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Numerical Investigation on the Effect of Nano-Particles in Automotive Radiator

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Abstract: With increase in power and addition of extended functionalities, the requirement of better cooling has been a necessity. Industries and researchers has been keen in investigating on better cooling technology to be applicable for radiator. Radiator cooling was found to be improving by using various methods like incorporating fins and extended surface, use of coolant additives for better heat dissipation and changes in radiator design. Not much investigation has done on the possibility of using Nano particles in Radiator. This paper investigates the possibility of using nano particles in radiator for betterment of heat rejected. The paper analyses the effect of heat transfer in radial flow pipe, straight flow pipes with nano particles and pipes with fins. It is found that nano fluid improves the heat transfer performance of radiator. But the use of extended surface in a radiator with nano fluid will not improve the equivalent heat transfer and will not be feasible.
Keywords: Radiator, Nano Fluid, Automobile, Cooling, Numerical, CFD

I. INTRODUCTION

Cooling requirement has always been an increased necessity for an optimum performance. With rise in requirements, more functionalities has been incorporated into systems demanding better cooling. High performance cooling has always been a prime area of research. Improving the cooling capacity of radiator has always been a challenge for automotive and other industries.

Researchers had been trying to incorporate various new methods for improvement of radiator performance. This includes modification in piping design, incorporating extended surfaces and fins, using of alternate fluids and additives etc. Using nano particles for the improvement of radiator performance is an area which the researchers are keen in investigating upon. Many researches has been going on in analysing the effects of various properties of nano particles.

Conventional fluids like water or ethylene glycol has poor heat transfer properties as compared to the one with additives such as nano particles. With higher thermal conductivity of nano particles the effective heat transfer property of nano fluid improves a lot. This is because, solids in comparison has the highest energy storage capacity and thermal conductivity.

After Maxwell's preliminary study on effects of suspended particles, there has been quite a lot of work done in analysing the behaviour of suspended particles in liquid and gas. Experimental investigations were also done to study behavioural pattern of solid particles in gas flow and liquid flows.

Boothroyd et. Al. [1] investigated the effect of addition of solid particles in gas. They found that there is a considerable increase in heat transfer. Similar study was conducted by suspending solid particles in liquid, by Sohn et. al,[2] and observed similar result as Boothrovd. This is due to the additional heat transfer possible by the suspended solid particles in the liquid. It is also pertained that addition of particles will disrupt the boundary layer formation, thereby yielding lower frictional heating and lower energy loss. But there are adverse effects for the addition of solid particles. This includes increase in pressure drop due to higher density, higher chances of clogging and agglomeration, settling down of the particles yielding to obstruction in flow, increased tear and wear of channel internals. This increased the doubts regarding the practical usability of nano particle injected flow. The earlier days challenges were also attributed to the difficulty in manufacturing the particles in nano scale. But with modern day manufacturing technologies, it is possible to manufacture particles in smaller scale. Hence, most of the disadvantages could be overcome with present day technologies.

Nano fluid is a mixture of fluid and solid. So it is a two-phase fluid in a sense. Experimental investigations have shown that the mixture has properties better than the base fluid in which nano particle is mixed. For a continuous flow with the particles agitated, It is observed that the mixture can be treated as single phase fluid with equivalent properties. Study by Masuda et.al [3] has shown that even a small fraction of suspended particles in a base fluid can improve the thermal properties of the base fluid by roughly 20% above the base. But these effects is directly dependent on many factors such as the diameter of the particle, the material of the particle, mixture fraction etc.

One among the recent works is that of Das et al who investigated the effect of temperature on nano fluid. The variation of thermal conductivity for different nano particles was analysed. But the amount of research work is still very low. It is further required to understand the effects of foam and shape of particles added to the base fluid.

The present work mainly focuses on investigating the effect of different nano fluid in heat transfer enhancement for radiator applications. Automotive radiator requires effective cooling system so that the engine can be maintained at the optimum operating temperature. In addition to the same, it is also a requirement that the particles are not agglomerated or settled down in the tube causing blocking of radiator pipes, which could lead to engine choking. The study aims to investigate whether nano fluid can improve automotive radiator thermal performance and whether it is feasible.

II. MATHEMATICAL MODELLING

A. Geometrical Configuration And Governing Equation

Fig. 1 shows the geometrical configurations under consideration. It is a radial flow pipe considered for validation of the physics and mesh setup. The geometry consists of a vertical pipe through which the nano fluid flows in. It strikes the base plate in a perpendicular direction and gets distributed to the outlet in radial direction, after absorbing the heat from the base plate. The base of plate is considered to be having a constant heat flux and all other sides are assumed to be perfectly insulated walls. Pressure outlet condition is given at the end of pipes. For simplicity, a half symmetrical model is assumed for the analysis.

