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Al2O3 a Nanofluid in Radiator to Increase Cooling Performance Based On Water

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Abstract*— Mixture of water and ethylene glycol as conventional coolants has been widely used in an automobile radiator for many years. Traditional coolant due to its low thermal conductivity results in less heat transfer. With advancement of nanotechnology, A new generation heat transfer fluid called nanofluid have been developed and researchers found that these fluid have higher thermal conductivity compared to that of conventional coolant. Al_2O_3/water nanofluid is used in this research because it is widely used in the research area due to requirements such as homogeneity, stability and continuous suspension without any considerable chemical change of the base fluid. Moreover the physical properties of Al_2O_3/ /water have been well documented. Three different concentrations of nanofluid 0.1,0.2& 0.3 vol % have been prepared by the addition of Al_2O_3 nanoparticles into the water. Results demonstrate that increasing the fluid circulating rate can improve the heat transfer performance.
***Keywords*— Nanofluid, Thermal conductivity, coolant**

I. INTRODUCTION

Nowadays, the high prices of energy motivate industries to apply energy saving methods, as much as possible, in their facilities. Continuous technological development in the automotive industries has increased the demand for high efficiency engines. A high efficiency engine is not only based on its performance but also for the better fuel economy and less emission. Addition of fins is one of the approaches to increase the cooling rate of the radiator. It provides a greater heat transfer area and enhances the air convective heat transfer coefficient. However, the traditional approach of increasing the cooling rate by using fins and microchannels has already reached to their limit. In addition, heat transfer fluids at air and fluid side such as water and ethylene glycol exhibit very low thermal conductivity. As a result, there is a need for new and innovative heat transfer fluids for the improving heat transfer rate in an automotive car radiator. Nanofluids seem to be a potential replacement for conventional coolants in engine cooling system. Nanofluids which consist of a carrier liquid, such as water, ethylene glycol dispersed with tiny nano-scale particles known as nanoparticles. This comprehensive study on cooling system importance, coolant used in automobiles and its limitations and applications and challenges of Nanofluids as a coolant have been compiled and reviewed for automobile radiator.

Ravikanth S. Vajjha et al [1] summarized numerical results with two different nanofluids Al_2O_3 and CuO in an ethylene glycol and water mixture circulating through flat tubes of an automobile radiator to evaluate their superiority over the base fluid for a three dimentional flow and heat transfer .The analysis shows that the average heat transfer coefficient increases with reynold number and also with the particle volumetric concentration.

M.Narakiet et al.[2] investigated the overall heat transfer coefficient of CuO/water nanoflud under laminar flow regime($100 \leq Re \leq 1000$) in a car radiator.Result showed that the overall heat transfer coefficient increased significantly with nanofluid flow rate. Enhancement in thermal conductivity may cause an increase of heat transfer coefficient in the thermal boundary layer around the wall side of tube. The results are statistically analyzed using Taguchi method by implementing Qualitek-4 software.It was also cleared that by increasing the fluid inlet temperature decreases the overall heat transfer coefficient of nanofluid. Conversly by increasing the flow rate of nanofluid overall heat transfer coefficient significantly increases.

D.Madhesh et al.[3] In this experiment investigated the heat transfer and flow charachterstcs of silver(Ag) ethylene glycol nanofluid flowing through a tubular heat exchanger. The addition of nanoparticle concentration and the increase in temperature cause an increase in the thermal conductivity of nanofluid and vice versa.Ag-EG nanofluid for different volume concentration as used of 0.1-2.0% and for various temperature of 303-363 K.At low reynold number the hydrodynamically fully developed laminar stream was observed where as at higher range of reynold number.It is noted that the convective heat transfer coefficient and the nusselt number were increase with nanoparticle concentration compared to the basefluid.

V.L.Bhimani et al.[4] assessed the convective turbulent heat transfer characterstics of nanofluid (TiO_2/water) with concentration i.e

0, 0.1, 0.3, 0.5, 0.7 & 1vol% and at different flow rate of 90,100,110 & 120 l/min were implemented as working fluid .Also it was seen that that the nusselt number in all the concentration has increased by increase in the flow rate of the fluid and consequently reynold number.It could be shown that wherever the concentration become greater heat transfer coefficient become larger .By the addition of 1 vol% of TiO_2 nanoparticle into the pure water ,an increase of about 30-45% in comparison with the pure water heat transfer coefficient was recorded . It seems that increase in the effective thermal conductivity and the variations of the other physical properties are not responsible for the large heat transfer enhancement.

