iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 9 **Issue:** IX **Month of publication:** September 2021

DOI: https://doi.org/10.22214/ijraset.2021.37971

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.429
Volume 9 Issue IX Sep 2021- Available at www.ijraset.com

CFD Analysis of Enhancement of Heat Transfer of Automobile Radiator with Hybrid Nanofluid as a Coolant

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Abstract: The performance of the radiator depends on the fluid used in it as a coolant. The conventional fluids like water, ethylene glycol used as a coolant have low thermal conductivity and are not enough for transferring the heat to more extend. Nanoparticles because of their high thermal conductivity enhances the performance of the radiator when added into the base fluid. In the present work Al_2O_3-CuO/ Water based hybrid nanofluid is used as a coolant for the CFD analysis of automobile radiator. Different mixing ratios (80:20, 60:40,50:50,40:60 and 20:80) of Al_2O_3-CuO nanoparticles are used in water with 1% volume concentration. The inlet temperature and volume flow rate of fluid are kept constant. The nanofluid with 20:80 mixing ratio of Al_2O_3-CuO gives maximum enhancement in heat transfer coefficient and Nusselt number than water by 72% and 65% respectively.

Keywords: Coolant, Heat Transfer Coefficient, Nusselt Number, Hybrid Nanofluids, Radiator

I. INTRODUCTION

The radiator is nothing but the heat exchanger which transfers heat from one medium to the another. It is the most important part in automobiles as it cools down the engine by removing excess of heat from it and maintain its temperature. Water and ethylene glycol plays an important role in thermal management but because of their poor thermal characteristics nanofluids are used over these conventional fluids. Nanofluids have higher thermal conductivity than the base fluids and their use in radiator not only just enhances its performance but also leads to the reduced size of the radiator. The heat transfer enhancement of nanofluids is primarily depends on thermal conductivity of nanoparticles, particle volume concentration and mass flow rates. Under constant particle volume concentrations and mass flow rates, the heat transfer enhancement only depends on the thermal conductivity of the nanoparticles. The thermal conductivity of the nanoparticles may be altered or changed by preparing hybrid nanoparticles. Hybrid nanoparticles are defined as the nanoparticles composed by two or more different materials of nanometer size. The fluids prepared with hybrid nanoparticles are known as hybrid nanofluids. Hybrid nanofluids are more effective heat transfer fluids than single nanoparticle based nanofluids or conventional fluids.

II. LITERATURE REVIEW

A I Ramadhan et al [6] has performed the experiment to study the heat transfer characteristics of car radiator with vertical aluminium tubes by using tri-hybrid nanofluids. Tri-hybrid nanofluids was prepared by two step method by adding 0.05 to 0.3% volume concentration of Al_2O_3-TiO_2-SiO_2 nanoparticles in a mixture of water/ethylene glycol (60:40). They have performed the experiment for different flow rates between 2 to 12 l/min for a working temperature of 70^{o}C. The velocity of air was kept constant as 4 m/s. The heat transfer coefficient of tri-hybrid nanofluid was found to be increased with increasing the volume concentration and temperatures. At 0.3% volume concentration the maximum enhancement of 39.7% was observed in heat transfer coefficient. By increasing the volume concentration of the nanofluids, the pressure drop and pumping power was increased. The lowest pressure drop and pumping power was observed at 0.05% volume concentration with 5 kPa and 0.001 kW respectively and the highest pressure drop and pumping power value was found to be at 0.3% volume concentration with 180 kPa and 0.035 kW respectively.

Neeshoun Asokan et al [7] has investigated experimentally the thermal performance of compact heat exchanger and the rheological properties of low concentration mono and hybrid nanofluids. The mono nanofluids were prepared by adding Al_2O_3 and CuO nanoparticles in 60:40 ratio of distilled water and ethylene glycol. The hybrid nanofluid was prepared by two step method by adding Al_2O_3 and CuO with the mixing ratio of 50:50 in a base fluid. Polyvinyl Pyrrolidone was used as a surfactant. The nanofluids were prepared with different volume concentration of 0.02%, 0.04% and 0.06%. The experiment was performed by varying two factors the initial maximum temperature and pump speed. The maximum temperature of 100^{O}C was used for the investigation and the pump speed was set at 1050, 850 and 650 RPM. The Nusselt number for hybrid nanofluid was found to be increased by 6.7% and 17.9% and the average heat transfer coefficient was found to be increased by 7.2% and 12.1% as compared to CuO and Al_2O_3 nanofluids respectively. It was observed that the hybrid nanofluid samples possessed the lower specific heat capacity values as compared to the other two mono nanofluids.

This means that the hybrid nanofluids are able to gain and loss the heat at faster rate compared to its mono nanofluids counterparts. The thermal conductivity of hybrid nanofluid was higher than the CuO and Al_2O_3 nanofluids by 2.3% and 3.6% respectively. The hybrid nanofluid has shown the maximum enhancement of 23.2% in heat transfer coefficient as compared to the base fluid.

Ali Karimi et al. [10] has studied numerically the effects of hybrid nanofluid, pipe arrangement and cross sections of tubes on the thermal performance of an air-cooled heat exchanger. In their study they have used water and MgO-MWCNT/EG hybrid nanofluid with different volume concentrations. The nanoparticles volume concentrations used were 0,0.1,0.2,0.4,0.8 and 1% and the Reynold's number ranging from 350 to 1060. They have studied the efficiency of the vertical and horizontal radiators using the experimental data for the thermo-physical properties of MgO-MWCNT/EG nanofluid. The efficiency of radiator with the vertical tubes is found to be better than the radiator with horizontal tubes. The tubes with circular and elliptical sections are also investigated for different flows, inlet temperature and concentrations. The results indicate that the radiator with circular pipes had lower pressure drop and those with elliptical pipes had higher Nusselt number. The improvement in the Nusselt number and increase in pressure drop was found by increasing the nanofluid concentration. The pressure drop was found to be decreased with the increase in radiator's inlet temperature and increases with the increase in the Reynold's number.

