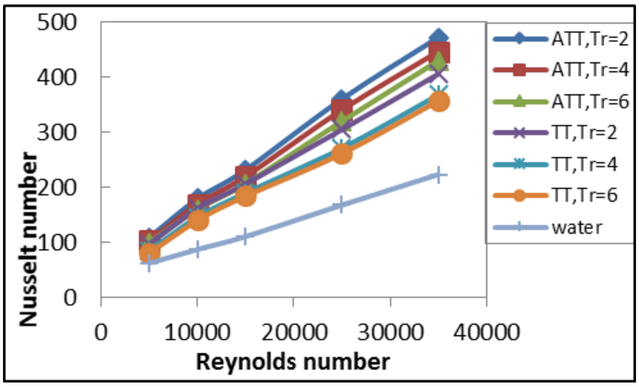


Figure-7. Variations of Nusselt number with Reynolds number for twin twist tape inserts with base fluid at different twist ratio.



a. φ=4%

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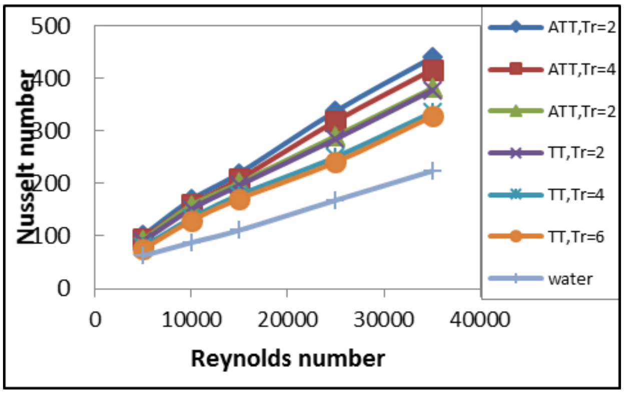
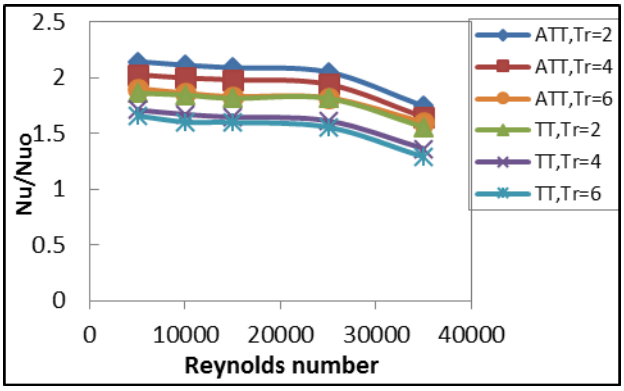
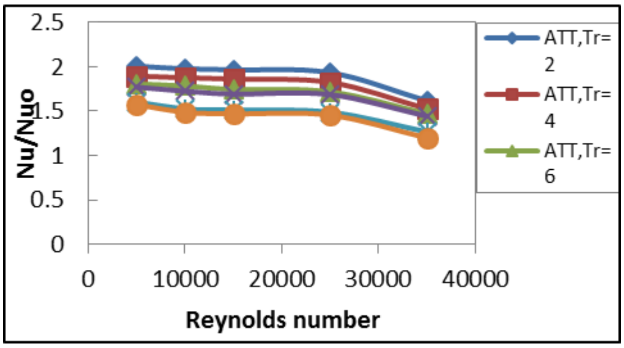


b. φ=0.5

Figure-8. Variations of Nusselt number with Reynolds number for twin twist tape inserts with Al_2o3- water at different twist ratio.



a. φ=4%



b. φ=0.5

Figure-9. Variations of thermal enhancement with Reynolds number for twin twist tape insert with Al_2o_3 at different twist ratio.

