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Anti-Corrosive Behaviour of *Pennisetum typhoideum* (Bajra) Leaf Extract Against Mild Steel in Acidic Conditions

Kumawat Y[1], Mathur P[2], Sharma A[3]
[1, 2]Department of Applied Science and Life Science, Bhagwant University, Ajmer
[3]Department of Chemistry, Seth K. N. Modi Government College Gudhagaorji Jhunjhunu

Abstract: The corrosion of metals and their alloys has prompted an increase in research efforts to lessen the harm caused by the corrosion process. The study analyses the ability of Bajra (Pennisetum typhoideum) leaf extract to suppress corrosion on metal in 0.1 N HCl solutions using thermometric and weight loss techniques. At all extract concentrations, it was shown that the leaf extract efficiently prevents mild steel corrosion. The findings of mass loss measurements indicate that inhibition efficiency increases with inhibitor concentration. Based on thermodynamic considerations, the extract's adsorption is exothermic and spontaneous. From the results and findings of the study, a physical adsorption mechanism is proposed for the adsorption of ethanol extract of Bajra leaf extract on mild steel surface. The inhibitory efficiency was projected using certain methods at 298K, 308K, and 318K temperatures. As the extract's concentration rose, the inhibition effectiveness rose as well, demonstrating the leaf extract's inhibitory ability. The thermodynamic variable demonstrates that physisorption was the mechanism of inhibition. Therefore, the current research shows a new, ecologically safe, and effective corrosion inhibitor for protecting mild steel surfaces in acidic environments.

Keyword: Pennisetum typhoideum, weight loss, physisorption.

I. INTRODUCTION

Although metals are refined before being used in industry, but corrosion will eventually cause them to return to their original ore condition. Corrosion causes large economic losses for industries including the petrochemical, oil and gas, and automobile sectors[1]. According to a thorough research carried out by the National Association of Corrosion Engineers (NACE) in a number of countries, corrosion has an annual economic effect of around 5% of the world's gross domestic product (GDP). In addition, corrosion leads to explosions in the chemical industry and the collapse of metallic structures including buildings, bridges, and overpasses. According to estimates, corrosion costs India Rs. 2 lakh crore (Rs. 2 trillion) every year[2-3].

Chemicals known as corrosion inhibitors engage adsorption to create a thin coating of molecules on the metal's surface, which slows down the corrosion process. This layer inhibits the metal's disintegration and keeps it from coming into direct contact with the atmosphere, which is the corrosive medium. By creating brittle passive layers, inorganic inhibitors can expose the metal surface to local corrosion assaults such pitting and cracks[4]. However, metal surfaces can be uniformly protected by organic green corrosion inhibitors, offering better defence against hostile media[5].

Although many inhibitors are toxic and hazardous to the environment, they are frequently employed to reduce corrosion. As a sustainable and eco-friendly substitute, green corrosion inhibitors derived from organic materials such as plant extracts have been created. Alkaloids, flavonoids, and phenols are among the organic chemicals found in plant extracts that have strong inhibitory effects[6-7]. One area of research that may result in the creation of ecologically friendly and sustainable corrosion inhibitors is the use of plant extracts to stop corrosion. They are also biodegradable, which makes disposal easier. Different plant parts, such as fruits, leaves, bark, roots, seeds, or peels, can be used to make plant extracts[8-9].

In western India (Gujarat, Rajasthan, and Haryana), pearl millet (*Pennisetum typhoideum*) is a significant coarse cereal crop. Phytochemicals including alkaloids, flavonoids, saponins, steroids, tannins, phenols, terpenoids, and glycosides are found in plants in the genus *Pennisetum*. Pharmacological investigations have demonstrated the antimicrobial, antibacterial, antidiabetic, antioxidant, antifungal, wound healing, and analgesic qualities of *Pennisetum* plants. Of the pearl millet produced, about 46% was used for food, 37.5% for cow feed, 7.7% for poultry feed, 8.8% for the alcohol industry, and as low as 0.4% for seed. Iron, calcium, and zinc are among the many minerals found in pearl millet, along with a high fat content. It is nutritionally comparable to or superior than major cereals due to its high protein and calorie content.

In present study, we describe the corrosion inhibitive activity of alcoholic leaf extract of plant *P. typhoideum* to identify non-toxic, affordable, and efficient green corrosion inhibitors from renewable sources.