Bharath R Bharadwaj et al. [12] has done the CFD analysis of heat transfer performance of graphene-based hybrid nanofluid in the radiator of Tata Indica car. They have made a model of radiator in SEIMENS NX. and CFD analysis was conducted in ANSYS FLUENT software. The effect of using Carboxyl-Graphene and Graphene-Oxide nanoparticles at 1%,2% and 3% volume concentration of each nanoparticles for different flow rates of 4,5 and 6 LPM was studied in their work through numerical approach. The air velocity was specified as 1.5 m/s. The nanofluid were considered incompressible and flow were assumed to be laminar. The authors have selected the medium mesh for the CFD analysis in order to save the computational resources and time. It has been seen from the results that the temperature drop of 0.251^{o}C which when extrapolated to the whole length of the tube of the radiator turns out to be 10.93^{o}C for a flow rate of 4LPM. The effectiveness was found to be increased as the concentration of nanofluid increased and the maximum enhancement in effectiveness was 10% as compared to base fluid upon addition of 3% Carboxyl-Graphene and 3% Graphene Oxide at a flow rate of 4LPM. The effectiveness decreases with increasing flow rate. Friction factor decreases when the flow rate increases. There is a slight increase in pumping power to compensate the friction losses.

Senthil Ramalingam et al [5] in their experiment has used hybrid nanofluids in automobile radiator with the horizontal tubes to find out its heat transfer characteristics. They have used the aluminium oxide (Al_2O_3) doped with unmilled silicon carbide (SiC_{UM}) nanoparticles and milled silicon (SiC_M) nanoparticles dispersed in distilled water (DW) and ethylene glycol (EG) at 50:50 volumetric proportion in their experimented study. The nanofluids were prepared by two step method. Four different nanofluids were prepared: NF1(Al_2O_3 doped with SiC_{UM} by the weight proportion 60:40) with the volume concentration of 0.4%, NF2 (Al_2O_3 doped with SiC_{UM} by the weight proportion 50:50) with the volume concentration 0.8%, NF3 (Al_2O_3 doped with SiC_M by the weight proportion 60:40) with the volume concentration of 0.4%) and NF4 (Al_2O_3 doped with SiC_M by the weight proportion 50:50) with the volume concentration 0.8%. An improvement regarding the overall thermal performance of 28.34% was observed by using NF4. The Nusselt number for NF1 was 8.68% higher than the base fluid and 28.35% than the NF2. The enhancement of Nusselt number for NF3 and NF4 was observed to be 6.213% and 15.21 % for the experimented flow rate. At different flow rates the friction factor was found to be decreased by 1.75% and 13.89% for 0.4% and 0.8% Al_2O_3/SiC_{UM} nanofluids. For Al_2O_3/SiC_M nanofluids it was increased by 2.34% for 0.4% volume concentration and reduced by 9.97% for 0.8% volume concentration during the same mass flow rate.

III. METHODOLOGY

A. *Geometrical Modelling*

Figure 1. shows the geometrical model of Maruti Alto 800 radiator. The geometry consists of a vertical tubes and fins attached to the wall of the tubes. Specifications of the radiator are mentioned in table 1.

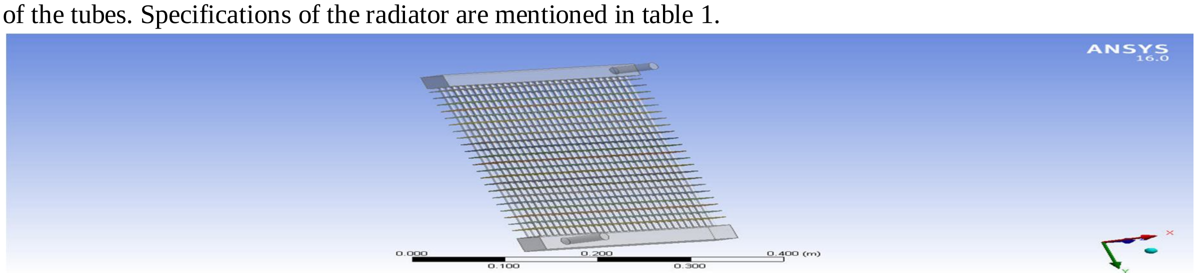

Fig.1 Geometrical model of the radiator

ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.429
Volume 9 Issue IX Sep 2021- Available at www.ijraset.com

Table 1. Specifications of radiator model

Sr. No.	Parameter	Value
1.	Radiator Length	420mm
2.	Radiator Height	460mm
3.	Radiator Width	45mm
4.	Tube Length(L)	395mm
5.	Tube Inner Diameter	5mm
6.	Tube Outer Diameter	6mm
7.	Number of Tubes	57
8.	Number of Fins	22
9.	Thickness of Fins	1mm

B. Computational Analysis

The simulation is carried out in ANSYS 16.0. Figure 2 shows the meshing of the model and the details of the meshing are mentioned in table 2. Hybrid nanofluid containing Al_2O_3-CuO with different mixing ratios (80:20, 60:40,50:50, 40:60 and 20:80) in water with 1% volume concentration used as a coolant in radiator. Inlet temperature, volume flow rate of fluid and inlet temperature of air are kept constant at 363.15K , 5 lpm and 303K respectively. For turbulent modelling standard k-ε turbulent model is used. Navier stokes equation, law of conservation of energy and continuity equation are taken into consideration and SIMPLEC scheme is used.