Friction factor

The variation in friction factor with Reynolds number for two different twisted tapes, with twisted ratio (Tr=2, 4 and 6) are depicted in Figure-10, respectively. It was noted that, the friction factor increases as twisted ratio decreased. As seen in Figure-11 (a and b), the use of twin twisted tapes with nano fluids offers rise to considerably higher friction than that of plain tube due to the growth of occupied fluid viscosity. Also, this could be explained by the fact that higher friction loss fundamentally get from the increased surface area and higher swirl intensity. The pattern of friction factor increment is precisely like the pattern of heat exchange change; implying that the utilization of twisted tapes in the tubes causes the most noteworthy increment in the friction factor. As the figure shows, the friction factor formed in tube with ATT was higher than that of the TT. This ascribed to the augment dissipation of dynamic pressure caused by a flow resistance whirl stream and in addition an additional turbulence at alternate points. Also, it can be seen that, the simultaneous utilization of nanofluid and ATT are extensively higher than those produced by the TT as shown in Figure-11.

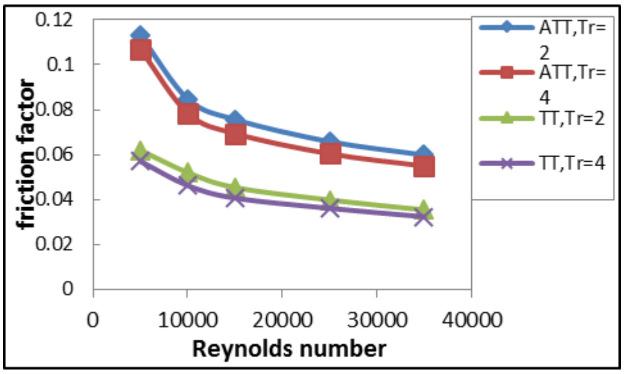
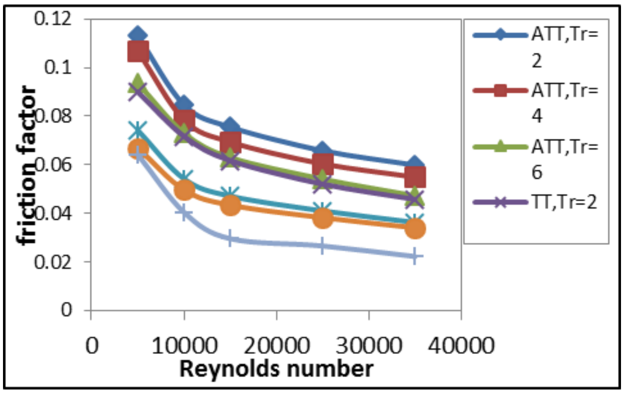
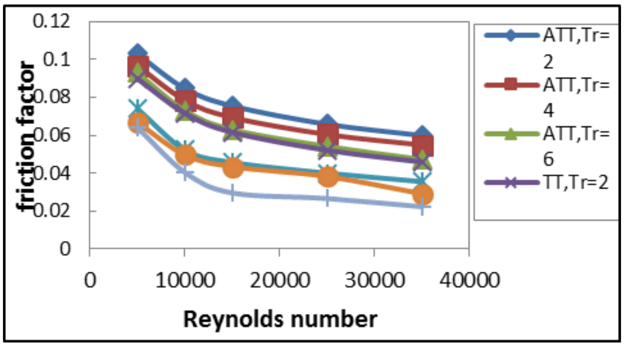


Figure-10. Variations of friction factor with Reynolds number for twin twist tape insert with base fluid at different twist ratio.



a. φ=4%



b. φ=0.5%

Figure-11. Variations of friction factor with Reynolds number for twin twist tape insert with Al_2O_3- water at different twist ratio.