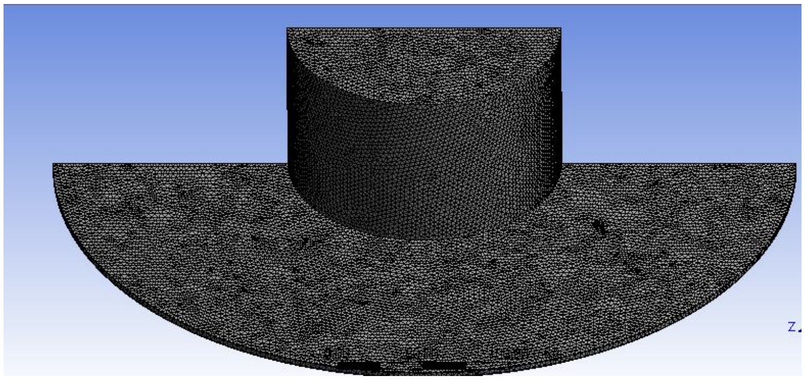


Fig. 1 Geometrical configuration with mesh

The tube considered for the flow is long enough so that a fully developed condition is obtained. Hence the thermal and fluid boundary layer are assumed to be of constant thickness. A constant mass flow was given at the inlet and the values obtained from the simulation agreed to what was observed by Maiga et al.[4] Grid Independency study was conducted to find the optimum number of elements, and it was found to be roughly 0.5 million cells. Fig.2 shows the results from grid independency study.

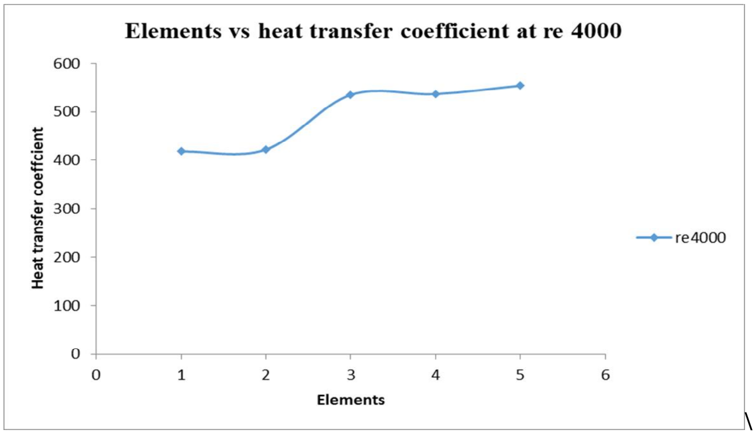
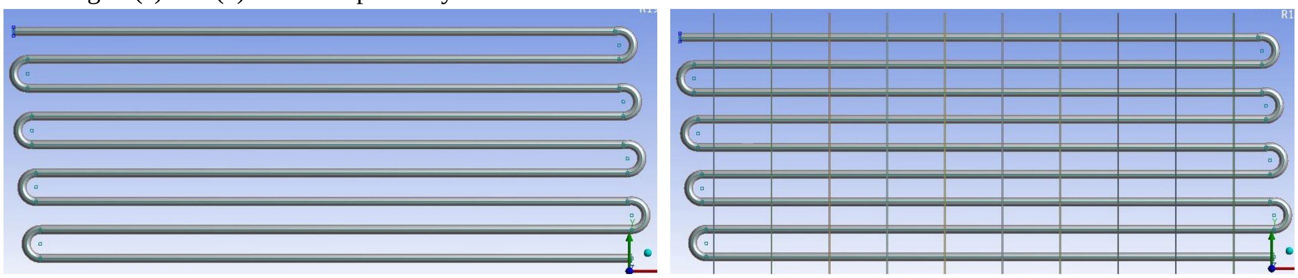


Fig.2. Grid Indpendency study

Five different nano particles at three different flow rates were considered to study the effects of variation of thermal properties when flowing through radial pipes. The best of the nano fluids were chosen for further study in straight pipes and pipes with fin to understand the practicality of the same in automotive radiators.

For the real study, a straight pipe was considered for simulation. It is assumed that the radiator pipes has similar flow patterns in all its branches and it is worthwhile to consider only one of the branch to understand the effects of nano fluids. The straight pipe was used to compare the best nano fluid obtained from the radial flow pipe with the conventional ethylene glycol, which is most commonly used in automotive radiators.

