HEAT TRANSFER ANALYSIS OF TRIANGULAR COIL WITH CORE ROD INSERTED IN Al_2O_3/WATER NANOFLUID FLOW IN A DOUBLE PIPE U-BEND HEAT EXCHANGER

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ABSTRACT: Heat exchangers are the devices that have a vital necessity in various sectors such as chemical industries, food processing units and process industries for heating and cooling purposes. Improving its performance through various attempts is of great concern for many researchers. Enhancement of heat transfer by use nanofluids and turbulators is one of such attempts now a days. A triangular coil with core-rod (TCCR) inserted in Al_2O_3/Water nanofluid flow in a double pipe U-Return heat exchanger is the matter of investigation in this study for heat transfer analysis and enhancement. Four concentrations of 0.00%, 0.02%, 0.04% and 0.06% Al_2O_3 nanofluid is made to flow in heat exchanger with three separate designs of p/d-1, p/d-1.34, and p/d-1.79 TCCR. 3D Ansys Fluent software was utilized for simulation of heat exchanger. Al_2O_3 nanofluid flows in the inner tube and water in the outer tube of heat exchanger. Various nanofluid properties like density, thermal conductivity and viscosity, also performance parameters like temperature profile, rate of heat flow, NTU and effectiveness are analysed. Obtained results are indicating that both the design of TCCR and concentration of nanofluid had a significant effect on heat transfer. The outlet temperature of Al_2O_3 nanofluid increase with increase in p/d ratio and it decrease with increase in particle concentration. The lowest temperature of nanofluid was observed at particle concentration of 0.06% for p/d ratio of 1. An improvement of heat transfer by 1.5%, 3.85% and 4.55% in first design, 4.28%, 8.40% and 11.78% in second design and 4.60%, 8.17% and 6.20% in third design was achieved for 0.02%, 0.04% and 0.06% particle concentrations respectively, when compared 0.00% of particle concentration. The reasons for the heat transfer improvement at p/d-1 of 0.06% particle concentration is because of a greater number of turns in TCCR insert at p/d-1 which causes the fluid to swirl more and improved thermal conductivity of nanofluid at 0.06% when compared to other considered concentrations.

Keywords: Triangular coil with core-rod (TCCR), Al_2O_3/Water nanofluid, Double pipe U-Return heat exchanger.

1. INTRODUCTION

The devices which have crucial importance for utilization and transformation of heat energy in various industries is known as heat exchanger. There are numerous types of heat exchangers available in the market based on the suitability, requirement and type of process. Regardless of the type of exchanger one the motivating objectives in this research field is to improve its performance through various attempts. Enhancement of heat transfer by use nanofluids and turbulators is one of such attempts now a days. Researches had been carried out on U-bend heat exchangers by using different turbulators like wire inserts, longitudinal strip inserts, trapezoidal cut twisted tape inserts, helical tape inserts and twisted tape inserts [1-5] respectively. Along with these turbulators few researches have also employed various nanofluids are employed such as Fe_3O_4 and Al_2O_3 [2-5] to study the effect of particle concentration on heat transfer. In present work the convective heat transfer performance and flow characteristics of Al_2O_3 nanofluid flowing was investigated. A triangular coil with core-rod (TCCR) inserted in Al_2O_3/Water nanofluid flow in a double pipe U-Return heat exchanger is the matter of investigation in this study for heat transfer analysis and enhancement. Four concentrations of 0.00%, 0.02%, 0.04% and 0.06% Al_2O_3 nanofluid is made to flow in heat exchanger with three separate designs of p/d-1, p/d-1.34, and p/d-

1.79 TCCR. Experiments have been carried out under turbulent conditions. The effect of particle concentration and TCCR design on the heat transfer performance and flow behaviour of the nanofluid has been determined.

2. GEOMETRY AND NUMERICAL SIMULATION OF HEAT EXCHANGER

2.1 Details of U-bend heat exchanger

It is a 5 m length double tube U-bend heat exchanger having 2.2 m each side and radius of the return 0.160 m. An aluminium triangular coil with core rod having different pitch to diameter ratios is inserted in the inner tube of heat exchanger. Aluminium is the material of 0.006 m thick inner tube whereas galvanized iron is used to 0.006 m thick outer tube. The outer tube is assumed to be adiabatic so that no heat can transfer out of heat exchanger. Hot fluid which is nanofluid having different volume concentrations in this case is allowed to pass through the inner tube with a constant mass flow rate of 0.133 kg/s whereas the cold fluid which is water in this case is passed through outer tube with same mass flow rate. Both fluids are made to flow in counter directions.

