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The Performance of Modified Catalytic Converter using Copper-Nickel as Catalysts to Reduce Exhaust Gas Emissions from CI Engine

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Abstract: Vehicular emission is the major contributor to the air pollution problem because of the increased vehicle population. The main primary pollutants from the automotive exhaust are CO, unburned hydrocarbon (HC) and nitrogen oxides (NOx). Out of various technologies available for automobile exhaust emission control, a catalytic converter is found to be the best option to control exhaust gas emissions. In the present study, Copper-Nickel (Cu-Ni) metal was selected as the catalyst. The selection of this combination of non-noble metals is due to their low-cost materials, abundant materials, low-cost production, and lower toxicity level. The main objective of this paper is to study the performance of the modified Three-way Catalytic Converter (TWC) installed at the exhaust manifold in converting exhaust gases of CO, HC, CO2 and NOx into less harmful gases. With OEM and modified TWCs, the experimentations were carried out on CI engine running at a constant speed at different loads such as 1 kg, 2 kg, 3 kg, 4 kg and 5 kg. The analysis of the emission from both catalytic converters was carried out using the gas analyzer. From the experimental results, it is found that the maximum reduction is 25.45%, 14.70%, 15.21% and 17.73% for CO, HC, CO2, and NOx respectively when compared to that of OEM catalytic converter. It can be concluded that copper and nickel are more effective catalysts than noble (Pt, Pd, and Rh) metal catalysts.

Keywords: Catalytic Converter, Non-noble Metal Catalysts, Exhaust Gas Emission, CI Engine, Electroplating.

I. INTRODUCTION

Air pollution generated from mobile sources such as automobiles contributes to major air quality problems in rural as well as urban and industrialized areas in both developed and developing countries. Most vehicular transportation relies on the combustion of gasoline, diesel and jet fuels spewing a large amount of emission of carbon monoxide (CO), unburned hydrocarbons (HC), nitrogen oxides (NOx) and particulates matter (PM) in the environment which is a huge matter of concern [1],[2].

These pollutants have a negative impact on air quality, environment and human health that leads to stringent norms of pollutant emission. Numbers of alternative technologies like improvement in engine design, fuel pretreatment, use of alternative fuels, fuel additives, exhaust treatment or better tuning of the combustion process, etc. are being considered to reduce the emission levels of the engine. Out of various technologies available for automobile exhaust emission control, a catalytic converter is found to be the best option to control CO, HC and NOx emissions from petrol-driven vehicles while diesel particulate filter and oxidation catalysts converter or diesel oxidation catalyst have so far been the most potent option to control particulates emissions from diesel driven vehicle. A catalytic converter is a vehicle emissions control device that is used to convert toxic by-products of combustion (occurring in the exhaust of an internal combustion engine) to less toxic substances by performing catalyzed chemical reactions. The function of the catalytic converter is to convert these harmful gases into CO2, water vapor, N2 and O2 [3].

The catalytic converter was specifically invented to decrease harmful pollution caused by the combustion of hydrocarbon-based fossil fuels in cars. Studies reveal that these devices can decrease hydrocarbon emissions by about almost 87%, carbon monoxide by 85%, and nitrous oxide by 62% during the expected life of a vehicle [4].

The Three-Way Catalytic Converter (TWC) works on all the three gaseous pollutants of concern: CO, unburned HC & NOx. TWC typically contains active catalytic materials which promote oxidation of CO & unburned HC and reduction of NOx [5]. Platinum (Pt) and Palladium (Pd) are used as oxidation catalyst while Rhodium (Rh) is used as a reducing catalyst for NOx reduction [6].

Makwana et al. [7] analysed the performance of catalytic converter using nickel as a catalyst in which maximum reduction of HC and CO was found to be 40% and 35% respectively. Venkatesan et al. [8] experimented by using copper oxide as catalyst in the catalytic converter in which results obtained from the experiments shows that the maximum reduction is 32%, 61% and 21% for HC, NOx, and CO respectively at 100% of maximum rated load when compared to that of without catalytic converter. Warju et al. [9] performed an experiment on catalytic converter by using chrome-coated copper metallic catalytic converter (Cu + Cr) as a catalyst in which it has been observed that the reduction of CO and HC emission produced by engine was at an average of 95.35% and 79.28% respectively as compared to the standard one.