Rahul A. Bhogare et al.[5]experimentally determined heat transfer performance of the automobile radiator by using different amount of Al_2O_3 nanoparticle have been added into the base fluid. Air reynold number has been changed in the range of 84391-91290.It has been recorded that heat transfer enhancement of about 70%as compared to base fluid.In present study .it also observed that adding particle in a base liquid increases density of the fluid and augments pressure drop at low percentage.

C Kanan et al[6] investigated the performance of Al_2O_3 nanofluid in an automotive car radiator. The heat transfer with water based nano fluid was experimentally compared to that of pure water as coolant in automobile radiator. It was observed an increase in the coolant flow rate optimistically influenced the amount of heat transferred. Also it was observed the nanofluid concentration was increased due to increased thermal conductivity due to the addition of nanoparticle in the base fluid water. The thermal conductivity was increased 0.7% & 1.4% for 0.25 & 0.50 vol % nanofuid concentration respectively.

Ghanbarali Sheikhzadeh et al[7]Conducted an experimental study on thermal performance in the car radiator by using Copper nanoparticle added to the ethylene glycol. It concluded that with increasing volume fraction ,overall heat transfer coefficient of air side also increases. Also with rise in the values of volume fraction of nanoparticle from 0 to 5% the rate of heat transfer increases for 29.6%. Enhancement of the reynold number will clearly result in a raise in the value of Q,where more the volume fraction of nanoparticle ,the more values of Q can be achieved.It was also cleared that by adding 5% of nanoparticle the performance of radiator in that weather of 50℃ will even be better than that of 20℃.

Ravi Adwani et al[8] presented an experimental investigation by using 2,3,4% proportions of Al_2O_3 nanoparticle by weight have been added to conventional fluid.It is observed that the heat transfer rate increase with the increase in the volume fraction of Al_2O_3 in water at constant flow rate.As the volume fraction of Al_2O_3 was increased beyond 6% the nanoparticle were getting settled at the bottom of tank.Due to this limitations he used nanoparticle upto 6% only.

J.R.Patel et al.[9] presented CFD modeling simulation of mass flow rate of air passing across the tubes and coolants in the tubes of an automotive radiator.Heat transfer analysis is successfully carried out by CFD analysis is good tool for avoiding cost and time consuming experimental work because CFD analysis result equally matched with experimental result.

Sandesh S. Chougule et al[10] performed test with CNT-water and Al_2O_3-water nano fluid with varied range of concentration (0.15,0.45,0.60,&1% by volume).It is observed that the thermal conductivity of nano fluid increases with the fluid temperature and the viscocity is found to decrease with temperature.The result also showed that the nusselt number increases with the increase in the reynold number.The experimental result show average deviation of 6% from theiritical results.CNT-water nanofluid was found to exhibit enormous heat transfer performance compared to Al_2O_3-water nanofluid for only value of coolant flow rate and nanoparticle concentration.

In this experiment the radiator consists of 36 vertical tubes with cylindrical cross section and air makes a cross flow to the tube bank with constant speed. Al_2O_3/water nanofluid is used in this research because it is widely used in the research area due to requirements such as homogeneity, stability, and continuous suspension without any considerable chemical change of the base fluid. Moreover the physical properties of Al2O3/water have been well documented. In this research two-step method is used for preparing the nanofluid. Al_2O_3 nanoparticles with an average diameter of 50 nm was dispersed in demineralized water at different volume concentrations (0.1,0.2 & 0.3vol. %) without any dispersant or stabilizer. Flow rate is varied in the range of 2 l/min – 5 l/min and inlet coolant to the radiator has a constant temperature which is changed at 50, 60 and 70 ℃.