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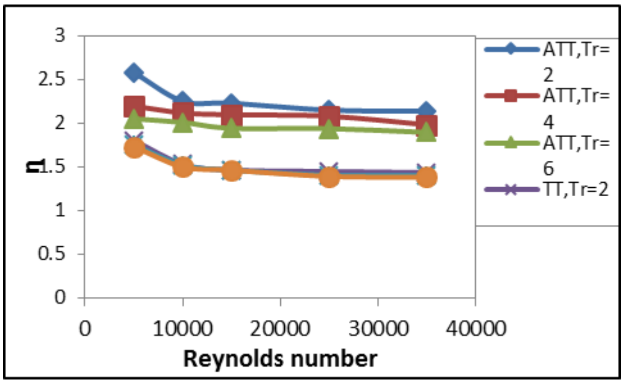
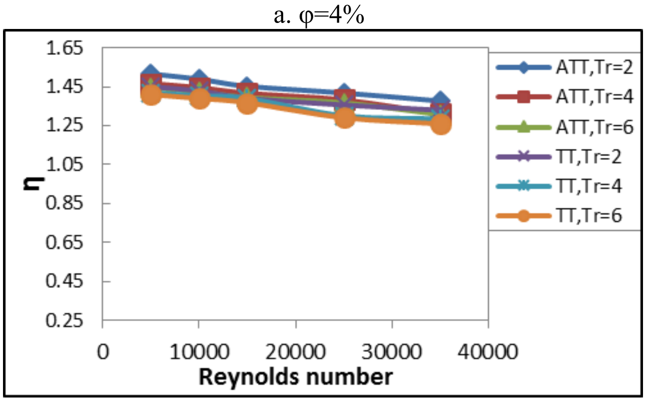
Overall thermal performance factor

The connection between overall thermal performance factor and Reynolds number for the studied cases are shown in Figure-12(a and b). The comparison data appear that the overall thermal enhancement increases with decreasing Reynolds number. In addition, it can be recognizable that reduced in twisted ratios produced greater overall thermal performance. The alternate twin twisted with nano fluid possessed higher thermal performance factors than that typical twin twisted tape. It must be noted that the overall thermal enhancement was increased with a growth in nanoparticles concentration. This means that use of both nanofluid and twin twisted tapes results in upper thermal performance than others.



a. φ=4%



b. φ=0.5%

Figure-12. Variations of overall thermal performance with Reynolds number for twin twist tape insert with Al_2O_3-water at different twist ratio.

The path line patterns for plain tube, a tube with typical twin twisted tape and with alternate twin twisted tape are presented in Figure-13. For a plain tube, smooth path lines are observed without any circulations regions. A swirling motion is noticed at typical twin twisted tape and alternate twin twisted tape. This swirl motion followed the complex shape twisted tape generated while the space between the double tapes adds more complexity to this trend. The high interaction between swirling flows as a result to using double twisted tape leads to better fluid mixing, and thus more active heat transfer as compared with the plain tube.

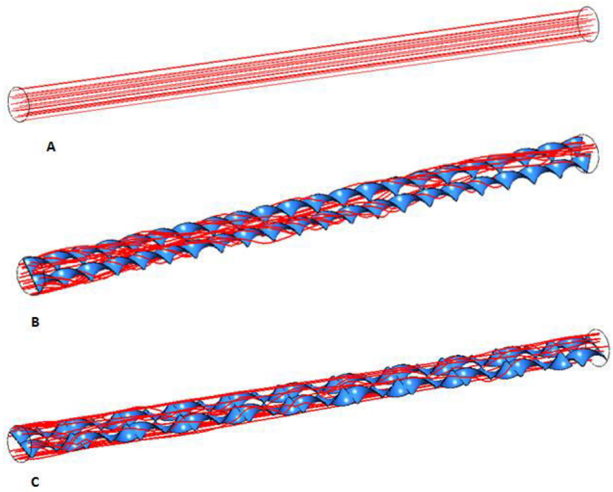


Figure-13. Path lines across the domain for nano fluid(A) plain tube (B) typical twisted tape and (C) alternate twin at Re=35000 Tr=2 and φ=4%.

Figure-14 shows the velocity vectors contours at a specified axial station for a plain tube, typical twin twisted tape and alternate twin twisted tape. In general for the plain tube as in (A), the maximum velocity occurs at the center. Furthermore, the velocity is nearly identical at all position. When the tube is inserted with twin twisted tape as in B and C, it is observed creating a swirling movement because of complex twisting geometry. This movement becomes more complicated due to interaction between twin twisting tape where this interaction leads to the generation of two zones of swirl flow. It is observed that the strength of swirling motion is larger in alternate twin twisted tape, consequently more influence on developing the boundary layer and heat transfer augmentation.

