ISSN: 0974-5823 Vol. 7 No. 1 January, 2022

International Journal of Mechanical Engineering

Evaluation the performance of the double tube heat exchanger by using combined twisted tube and nano fluid

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Abstract

The turbulent flow and thermal characteristics with (Al2O3-Water) nano fluid in the double circular twisted tube heat exchanger was studied numerically. The prime objective of this study is to improve the performance of the double circular tube heat exchanger by utilizing the hybrid approach of twisting tube and nanofluids. Nanoparticles of (Al2O3) are used with pure water as base fluid. The volume concentrations of nanoparticles studied were (0.05, 1, 2.5, 4) % and Reynold number ranging (5000-30000) for a twist ratio (Tr=5). The continuity, Navier-Stocks and energy equations with k- ϵ model were used to model the flow and thermal field. Ansys fluent 18.2 was adopted for solving these equations. The consequences exposed that the heat transfer rate is directly proportional to with increased the volume concentration of nano fluid and decreasing the twisted ratio (Tr). This means that the heat exchanger performs better with a lower twist ratio. In addition, the effectiveness of the heat exchanger is improved when using the nano fluid as 6%, as it reaches the highest value at the Re number of 30000 and volume concentrations at 4%. In addition, the pressure loss increases with increasing Re number and nano fluid volume concentration.

Keywords: twisted tube, heat exchanger, CFD, Nano fluid.

NOMENCLATURE

LMTD	Logarithmic mean temperature difference
ϵ	Effectiveness
Cp	Specific heat (J/kg.K)
m	mass (kg)
ΔP	Pressure drop (pa)
Re	Reynolds number
Tr	Twisted ratio
P	Twisted pitch (mm)
K	Thermal conductivity (W/m·K)
	Greek symbols
μ	Dynamic viscosity (kg. m^{-1}. s^{-1})
ρ	Density (kg/m3)
η	Overall Performance
Φ	concentration of nanofluid, (%)

1. Introduction

Recent technical advancements have resulted in a substantial paradigm shift toward smaller, more efficient heat transfer systems in response to the increased need for energy-efficient technologies. As a result, developing novel technologies for enhancing heat transmission will continue to be a primary effort of global research and development operations in the foreseeable future. Any effort in this field will increase energy efficiency across a range of businesses from large-scale power generation, refineries, small-scale manufacturing and electronics. Enhancing the thermos physical properties of the working fluid is another way to improve heat transfer. This can be accomplished by adding nanoparticles to the working fluid. In cases where there is an increase in the heat transfer that results in a rise in the pressure drop further research in that area is justified. Heat exchangers should be constructed using twisted tubes with nanofluids as a working fluid. [1-4]. Bhattacharyya and Chattopadhyay. [5] studied Numerically turbulent flow within an twisted elliptical duct and its effect on heat transfer using CFD modeling. To portend the variation of flow regime from laminar to turbulent use Transition-SST model in simulations. The main variants of the twisted elliptical duct are the width to height ratio (aspect ratio) of 0.5 and the pitch length between 0.5 and 1. The outcomes showed that the Nusselt number of the twisted elliptical duct was higher than that of the circular plain tube. The friction factor increases with the increase in the Reynolds number. Salman et al. [6] simulated numerically laminar flow with swirl flow in an elliptic-cut with a twist tape to enhance heat transfer and coefficient of friction. The Reynolds number ranges between 200-2100, the twist ratio (Tr=2.93, 3.91, 4.89), and the depth of cut from 0.4 to 1.4, with an increment of 0.4. They outcomes that the decreasing the twist ratio and depths of cut leads to an increase in both the Nusselt number and the coefficient of friction in the elliptic-cut. Moreover, the highest heat transfer rate and friction factor in the elliptic-cut was found when Tr=2.93 and the depth of cut was 0.4 compared with the plain tube and twisted tapes. Kim et al. [7] studied numerically the flow characteristics and heat transfer enhancement in an elliptical twisted tube. The effect of geometric variables such as width to length ratio (aspect ratio) and number of rotations in the elliptical twisted tube was also examined, and a three-dimensional simulation was made. The k-ε turbulence model and Navier-Stokes equations used in analyze fully developed flow in the elliptical twisted tube. The Reynolds numbers ranging 100-10000. They conducted that the effect of convection on heat transfer with an increase in pressure drop and an increase in the thermal performance of the elliptical twisted tube being better than the plain tube in terms of size and area. Wu et al. [8] studied numerically effect of Reynolds number and the twist ratio on the overall thermal-hydraulic performance and heat transfer of water in the elliptical twisted tube. They founded that the twisting that causes secondary flow and increases turbulence enhancement heat transfer in the elliptical twisted tube when compared with the normal tube. Whereas, when the radius of the tube is 96 mm, the number of Nusselt increases by 16%-19%, and the pressure drop increases by 58%-60% if compared with the normal tube. While the elliptical twisted tube reduces the thermal resistance based on thermal insulation. The hydraulic thermal performance reaches its highest value when the radius is 128mm

Khudheyer and Farah. [9] discussed numerically the use of a nanofluid with a heated circular tube in which the combined twin twisted tape is embedded to increase heat transfer. The Reynolds number ranges between 5000-35000 and the twist ratio (2, 4, 6). They concluded that the heat transfer enhancement increases when using twin twist when compared with normal twist. In addition, the thermal performance is better when the twisted tape is used in a counterclockwise. Mashayekhi et al. [10] investigated numerically of the effect of introducing a twisted conical strip insert in an oval channel on fluid flow and thermal properties when using a two-phase mixture model. The Reynolds number ranging from 250-1000 and the volume fraction of nanofluids is 1-3%. They showed that the increase in the Reynolds number with the increase in the volume fraction of nano fluids will increase the thermal performance of the channel. The inward Co-Conical boosted heat transfer by 17%. While the pressure drop is negligible when using the three twisted conical inserts. Mushatet and Youssif. [11] conducted Numerically the effect of Al_2O_3/water nano fluid flowing in pipe with a double twisted tape. The Reynolds number ranges between 5000-35000, the twist ratio of 2, 4, and 6, and the volume fraction of nanoparticles is 0.5%-4%. They revealed that the overall performance coefficient and the Nusselt number increased with decreasing twist ratio.

