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Investigation on the Performance of CuO/Benzene Nanofluid in Heat Pipe Applications

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Abstract: Nanofluids can be used in different aspects such as improvement of heat transfer, reduction of size of heat exchanger and in pumping power for cryogenic applications. Similarly, in radiators, engine oil, different engineering and medical applications, Nanofluid can be used. In the present work, the performance of Benzene/Copper Oxide (CuO) Nanofluid in heat pipe is considered and different correlations are used to investigate the thermal properties of Nanofluid. Copper Oxide is used as a nanoparticles and Benzene as base fluid. Different concentrations of CuO (1 to 5 % by volume) nanoparticles and six base fluids are selected to find the thermal properties of Nanofluids, in other hand also the thermal conductivity of base fluid is to be determined. The thermal conductivity of Benzene (C_6H_6) base fluid is found and the result shows that the thermal conductivity of benzene is higher than the other two aromatic, two unsaturated hydrocarbon and one saturated hydrocarbon base fluids. The thermal conductivity of CuO is obtained from literature and CuO/C_6H_6 Nanofluid is computed with Benzene base fluid. At 1% by volume 3% and at 5% by volume 15% increment of the effective thermal conductivity is observed.
Keywords: Heat transfer, Nanofluids, Heat pipe, Thermal Properties

I. INTRODUCTION

The thermal conductivity of a Nanofluid is an important property which governs its heat transfer performance and can be used in many applications which are discussed before. There are many research works are going on Nano technology, and researchers are still trying to enhance the thermal conductivity of Nanofluid using the Maxwell effective medium theory. Initially, to get better heat transfer performance were failing because of millimeter and micrometre size particles. These particles have many drawbacks like sedimentation, pressure drop, proper concentration, low thermal conductivity, etc. Which leads to reconsider the new particle size continuously until particles will suspend in liquid and enhance the thermal properties as well as heat transfer performance. After all heat transfer enhancement using Nanofluid is considered. The heat transfer characteristic is studied using different volume concentrations of alumina Nano-particles by Bang et al [1]. Spherical and smooth particles are better in enhancing the heat transfer with reasonable pressure losses which is proposed by Meriläinen et al [2]. Thermal conductivity enhancement of Non-Newtonian Nanofluid is investigated by Hojjat et al [3]. Agarwal et al [4] investigated Kerosene-alumina Nano-fluid for thrust chamber cooling in a semi-cryogenic rocket engine and also stability. Similarly, thermal conductivity and viscosity at low volume concentration of Nanofluid is determined. Thermal conductivity of copper Oxide (CuO) /Water Nanofluid is compared with pure water and it is found that the thermal conductivity is 14% higher than the pure water in double tube helical heat exchanger [5]. At the 90° angle heat pipe is kept which shows a maximum heat reduction, which is proposed by Madhusree et al [6]. Physical property, heat and mass transfer of two-layer flows of third-grade nano-fluid is studded in a vertical channel by Farooq et al [7]. A review of the application of Nanofluids in heat exchangers is studied [8]. Davis [9] studied the effective thermal conductivity of a composite material with spherical inclusions. Also Dayal Raj et al [10] has investigated the enhancement of heat transfer in heat pipe using TiO_2/Benzene based nano-coolant. All these literatures show that there is a huge work associated with Nanofluid hence, the performance of Nanofluid in heat pipe is taken as a consideration.

Nomenclature	
k_{eff}	Effective thermal conductivity (W/m.K)
k_p	Thermal conductivity of particles (W/m.K)
k_f	Thermal conductivity of base fluid (W/m.K)
ϕ	Concentration of nanoparticles (in %)
T	Temperature (K)

II. PROBLEM SPECIFICATION AND RESULTS

In this paper, different types of base fluids are selected in which CuO nanoparticles are introduced to prepare Nanofluids and evaluated thermal conductivity by computational methods. Different types of base fluids having different types of Physical properties. The thermal conductivity of all the base fluids at 300K temperature is evaluated and compared, which is expressed in the figure 1.