Table 1 Geometrical details of heat exchanger

S.NO	Description of the heat exchanger	Material	Dimension
1	Inner tube diameter	Aluminium	0.019 m ID 0.025 m OD
2	Outer tube diameter	Galvanized iron	0.05 m ID 0.056 m OD
3	Length of the heat exchanger	------	5 m
4	TCCR	Aluminium	For Design 1: 0.014m For Design 2: 0.01876 m For Design 3: 0.02506 m

2.2 Geometry Creation

All geometries in present research work problems were created by ANSYS Space Claim. There are total three designs in the geometries viz p/d-1, 1.34 and 1.79.

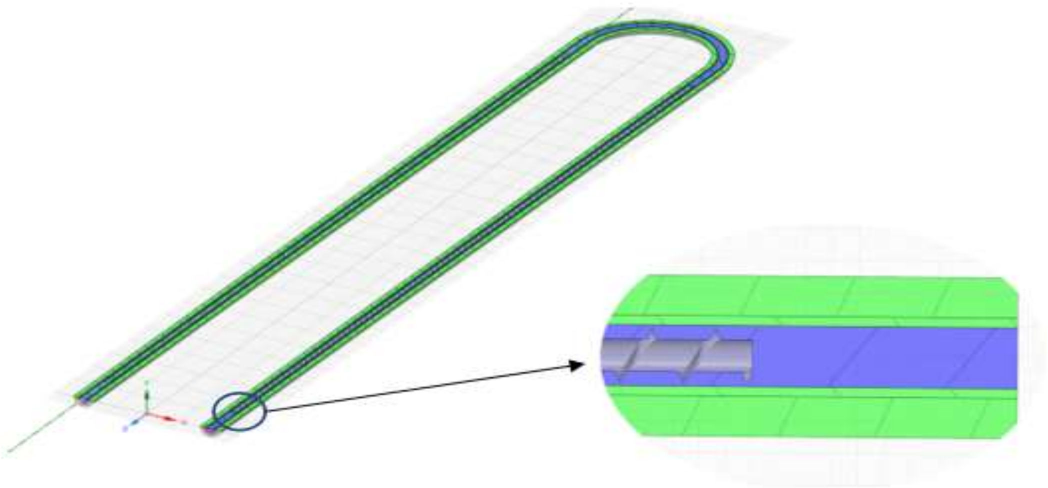
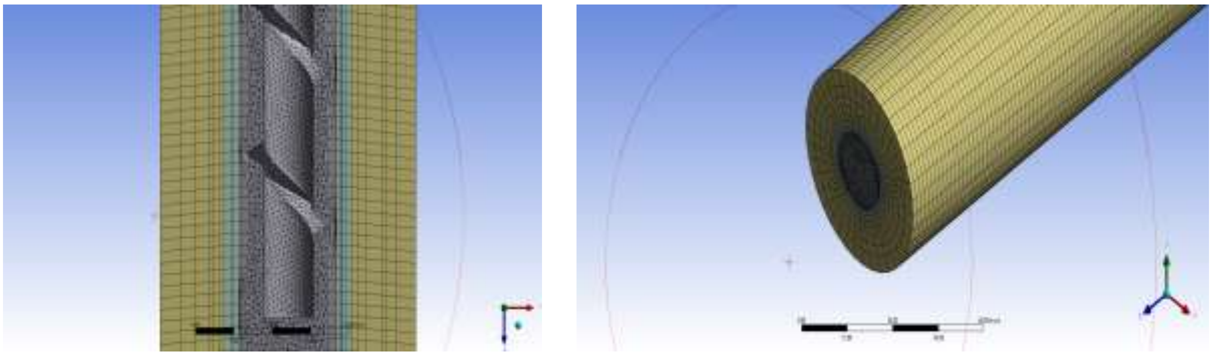


Fig.1 Sectional plane isometric view of heat exchanger geometry.

2.3 Mesh Generation



(a) (b)

Fig.2 (a) Section view of meshed geometry, **(b)** Isometric view of meshed geometry of heat exchanger in ANSYS fluent.