Whereas use double twisted tape with Al_2O_3/water nano fluid, thermal performance is improved by 181 percent. Singh and Sarkar. [12] investigated experimentally the hydrothermal properties of turbulent flowing nanofluids in a double tube exchanger with twisted tape inserts modified V-cuts. Nano fluids (Tio2 and Al2o3) at 0.1% volume fraction. They founded that the decreasing both the twist ratio, width ratio and inlet temperature increases the Nusselt number and the coefficient of friction. Also, the best improvement for Nusselt number and coefficient of friction was 132% and 55%, respectively, compared to the normal tube. Ju et al. [13] studied numerically the hydrothermal performance of nano fluid flow in a heat exchanger pipe with semi-twisted tapes and the best case for enhancing heat transfer with the lowest coefficient of friction. They founded that the Nusselt number and the coefficient of friction increase in the presence of the eddy flow generated by the semi-twisted tapes. Where the Nusselt number reaches 28.5 and the coefficient of friction decreases to 0.052 when using four semi-twisted tapes. Also, the Nusselt number improved by 6.41% when increasing the volume fraction of nano fluids to 3%. The highest thermal performance is equal to 1.66 at a Reynolds number 750 and a volume fraction of 3%.

Alempour et al. [14] investigated numerically of the effect of turbulent flow on the flow characteristics and heat transfer of liquid flow inside a three-dimensional tube with circular and elliptic sections. They found that the heat transfer rate increased by 20% when using the elliptical twisted tube when compared with the normal tube. When the tube is transformed from a circular shape to an elliptical with a low twist pitch a secondary flow generated, which increases the fluid mixing and the intensity of turbulence thus increasing the coefficient of friction and the transmission of water. At Re= 16000, the introduction of carbon nanoparticles in the twisted elliptical tube results in a 32 percent increase in heat transfer efficiency. Shahsavar et al. [15] investigated numerically the effect of the volume fraction of nano fluid and twist ratio on the performance of a double pipe heat exchanger with combined twisted tubes. The pure fluid is the hydrous solution of 0.5% carboxymethyl cellulose. They showed that the increase heat transfer and effectiveness of heat exchanger with increasing Reynolds number. Moreover, the overall hydrothermal performance of double twisted pipe heat exchanger is greater than plain pipe, and its great value is 2.671, when Reynolds number= 2000, the volume concentration = 3% and twist pitch = 4 mm. Mushatet et al. [16] Studied numerically and experimentally a new design for twisted tapes and its effect on thermal and hydrodynamic fields and to provide the highest thermal performance. The twisted tapes were inserted into a circular tube exposed to a constant heat flux in which air flows as the working fluid and the Reynolds number varies $10,000 \leq Re \leq 40,000$. They discovered that the Nusselt number increases by 75% and 100%, respectively, based on experimental and numerical results. Likewise, the maximum thermal performance factor was 1.19 and 1.37, respectively. They also found the importance of the twisted tapes with tapered configurations inside a tube in increasing the number of Nusselt and increasing the overall thermal performance as in [17]. Mushatet and Hamood.[18] investigated Numerically the effect of the twisted triangle tube on increasing turbulent heat transfer and increasing heat exchanger performance. The Reynolds number ranges between (Re=5000 to 25000) consequently and (twist ratios (5, 10 and 20). They showed that the heat transfer of the twisted tube increased when compared with the normal tube. The heat transfer improved by 150% for Tr=5. Abdul Razzaq and Mushatet [19] studied numerically the heat transfer characteristics of the double circular twisted tube heat exchanger. The working liquid is the water when the effect of the turbulence. Where the Reynolds number ranging 5000 and 30000 and the twist ratio is 5, 10, 15, respectively. They founded that the twisted tube increases the heat transfer when compared with the normal tube. The effectiveness of heat exchanger is increases when increasing the Reynolds number and decreasing the twist ratio.

According the above literature review, which discussed improving the heat transfer and general performance of the heat exchanger through additions such as (twisted tapes, ribs and conical rings….). In addition, changing the geometry of the tubes used in heat exchangers, and on the other hand, using highly conductive liquids such as nano fluids. The impact of the twisting the circular tubes with different the volume concentration on the heat transfer and flow characteristics has not been discussed inclusive. Thus, in the present study, the effect of twist ratio, volume fraction of nanoparticle and the effect of the circular section of the tube on heat transfer and flow field were analyzed numerically. To achieve the maximum performance of the double twisted tube heat exchanger, nano fluids (Al2o3) were used as working fluid with various volume fraction in addition to pure water.

Methodology

The proposed system under examination is schematically depicted in Fig.1. Computational modeling was done using a three-dimensional geometry of the double twisted circular tube. The heat exchanger measures 1000mm in length and has an inner and outer tube diameter of 25 and 50mm, respectively, and a twisted tubes thickness of 0.4 mm and an equivalent twisted ratio of 5. Reynolds numbers ranging (5000-30000) are used when determining the temperature of the Al_2O_3-water nano fluid at 298K as it enters the outer tube and the temperature of the hot water at 343K as it enters the inner tube.