II. EXPERIMENTAL RIG

As shown in fig.1,the schematic of experimental system used in this research includes a reservoir plastic tank, electrical heater, a centrifugal pump, a flow meter, tubes, valves, a fan, a power supply; 8 T-type thermocouples for temperature measurement, manometer tube with mercury and heat exchanger (car radiator) which was installed inside the air flow channel.The fins and tubes are made with aluminium. The working fluid fills 25% of the feed tank which has 30 L total volume (height of 35 cm and diameter of 30 cm). A radiator consists 36 vertical tubes with circular cross section with diameter of 8 mm. An electrical heater of 3000W inside a plastic storage put to represent the engine and to heat the fluid. A flow meter of capacity 0 - 600 LPH and two valves used

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to measure and control the flow rate. The fluid flows through plastic tubes (8 mm) By a centrifugal pump from the tank to the radiator at the flow rate range 2–5 LPM. The capacity of centrifugal pump is 0.5 HP. The total volume of the circulating fluid is 3 l and constant in all the experimental steps. Two thermocouples have been fixed on the flow line for determining inlet and outlet fluid temperatures. Six thermocouples have been fixed to the radiator surface to measure wall temperature. For cooling the liquid,a forced fan (Techno Pars 1400 rpm)which is capable of adjusting the speed was installed close and face to face to the radiator at the beginning of a 2.5m air flow duct. Below fig 3 shows the ultrasonicator used to prepare the nanofluid. Capcity of ultrasonicator is 3.5 liter.

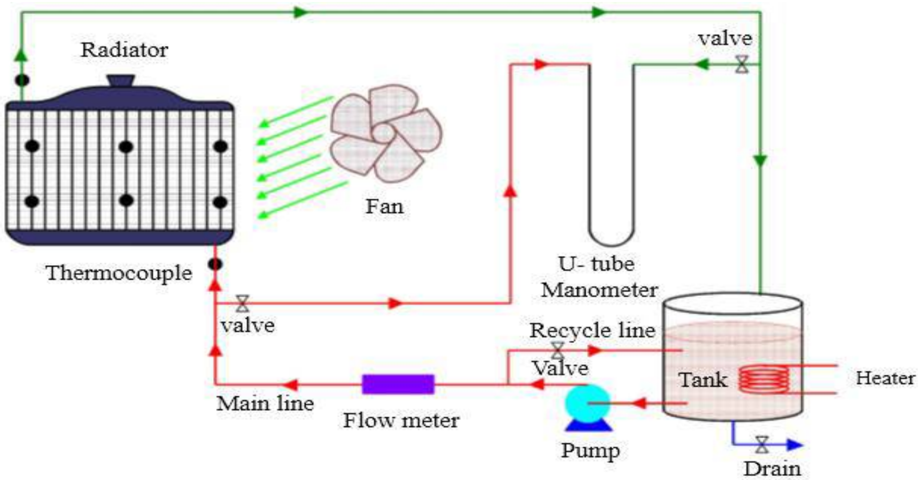

Fig.1: Schematic diagram of experimental Setup

III. NANOFLUID PHYSICAL PROPERTIES

The particle concentration can be considered uniform throughout the system by assuming that the nanoparticles are well dispersed within the basefluid to evaluated the effective physical properties of nanofluid using formulas.The important properties of the Al_2O_3 are as shown in Table 1. The following correlation has been used to predict nanofluid density at different temperature and concentration :

$$\rho_{nf} = \rho_p \emptyset + (1 - \emptyset)\rho_{bf} \qquad (1)$$

Where ρ_{nf} is density of nanofluid , ρ_p is density of nanoparticles , ρ_{bf} is density of basefluid and $\emptyset$ is the volume fraction of nanoparticles.The specific heat of nanofluid can be calculated by using energy balance ,given by equation :

$$C_{nf} = \frac{\emptyset\rho_p C_p + (1-\emptyset)\rho_{bf} C_{bf}}{\rho_{nf}} \qquad (2)$$

Where C_{nf}, C_p and C_{bf} are the specific heat of nanofluid, nanoparticles and basefluid, respectively.

