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Review Article on Cement Kiln Dust Based Low-Cost Adsorbents for COD Removal from Domestic Wastewater

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Abstract: ***The increasing levels of Chemical Oxygen Demand (COD) in domestic wastewater pose significant environmental challenges. Conventional treatment methods often prove costly and ineffective for large-scale applications. Cement Kiln Dust (CKD), a by-product of cement manufacturing, has emerged as a promising low-cost adsorbent for COD removal. This review explores the adsorption potential of CKD, its physicochemical properties, and its effectiveness in treating domestic wastewater. Various studies suggest that CKD exhibits high adsorption efficiency, making it a sustainable alternative to traditional adsorbents. However, concerns such as leaching of heavy metals and long-term stability require further investigation. This paper aims to provide an overview of CKD's applicability, optimization parameters, and future research directions for its integration into wastewater treatment systems.***

Keywords: Cement Kiln Dust, COD Removal, Wastewater Treatment, Low-Cost Adsorbent, Adsorption Efficiency, Environmental Sustainability

I. INTRODUCTION

Cement Kiln Dust (CKD) is a by-product of cement manufacturing and has gained attention for its potential applications in environmental engineering. One such application is its use as a low-cost adsorbent for the removal of Chemical Oxygen Demand (COD) from domestic wastewater. COD is a crucial parameter that determines the level of organic pollution in wastewater, and its effective removal is necessary to ensure environmental compliance and water quality improvement. The use of CKD as an adsorbent presents a sustainable and cost-effective alternative to conventional treatment methods. This review article explores the feasibility of CKD for COD removal, its adsorption efficiency, and the challenges associated with its application. The increasing generation of domestic wastewater due to rapid urbanization and population growth poses significant environmental challenges. Traditional wastewater treatment methods are often expensive, energy-intensive, and may not effectively remove high levels of organic pollutants, particularly Chemical Oxygen Demand (COD). Cement Kiln Dust (CKD), a byproduct of cement manufacturing, is generated in large quantities and is often disposed of in landfills, contributing to environmental degradation. There is a critical need to explore sustainable and cost-effective treatment methods that utilize industrial waste materials like CKD for wastewater purification. CKD possesses favorable physicochemical properties such as high alkalinity and porous structure, making it a potential low-cost adsorbent for COD removal. By converting CKD into an effective adsorbent, this research aims to address two major environmental concerns: wastewater pollution and industrial waste management. Additionally, utilizing CKD for COD removal aligns with sustainable development goals by promoting waste valorization and reducing the carbon footprint of wastewater treatment processes. This research can contribute to developing an economical and eco-friendly solution, particularly beneficial for small-scale wastewater treatment plants and rural communities lacking access to advanced treatment technologies.

II. LITERATURE REVIEW

This section presents a comprehensive review of previous studies on the utilization of CKD as an adsorbent for wastewater treatment. Various researchers have explored the physicochemical properties of CKD, its adsorption capacity, and the factors affecting COD removal efficiency. Some key studies include:

1) Investigations on the surface characteristics and chemical composition of CKD for adsorption applications.
2) Case studies on the removal of organic contaminants from wastewater using CKD-based adsorbents.
3) Comparative analysis of CKD with other low-cost adsorbents such as fly ash, activated carbon, and biochar.
4) The impact of pH, contact time, adsorbent dosage, and temperature on COD removal efficiency.

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Domestic wastewater, which includes effluents from households, commercial establishments, and small-scale industries, is a significant contributor to water pollution. One of the primary concerns in the treatment of such wastewater is the removal of Chemical Oxygen Demand (COD), which serves as a critical indicator of organic pollution. High COD levels in wastewater can lead to severe environmental problems, such as oxygen depletion in receiving water bodies, degradation of aquatic life, and the overall deterioration of water quality, posing risks to both human health and biodiversity.

Traditional wastewater treatment methods, including biological treatments (e.g., activated sludge processes) and chemical treatments (e.g., coagulation-flocculation), often come with high operational costs, limited efficiency under varying conditions, and increased sludge production. In many developing regions or smaller-scale treatment plants, these methods may not be affordable or feasible.

An alternative, low-cost, and effective method is required to address this challenge. Cement Kiln Dust (CKD), a by-product of the cement manufacturing process, is often produced in large quantities and poses disposal challenges for the cement industry. Despite its abundance, CKD is typically discarded as waste, contributing to environmental pollution. However, recent studies suggest that CKD has the potential to be repurposed as an adsorbent material for the removal of various contaminants, including organic pollutants like COD, from wastewater.

The problem this research seeks to address is twofold:

- High levels of COD in domestic wastewater, which require effective removal to mitigate environmental and public health risks.
- Underutilization of Cement Kiln Dust as a valuable resource, leading to environmental concerns regarding its disposal.