The purpose of this paper is to focus upon the reduction of such emissions by using copper and nickel as a catalyst in catalytic converter. Since the conventional catalysts viz. Pt, Pd, and Rh are very expensive and have very limited supply sources.

II. DEVELOPMENT OF CATALYTIC CONVERTER

The choice of the appropriate catalyst for catalytic converters is a fundamental step to hold the danger of vehicular pollution, in terms of activity, selectivity, durability, availability, and cost, for the ever increasing number of vehicles on roads. Noble metal catalysts such as Platinum (Pt), Palladium (Pd) and Rhodium (Rh) are the most common oxidation and reduction catalysts. This is due to their high selectivity to oxidation and reduction reactions. The use of noble metals has stringent effects on the commercial cost of the catalyst, so a great interest has recently turned to non-noble catalysts. Non-noble metal catalysts are a low-cost alternative to replace the noble metal catalysts. Also, non-noble metals offer greater supply and lower toxicity levels than noble metals.

A. Material selection for Catalyst

Copper and nickel metal are selected for the present work as both are cheap and easily available. Also, the base metals like copper and copper-based catalysts have attracted much attention in heterogeneous catalysis [10] and nickel has a property of facile activation, easier accessibility of oxidation states and transformation of molecules that are chemically less reactive [11].

B. Engine Selection

For the testing and calculation purpose four-stroke single cylinder, Kirloskar make CI engine is used. The specifications of the engine are shown in Table 1.

TABLE I
ENGINE SPECIFICATIONS

Parameters	Specifications
Make	Kirloskar
Type	Verticals 4S High-Speed CI engine
Maximum Rated Speed	1500 rpm
Number of Cylinders	Single Cylinder
Rated Output	5HP at 1500rpm
Type of Dynamometer	Eddy Current
Method of Cooling	Water Cooled
Bore	87.5 mm
Stroke	110 mm
Cubic Capacity	661 cc

C. Design Calculations

The specifications of the Kirloskar engine was considered for designing of the catalytic converter. As described earlier, catalytic converter design is the function of exhaust gas flow rate from the engine. So, by determining the maximum exhaust flow from engine specifications, the dimensions of the model can be calculated. The exhaust gas flow rate can be determined by calculating the swept volume and number of intake strokes. The swept volume can be estimated by the dimensions of the cylinder i.e. bore and stroke. Also, the number of intake strokes can be calculated by the rated speed of the engine.

No. of intake strokes/hr = (Max RPM/2) × 60
= 45000/hr

Vol. of flow rate = Swept vol. × No. of intake strokes/hr
= 29.763 m3/hr

Space Velocity can be defined as the space time necessary to process one reactor volume of fluid per unit time.

Space Velocity = (Volume Flow Rate) / (Catalyst Volume)

Space velocity for a single cylinder diesel engine, having flow rate of 29.76 m3 and capacity of 661 cc considered to be 20,000 per hour.

Catalyst Volume = 1.48815 × 10-3 m3 = 1488150 mm3

The dimensions of the substrate or catalyst support can be determined from the catalyst volume. The shape of the substrate is cylindrical since cylindrical shape provides ease of manufacturing, minimum assembly time, rigidity and easier maintenance. So, evaluating the volume of cylinder equal to the catalyst volume, we can determine the diameter and length of the substrate or catalyst support.

Catalyst Volume = (π/4)2 × D × L = 1488150 mm3

Where,

D = Diameter of substrate &

L = Total Length of substrate

Generally, the length of substrate considered to be twice that of its diameter.