Table 2. Meshing details

Sr. No.	Parameter	Value
1.	Number of nodes	1904600
2.	Number of elements	7302071
3.	Element quality	0.86066
4.	Orthogonality	0.86157
5.	Aspect ratio	1.8448

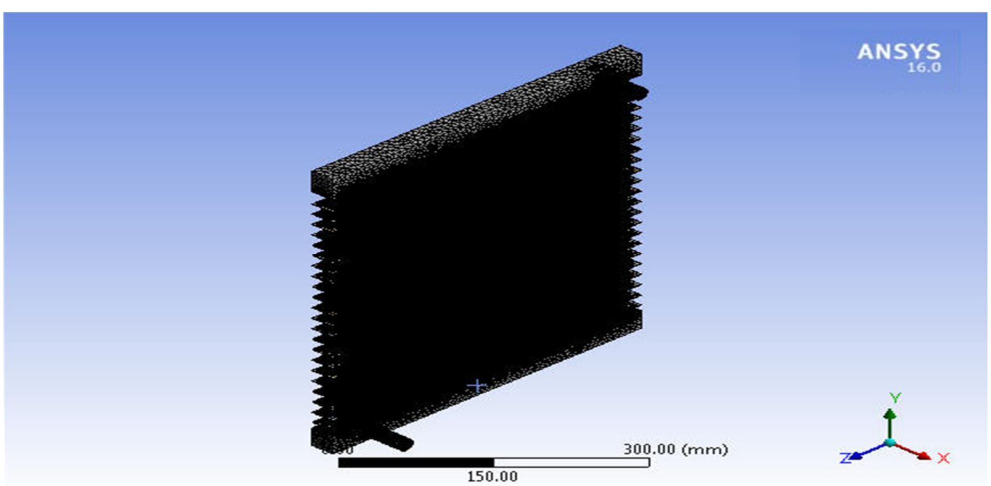

Fig 2. Mesh model

C. Thermophysical Properties of Nanofluid

Hybrid nanofluid of Al2O3-CuO with the mixing ratio of 80:20, 60:40, 50:50, 40:60 and 20:80 in water with 1% volume concentration is used in present study. Table 3 shows the properties of the nanofluids. The properties of the hybrid nanofluids are calculated by the following correlations,

1) Density

$$\rho_{hnf} = (\varphi_{Al2O3} * \rho_{Al2O3}) + (\varphi_{CuO} * \rho_{CuO}) + (1-\varphi) * \rho_{bf}$$

where φ is the overall volume concentration of two different types of nanoparticles dispersed in a hybrid nanofluid

$$\varphi = \varphi_{Al2O3} + \varphi_{CuO}$$

2) Dynamic Viscosity

$$\mu_{hnf} = \left(1 - \frac{\phi}{\phi_m}\right)^{-\eta * \phi m} \mu_{bf}$$

where η is the Einstein coefficient, $\eta = 2.5$ and $\varphi_m = 0.65$

3) Specific Heat

$$C_{hnf} = \varphi_{Al2O3}\, \rho_{Al2O3}\, C_{p\ Al2O3} + \varphi_{CuO}\, \rho_{CuO}\, C_{p\ CuO} + (1-\varphi) C_{p\ bf}\ \rho_{hnf}$$

4) Thermal Conductivity

$$K_{hnf} = \frac{[(\varphi Al2O3\ kAl2O3 + \varphi CuO\ kCuO) / (\varphi Al2O3 + \varphi CuO)] + 2kbf + 2(\varphi Al2O3\ kAl2O3 + \varphi CuO\ kCuO) - 2\varphi kbf}{[(\varphi Al2O3\ kAl2O3 + \varphi CuO\ kCuO) / (\varphi Al2O3 + \varphi CuO)] + 2kbf - 2(\varphi Al2O3\ kAl2O3 + \varphi CuO\ kCuO) - 2\varphi kbf}\ k_{bf}$$

Table 3. Thermophysical properties of nanofluids

Sr. No.	Fluid	Density (kg/m^3)	Dynamic viscosity (Ns/m^2)	Specific heat (J/kg-K)	Thermal conductivity (W/m-K)
1.	Water	964.45	3.07E-04	4074.7	0.67606
2.	Al2O3	3970	-	765	46
3.	CuO	6500	-	535.6	20
4.	Al2O3-CuO (80:20)/water	999.5655	0.000315	3923.51	0.70276
5.	Al2O3-CuO (60:40)/water	1004.626	0.000315	3904.633	0.702635
6.	Al2O3-CuO (50:50)/water	1007.156	0.000315	3895.266	0.702558
7.	Al2O3-CuO (40:60)/water	1009.626	0.000315	3885.945	0.702468
8.	Al2O3-CuO (20:80)/water	1014.746	0.000315	3867.444	0.702235

5) Thermal Analysis of Radiator

Surface area of Radiator Tube

$$A_s = \pi\, D_h\, L$$

Heat transfer coefficient

$$h = \frac{\dot{m}\, C_P\, (T_{in} - T_{out})}{A_s\, (T_b - T_s)}$$

where $T_b = \frac{T_{in} - T_{out}}{2}$ and T_s = surface temperature of tube walls

Heat transfer rate

$$Q = \dot{m}\, C_p\, (T_{in} - T_{out})$$

Reynold Number can be calculated as,

$$Re = \frac{4\dot{m}}{\pi\, \mu\, D_h}$$

Nusselt number can be calculated as,

$$Nu = \frac{h\, D_h}{k}$$

IV. RESULTS AND DISCUSSION

In the present work the hybrid nanofluids of Al2O3-CuO nanoparticles in water with 1% volume concentration are used. Five mixing ratios (80:20, 60:40, 50:50, 40:60 and 20:80) of the nanoparticles are used for the computational analysis of radiator. Inlet temperature of the fluid is kept constant at 363.15 K and the outlet temperature for each of the fluid is estimated. Variation in Reynolds number, Nusselt number, heat transfer coefficient and heat transfer rate with different mixing ratios of nanoparticles are estimated. Figures 3 to 8 shows the temperature contour for all the fluids used in the present work as a coolant in radiator. The outlet temperature of the hybrid nanofluid for all the mixing ratios was found to be lower than the outlet temperature of water. The maximum drop in temperature of 16.17 K was found for the hybrid nanofluid with 20:80 mixing ratio.