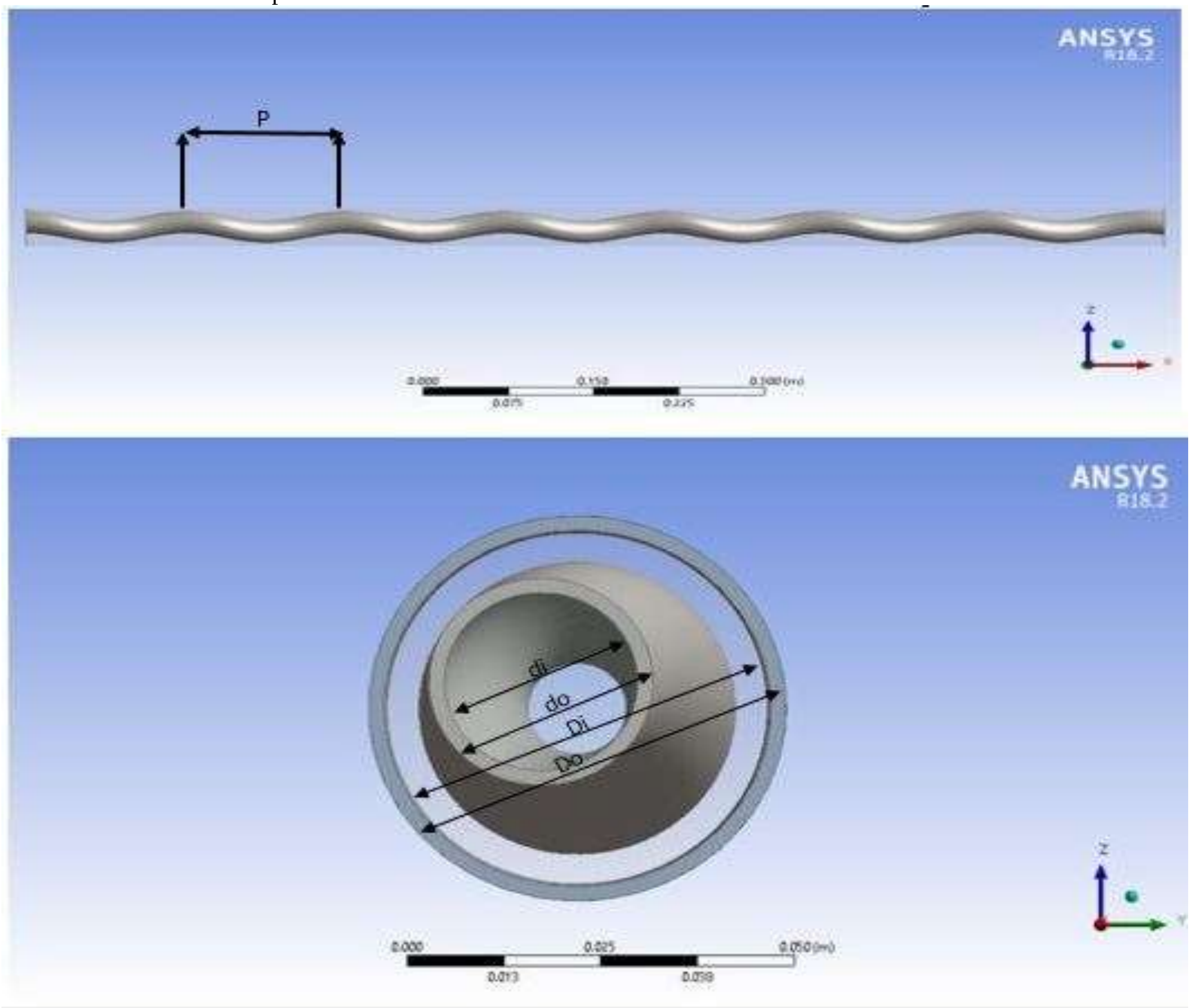

Fig.1. Schematic of the studied system using inner circular twisted tube

The model problem is based on the following presumptions:
1- Three-dimensional flow
2- Steady-state flow.
3- Turbulent flow.
4- Body force is neglected.
5- Incompressible flow.

The governing equations for the preservation equations for mass, momentum, and energy are written as following:
Continuity Equation:

$$\frac{\partial \rho u}{\partial x}+\frac{\partial \rho v}{\partial y}+\frac{\partial \rho w}{\partial z}=0 \qquad (1)$$

Momentum equations:

$$\frac{\partial}{\partial xj}\left(\rho u_i u_j\right)=-\frac{\partial p}{\partial xi}+\frac{\partial}{\partial xj}\left[\mu\left(\frac{\partial ui}{\partial xj}+\frac{\partial uj}{\partial xi}\right)\right] \qquad (2)$$

Energy equations:

$$\frac{\partial}{\partial xj}\left(\rho uj c_p T-k\, \partial T/\partial xj\right)=0 \qquad (3)$$

The properties of water-Al2O3 nano fluid are given as [12]:

$$\frac{k_{nf}}{k_f}=\frac{k_s+2k_f+2\emptyset(k_f-k_s)}{k_s+2k_f-\emptyset(k_f-k_s)} \qquad (4)$$

$$\rho_{nf}=(1\text{-}\emptyset)\rho_{nf}+\emptyset\rho_s \qquad (5)$$

$$cp_{nf}=\frac{(1-\emptyset)\rho_f cp_f+\emptyset\rho_s cp_s}{\rho_{nf}} \qquad (6)$$

$$\mu_{nf}=\frac{\mu_f}{(1-\emptyset)^{2.5}} \qquad (7)$$

The present investigation employs a water-Al2O3 nano fluid with four different concentration factors, as shown in Table 1. The parameters of the nano fluid are computed using above equations.

Table 1. The characteristics of the water-Al2O3 nano fluid.

	ρ (kg/m3)	cp (J/kgK)	k (W/mK)	μ (kg/ms)
	3970	765	40	————
Nanoparticle Characteristics				
ø = 0%	998.2	4182	0.613	0.001003
ø = 0.05%	1013.059	4115.046891	0.621	0.001016
ø = 0.1%	1027.918	4050.029454	0.631	0.001029
ø = 0.25%	1072.495	3865.786638	0.657	0.001069
ø = 0.4%	1117.072	3696.248321	0.686	0.001111

Constant temperature (Tci=298, Thi=343) and Reynolds number (5000 -30000) are used at the two-tube inlet, whereas the two-fluid outlets are both set to zero relative gauge pressure. The twisted tube was twisting at Tr=5, with an adiabatic out wall of the outer tube.