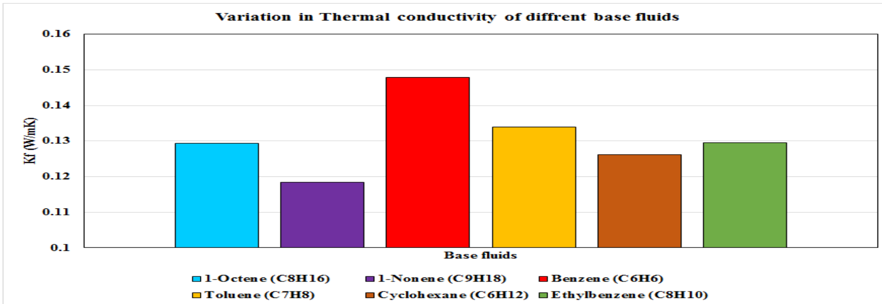

Fig 1 Comparison of thermal conductivity of different types of Base fluids

The figure 1 shows that the thermal conductivity of Benzene (C_6H_6) base fluid is higher compared to other base fluids. Benzene (C_6H_6), Toluene (C_7H_8), 1-Octene (C_8H_{18}), Ethylbenzene (C_8H_{10}), Cyclohexane (C_6H_{12}), 1-Nonene (C_9H_{18}) these base fluids are in decreasing order of thermal conductivity. Toluene and 1-Octene base fluids can be used to prepare Nanofluids, however Benzene is considered in the present work. The thermal conductivity of base fluids are shown in the table 1.

Table I Thermal Conductivity Of Base Fluids

Base fluids	Thermal conductivity (W/m-K)
Benzene (C_6H_6)	0.14781
Toluene (C_7H_8)	0.13391
1-Octene (C_8H_{18})	0.12928
Ethylbenzene (C_8H_{10})	0.12947
Cyclohexane (C_6H_{12})	0.1261
1-nonene (C_9H_{18})	0.11832

Thermal conductivity of Copper Oxide is 20 W/m-K is considered from the literature. Different base fluids and CuO nanoparticles are used to prepare Nanofluids. Various correlations are used to find a thermal conductivity of Nanofluids which are shown in table 2. 1 to 5 % by volume CuO nanoparticles are introduced into the base fluid at room temperature to make Nanofluids. These Nanofluids are used in heat pipe which increase the thermal conductivity. In figure 2 a correlation is used to find the thermal conductivity of Nanofluids [8]. Similarly, Hamilton and Crosser correlation are also used to find the thermal conductivity of Nanofluid as shown in table [2]. Hence, both the correlations gives the approximate same value (figure 3). Result shows the enhancement in thermal conductivity of Nanofluid. Hamilton and Crosser correlation is applicable when the ratio of thermal conductivity of particle and base fluid is greater than 100 [8].

A. Theoretical Correlations

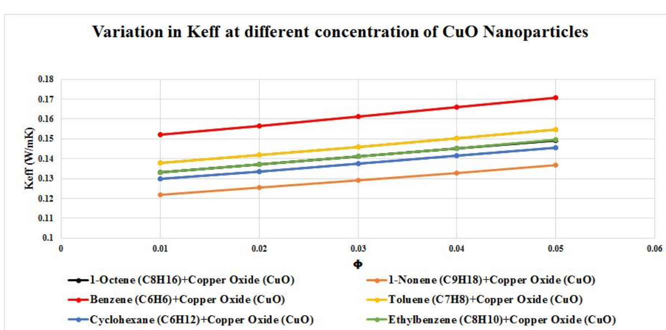

Fig 2. Variation in K_{eff} at different concentrations of CuO Nanoparticles by Maxwell correlation