1) Utilizing Cement Kiln Dust as an Efficient Adsorbent for Heavy Metal Removal in Wastewater Treatment (2025) Authors- Elmaadawy, Khaled, Mohamed R. Hamed, Hussein Al-Hazmi, and Gamal K. Hassan Cement Kiln Dust (CKD), a by-product of the cement manufacturing process, has gained attention as a potential low-cost and eco-friendly adsorbent for wastewater treatment, particularly for removing heavy metals. CKD is typically composed of fine particles containing calcium, silica, and other metal oxides, making it suitable for adsorbing pollutants such as lead (Pb), zinc (Zn), copper (Cu), and cadmium (Cd). Recent studies, including one by Elmaadawy et al. (2025), have demonstrated CKD's effectiveness in removing heavy metals from wastewater. The study showed that CKD could achieve removal efficiencies of 98% for Pb, 94% for Zn, 92% for Cu, and 90% for Cd within just 4 hours of contact time. This makes CKD a promising alternative to conventional methods, which often involve high operational costs and result in significant sludge formation. The adsorption process is influenced by several factors, including pH, contact time, adsorbent dosage, and initial heavy metal concentrations. The optimal pH for metal removal was found to be slightly alkaline, with CKD showing high adsorption capacity under these conditions. The adsorption process followed the Langmuir isotherm model, indicating that CKD acts as a monolayer adsorbent, where metal ions are uniformly distributed on its surface. In addition to its high adsorption efficiency, CKD also reduces the formation of hazardous sludge, a common issue with traditional chemical precipitation methods. As a by-product of cement production, CKD offers a sustainable solution for both waste disposal and wastewater treatment, making it a cost-effective and environmentally friendly option for heavy metal removal from wastewater.

2) Effect of water treatment residuals and cement kiln dust on COD adsorption and heavy metals from textile wastewater (2020)\, Authors- Esawy Mahmoud, Wafaa Hammad, Othman Hakami , The study conducted by Esawy Mahmoud, Wafaa Hammad, and Othman Hakami explores the potential of Cement Kiln Dust (CKD) and Water Treatment Residuals (WTR) as adsorbents for removing pollutants from textile wastewater, specifically targeting Chemical Oxygen Demand (COD), color, and heavy metals. The research demonstrates that both CKD and WTR significantly enhance COD adsorption, with the highest adsorption occurring within 2 hours of contact time. The adsorption data for CKD fitted well to both Langmuir and Freundlich isotherm models, with CKD alone achieving a maximum Langmuir adsorption capacity of 14.3 mg/g. However, the addition of WTR improved the adsorption capacity significantly, reaching 100.0 mg/g for Langmuir isotherms. The study further revealed that wastewater treated with CKD or WTR met environmental guidelines for heavy metals set by the Egyptian and United States Environmental Protection Agencies (EPA), indicating that both materials are effective in reducing hazardous pollutants to safe levels for irrigation. Additionally, the study highlighted that the combination of alum with WTR at a concentration of 200 mg/L was more effective for removing turbidity, color, and COD than using WTR alone at higher concentrations (500 mg/L). The findings underscore the feasibility of using CKD and WTR as low-cost, eco-friendly adsorbents for treating textile wastewater, offering a sustainable approach to mitigate water pollution while recycling industrial by-products.

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3) Cement kiln dust as an alternative technique for wastewater treatment (2021) Authors- Amany F. Hasaballah, T.A. Hegazy, M.S. Ibrahim, Doaa A. El-Emam, The study by Amany F. Hasaballah, T.A. Hegazy, M.S. Ibrahim, and Doaa A. El-Emam investigates the effectiveness of Cement Kiln Dust (CKD) as an alternative technique for wastewater treatment. The research aimed to evaluate CKD's potential for removing a range of pollutants, including biochemical oxygen demand (BOD), chemical oxygen demand (COD), total phosphorus (TP), total nitrogen (TN), and heavy metals. Using a jar test technique, the optimal treatment conditions were determined, including a pH of 8.1, CKD dosage of 1.9 g, a grain size of 0.1 mm, and a contact time of 30 minutes at 150 rpm. The results showed that CKD achieved removal efficiencies of 85.3% for BOD, 81.6% for COD, 97.1% for TP, and 94.6% for turbidity, with significant improvements in dissolved oxygen (DO) levels (84% increase). In terms of heavy metal removal, CKD demonstrated high efficiency with Pb removal at 88.4%, Cd at 90.9%, and Zn at 88.5%, surpassing conventional coagulants like alum in certain parameters. The study concluded that CKD can serve as a cost-effective, environmentally friendly coagulant, offering performance similar to alum, making it a viable alternative for treating low to moderate strength wastewater. Its ability to efficiently remove both organic pollutants and heavy metals highlights CKD's potential as a sustainable solution in wastewater treatment.