The hydrothermal parameters investigated together with the logarithmic mean temperature difference, the overall performance, and the effectiveness of heat exchanger which are calculated, respectively, as following:

$$\text{LMTD}=\frac{\Delta T1-\Delta T2}{\ln\left(\frac{\Delta T1}{\Delta T2}\right)} \qquad (8)$$

$$\epsilon=\frac{qact}{q_{max}} \qquad (9)$$

$$\eta=\frac{\epsilon}{\Delta PT} \qquad (10)$$

The overall performance of a double circular twisted tube heat exchanger was studied to prophesy and demonstrate the influence of twisted circular tube configuration on flow stability during steady-state turbulent flow. In fluid dynamics, the preservation equations for mass, momentum, and energy are used as computational parameters to provide numerical solutions of the fluid flow and heat equations that mentioned above [1, 2, and 3].

Given the benefits of structured meshes over unstructured meshes, including greater quality outcomes, faster convergence, and ease of convergence, as well as the use of fewer cells. A structured mesh was constructed in this study. The present mesh was created using the ANSYS meshing program. A high-level overview of the computing grid for the purpose of analyzing the independence of the solutions from the generated mesh. The computational domain is mesh by tetrahedral elements. The mesh system has 1723287 elements.

Result and discussion

The heat transmission and flow characteristics of a double circular twisted tube flowing in it (Al2o3-water) at various concentrations were investigated. While the overall performance, heat exchanger effectiveness, and the outlet temperature are evaluated through the effects of change the twist pitch on the flow path, a multitude of flow, heat transfer and flow field measurements are performed to document the change.

Figure 2 explains the relation of the hot fluid outlet temperature with the Reynolds number for double twisted tube heat exchanger with Tr=5. From the figure, it can be noted that the Tho is increased when the Re increased due to the increased in the hot water flow velocity, which reduces the time of heat transfer exchange. While the heat exchange increases when the concentration of the nano fluid increases and the flow rate decreases, where the highest value is at (0.4) due to the increase in the thermal conductivity of nano fluids back to the presence of nano particles. Figure 3 represents the cold fluid outlet temperature variation with the Reynolds number for Double twisted tube Heat exchanger with Tr=5. This figure indicates that the Tco is decreased as the Re increases. This is due to the increasing flow velocity of cold water, which reduces the time of water to exchange heat. Also, this figure shows that the zero concentration (pure water) has the lower Tco and the nano fluid at the concentration (0.4) has the higher Tco when the thermal conductivity of nano fluid because of the volume concentration, which increases the number of nanoparticles in base fluid.

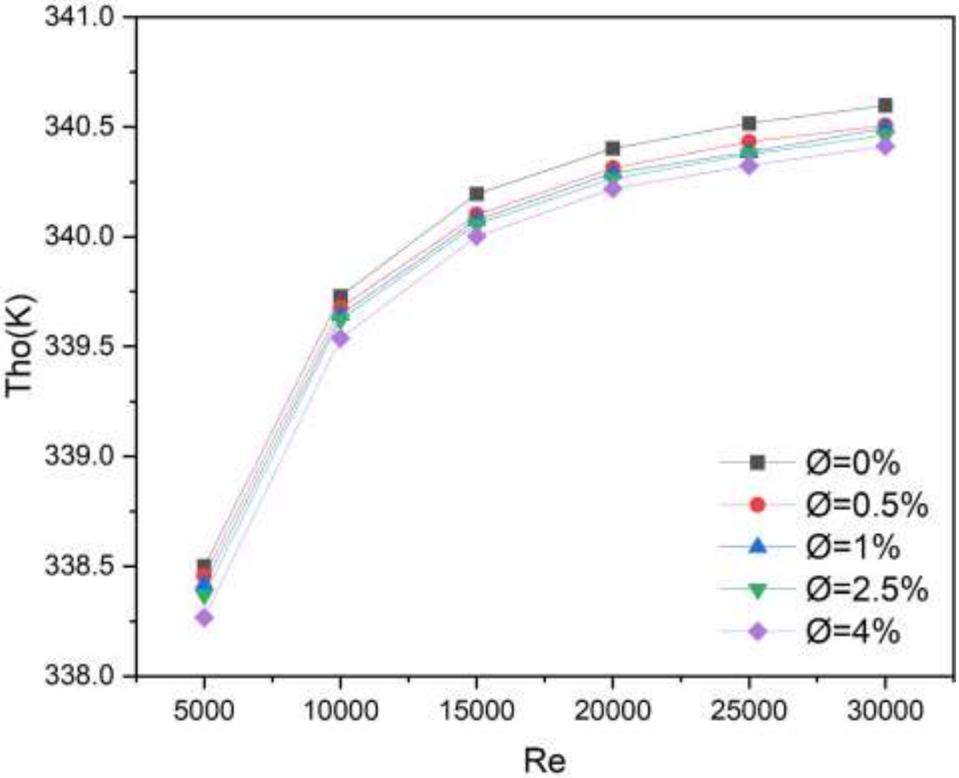

Fig.2. Difference of the hot fluid outflow temperature with Re for various nano fluid volume fractions, Tr=5.