II. MATERIALS AND METHODOLOGY

A. Extraction of Plants Shrubs

This study used weight loss and electrochemical techniques to examine the possible corrosion-inhibitory effects of an extract from *Pennisetum typhoideum* leaves. The collected leaves were ground into a powder, allowed to dry outside, and then submerged in 95% ethanol for three days[10]. The Soxhlet technique was then used to create the extract.

B. Weight Loss Method

Weight loss is the most widely used method for assessing damage caused by corrosion. You can determine how much metal an object would lose due to corrosion by weighing it both before and after exposure. For the weight loss investigation, mild steel coupons measuring 2.5 cm X 1 cm X 0.1 cm^3 that had previously been washed and degreased were used[11]. Previously weighed MS coupons were individually submerged for three hours at a temperature between 298–318 K in 100 mL of beaker media containing and excluding the inhibitor at several quantities, such as 50, 100, 200 and 500 ppm.

Inhibitor's efficacy in preventing inhibition was determined by-

$$IE\% = \frac{w_0 - w_i}{w_0} \times 100$$

IE- Inhibition efficiency; W is the weight loss with (i) or without (0) influence of the inhibitor.

Surface coverage (θ) was calculated using formula

$$\text{Surface Coverage } (\theta) = \frac{\Delta M_u - \Delta M_i}{\Delta M_u}$$

C. Langmuir Adsorption Isotherm

Several adsorption isotherms, including as Langmuir, Frumkin and Freundlich, were used to characterise the adsorption of leaves extracts on the mild steel surface in HCl solution[12]. The Langmuir adsorption isotherm best described the experimental data, which can be expressed as

$C/\theta = (1/K_{ads}) + C$

Where C is a concentration of inhibitor molecules, θ is surface coverage, and Kads is the equilibrium constant of the adsorption process.

D. Determination of Activation Energy (Ea)

The following Arrhenius equation was employed for calculating the activation energy for the corrosion of mild steel in an aqueous media.

$$CR = A \exp\left(\frac{-Ea}{RT}\right)$$

Where, CR - Corrosion Rate of mild steel, A = Arrhenius or pre-exponential constant

Ea = Apparent activation energy, R = Universal gas constant, T = Absolute temperature.

The logarithms of both sides of equation-

$$\log CR = \log A - \left(\frac{Ea}{2.303RT}\right)$$

Applying the formula Ea = - 2.303 × R × Slope

III. RESULTS AND DISCUSSION

The corrosion potential of thin metal in 0.1 N hydrochloric acid was examined at 298 ±1.0 K using weight loss measurements with and without extracts of *Pennisetum typhoideum* leaves (ethanol fraction) at various concentrations (i.e., 50, 100, 200, and 500 ppm), and the percentage of inhibitory activity was found. The corrosion rate (mmpy) and inhibition effectiveness as the inhibitor concentration (in ppm) increases are shown in Table 1.

The data indicates that while corrosion inhibition rises with increasing inhibitor concentration, corrosion rate significantly decreases with increasing inhibitor concentration[13-14]. Upon immersing 500 ppm of leaf extract in 0.1 N hydrochloric acid for 24 hours, the inhibitory activity was determined to be 84.71 percent effective. This is because of adsorbent inhibition with the base metal surface rises with accumulation of inhibitor.

Table 1 displays the corrosion metrics for extracts from *Pennisetum typhoideum* leaves, such as surface coverage (θ), inhibition efficiency percentage (IE %), and corrosion rates (mmpy). Additionally, Figure 1 illustrates the relationship between inhibitor concentration and corrosion inhibition effectiveness. The weight loss–time curves for mild steel in 0.1 N HCl at various intervals (1, 6, and 24 hours), with and without varying amounts of leaves extract are displayed in the figures. Area of exposure - 7.75cm^2