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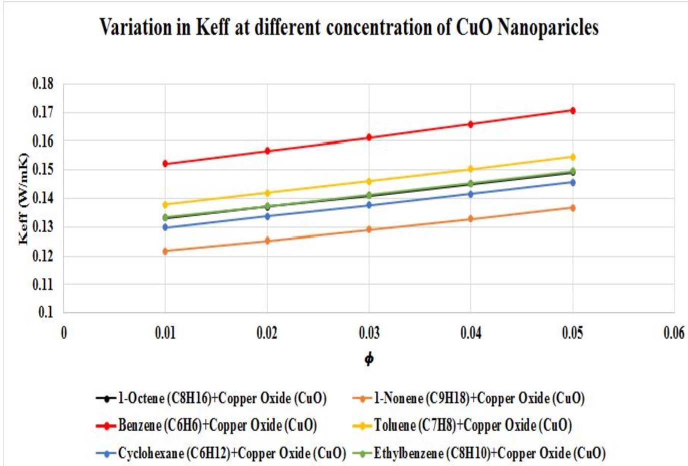

Fig 3. Variation in K_{eff} at different concentrations of CuO Nanoparticles by Hamilton and Crosser correlation

TABLE II Different Theoretical And Experimental Correlations Of Thermal Conductivity

	Reference	Year	Correlation	Relevant information
Theoretical	Maxwell [8]	1881	$\frac{k_{eff}}{k_f}=\frac{k_p+2k_f+2\phi(k_p-k_f)}{k_p+2k_f-\phi(k_p-k_f)}$	Liquid and Solid Suspension Spherical Particles
	Hamilton and Crosser [8]	1962	$\frac{k_{eff}}{k_f}=\frac{k_p+(n-1)k_f+(n-1)\varphi(k_p-k_f)}{k_p+(n-1)k_f-\varphi(k_p-k_f)}$ $=4.97\varphi^2+2.72\varphi+1$	$where\ \frac{k_p}{k_f}>100,\quad n=3$ Spherical and Non-Spherical Particles Micro-dimension
	Wasp [8]	1977	$\frac{k_{eff}}{k_f}=\frac{k_p+2k_f+2\phi(k_p-k_f)}{k_p+2k_f-\phi(k_p-k_f)}$	Various Particle shape
	Davis [8,9]	1986	$\frac{k_{eff}}{k_f}=1+\frac{3(k-1)}{(k-2)-\phi(k-1)}\left[\phi+f(k)\phi^3+O\phi^3\right]$	$f(k)=2.5\ for:k=10$ $f(k)=0.5\ for:k=\infty$ Spherical and Non-spherical particles
Experimental	Li and Peterson [8]	2006	$\frac{k_{eff}-k_f}{k_f}=0.764\phi+0.0187(T-273.15)-0.462$ $\frac{k_{eff}-k_f}{k_f}=3.761\phi+0.0179(T-273.15)-0.307$	Al_2O_3/Water Nanofluids CuO/Water Nanofluids
	Timofeeva et al [8]	2007	$k_{eff}=(1+3\phi)k_f$	Al_2O_3/Water Nanofluids
	Duangthongsu and Wongwises [8]	2009	$\frac{k_{eff}}{k_f}=a+b\phi$	$a=1.0225, b=0.0272 at: T=15°C$ $a=1.0204, b=0.0249 at: T=25°C$ $a=1.0139, b=0.0250 at: T=35°C$
	Godson et al [8]	2010	$\frac{k_{eff}}{k_f}=0.9692\phi+0.9508$	EG/Water Nanofluids Ag/Water Nanofluids

Theoretical correlation of wasp and Davis [8] is shown in table 2 by which the thermal conductivity of Nanofluid is analysed. In Davis correlation higher term is neglected and then it is implied to examine thermal conductivity of Nanofluids. Figure 4 and 5 shows near the same values as discussed before in figure 2 and 3. These all the four theoretical correlations give the same value.