4) Feasibility Study of Using Cement Kiln Dust for COD Reduction in the Treatment of Municipal wastewater (2015) Authors- Shneha G. Galagali, Mahesh S. Salunkhe, The study conducted by Shneha G. Galagali and Mahesh S. Salunkhe (2015) investigates the feasibility of using Cement Kiln Dust (CKD) as a coagulant for the treatment of municipal wastewater with a focus on reducing Chemical Oxygen Demand (COD). Municipal wastewater contains a mix of organic and inorganic pollutants, which can be effectively removed through chemical coagulation. CKD, a byproduct of the cement industry, contains high levels of lime, making it a potential low-cost alternative to conventional coagulants. The study tested various CKD dosages (ranging from 0.5 to 3.0 g/L) and determined the optimum dose for maximum COD removal. The results indicated that CKD could be used effectively at an optimal dosage of 2 g/L, achieving significant reductions in COD, thus proving its feasibility as an efficient and sustainable treatment option for municipal wastewater. This study highlights the potential of CKD, not only as a waste product but also as a valuable resource in wastewater treatment, offering an eco-friendly and cost-effective solution for improving water quality in municipal settings.

5) The effective treatment of dye-containing simulated wastewater by using the cement kiln dust as an industrial waste adsorbent (2025), Authors- Eslam Syala, Wagih A Sadik, Abdel-Ghaffar M El-Demerdash, Waffa Mekhamer, M Essam El-Rafey , The study by Eslam Syala, Wagih A. Sadik, Abdel-Ghaffar M. El-Demerdash, Waffa Mekhamer, and M. Essam El-Rafey investigates the potential of Cement Kiln Dust (CKD) as an adsorbent for the removal of Methylene Blue (MB) and Congo Red (CR) dyes from simulated wastewater. The research involved characterizing CKD using techniques like X-ray Fluorescence (XRF), X-ray Diffraction (XRD), BET surface area analysis, Fourier Transform Infrared Spectroscopy (FTIR), and Scanning Electron Microscopy (SEM). Batch adsorption experiments were conducted, exploring the effects of parameters such as contact time, temperature, pH, initial dye concentration, and adsorbent dosage. The study found that the pseudo-second-order model best described the adsorption kinetics, suggesting a chemisorption mechanism. The thermodynamic analysis indicated that the adsorption process was endothermic. Adsorption isotherms showed that the process followed both homogeneous mono-layer (Langmuir) and heterogeneous multilayer (Freundlich) models. The results revealed that CKD could adsorb 58.43 mg/g of Methylene Blue and 123.42 mg/g of Congo Red. These findings demonstrate that CKD is an effective, low-cost adsorbent for treating dye-containing wastewater, offering a promising solution for pollution remediation. The study highlights the potential of CKD as a sustainable material for wastewater treatment, especially in the context of textile industries where dye contamination is a common issue.

6) Review of beneficial uses of cement kiln dust (CKD), fly ash (FA) and their mixture (2019 Authors- A. A. Elbaz, A. M. Aboulfotoh, A. M. Dohdoh, A.M.Wahba, The article by A. A. Elbaz, A. M. Aboulfotoh, A. M. Dohdoh, and A.M. Wahba (2019) offers a comprehensive review of the beneficial uses of Cement Kiln Dust (CKD) and Fly Ash (FA), two significant industrial by-products. Both CKD and FA are formed during the manufacture of cement and coal-fired electricity generation, respectively. The study highlights the economic and environmental benefits of utilizing these by-products in various industries, including agriculture, waste treatment, soil stabilization, and the concrete and cement industries. CKD is a fine powder produced in the cement manufacturing process, typically destined for landfills. The article explores how CKD, despite its historical disposal as waste, can be repurposed effectively in several applications, such as enhancing soil quality and contributing to the construction sector. Fly Ash (FA), a by-product from coal combustion in power plants, shares similar potential in mitigating environmental challenges by reducing reliance on virgin resources and minimizing landfill disposal. The study emphasizes the environmental benefits of using CKD and FA, such as reduced greenhouse gas emissions, minimized

landfilling, and conservation of natural resources. On the economic front, the beneficial use of these by-products offers cost savings from the substitution of more expensive materials and job creation in the recycling and reprocessing industries. Furthermore, the reuse of CKD and FA not only contributes to sustainable development but also presents a practical solution to address the growing environmental concerns related to industrial waste management.