2.4 Boundary Conditions and Numerical Simulation

Table 2 Boundary conditions imposed for heat exchanger

S.NO	Volume fraction	Nanofluid mass inlet	Inlet temperature of nanofluid	Mass flow rate of water	Inlet temperature of water
1	0	0.133 kg/s	333.15 K	0.133 kg/s	302.15 K
2	0.02	0.133 kg/s	333.15 K	0.133 kg/s	302.15 K
3	0.04	0.133 kg/s	333.15 K	0.133 kg/s	302.15 K
4	0.06	0.133 kg/s	333.15 K	0.133 kg/s	302.15 K

After creation of the model and appropriate mesh generation, boundary conditions were imposed and then numerical simulation was in ANSYS FLUENT Software. The following figures illustrates the few temperature contours of the designs.

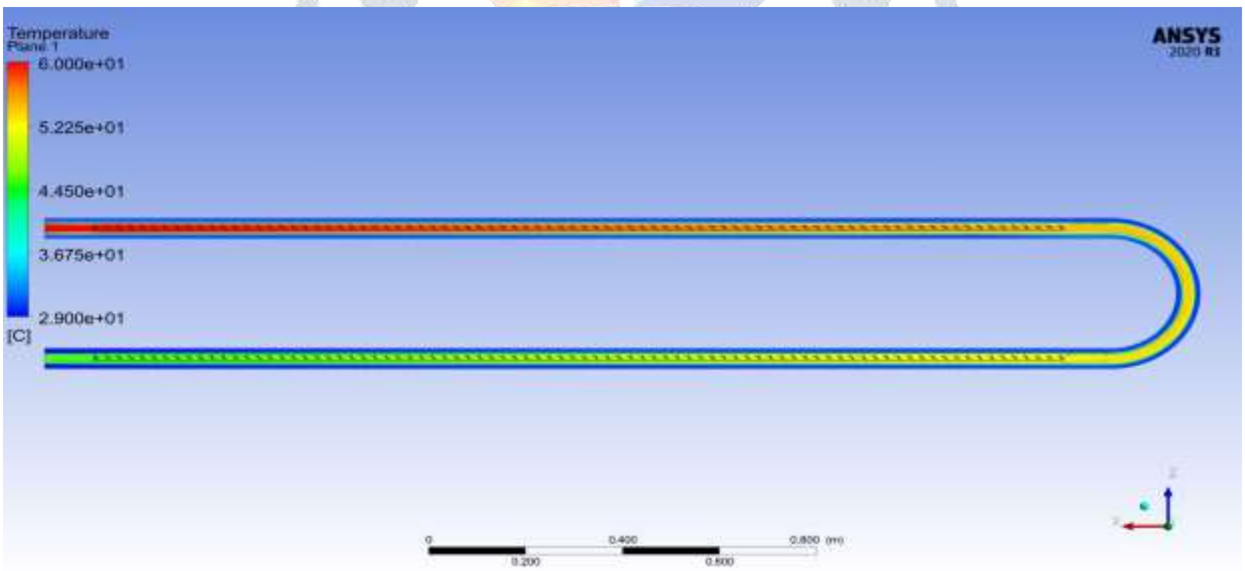


Fig.3 Temperature contour of heat exchanger with p/d-1 at 0.00% volume concentration.