Similarly, experimental correlations are also used to investigate the effective thermal conductivity of Nanofluids. Li and Peterson, Timofeeva et al, Duangthongsu and Wongwises, Godson et al [8] gives such types of correlations having different considerations. All these considerations are taken for certain nanoparticles, however, here it is used for CuO/Benzene Nanofluids. Here, Li and Peterson's [8] first equation is used to investigate the thermal property of CuO/Benzene Nanofluids which is shown in figure 6. Hence, the same result is obtained as theoretical correlations. In other hand, Timofeev et al [8] correlation is also used to investigate the effective thermal conductivity. The increasing order of thermal conductivity is shown in figure 7. When these all figure are compared then it is found that the thermal conductivity of benzene based Nanofluid is maximum. By Godson et al, Dungthongsu and Wongwises [8] correlations also gave the same result which is shown in figure 8 and 9 respectively. The variation of thermal conductivity in figure 8 and 9 is higher than the other resultant graph. After investigation using theoretical and experimental correlations it is absorbed that the thermal conductivity of Nanofluid is increasing.

The correlations which are shown in table 2 are used to find the thermal conductivity of Nanofluids and it is compared with each other.

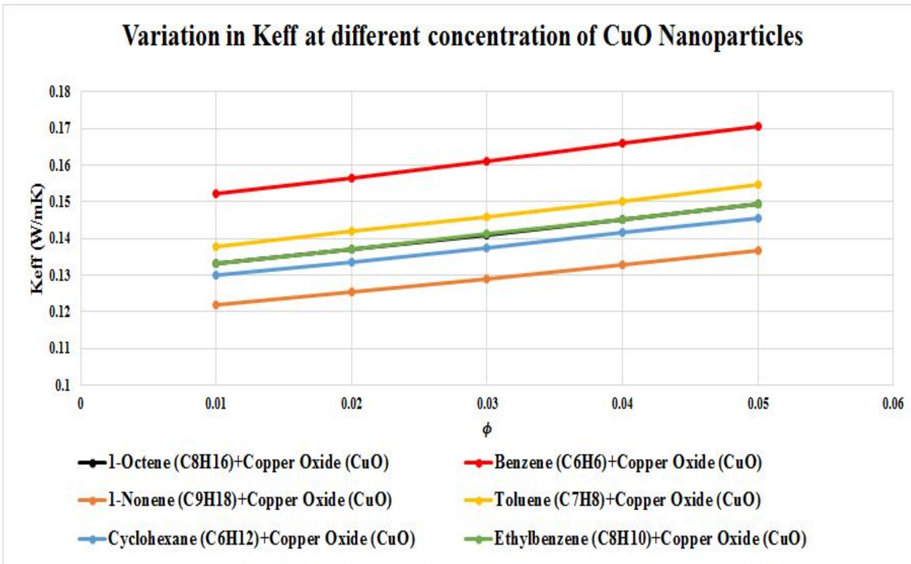

Fig 4. Variation in K_{eff} at different concentrations of CuO Nanoparticles by Wasp correlation