A. Temperature Contour Of Water

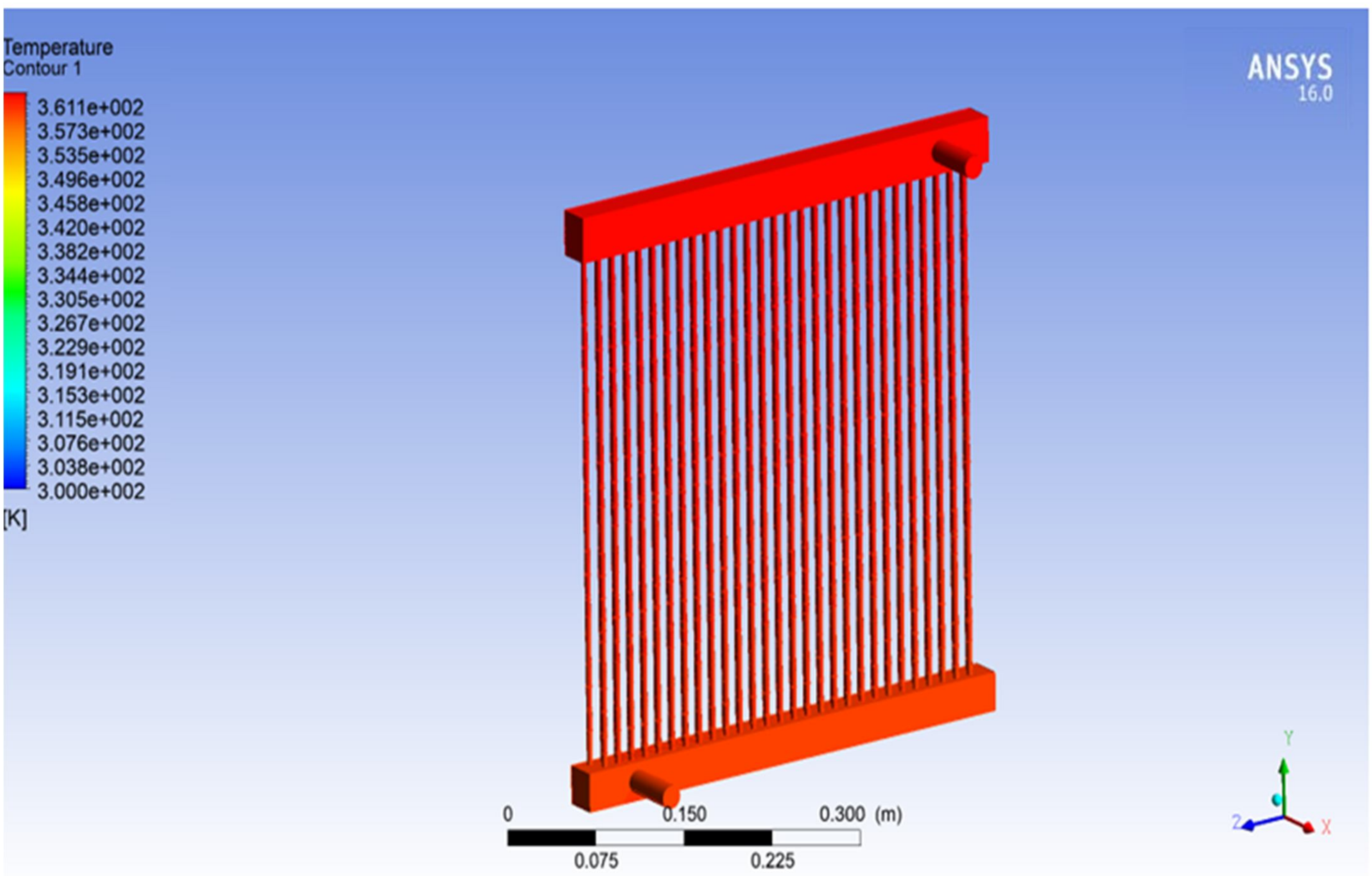

Figure 3. Temperature contour for Water

The output temperature of water obtained was 357.14 K i.e. for water the temperature difference between inlet and outlet was found to be of 6.01K.

B. Temperature Contour of 80:20 Al2O3-CuO/water

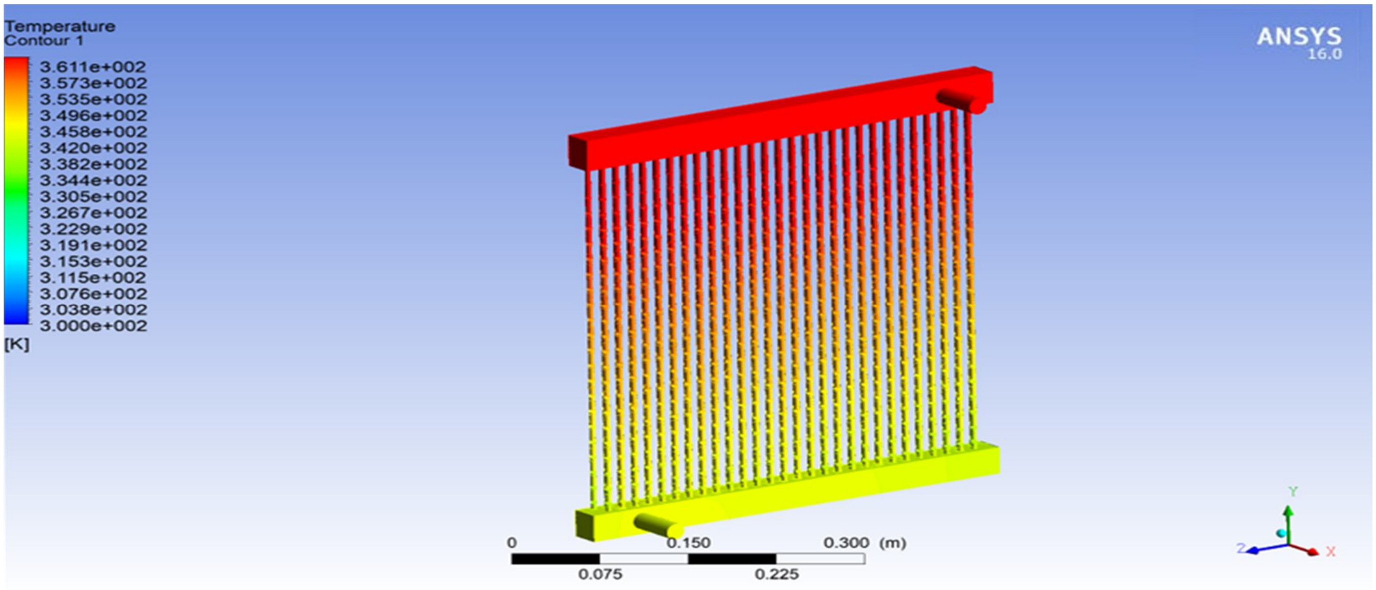

Figure 4. Temperature contour for 80:20 Al2O3-CuO/Water

The output temperature of Al2O3-CuO/water nanofluid with 80:20 mixing ratio obtained was 348.94 K i.e. for Al2O3-CuO/water nanofluid the temperature difference between the inlet and outlet was found to be of 14.21 K.