Hence, 2 × D = L

So, D = 98.21 mm ≈ 100 mm

& L = 200 mm

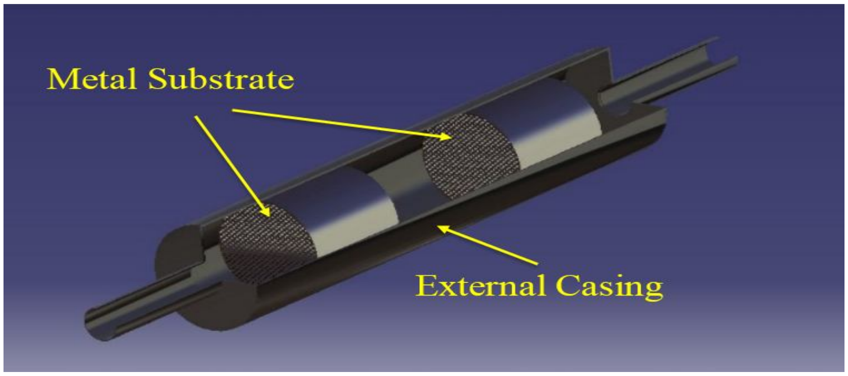

Figure 1. Section-view of Modified TWC

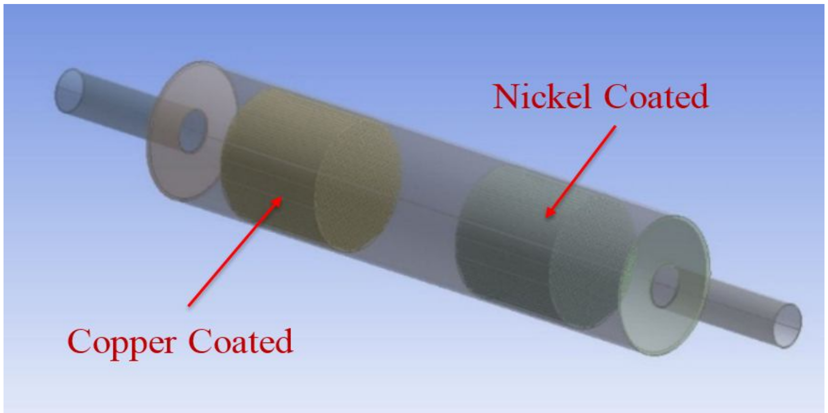

Figure 2. 3D Model of Modified TWC

Figure 3. Actual Model of Catalytic converter

D. Coating of Catalyst on Metallic Substrate

Different type of processes can be used for coating catalyst on metallic substrate viz. wet impregnation, deposition-precipitation, sol-gel coating, electroplating. Among these electroplating has been selected for coating of catalysts. Since electroplating gives a homogeneous thickness of deposition and good adherence of catalyst on the metal substrate. Also, the process can plate recesses and blind holes with stable thickness. Electroplating of copper and nickel of layer thickness 2 microns has been done on two separate substrates.

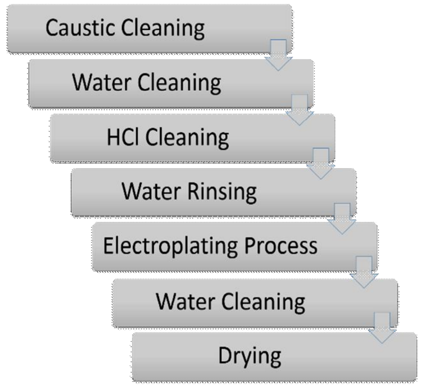

Figure 4. Electroplating Flow chart

Figure 5. Copper coated Substrate

Figure 6. Nickel coated Substrate

III.EXPEIMENTAL WORK

The engine test rig is a Kirloskar make, single cylinder, water cooled, four stroke CI engine with dual mode (Both Petrol and Diesel) connected to an Eddy Current Dynamometer for loading. The test rig is installed with a NI USB 6210 data logger for data acquisition from the sensors mounted at various places. The emissions are measured using the AVL Di-gas 444 exhaust gas analyser shown in Figure 8. The specifications of the gas analyser are shown in Table 2. Figure 7 shows the photographic view of the test facility.