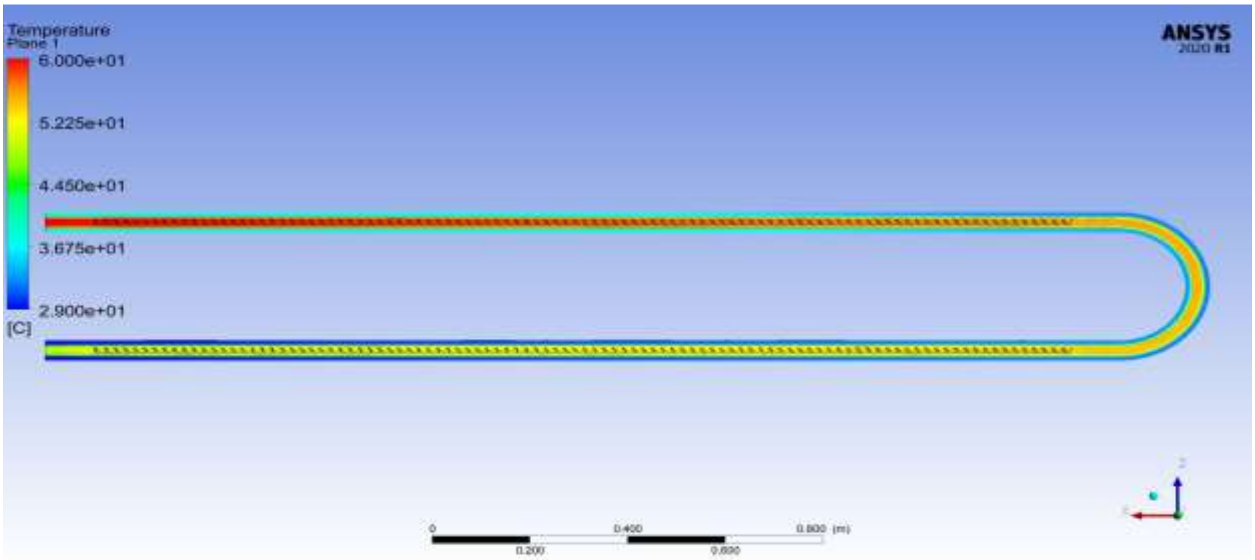


Fig.4 Temperature contour of heat exchanger with p/d-1.34 at 0.02% volume concentration.

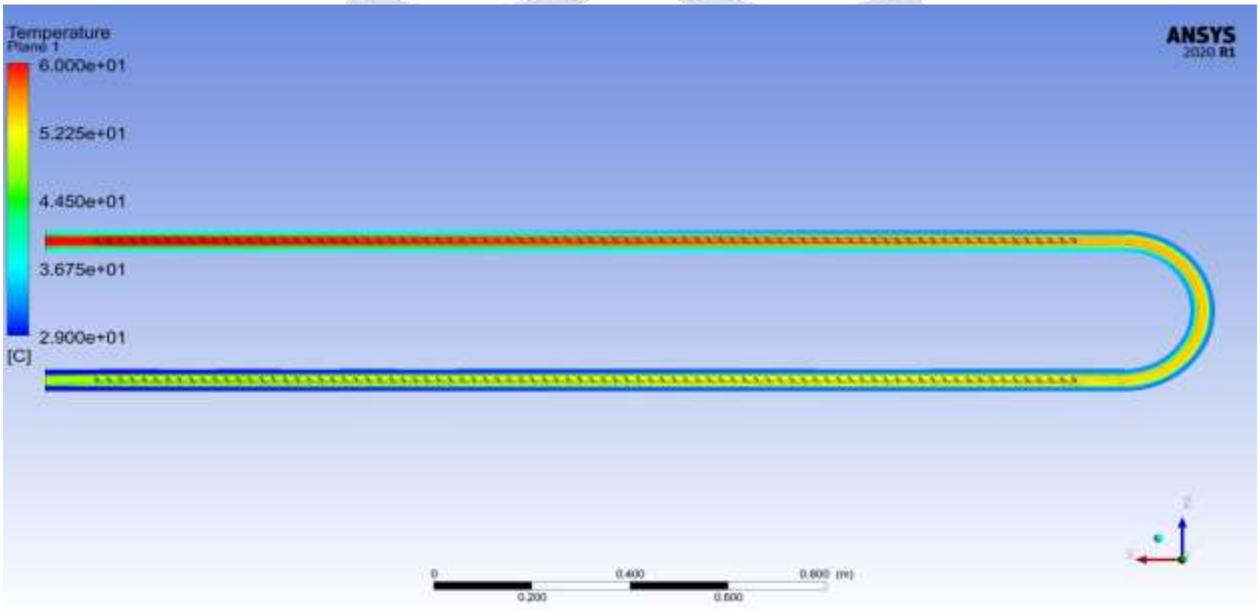


Fig.5 Temperature contour of heat exchanger with p/d-1.79 at 0.06% volume concentration.

3. HEAT EXCHANGER PERFORMANCE CALCULATIONS

3.1 Rate of Heat Flow

Rate of heat flow (Nanofluid), $Q_h = \dot{m}_h x C_{p.h} x (T_{h.i} - T_{h.o})$ (1)

Rate of heat flow (Water), $Q_c = \dot{m}_c x C_{p.c} x (T_{c.o} - T_{c.i})$ (2)

Where, $\dot{m}_h$, $\dot{m}_c$ are mass flow rates of hot and cold fluid respectively.

$C_{p.h}, C_{p.c}$ are specific heats of hot and cold fluid evaluated at mean temperatures respectively.

$T_{h.i}, T_{h.o}$ are temperatures at inlet and outlet for hot fluid.