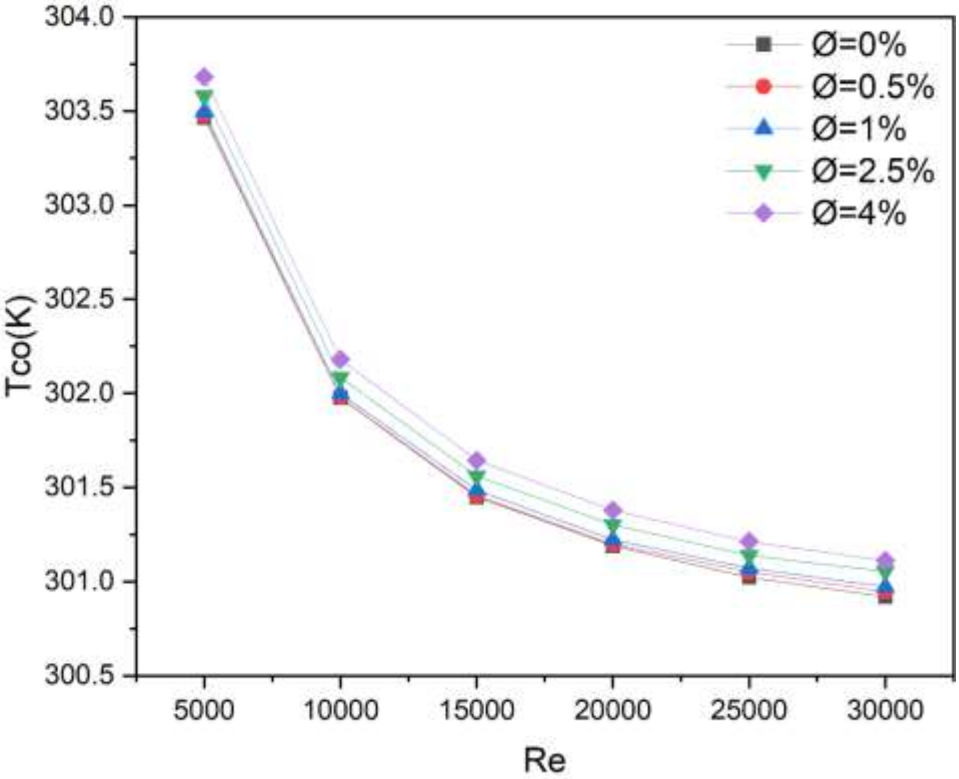

Fig. 3. Variation of cold fluid outlet temperature with Re for different volume fraction of nano fluid, Tr=5.

Figure 4 represents the difference between hot and cold fluid outlet temperature with Re number for double twisted tube heat exchanger with volume concentration. The rising temperatures at the hot and cold fluid output may be seen in the figure as the (Th-Tc) o grows with increasing Re. Also, the secondary flow is formed on the lengthways of the path and increase due to the twisting of inner tube having a lower twisted ratio. In order to optimize heat transfer, it is necessary to boost mixing and turbulence intensity.

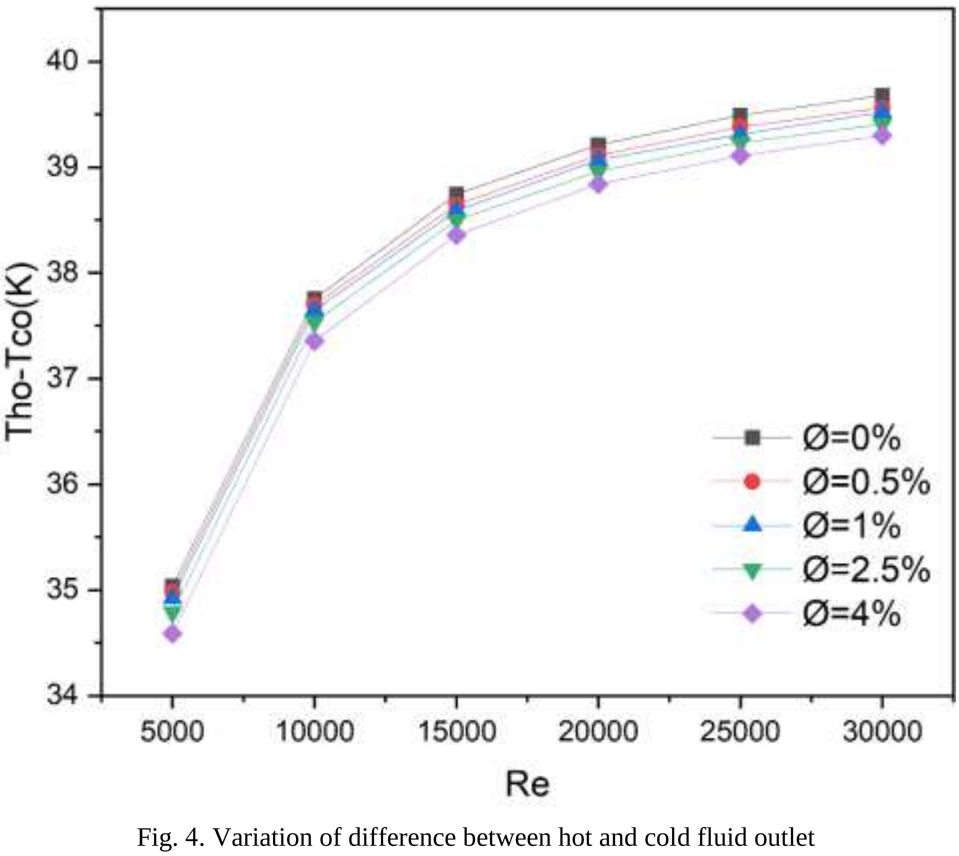

Fig. 4. Variation of difference between hot and cold fluid outlet
Temperature with Re for different volume fraction of nano fluid, Tr=5.

Figure 5 shows the variation of heat exchanger effectiveness with Reynold number for fluid flow. Because of the increased heat dissipated in nanofluid as a result of dispersing an additional amount of nanoparticles, the effectiveness increases as the volume concentration increases, as shown in this figure. This is due to the increased thermal conductivity of nano fluid with the increasing volume concentration value resulting from dispersing an additional amount of nanoparticles. Also found that the Al2O3-water nano fluid effectiveness is higher at Ø =%4than that pure water for all values of Re. The increased amount of heat exchanged when using nano fluid instead of pure water causes a more significant thermal conductivity.