Later on, further complex pipe having more similarity to automotive radiator, with multiple branches and fin were simulated for comparison. Fig. 3 (a) and (b) shows respectively automotive radiator modelled without and with fins.



(a) (b)

Fig.3 Automotive radiator modelled (a) without fin (b) with fin to simulate extended surface heat conduction

The more complex models allowed to model the turbulence and the effects of bends and energy losses due to the same more effectively, as compared to the straight pipes and radial pipes. The pipes were modelled in 3D so as to ensure the capture of all the physics

B. Assumptions and Boundary Conditions

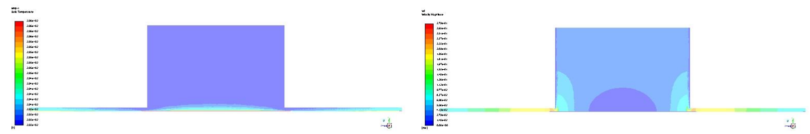
The major assumption is the half symmetry condition and insulated condition. It is assumed that the flow physics is satisfactorily symmetric across the perpendicular plane. Although this is a satisfactory assumption for fully developed flows, at regions were the turbulence is heavy, the values may deviated.

In actual condition, naon fluids are multiphase fluids with one solid phase and one fluid phase. Due to the complexity in simulating suspended particles in fluid, researchers use different techniques to simulate the flow conditions. In this paper, it is assumed that the nano particle and base fluid together acts as one single fluid with equivalent properties. This has been found as a satisfactory assumption, assuming that the flow is completely agitated and the settling and agglomeration of nano particles are completely neglected. The third assumption is the insulation provided. It is assumed that the only mode of heat transfer is from the base plate to the fluid in case of radial flow pipes. All other walls are assumed to be completely insulated from energy loss to the surroundings. In case of straight pipe flow and radiator pipe flows, it is assumed that the fluid heat is convected from the pipe walls at ambient condition. Conductive resistance through the fluid walls are completely neglected.

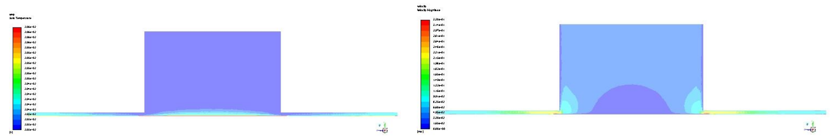
To simulate the physics, five different nano particles viz. Al_2O_3, CuO, Fe_3O_4, ZnO, MgO have been considered. The nano particles were simulated using three different Reynolds number viz. 1000, 2000 and 4000. In addition, ethylene glycol was also used to compare the effect with traditional fluids.

III. RESULTS AND DISCUSSION

It is observed that the pattern remains the same for all the nano fluids, but the thermal performance changes between the nano fluids. Fig. 4 shows the variation of different properties for nano-fluids



(a1) (a2)



(b1) (b2)

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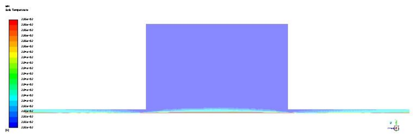
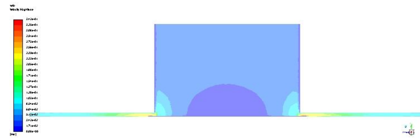


(c1)



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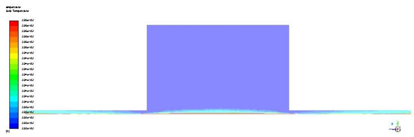

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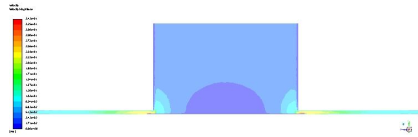

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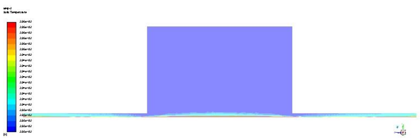
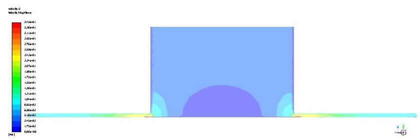


(e1)



(e2)

Fig. 4. 1 and 2 are respectively Temeprature contour and velocity contour; (a) Al2O3 (b) CuO (c) Fe3O4 (d) ZnO (e) MgO. Contours are for Re = 4000

The contour of velocity and temperature shown above in Fig 4 shows that the nano fluid flow is independent of nano particle material. All the nano particle are modelled with same diameter and properties are assumed to be temperature independent. The variation in heat transfer is mainly due to changes in the equivalent properties of the fluid and not due to the changes of flow pattern, especially with higher Reynolds number flows.