Figure 7. Photographic view of Test Facility

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TABLE II
GAS ANALYZER SPECIFICATIONS

Exhaust Emission	Measurement Range	Resolution
CO	0-10 % Vol	0.01% vol
HC	0-20000 ppm	1 ppm
CO_2	0-20% Vol	0.1% vol
NOx	0-5000 ppm	1 ppm

Figure 8. Photographic View of Gas Analyser

Initially, the engine allowed running on idle using Diesel so that it gets warmed up. The engine was run at a constant speed. Later, the load was applied to the engine using Eddy Current Dynamometer which increased torque on the engine for which exhaust gas data was recorded. The engine allowed to cool for an hour before testing another catalytic converter. The testing was carried out on different loads viz. 1 kg, 2 kg, 3 kg, 4 kg and 5kg. This methodology was used to test both OEM and modified TWCs for emission characteristics at different loads.

IV. RESULTS AND DISCUSSIONS

The exhaust emission measurements were carried out by using a calibrated standard instruments AVL Di-gas 444 exhaust gas analyzer for CO, HC, CO2, and NOx at each operating point for both conditions with OEM and modified catalytic converter is recorded and graphs were plotted between varying load and pollutant concentration.

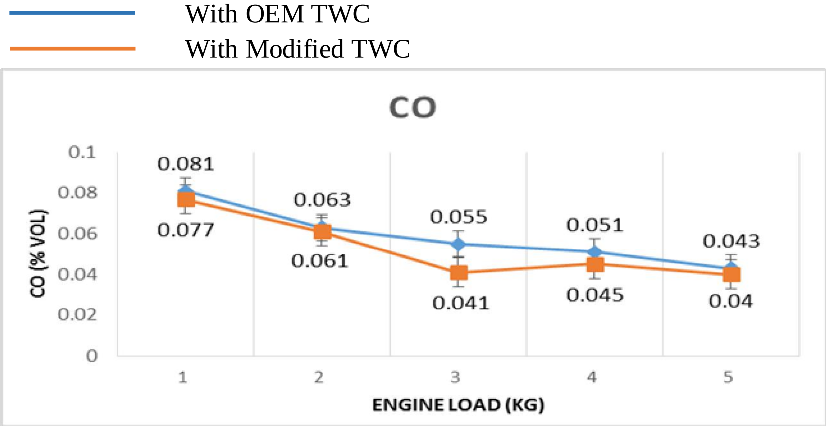

Figure 9. Engine Load vs. CO emissions

The characteristics of CO emission are shown in Figure 9. For each fuel, there is a decrease of CO emission on the increase of the engine load. The above graph compares CO emissions with OEM and modified catalytic converter from load 1 to 5 kg. It indicates that CO emissions are less for modified TWC as compared with OEM and there is a significant decrease at 3 kg load. The CO emissions are well controlled throughout the applications of various engine loads. The maximum reduction of CO emissions is found to be 0.014 % vol i.e. 25.45% reduction compared with OEM.

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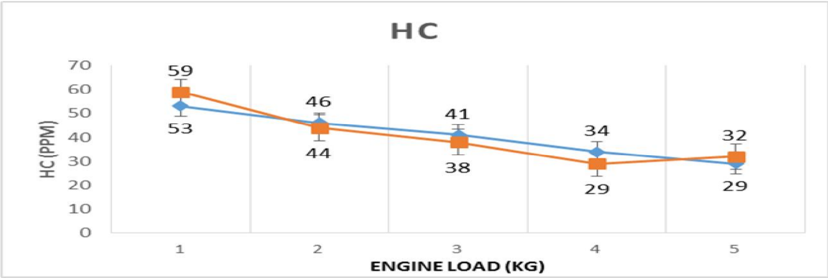

Figure 10. Engine Load vs. HC emissions

As shown in Figure 10, for Diesel, the HC emission decreases with the increase of engine load, due to the increase in combustion temperature associated with higher engine load. The control of modified TWC at lower engine load is poor and as engine load increases HC emissions from modified TWC is less as compared to OEM catalytic converter. The maximum reduction of HC emission is 14.70% observed at 4kg when compared to OEM catalytic converter. From the graph, it is observed that the modified catalytic converter is efficient in between 2 kg and 4 kg engine load.