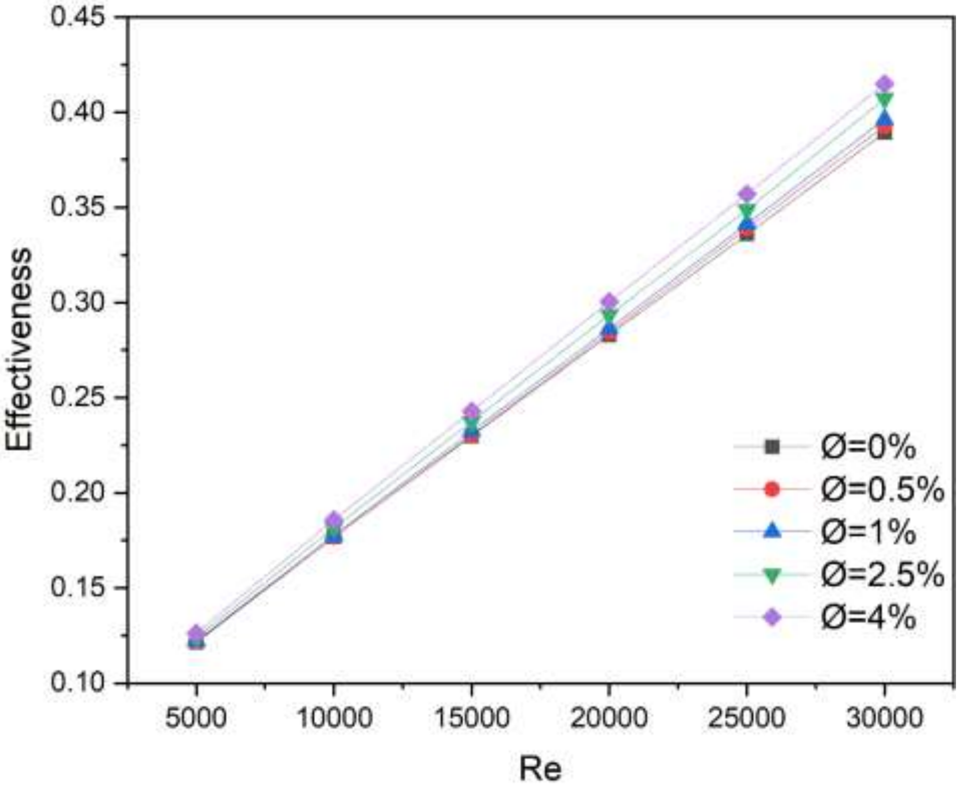

Fig. 5. The variation of Effectiveness with Re for different volume fraction of nano fluid, Tr=5.

The difference of pressure drop with Reynold number is presented in Figure 6. The pressure drop occurs caused by an increase in the viscosity of the nano fluid due to a significant increase in the concentration of nanoparticles in the base fluid. In addition, the secondary flow and the increased intensity of turbulence and vortices caused by the twisting of the inner tube will increase the pressure drop. It is essential to get insight into the overall performance considering both the thermal and hydrodynamic performance. So that investigate the overall performance of the heat exchanger, as shown in Figure 7. The overall thermal performance increases due to the increase in the concentration of nanoparticles in the base liquid. Which in turn, leads to an increase in the rate of heat transfer caused by the increase in the conductivity of the nano fluid when compared with the regular liquid. In addition, the twisting of the inner tube generates a secondary flow that pushes the nano fluid towards the tube wall, thus increasing the heat conduction process. From the above, the effectiveness of the heat exchanger will increase and be as high as possible at the highest concentration of the nano fluid. Simultaneously, the pressure drop increases due to eddies, and the viscosity of the nano fluid increases. Thus, the overall performance of the heat exchanger, which is the result of its division, thermal performance over hydraulic performance, will increase to reach the highest percentage at the highest concentration of nanoparticles Ø=%4.

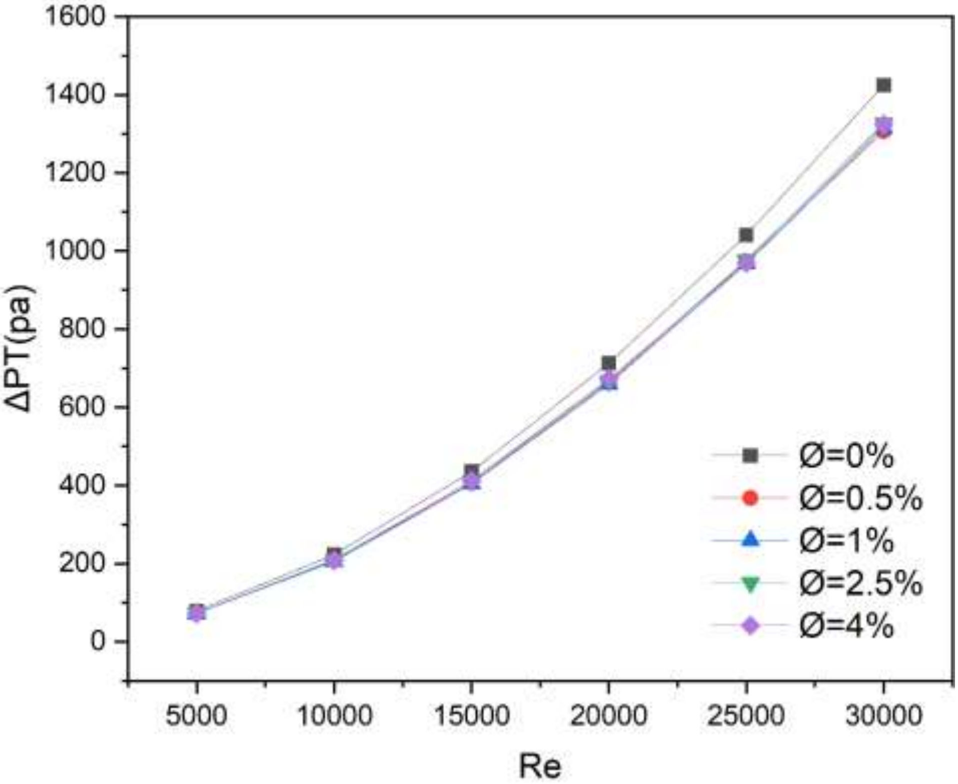

Fig. 6. Variation in pressure drop as a function of Re for various volume fractions of nano fluid, Tr=5.