C. Temperature Contour of 60:40 Al2O3-CuO/water

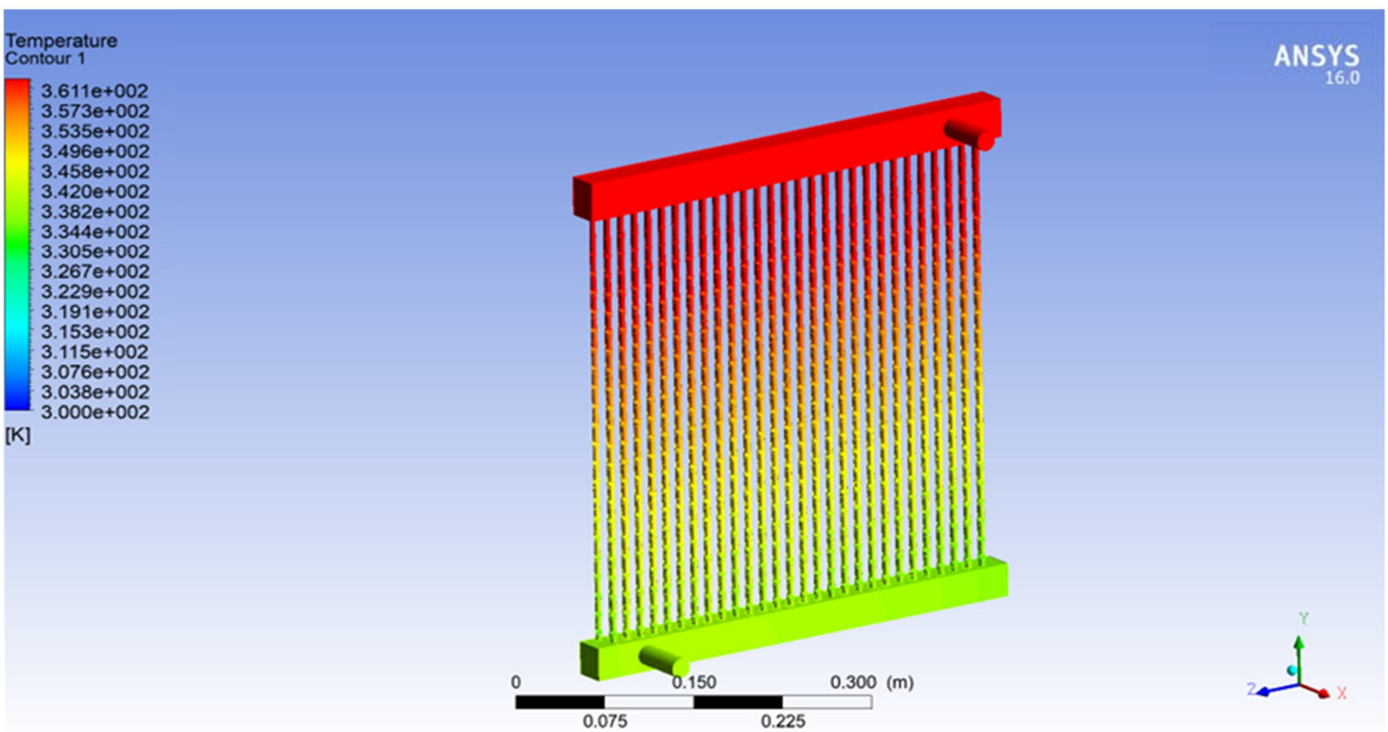

Figure 5. Temperature contour for 60:40 Al2O3-CuO/Water

The output temperature of Al2O3-CuO/water hybrid nanofluid with 60:40 mixing ratio obtained was 348.13 K i.e the temperature difference between inlet and outlet was found to be of 15.02 K.