Time Duration 1 hr					Temperature 298 K	
S. NO.	Inhibitor Concentration	Mass Loss (ΔM) mg	Inhibition Efficacy (η%)	Corrosion Rate (mmpy)	Surface Coverage (θ)	Log(θ/1-θ)
1	Blank	101	0.00	145.4300	0.0000	
2	50	92	8.91	132.4709	0.0891	-1.0095
3	100	82	18.81	118.0719	0.1881	-0.6351
4	200	53	47.52	76.3148	0.4752	-0.0430
5	500	28	72.28	40.3172	0.7228	0.4162
Time Duration 6 hr					Temperature 298 K	
1	Blank	518	0.00	124.3115		
2	50	452	12.74	108.4726	0.1274	-0.8356
3	100	348	32.82	83.5143	0.3282	-0.3111
4	200	220	57.53	52.7964	0.5753	0.1318
5	500	105	79.73	25.1983	0.7973	0.5948
Time Duration 24 hr						Temperature 298 K
1	Blank	641	0.00	38.4574	0.0000	
2	50	428	33.23	25.6782	0.3323	-0.3031
3	100	354	44.77	21.2385	0.4477	-0.0911
4	200	221	65.52	13.2591	0.6552	0.2789
5	500	98	84.71	5.8796	0.8471	0.7436

Plotting Log (θ/1-θ) vs Log c with gradient equal to one should result in a straight line, according to the Langmuir adsorption isotherm. The interaction of the adsorbed molecules on the metal surface in our work provides an explanation for the departure from unit behaviour[15].

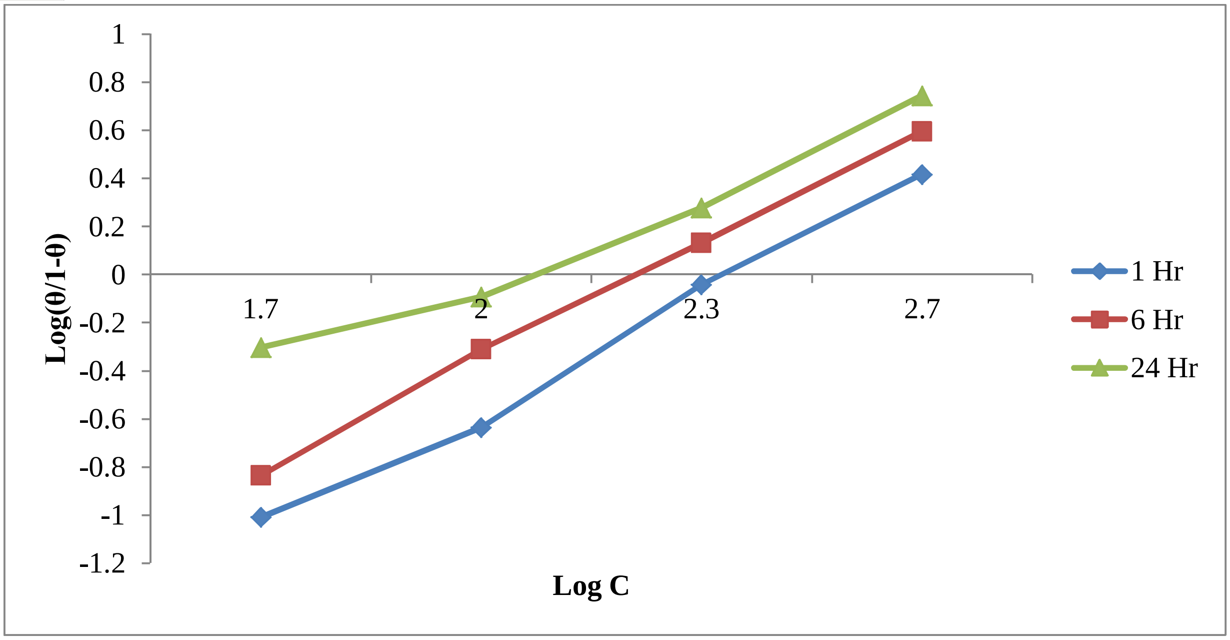

Fig 1 Mass loss curves in between variation of log (θ /1-θ) with log C using *Pennisetum typhoideum* leaves extract for Mild steel in 0.1 N HCl at 298 ±1.0 K, Time at 1 h, 6 h, 24 hrs.