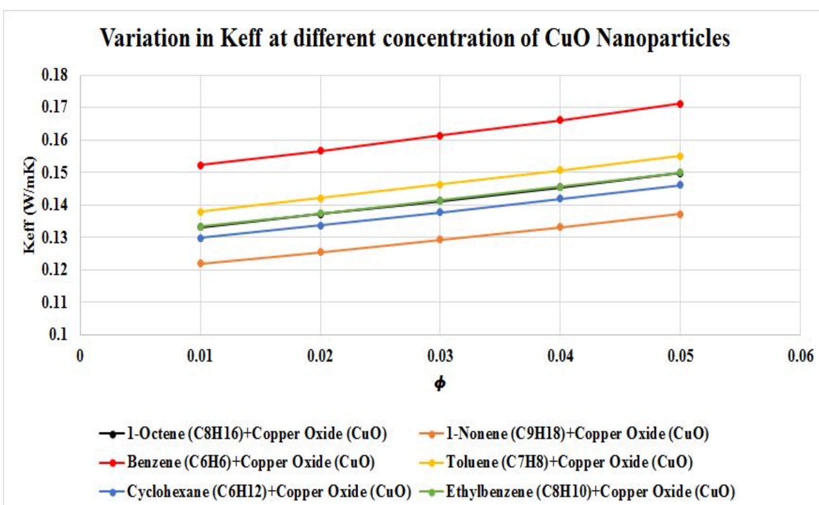

Fig 5. Variation in K_{eff} at different concentrations of CuO Nanoparticles by Davis correlation

B. Experimental Correlations

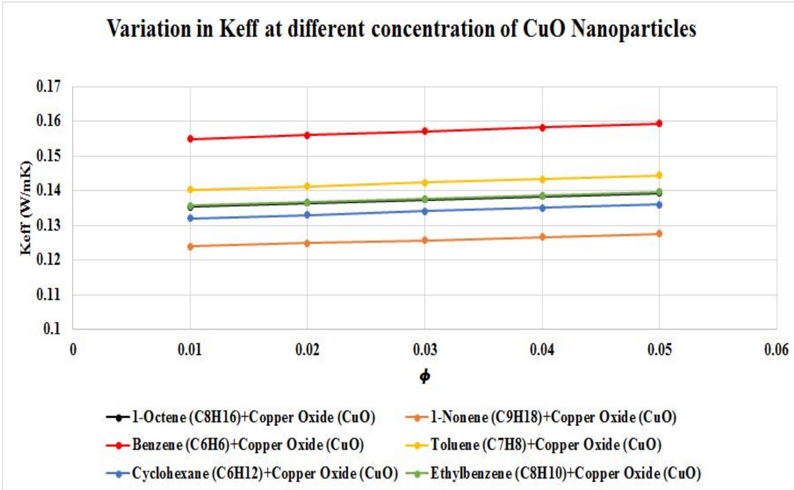

Fig 6. Variation in K_{eff} at different concentrations of CuO Nanoparticles by Li and Peterson correlation

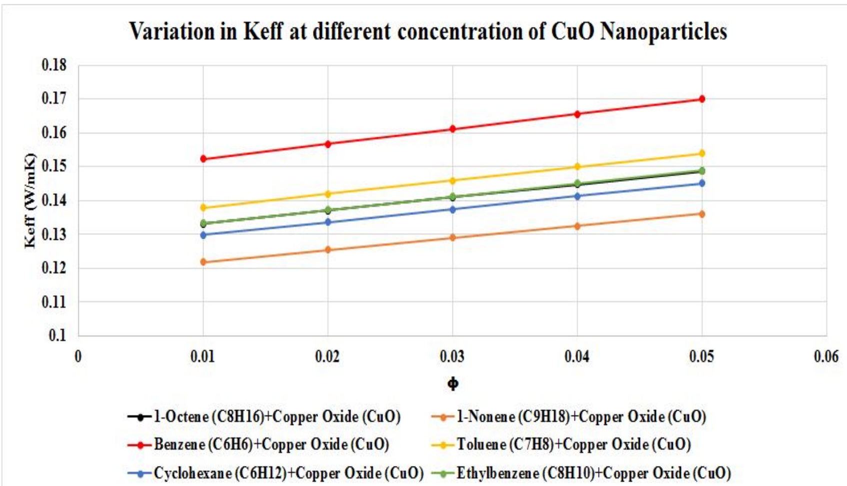

Fig 7. Variation in K_{eff} at different concentrations of CuO Nanoparticles by Timofeeva et al correlation