D. Temperature Contour of 50:50 Al2O3-CuO/water

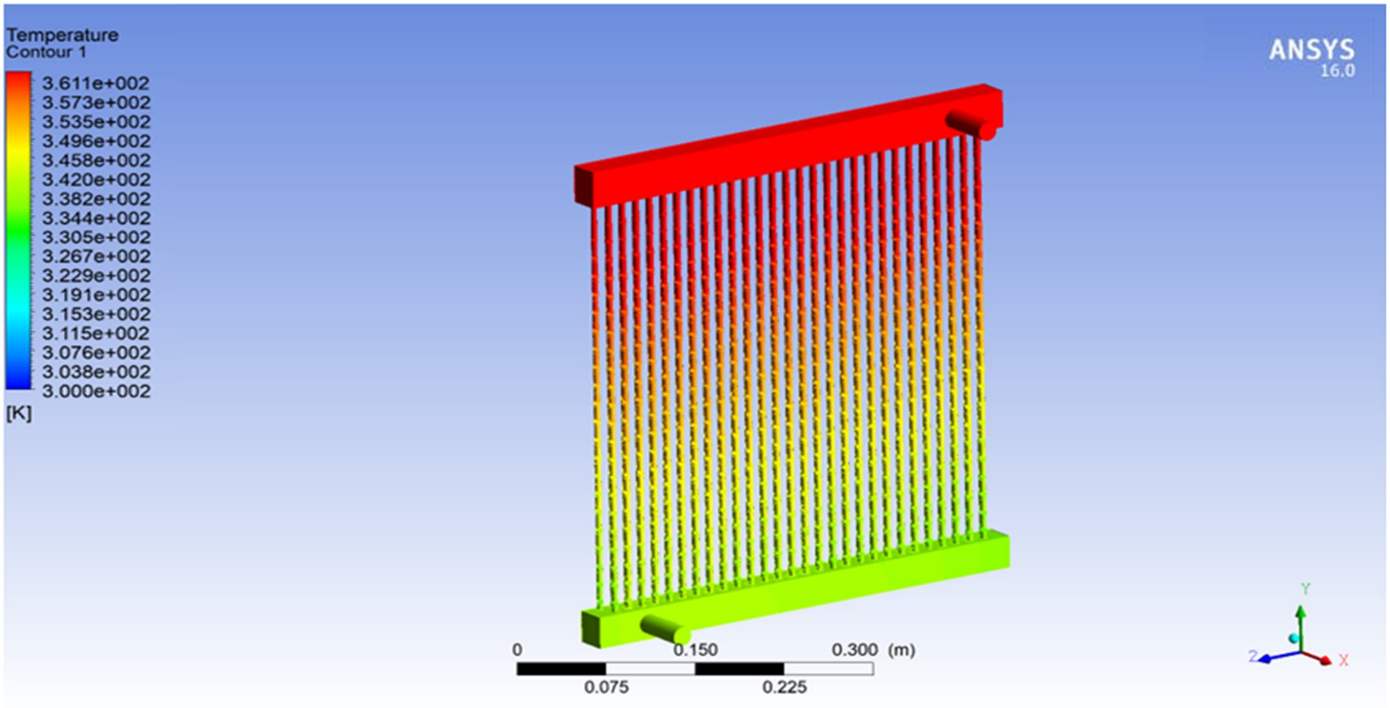

Figure 6. Temperature contour for 50:50 Al2O3-CuO/Water

The output temperature of Al2O3-CuO/water hybrid nanofluid with 50:50 mixing ratio obtained was 348.01 K i.e the temperature difference between inlet and outlet was found to be of 15.14 K.

E. Temperature Contour of 40:60 Al2O3-CuO/water

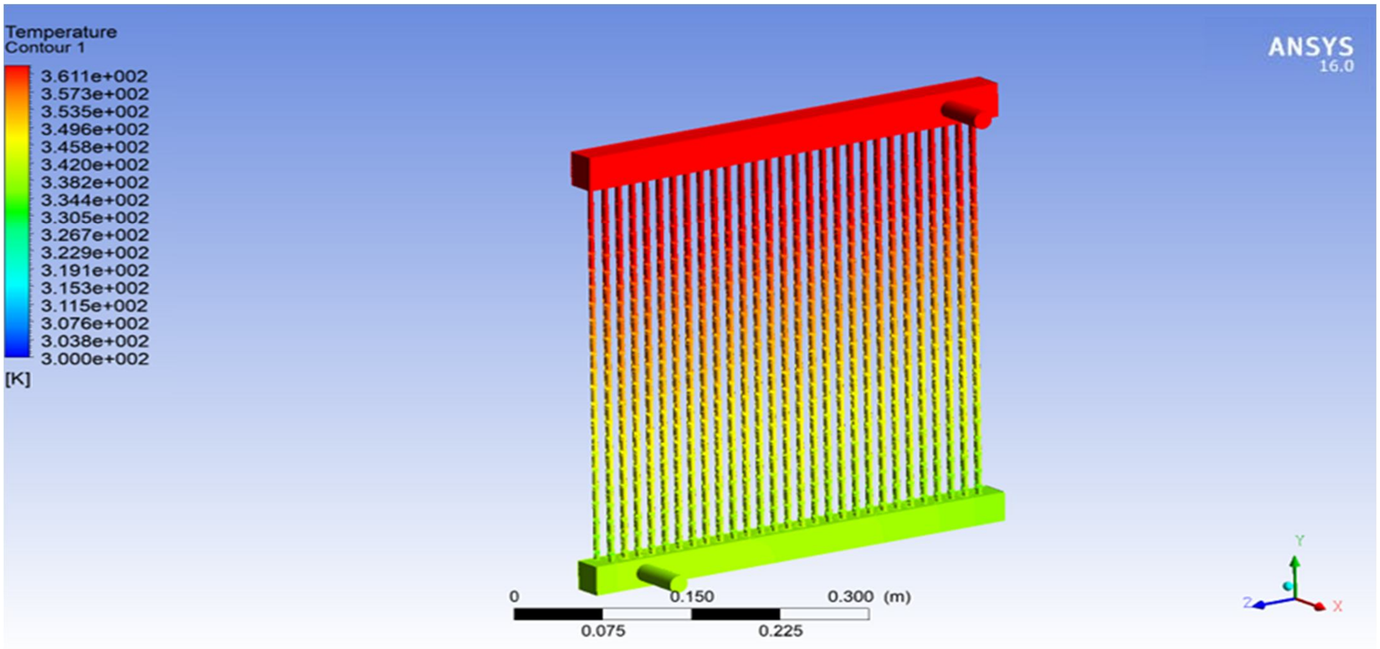

Figure 7. Temperature contour for 40:60 Al2O3-CuO/Water

The output temperature of Al2O3-CuO/water hybrid nanofluid with 40:60 mixing ratio obtained was 347.39 K i.e the temperature difference between inlet and outlet was found to be of 15.76 K.