Table.1 Property variation of different nano particles

Re	Nano Particle	Temperature (K)		Velocity (m/s)		Heat transfer coefficient h (W/m2K)	Mass flow (kg/s)	Pressure (Pa)	
		Inlet	Outlet	Inlet	Outlet			Inlet	outlet
4000	Al2O3	293	293	0.03	0.0866275	418.00569	26.61897	58.1753	0
	CuO	293	293.767	0.03	0.0948625	422.0043	27.8903	67.7123	0
	Fe3O4	293	293.711	0.03	0.0946824	536.9085	27.5066	37.914	0
	ZnO	293	293.717	0.03	0.0946808	535.2602	27.2931	37.6836	0
	MgO	293	293.765	0.03	0.0946587	554.225	25.7247	33.1785	0

Table.1 above shows the variation of different properties like heat transfer coefficient and pressure drop for different nano particles for Re 4000. From the table it is evident that MgO has the highest heat transfer coefficient out of all. The Pressure drop is highest for CuO and lowest for MgO. Hence, it can satisfactorily assumed that MgO gives the best performance heat transfer for automotive radiator.

Fig.5 shows the variation of pressure with Reynolds number for different nano fluids. From the figure, it can be concluded that the pressure drop increases with increase in Reynolds number. This is because more amount of flow is happening inside the channel, with more nano particles. The increase in pressure drop attribute to a larger pumping power requirement, which can lead to reduction of engine efficiency since more power is drawn from engine. It is evident from the figure that MgO is the best performer. Hence, MgO is selected for further analysis in straight pipe and radiator pipe with and without fin to analyse the property variations.

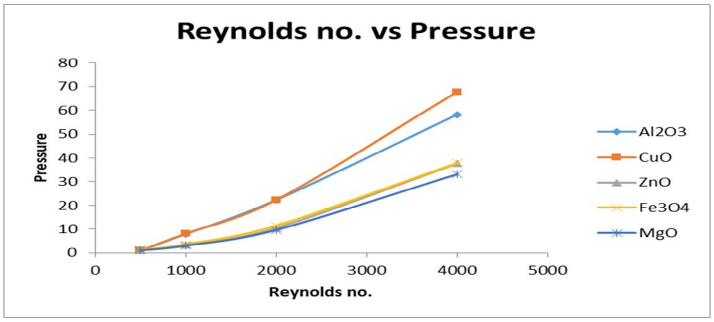


Fig. 5 Variation of Pressure with Reynolds number for different nano fluids

Based on the conclusion from radial pipe, MgO was taken as the best nano fluid and was analysed for its effectiveness in straight pipe, comparing with the traditional ethylene glycol. Table.2 below shows the property comparison of MgO nano fluid with ethylene glycol. From the table, it is clear that the heat transfer rate of MgO nano fluid is higher than ethylene glycol and the pressure drop is lower. Hence nano fluid can give great advantage in terms of lower pumping power and higher heat transfer rate, as compared to traditional fluids.

Table. 2 Comparison of Properties between ethylene glycol and MgO nano fluid

Nano Particle	Temperature (K)		Velocity (m/s)		Heat Transfer Rate h (W/m2K)	Mass Flow Rate (kg/s)	Pressure (Pa)	
	Inlet	Outlet	Inlet	Outlet			Inlet	Outlet
MgO	355.5	347.293	0.031	0.0311	181.077	0.004	2.773	0
Ethylene Glycol	355.5	346.009	0.031	0.0311	124.55	0.005	6.561	0

To further understand the applicability of extended surface for radiator with nano fluids, radiator with flat plate type extended surface was modelled for comparison with simple bend pipe. It was found that when nano fluid is used, it is not necessary to give extended surface as the improvement of heat transfer coefficient is negligible in comparison to the manufacturing cost in making radiator pipes with fins or extended surface.

IV. CONCLUSIONS

Applicability of nano fluids in automotive radiator was studied in the paper. Three different geometries were taken into consideration which are radial flow pipe, simple pipe and bend pipe with multiple channels with and without extended surfaces. Five different nano fluids were considered for study, compared to the conventional ethylene glycol, to understand how nano fluids is advantageous in automotive radiator.

From the study, the following points can be concluded

1) Nano fluids can have an attractive advantage in terms of better heat transfer coefficient. Variation in nano particle does not vary the flow pattern in the channel. Agglomeration or deposit is not considered in the study. But for high Reynolds number flows, the values may not be dependent on the nano particle used, if the diameter remains the same across all.
2) Out of the five nano particle considered, it is found that MgO has the best thermal and flow properties. Itb has the elast pressure drop owing to lower pumping power, and it has the best heat transfer properties.
3) MgO nano particle gives a better thermal and flow properties as compared to the traditional Ethylene Glycol. MgO has a lower pressure drop and higher heat transfer coefficient as compared to ethylene glycol.