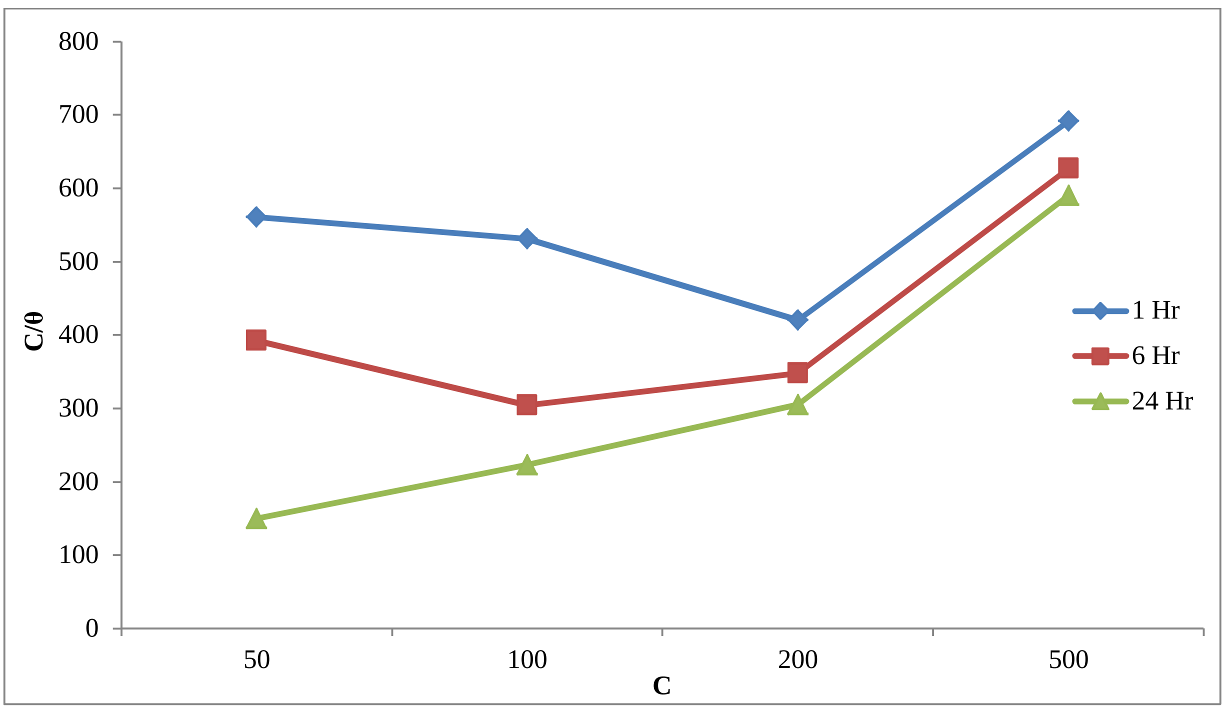

Fig. 2 Mass loss curves in between variation of C/θ with C using *Pennisetum typhoideum* leaves extract for Mild steel in 0.1 N HCl at 298 ±1.0 K, Time at 1 h, 6 h, 24 hrs.

Table 2 & Figure 3 depict the temperature dependence of the inhibitor's percentage inhibition at varying temperatures. The data suggests that when the temperature rises, the inhibition efficiency falls. A decrease in the inhibition tendency as the temperature rises indicates that the inhibitor has separated from the base metal's surface. This is because mild steel disintegrates more quickly and the inhibition from the base metal substrate partially decomposes as the temperature rises.

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Table 2. Comparisons of Inhibition Efficacy (η%) at different temperature in HCl medium using *Pennisetum typhoideum* leaves extract after duration 24 hrs.

		298K		308K		318K	
S. NO.	Inhibitor Concentration	Inhibition Efficacy (η%)	Corrosion Rate (mmpy)	Inhibition Efficacy (η%)	Corrosion Rate (mmpy)	Inhibition Efficacy (η%)	Corrosion Rate (mmpy)
1	Blank	0	38.45737	0	31.67783	0	30.5979
2	50	33.22933	25.67824	22.34848	24.59832	20.58824	24.29834
3	100	44.77379	21.23855	33.71212	20.99856	35.68627	19.67865
4	200	65.52262	13.25909	60.60606	12.47915	62.35294	11.51921
5	500	84.71139	5.879597	82.57576	5.519622	83.33333	5.099651