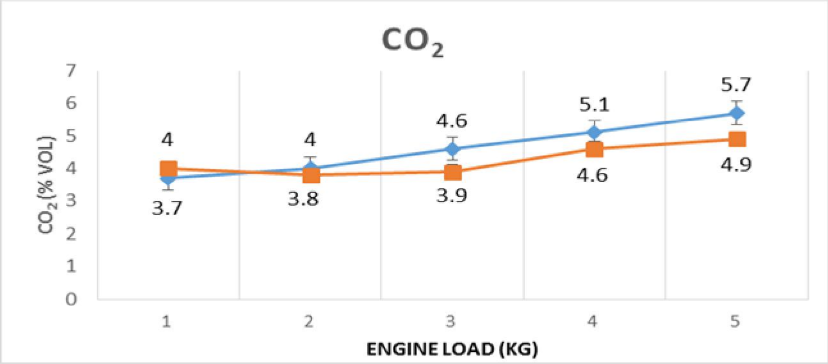

Figure 11. Engine Load vs. CO2 emissions

As engine load increases, CO2 emissions increases since combustion temperature increases. Although the graph in Figure 11 indicates an increasing trend in both the cases, but at 1 kg load the emissions of CO2 from modified TWC are more than OEM. As engine load increases CO2 emissions from modified are less as compared to OEM catalytic converter. The maximum reduction of CO2 from modified TWC is 15.21% when compared with OEM. More amount of CO2 in exhaust emission is an indication of the complete combustion of fuel. This supports the higher value of exhaust gas temperature.

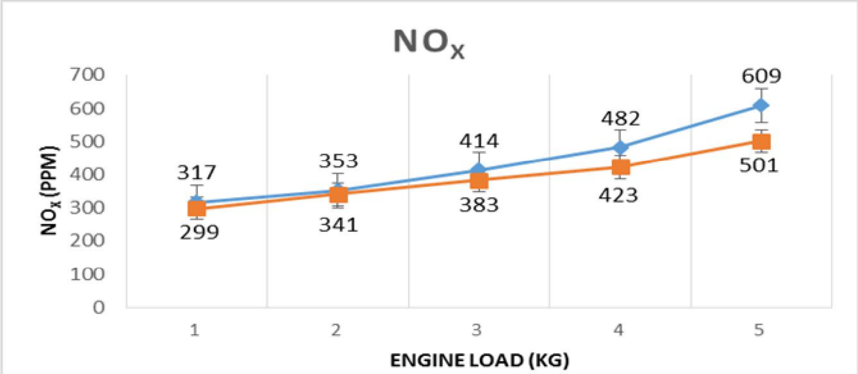

Figure 12. Engine Load vs. NOx emissions

The graph in Figure 12 represents a comparison between engine loads vs. NOx emissions. The NOx concentration increases with the increase of engine load for all the fuels. The graph indicates that NOx emissions from modified TWC are very well controlled compared with OEM. At low load, the difference between the NOx emissions from both catalytic converters is less. But as load increases, a significant difference is observed in NOx emissions. The maximum NOx reduction is 17.73% observed at higher load i.e. at 5 kg compared to that OEM catalytic converter.

V. CONCLUSIONS AND FUTURE SCOPE

The experimental investigation performed in this paper identifies the emissions characteristics of the diesel engine by modifying TWC and then the results are compared with the corresponding OEM catalytic converter. The materials we used for fabricating catalytic converters are copper and nickel which are economically cost-effective when compared with present noble catalysts. Also from the results, it is clear that these catalysts are more efficient for oxidation and reduction, as it has shown a reduction in emissions of CO, HC, CO2, and NOx.

The exhaustive testing at constant engine speed i.e. at 1500 rpm with varying load showed a major reduction in CO, HC, CO2 and NOx emissions with 25.45%, 14.70%, 15.21%, and 17.73% respectively compared to the OEM catalytic converter. From the results and discussions, we can get that the Cu-Ni catalysts prepared by electroplating method have higher catalytic activity. Thus Cu-Ni based catalysts system can be an effective approach in place of the expensive noble metal-based catalytic converter.