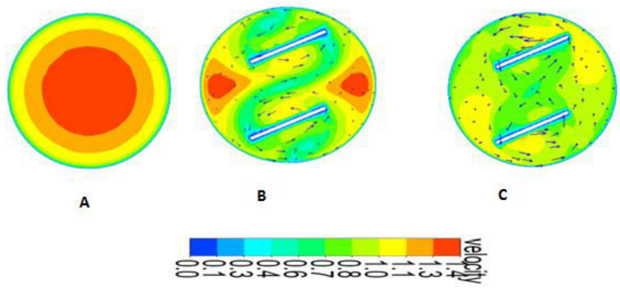


Figure-14. Vector plot appended on velocity vector for, (A) plain tube (B) typical twin twisted tape and (C) alternate twin twist at Re=35000, Tr=2 and φ=4% at location 0.5m.

Figure-15 shows the streamline at a specified axial station for a plain tube, typical twin and alternate twin twisted tape. In the case of the plain tube frame (A), it is seen that the concentration of the streamlines near the wall is weak because of absence the twisted tape. At inserting the typical twin twisted tape, frame (B), the streamlines distribution is shown be uniform in the

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domain. This is concerned to the appearance of twin twisted which forces the flow of fluid in a swirling model. While the streamlines of the alternate twin twisted tape is increased concentration near the tube wall of the domain, frame C. This is related to the alternate - axes which generates additional disturbance to the flow, better mixing and increasing the angular _ momentum of fluid particles. The intensity of the streamline in the alternate twin twisted tape, frame (C), is higher than that in the typical twin twisted tape, frame (B).

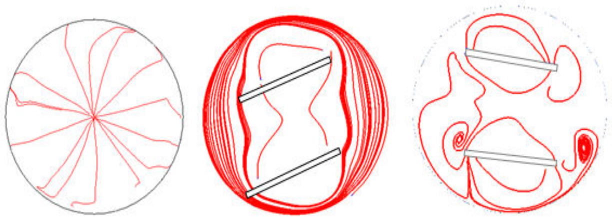
A B C

Figure-15. Streamline across the domain cross -section of twin twisted tape (A) plain tube (B) typical twin twisted tape (C) alternate twin twisted tape.

CONCLUSIONS

The present study displays the feasibility of convection heat transfer enhancement by inserting the alternate twin twisted tape and typical twin twisted tape with Al_2O_3 - water for turbulent flow with a uniform heat flux. Main findings of this search can be summarized as below:

a) The alternate twin twisted tape with Al2O3/water can promote the heat transfer than plain tube by approximately 214% at the highest volume concentration (φ=4%) and twisted ratio(Tr=2).

b) The arrangement of the typical twin twisted tape with Al2O3/water could augment the heat transfer than plain tube by approximately 181%.

c) The maximum value of the thermal performance factor was 2.25 in the case of the highest volume concentration of Al2O3/water and twisted ratio of (Tr=2) for alternate twin twisted tape.

d) The heat transfer enhancement is upgraded with the increase of nanoparticle concentration. However, it decreased with the increase of the twisted ratio.

e) The alternate twin twisted tape can improve the heat transfer more professionally than the typical twin twisted tape.

Nomenclature

cp	specific heat of fluid, J $kg^{-1}k^{-1}$
D	inside diameter of test tube, m
dp	diameter of nanoparticles(nm)
f	friction factor
h	heat transfer coefficient
K	thermal conductivity,wm/k
L	length of test section, m
Nu	Nusselt number = hD/k
Pr	Prandtl number =μCp/k
q	heat flux,W
Re	Reynolds number = ρUD/μ
T	temperature, C
Tb	mean temperature, C
U	average velocity, m s^{-1}
W	tape width, m
y	pitch length of twisted tape, m
y/w	twist ratio

Greek symbols

ρ	fluid density, kg m^{-3}
δ	tape thickness, mm
μ	fluid dynamic viscosity, kg s^{-1} m^{-1}
η	overall thermal performance factor
φ	concentration of nanofluid, % by volume

Subscripts

TT	typical twin twisted tape
ATT	alternate axis twin twisted tape
Tr	twisted ratio
nf	nano fluid
w	wall
bf	base fluid

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