$T_{c.o}, T_{c.i}$ are temperatures at inlet and outlet for cold fluid.

3.2 NTU-Effectiveness

Eq.3 and Eq.4 are used to determine the NTU and effectiveness of the heat exchanger.

Number of transfer units, NTU = $\frac{Q}{(\Delta T)_{LMTD}\ x\ C_{min}}$ (3)

Effectiveness, ε= $\frac{1-\exp[-NTU(1-Z)]}{1-Z\exp[-NTU(1-Z)]}$ (4)

Where, where C_{min} is the smaller of C_c and C_h

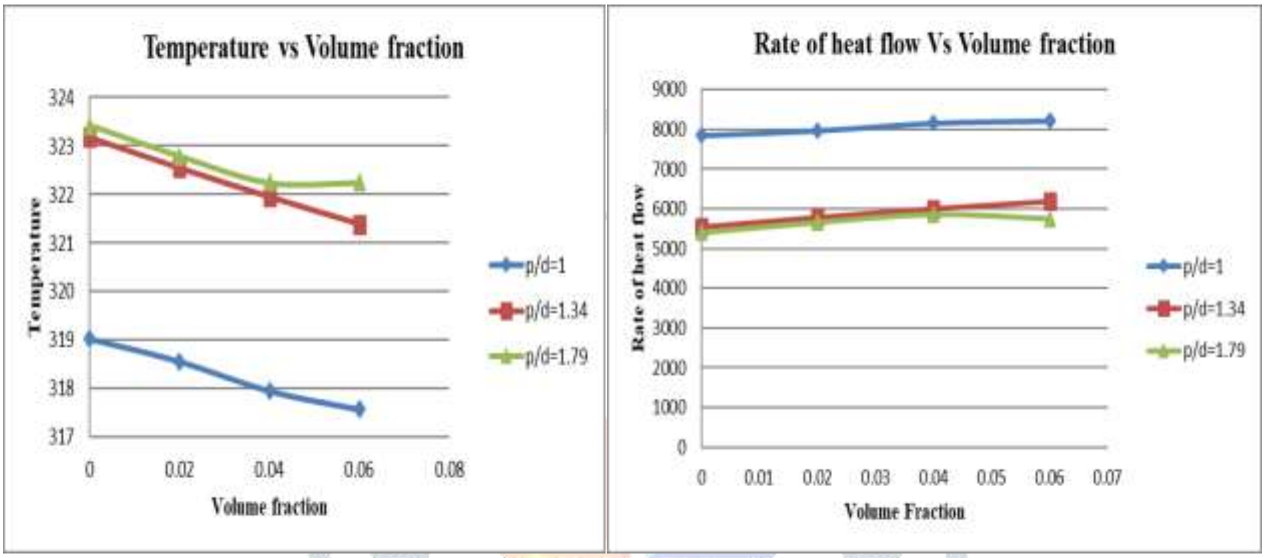
Heat capacity of tube side fluid, $c_h = \dot{m}_h \times C_h$ (5)

Heat capacity of annulus side fluid, $c_c = \dot{m}_c \times C_c$ (6)

4. RESULTS AND DISCUSSION

In the present section, the results are introduced and discussed for the heat transfer enhancement characteristics of Aluminium oxide nanofluid in a double pipe heat exchanger. Various volume fractions (0.00, 0.02, 0.04 and 0.06 %) were tested and the influence of the volume fraction was studied and found that the increase in volume fraction is in favour of heat transfer.