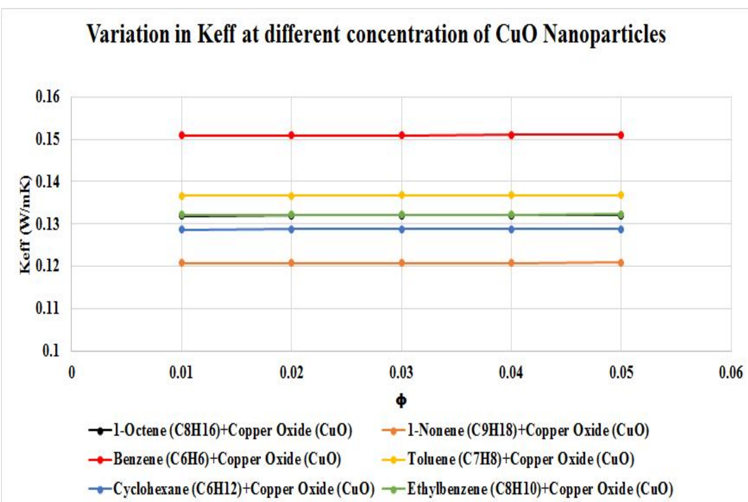

Fig 8. Variation in K_{eff} at different concentrations of CuO Nanoparticles by Duangthongsu and Wongwises correlation

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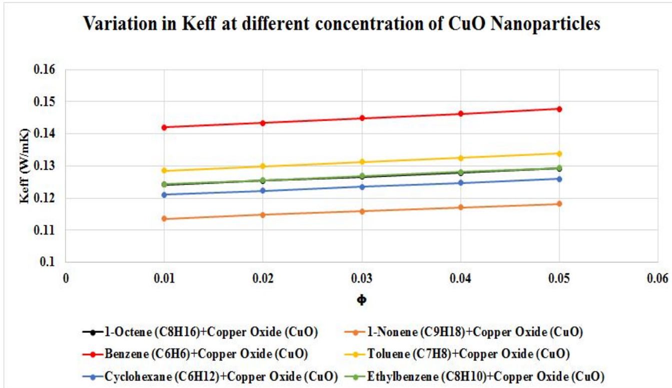

Fig 9 . Variation in K_{eff} at different concentrations of CuO Nanoparticles by Godson et al correlation

These Nanofluid are used in heat pipe which increase the cooling effect of the devices. The thermal conductivity at lower concentrations and higher concentration of nanoparticles is shown by various correlations in table 3. From the Table 3 Davis [8] correlation shows the maximum enhancement in thermal conductivity at higher concentration (5% by volume) and minimum enhancement by Godsen et al [8] (1% by volume).

TABLE III Effective Thermal Conductivity At Different Concentrations Of Nanoparticles

Name	Φ	K_{eff} (W/m-K)
Maxwell	0.01	0.152228844
	0.05	0.170821471
Hamilton and Crosser	0.01	0.152228844
	0.05	0.170821471
Wasp	0.01	0.152228844
	0.05	0.170821471
Davis	0.01	0.152250938
	0.05	0.171396758
Li and Peterson	0.01	0.15486571
	0.05	0.159382784
Timofeeva et al	0.01	0.1522443
	0.05	0.1699815
Duangthongsu and Wongwises	0.01	0.150862129
	0.05	0.151009347
Godson et al	0.01	0.141970323
	0.05	0.147700621

III. CONCLUSION

Thermal conductivity of different types of base fluids is investigated in which the benzene having higher thermal conductivity. Using CuO as a nanoparticles with different concentrations (1 to 5 % by volume) Nanofluid is prepared. Maximum enhancement in thermal conductivity of CuO/Benzene Nanofluid is found at 300K temperature. When different concentrations of CuO Nanoparticles are mixed with base fluid at 300K, effective thermal conductivity of Nanofluid is increased. At 1% by volume of Nanoparticles 3% of thermal conductivity is increased compared to base fluid. Similarly, at 5% by volume of nanoparticles, 15% of thermal conductivity is increased.