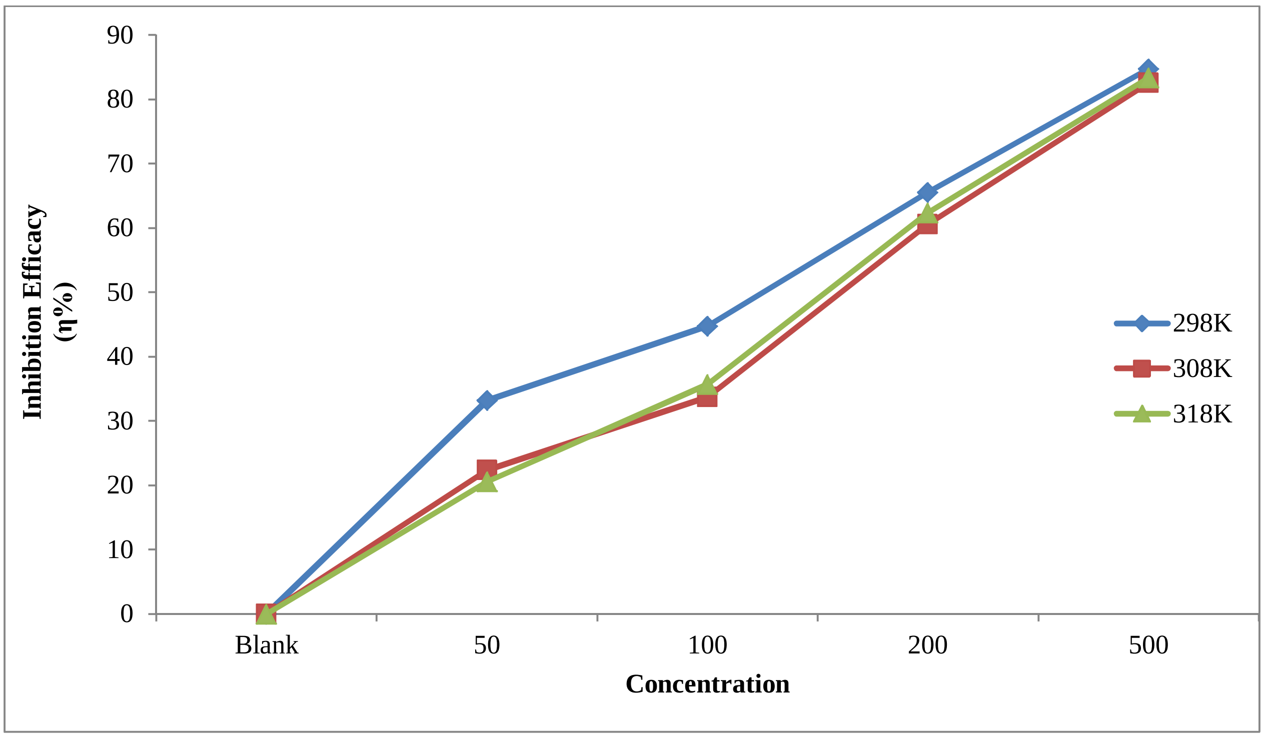

Fig 3 Changes in Inhibition Efficacy (η%) with Inhibitor *Pennisetum typhoideum* leaves extract at various temperature in 0.1 N HCl.

It is evident that compared to the freely distributed solution, the inhibited solution has a greater activation energy E_a value. Because the inhibitor adheres to the metal surface, it provides a protective layer that reduces ferrous dissolution, increasing the corrosion reaction harder and raising the reaction's energy threshold[16-17].

Table-3 Calculation of E_a (KJ/ Mol) by using slope of graph plotted between Log (Corrosion Rate) & 1/T in HCl medium for 24 hour.

S. NO.	Inhibitor Concentration	Log CR at 298 K	Log CR at 308 K	Log CR at 318 K	Activation energy (Ea) (KJ/ mol)
1	Blank	1.58498	1.500755	1.485692	10.4103
2	50	1.409565	1.390905	1.385577	5.3382
3	100	1.327125	1.32219	1.293995	4.5148
4	200	1.122514	1.096185	1.061423	-0.1783
5	500	0.769348	0.741909	0.70754	14.9328

IV. CONCLUSIONS

The difficult fight against corrosion demands creative preventive strategies. The safety and environmental advantages of green corrosion inhibitors, especially those made from plants, are drawing a lot of attention. They have a clear benefit over conventional inhibitors and are safer to handle and less harmful to the environment. A more comprehensive and efficient corrosion inhibition mechanism is produced by the synergistic action of plant extracts' intrinsic chemical diversity. In present study, the alcoholic leaves extracts of *Pennisetum typhoideum* are found to be influential inhibitor in acid media giving up to 84.71% efficiency at higher concentration (500ppm) at given temperature 298 K and can be safely used without toxic effects and pollution.