The effective thermal conductivity of nanofluid at different temperature is calculated by using a modified Maxwell equation which is modified by Yu and Choi [16]. The modified equation includes the effect of a liquid nanolayer on the surface of nanoparticles.The equation is given as

$$k_{nf} = \left[\frac{k_p + 2k_{bf} + 2(k_p - k_{bf})(1+\beta)^3\emptyset}{k_p + 2k_{bf} - 2(k_p - k_{bf})(1+\beta)^3\emptyset}\right]k_{bf} \qquad (3)$$

β is the ratio of a nanolayer thickness to the original particle radius and is taken as 0.1 for this study.The viscosity data for Al_2O_3 water was estimated by using Einstien's equation which was given as

$$\mu_{nf} = \mu_w(1 + 2.5\emptyset) \qquad (4)$$

IV. HEAT TRANSFER COEFFICIENT CALCULATION

According to Newton's cooling law,the following procedure has been performed to obtain heat transfer coefficient

$$Q = h\,A(T_b - T_w) \qquad (5)$$

Heat transfer rate can be calculated as follows :

$$Q= mC_p(T_{in} - T_{out}) \quad (6)$$

By using equality of above two equations:

$$N_u = \frac{h_{exp} d_{hy}}{k} = \frac{mC_p(T_{in} - T_{out})}{A\,(T_b - T_w)} \quad (7)$$

In eq.(7), Nu is average nusselt number for the whole radiator, m is mass flow rate which is the product of density and volume flow rate of fluid, C_p is fluid specific heat capacity,A is peripheral area of radiator tubes , T_{in} and T_{out} are inlet and outlet temperature, T_b is bulk temperature which was asuumed to be the average values of inlet and outlet temperature of the fluid moving through the radiator , and T_w is tube wall temperature which is the mean values by six surface thermocuples. In this equation, k is fluid thermal conductivity and d_{hy} is hydraulic diameter of the tube .All the physical properties were calculated at fluid bulk temperature.

V. RESULT AND DISCUSSION

A. Pure Water

Before conducting systematic experiments on the application of nanofluids in the radiator .In order to check the reliability and accuracy of the experimental setup,some experiments runs with pure water . Comparison was made between the experimental data and two well known correlation: one of them suggested by Dittus –boelter and the other developed by Gnielinskey correlation .These two relations were shown shown in eqs.(8) and (9) respectively. In eq. (9), f is friction factor and was calculated using eq.(10) suggested by Filonenko.

$$Nu=0.0236\, Re^{0.8}\, Pr^{0.3} \quad (8)$$

$$Nu=\frac{\left(\frac{f}{8}\right)(Re-1000)\,Pr}{1+12.7\left(\frac{f}{8}\right)\left(Pr^{\frac{2}{3}}-1\right)} \quad (9)$$

$$f =(0.79\ln Re - 1.69)^{-2} \quad (10)$$

B. Nano fluid

The nano fluid is implemented in different Al_2O_3 concentrations , i.e 0.1,0.2& 0.3 vol% and at different flow rates of 2,3,4& 5 l/min were implemented as the working fluids.

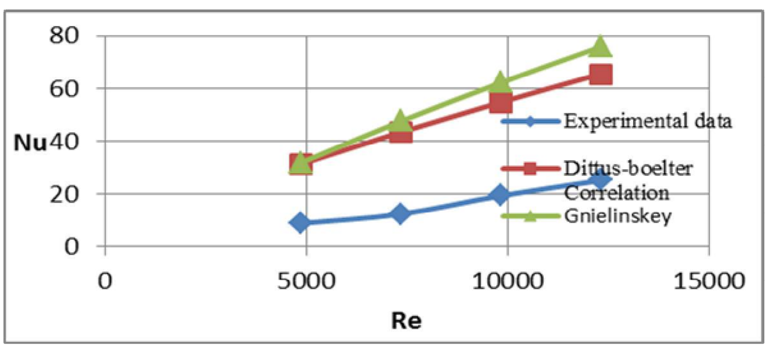

Fig2: Experiental results for pure water in comparison with the existing correlations.

Fig.2 shows experimental results for constant inlet temperature of 50℃.As expected,the nusselt number is seen to increase for increasing the Reynold number.

Fig.3 shows heat transfer coefficient in all the concentrations has increased by increase in the flow rate of fluid and consequently Re number.It can be seen that whenever the concentrations increases,heat transfer coefficient also increases.The concentration of nanoparticle plays an important role in heat transfer efficiency.