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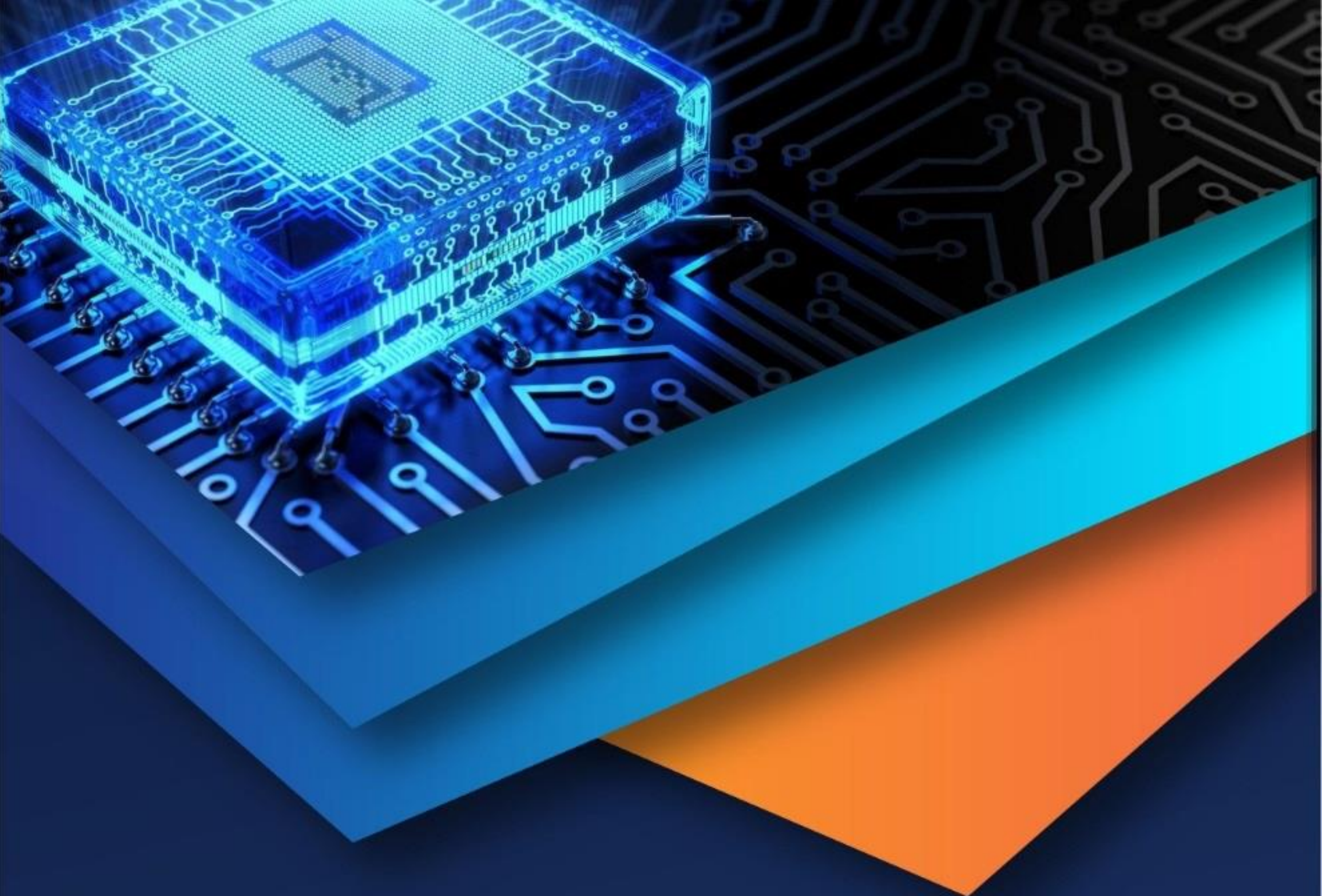

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