F. Temperature Contour of 20:80 Al2O3-CuO/water

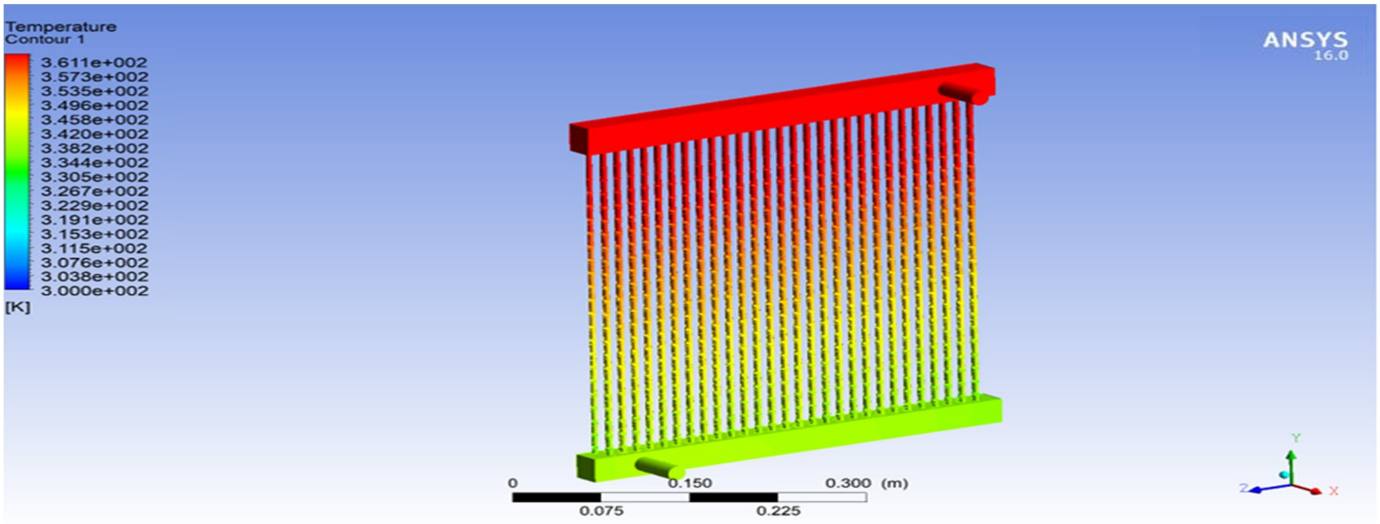

Figure 8. Temperature contour for 20:80 Al2O3-CuO/Water

The output temperature of Al2O3-CuO/water hybrid nanofluid with 20:80 mixing ratio obtained was 347.05 K i.e the temperature difference between inlet and outlet was found to be of 16.1 K.

The variation in Reynolds number, Nusselt number, heat transfer coefficient and heat transfer rate for different mixing ratios of hybrid nanofluid are shown in figure 9,10,11 and 12 respectively. The maximum enhancement in Nusselt number and heat transfer coefficient than water are 65% and 72% respectively for the nanofluid with mixing ratio 20:80.

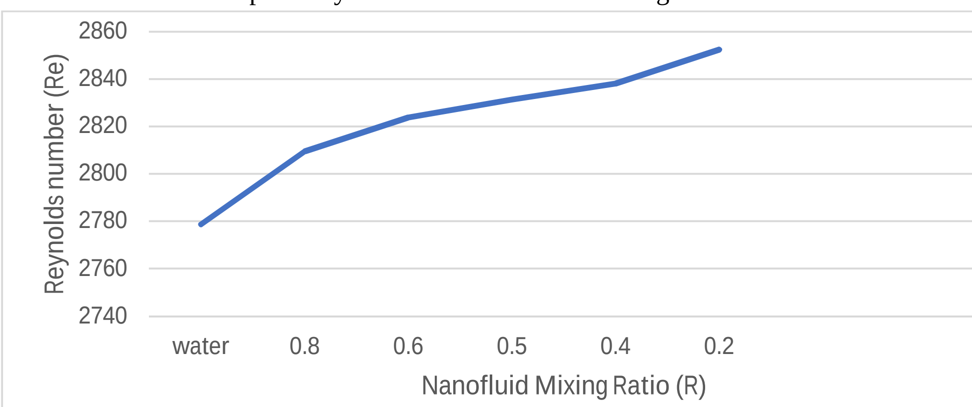

Fig. 9 Variation in Reynolds number for different mixing ratios of nanofluid

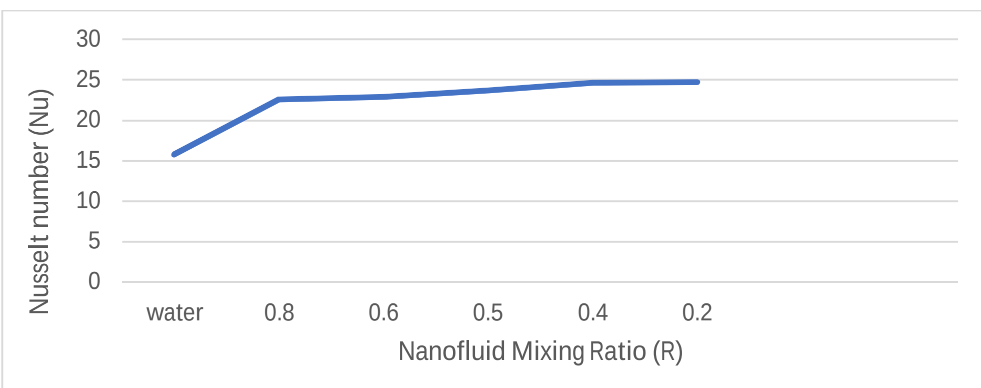

Fig. 9 Variation in Nusselt number for different mixing ratios of nanofluid

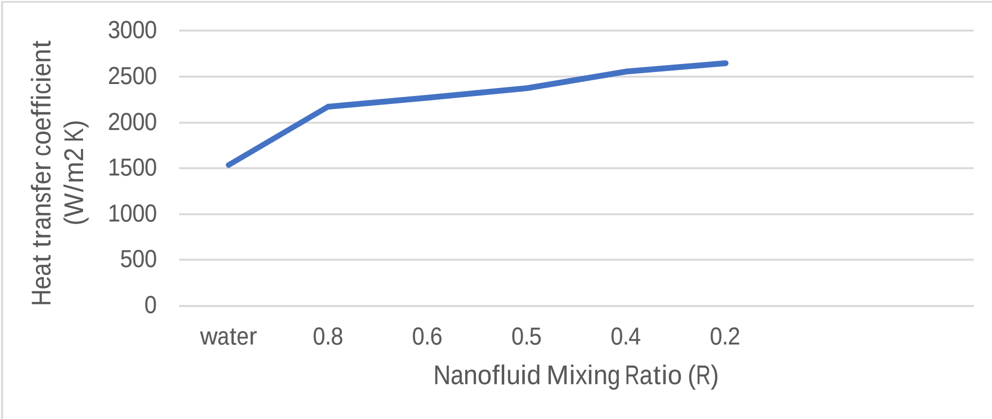

Fig. 10 Variation in heat transfer coefficient for different mixing ratios of nanofluid