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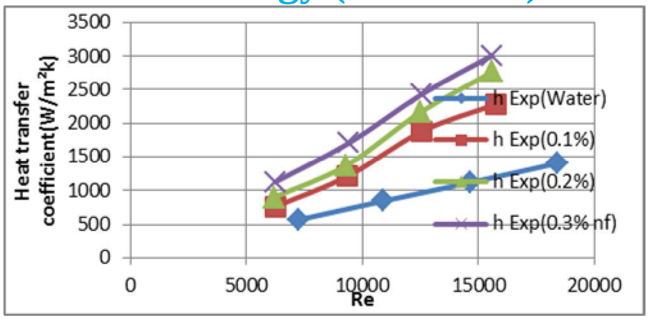

Fig.3 Heat transfer coefficient enhancement for different volume concentrations of nanofluid and Re number.

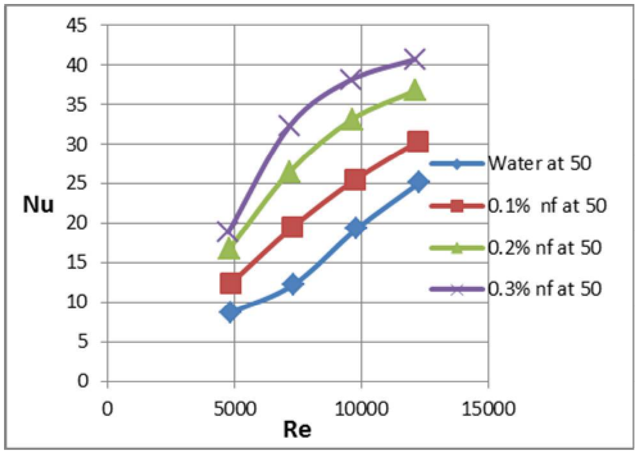

Fig.4: Nusselt number for different volume concentrations of nanofluid and Re number at 50℃.

Fig.4 shows experimental results for all runs.From fig it shows that addition of small amount of nanoparticles to pure water give efficient result of heat transfer performance.

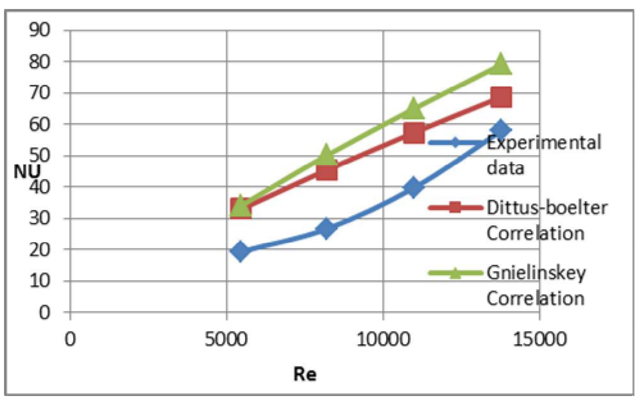

Fig.5 Comparison of experimental nusselt number with predicted nusselt number by correlations at 60℃.

Fig.5 shows the comparison between experimental nusselt number and predicted nusselt number by Dittus-boelter and Gnielinskey correlation for 0.2% volume concentrations.It can be observed that theoretical results are more than that of experimental values. Dittus-boelter correlation give comparatively close prediction as compare to Gnielinskey correlation.

VI. CONCLUSIONS

In this study , experimental heat transfer coefficient has been measured with two distinct working fluids : pure water and water based nanofluid (with varying vol.% concentrations and different flow rates).Following conclusions are obtained based on the present experimental work:

Increasing the flow rate of working fluid (or equally Re) enhances the heat transfer coefficient for both pure water and nanofluid considerably.

The presence of Al_2O_3 nanoparticle in water can enhance the heat transfer rate of automobile radiator .The degree of the heat transfer enhancement depends on the amount of nanoparticle added to pure water.

Many heat transfer correlations do not predict the heat transfer behavior of nanofluids.New correlations which will predict heat transfer performance using nanofluid is required to be developed.

Some associated problems with nanofluid like stability and sedimentation should also be studied with details.