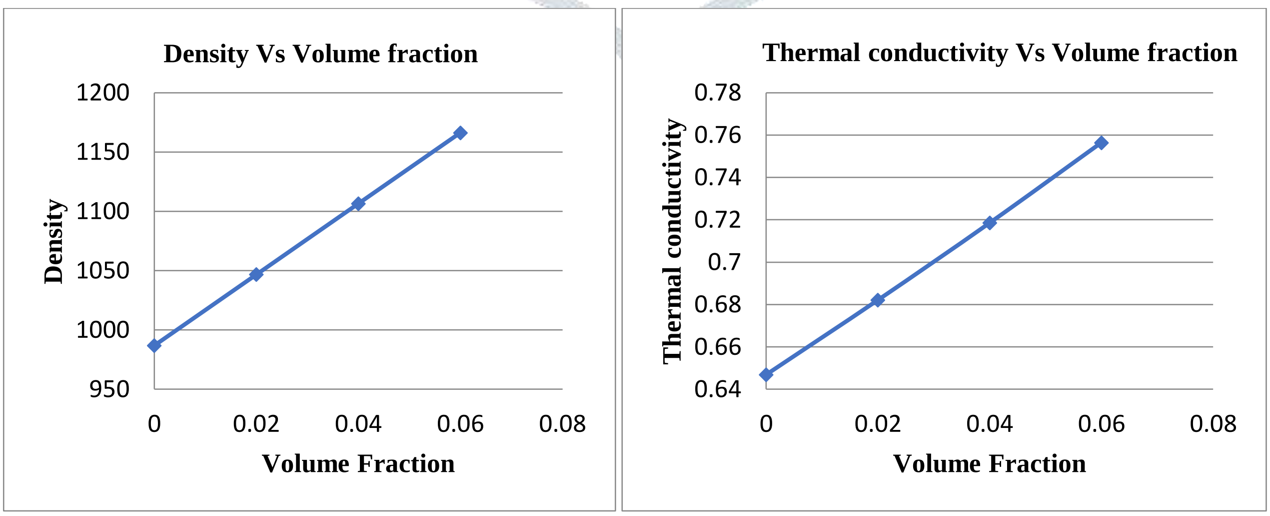
The outlet temperature of nanofluid variation with the volume concentration was investigated, and the results are shown in graph.1(a). The outlet temperature of nanofluid is observed to be raising with the raise in p/d ratio. The graph shown represents the gradual decrease in outlet temperature of nanofluid in corresponding p/d ratio.



(a) (b)

Graph.1 (a) Outlet temperature of nanofluid Vs volume fraction, (b) Rate of heat flow of nanofluid Vs Volume Fraction.

The decrease in outlet temperature of nanofluid is resulted from the increase rate of heat flow of nanofluid. The rate of heat flow increases with the increase in volume fraction. This happens because the thermal conductivity of the water has been enhanced by the Aluminium Oxide nanoparticles. Graph.1(b) shown represents the gradual Increase in rate of heat flow of nanofluid with respect to volume fraction. Further the rate of heat flow decreases with increase in p/d ratio.



(a) (b)

Graph.2 (a) Density of nanofluid Vs volume fraction, (b) Thermal conductivity of nanofluid Vs Volume Fraction.

As the p/d ratio increases the velocity of the fluid decreases. This is due to hydraulic diameter which increases with the p/d ratio. More the hydraulic diameter means more the fluid flowing cross section. On the other hand, the velocity obviously decreases with increase in particle concentration.

Properties like density and thermal conductivity nanofluid are plotted with respect to the particle concentration in the graph shown in the graphs.2(a) and 2(b). These mentioned property values along with viscosity have seen to get increased with particle concentration. More the concentration of nanoparticles in the base fluid more is the density, thermal conductivity and viscosity.

5. CONCLUSIONS

The present work deals with the estimation of various parameters of Al_2O_3 nanofluid flow having different volume concentrations in a horizontal double tube U-bend heat exchanger inserted with triangular coil core rod of different p/d ratios. The whole geometry creation, meshing and simulation was carried out using ANSYS 2020 Software. The effectiveness and NTU is also estimated for different concentrations of nanofluids. The outlet temperature of Al_2O_3 nanofluid increase with increase in p/d ratio and it decrease with increase in particle concentration. The lowest temperature of nanofluid was observed at particle concentration of 0.06% for p/d ratio 1. The rate of heat flow therefore behaves in opposite fashion to the above explanation. It decreases with increase in p/d ratio and increases with increase in particle concentration. An improvement of heat transfer by 1.5%, 3.85% and 4.55% in first design, 4.28%, 8.40% and 11.78% in second design and 4.60%, 8.17% and 6.20% in third design was achieved for 0.02%, 0.04% and 0.06% particle concentrations respectively, when compared 0.00% of particle concentration. The velocity of the nanofluid changes inversely with the p/d ratio of the TCCR insert. Various properties like density, thermal conductivity and viscosity of the nanofluid are increased with particle concentrations. To sum up with, from simulation and theoretical results it can be concluded that both the design of TCCR and concentration of nanofluid had a significant effect on heat transfer. The reasons for the heat transfer improvement at p/d-1 of 0.06% particle concentration is because of a greater number of turns in TCCR insert at p/d-1 which causes the fluid to swirl more and improved thermal conductivity of nanofluid at 0.06% when compared to other considered concentrations.

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