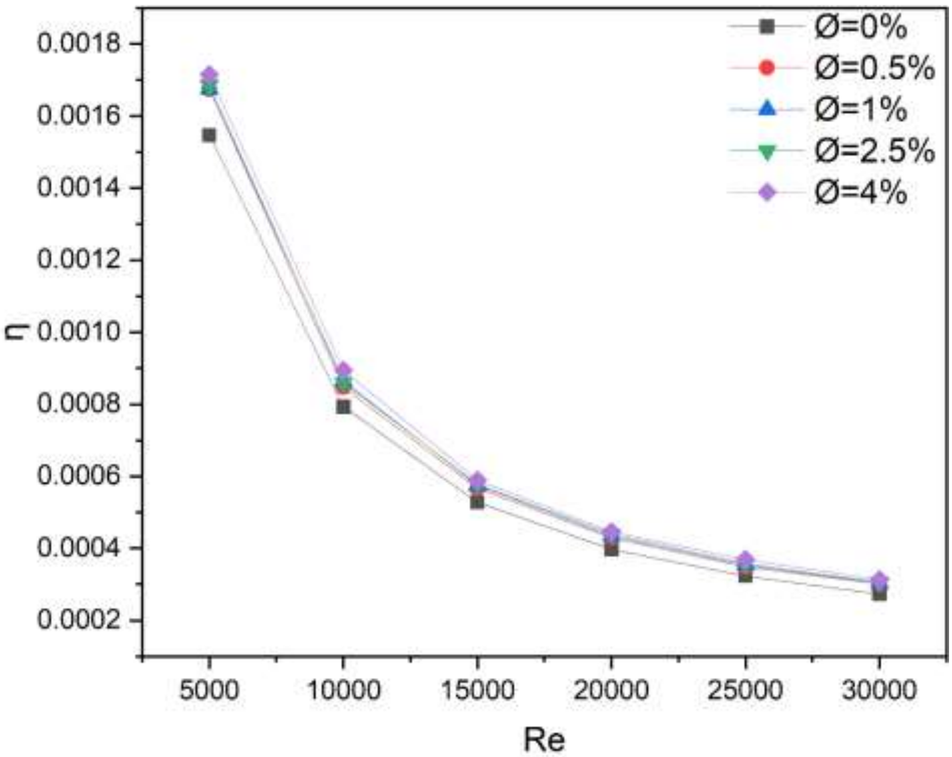

Fig. 7. The variation of overall performance with Re for different volume fraction nano fluid, Tr=5.

Figure 8 shows the temperature range of the cross-section at x= (0.4,0.6,0.8) for a circular twisted tube Tr=5. The thickness of the boundary layer decreases due to the increase in fluid mixing in the twisted tube when compared to the normal tube. The fluid flows rotationally and secondary flow is generated which enhances fluid mixing in the annulus when the circular twisted tube in the annulus. The area closest to the wall has a high thermal boundary thickness. The temperature field is more disordered due to the vortices and swirl flow generated in the twisted tube, so the temperature difference becomes less between the core region and the region close to the wall if compared with the normal tube. When the twisting is large, the border area is thinner. While the temperature of the twisted inner tube annulus is greater than that of the straight tube annulus. Also, the temperature is symmetrical around core the inner twisted tube. Because of the high velocity, large turbulence and secondary flow when the value of Tr is small, the thermal boundary layer is destroyed.

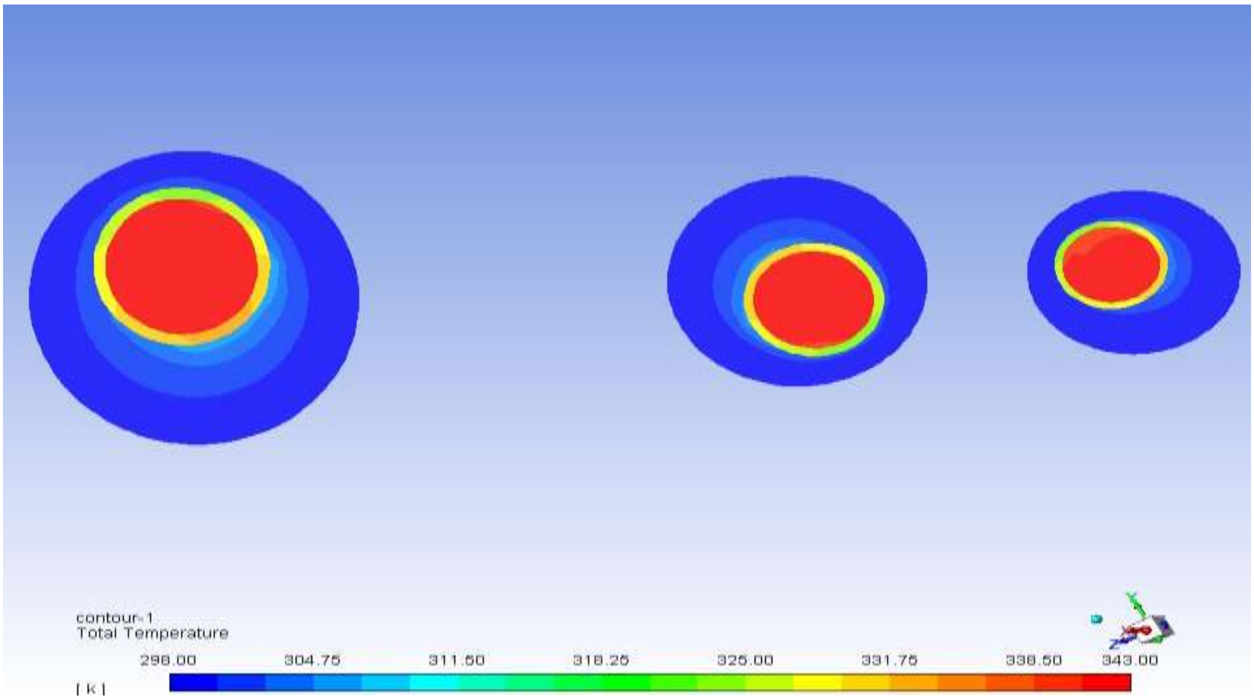

Fig. 8. Temperature fields for cross sections of Tr=5 for x= (0.4, 0.6, 0.8) m at Re = 30000.