4) Using extended surfaces for radiator pipe will be costly in terms of manufacturing as the extended surface is not yielding much increase in heat transfer as compared to the one without extended surface. Hence it is advisable to use simple bend tubes as radiator pipes when using nano fluids.

More study can be conducted to analyze various parameters which are not considered in this study. This include the foam parameters, temperature dependency of nano particles, diameter of nano particles, effect of agglomeration or deposits or obstruction in the flow channel etc. Further study considering such parameters will give a better insight into nanofluids.

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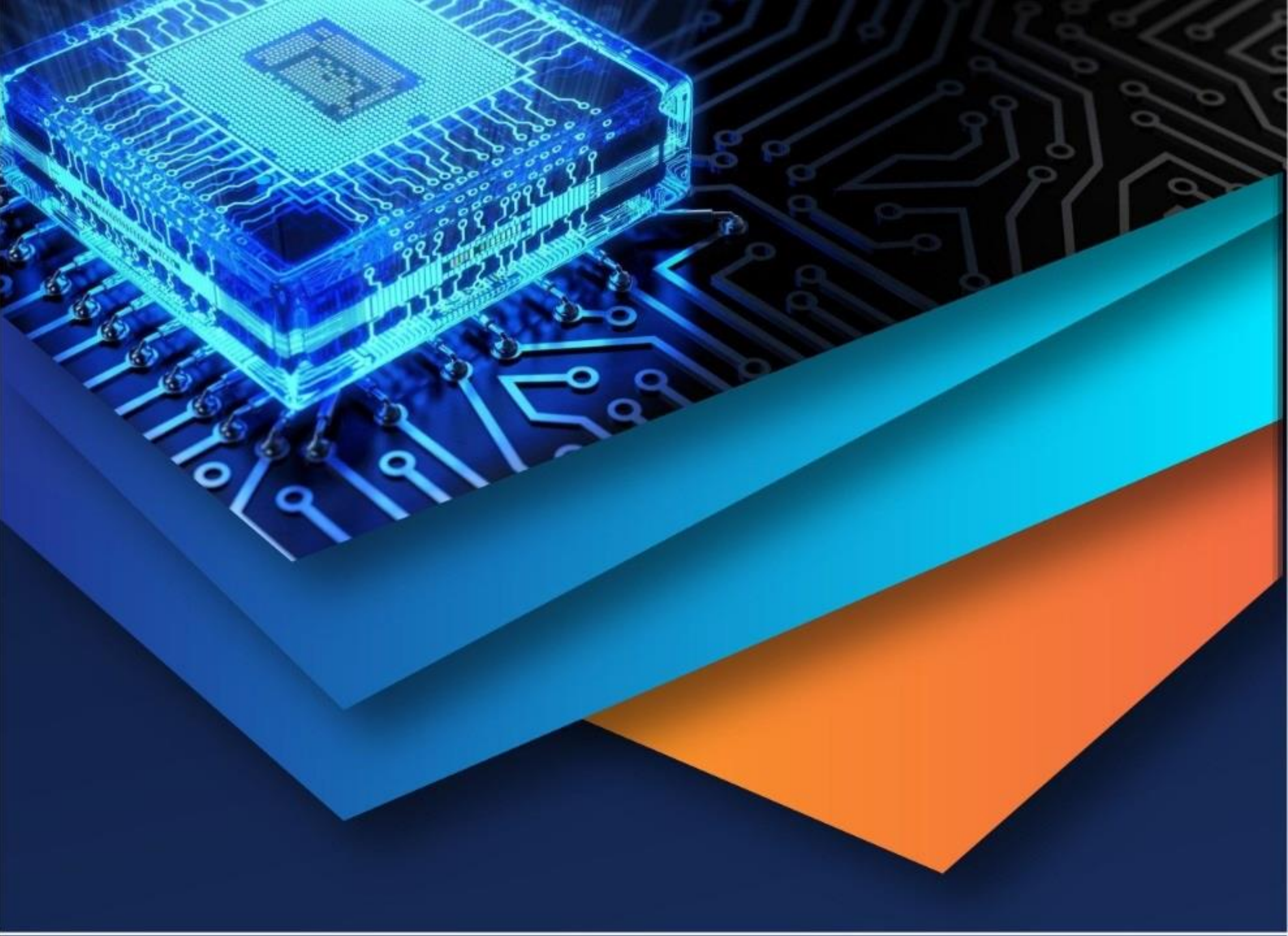

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