Future scope of this work is that the feasibility of the system of this kind can be checked by Cu-Ni catalyst doping with different noble or non-noble metals and can be used as catalysts to get an increase in the conversion efficiency of exhaust gases.

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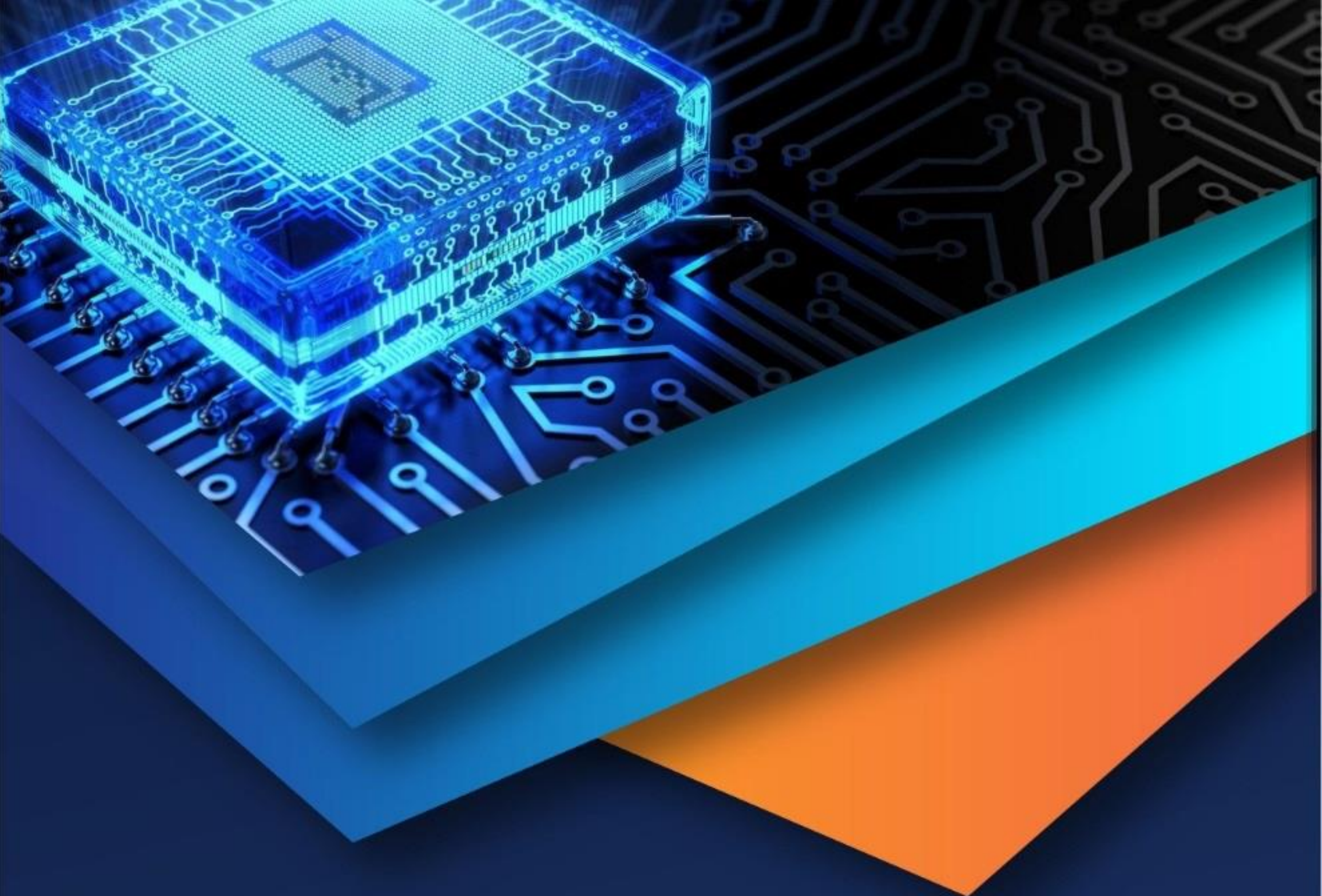

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