Figure 9 shows the velocity flow streamlines of the double twisted tube heat exchanger. Spiraling lines are visible near the inner twisting tube's walls due to changes in flow direction caused by twisting. Because of this secondary flow, the velocity will increase, which will increase the intensity of the turbulence and lead to the destruction of the boundary layer. Secondary flow and fluid mixing increase with decreasing torsion ratio. So the secondary flow enhances heat transfer and improve heat exchanger heat performance. This causes more fluid to move in a vortex while the secondary flow between the base fluid and the tube wall is enhanced. It is noted that the maximum value of the velocity is about 65% of the average velocity when the Reynolds number is 30000.

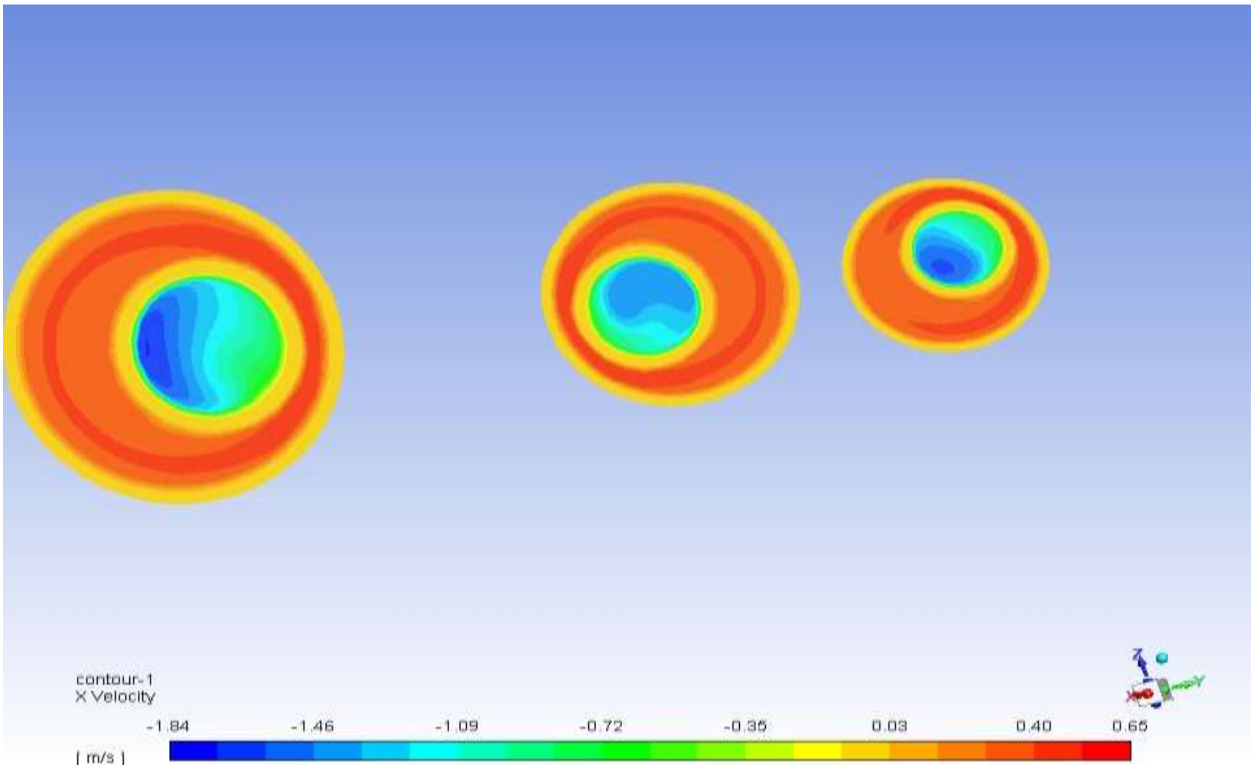

Fig. 9. Cross-sectional velocity contours of Tr=5 for x= (0.4, 0.6, 0.8) m at Re = 30000.

Conclusions

Numerical calculations were used to assess the effect of an inner circular twisted tube with Al2O3/water nano fluids on heat transfer from a double twisted tubular heat exchanger. The following are the findings of this research.

1. The double twisted circular tube exhibited superior overall performance with nano fluid (Al2o3-water) at Ø =%4 than the pure water by about 10.7% because higher thermal conductivity of nanofluids.
2. Using nano fluid causes the increase of effectiveness of counterflow double circular twisted tube heat exchanger at Ø =%4 by 5.6 than pure water.
3. The highest thermal performance in a double circular twisted tube heat exchanger when the nanofluid concentration is Ø =%4 due to the additional improvement of the heat transfer process.
4. When the flow rate dcreases, the effect of nano fluids increases, while it is negligible when the flow rate rises.
5. Because of the high thermal conductivity of the nanoparticles, the Al2O3-water nano fluid is more efficient in heat transfer than pure water..
6. The double twisted circular tube heat exchanger is more efficient in performance compared to plain heat exchanger. The thermal performance also increases with the increase in the Reynolds number and the concentration of nanoparticles in the working fluid compared to the plain tube.

7- Enhances the heat transfer rate at low twisted ratio accompanied by the intensity of turbulence, which increases the resistance to flow

8- The wall of the twisted inner tube generates a longitudinal vortex that improves the synergy between the velocity vector and the temperature gradient, which increases the rate of thermal conductivity, and the smaller the synergy angle the higher the rate of thermal conductivity.

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