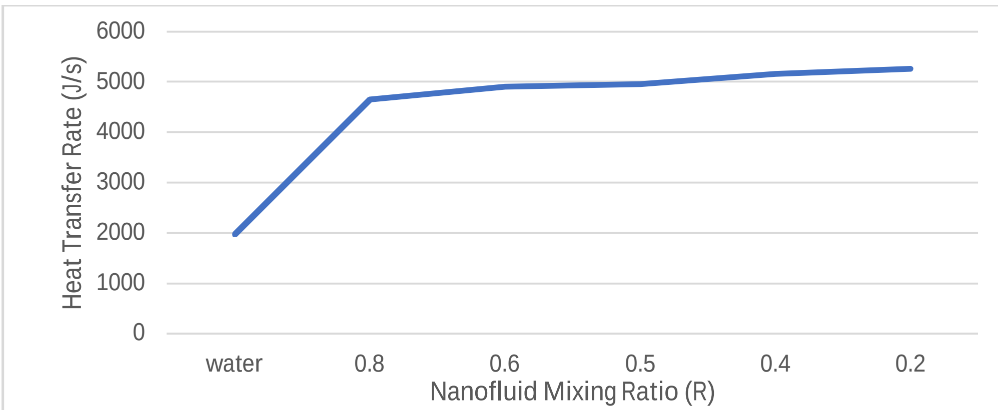

Fig. 11 Variation in heat transfer rate for different mixing ratios of nanofluid

V. CONCLUSION

In this present work heat transfer rate, heat transfer coefficient and Nusselt number are investigated for the different mixing ratios (80:20,60:40, 50:50, 40:60 and 20:80) of Al2O3-CuO water-based hybrid nanofluid. The volume concentration of nanofluid is kept constant at 1%. Following conclusions are drawn from this numerical analysis

A. Hybrid nanofluid with all the mixing ratios exhibits better thermo physical properties than water.
B. The drop in temperature for hybrid nanofluid is more than that the water. The maximum drop in temperature is 16.1K for the hybrid nanofluid with the mixing ratio 20:80.
C. Nanofluid enhances the performance of the radiator. The maximum enhancement in Nusselt number and heat transfer coefficient are 65% and 72% respectively for the hybrid nanofluid with the mixing ratio 20:80.

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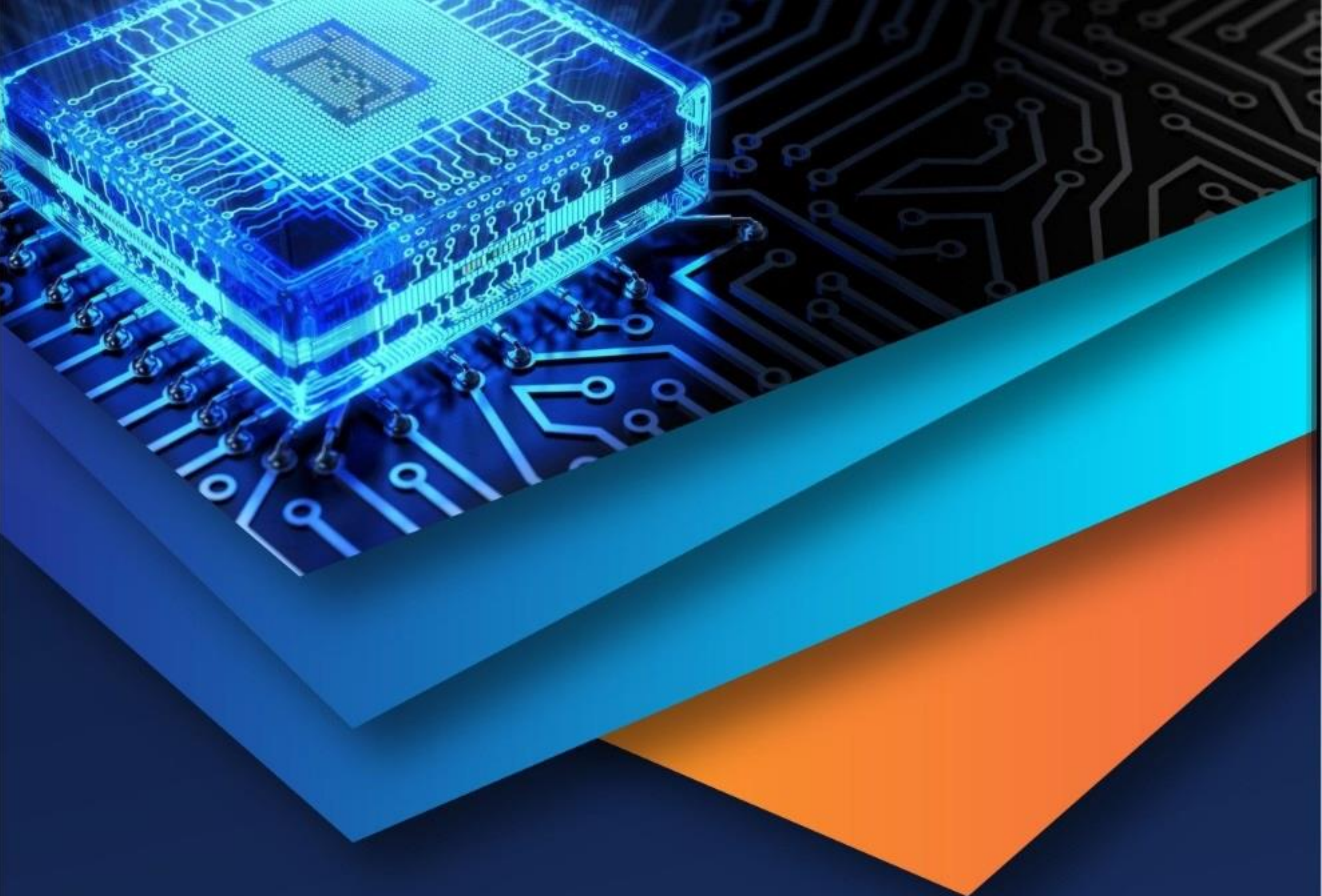

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