It seems that the increase in the effective thermal conductivity and the variations of the other physical properties are not responsible for the large heat transfer enhancement .Brownian motion of nanoparticle may be one of the factors in the enhancement of heat transfer.Although there are recent advances in the study of heat transfer with nanofluids ,more experimental results and theoreticle understanding of the mechanisms of the particle movements are needed to expain heat transfer behavior of nanofluids.

VII. ACKNOWLEDGMENT

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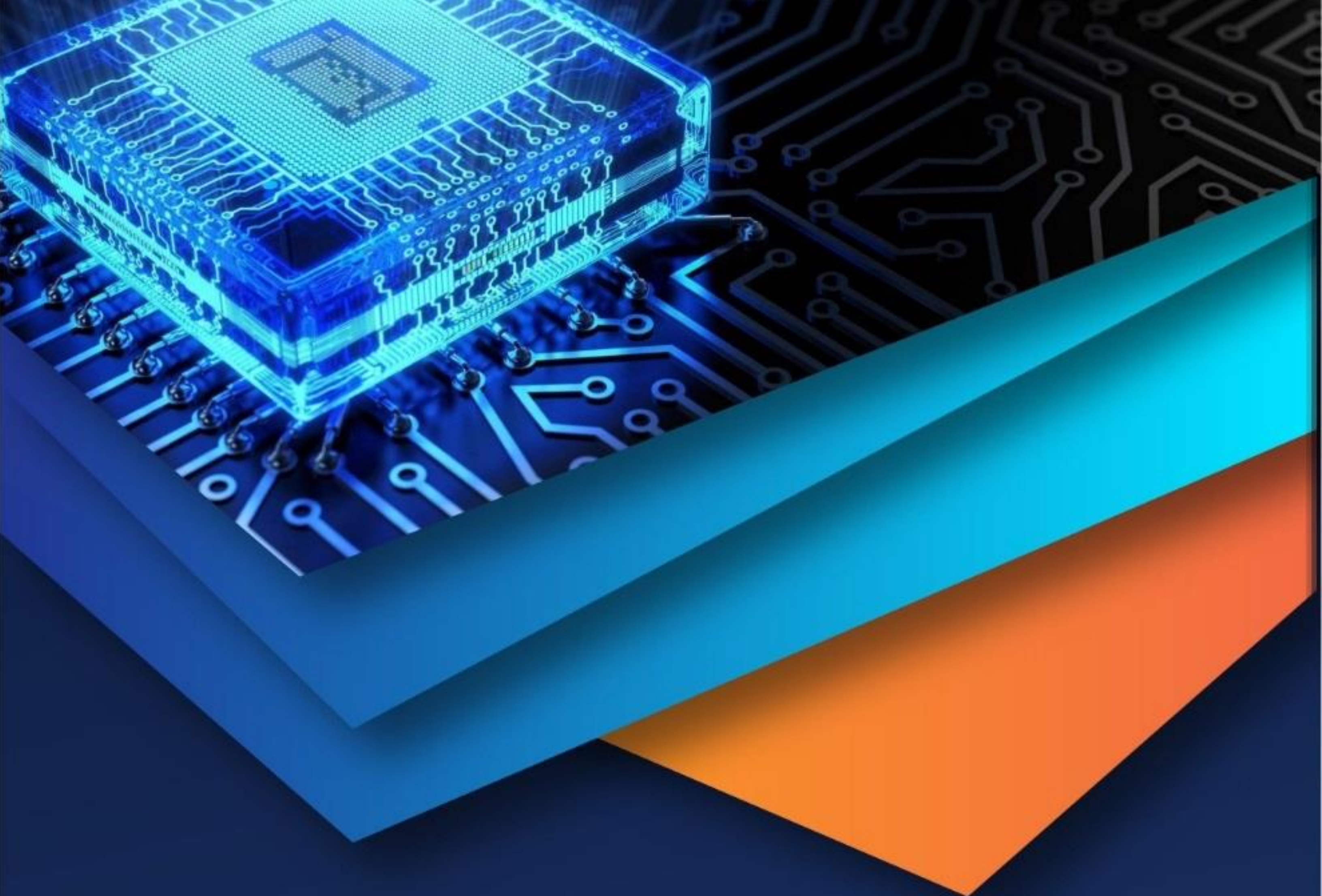

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