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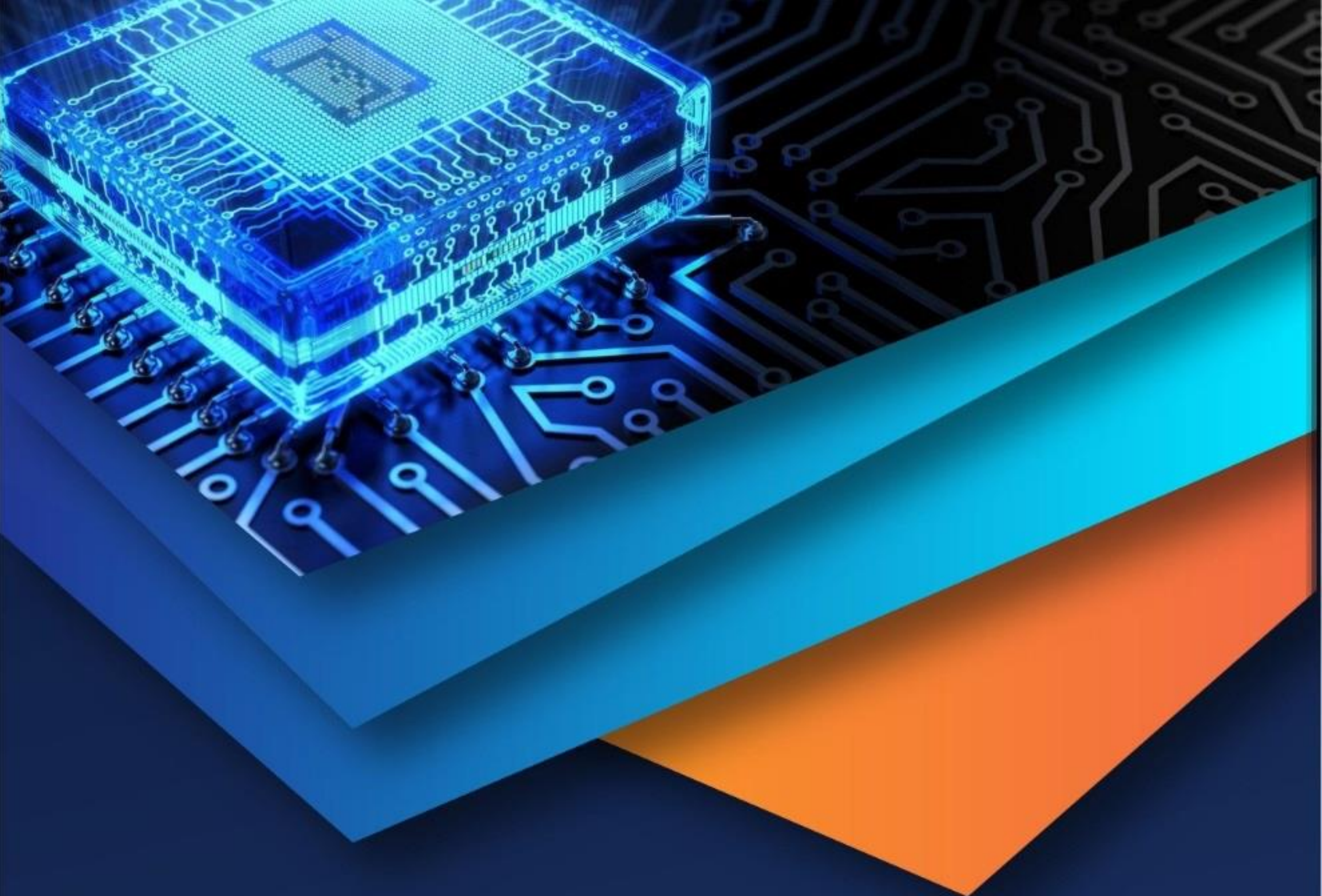

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