7) Effectiveness of using cement kiln dust as a coagulant in wastewater treatment (2021) Authors- N. Pavitra and A. Rajkumar, The study by N. Pavithra and A. Rajkumar (2021) examines the effectiveness of using Cement Kiln Dust (CKD) as a coagulant for treating domestic wastewater through the coagulation-flocculation process. CKD, a by-product of cement manufacturing, has traditionally been viewed as a waste material, but the study explores its potential in improving wastewater treatment. The coagulation-flocculation process is used to remove colloidal particles and fine suspended solids, and CKD is considered a viable alternative to traditional chemical coagulants. The research highlights how CKD can significantly alter key effluent characteristics such as pH, Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Dissolved Solids (TDS), and Total Suspended Solids (TSS). Through Scanning Electron Microscopy (SEM) and Energy Dispersive X-ray Diffraction (EDX), the study investigates the physical and chemical properties of CKD that contribute to its effectiveness as a coagulant. The findings suggest that CKD can be an efficient, cost-effective solution for treating domestic wastewater, offering a dual benefit: reducing wastewater pollutants and addressing the environmental disposal issues associated with cement manufacturing by utilizing CKD in wastewater treatment. This study is important because it suggests that CKD could be a sustainable alternative to conventional chemical coagulants, helping improve water quality while also reducing the environmental burden of CKD disposal.

III. PROPOSED METHODOLOGY

The proposed methodology outlines a systematic approach to evaluate the potential of Cement Kiln Dust (CKD) as a low-cost adsorbent for the removal of Chemical Oxygen Demand (COD) from domestic wastewater. The methodology includes several stages, from the preparation and characterization of CKD to conducting adsorption experiments and analyzing the results.

A. Characterization of Cement Kiln Dust (CKD)

The first step is to analyze the physical and chemical properties of the CKD to determine its suitability as an adsorbent. The following techniques will be used:

- Chemical Composition Analysis: The chemical composition of CKD will be determined using X-ray fluorescence (XRF) to identify the major elements and compounds present.
- Surface Area and Porosity Analysis: Brunauer-Emmett-Teller (BET) analysis will be used to measure the surface area and porosity of CKD, which are crucial for its adsorptive capacity.
- Microscopic Analysis: Scanning Electron Microscopy (SEM) will be employed to examine the surface morphology of CKD and determine its texture, particle size, and structure.
- X-ray Diffraction (XRD): This technique will be used to identify the crystalline phases present in CKD, which can influence its adsorptive properties.

B. Preparation of Adsorbent

- Activation/Modification of CKD: To enhance the adsorption efficiency of CKD, the material may be activated or modified through chemical or thermal processes (e.g., acid activation, heat treatment). The modified CKD will be tested for improved adsorptive properties.
- Preparation of Adsorbent for Batch Studies: CKD will be ground to a fine powder and sieved to achieve uniform particle sizes suitable for adsorption experiments.

C. Collection of Domestic Wastewater

- Sample Collection: Domestic wastewater samples will be collected from local residential or municipal sources. The samples will be analyzed for initial COD levels, pH, and other relevant parameters (e.g., Total Suspended Solids (TSS), biochemical oxygen demand (BOD)).

D. Batch Adsorption Experiments

Experimental Design:

Batch adsorption experiments will be carried out to evaluate the removal efficiency of COD from domestic wastewater. The following parameters will be varied:

- pH: The impact of pH on adsorption will be investigated by testing different pH values (e.g., acidic, neutral, and alkaline conditions).
- Adsorbent Dosage: The influence of varying CKD doses (e.g., 1 g/L, 5 g/L, 10 g/L) will be studied to identify the optimal amount of adsorbent for maximum COD removal.
- Contact Time: The effect of contact time (ranging from a few minutes to several hours) on the COD removal will be analyzed to determine the equilibrium time.
- Initial COD Concentration: Different initial COD concentrations will be tested to evaluate the adsorbent's capacity to remove contaminants at varying pollution levels.

E. Comparison with Conventional Adsorbents

- Selection of Conventional Adsorbents: Common adsorbents such as activated carbon and clay minerals will be used as reference materials to compare their performance with CKD-based adsorbents.
- Experimental Procedure: The batch adsorption experiments for conventional adsorbents will be conducted using the same procedure, and the COD removal efficiency, cost, and material characteristics will be compared with CKD.

IV. CONCLUSION

The review highlights the potential of CKD as a sustainable and economical adsorbent for COD removal from domestic wastewater. Preliminary findings suggest that CKD exhibits promising adsorption efficiency, but further research is needed to address challenges such as leaching of heavy metals, long-term stability, and large-scale applicability. Future studies should focus on process optimization, pilot-scale investigations, and integration with existing wastewater treatment technologies to enhance the feasibility of CKD-based treatment systems.

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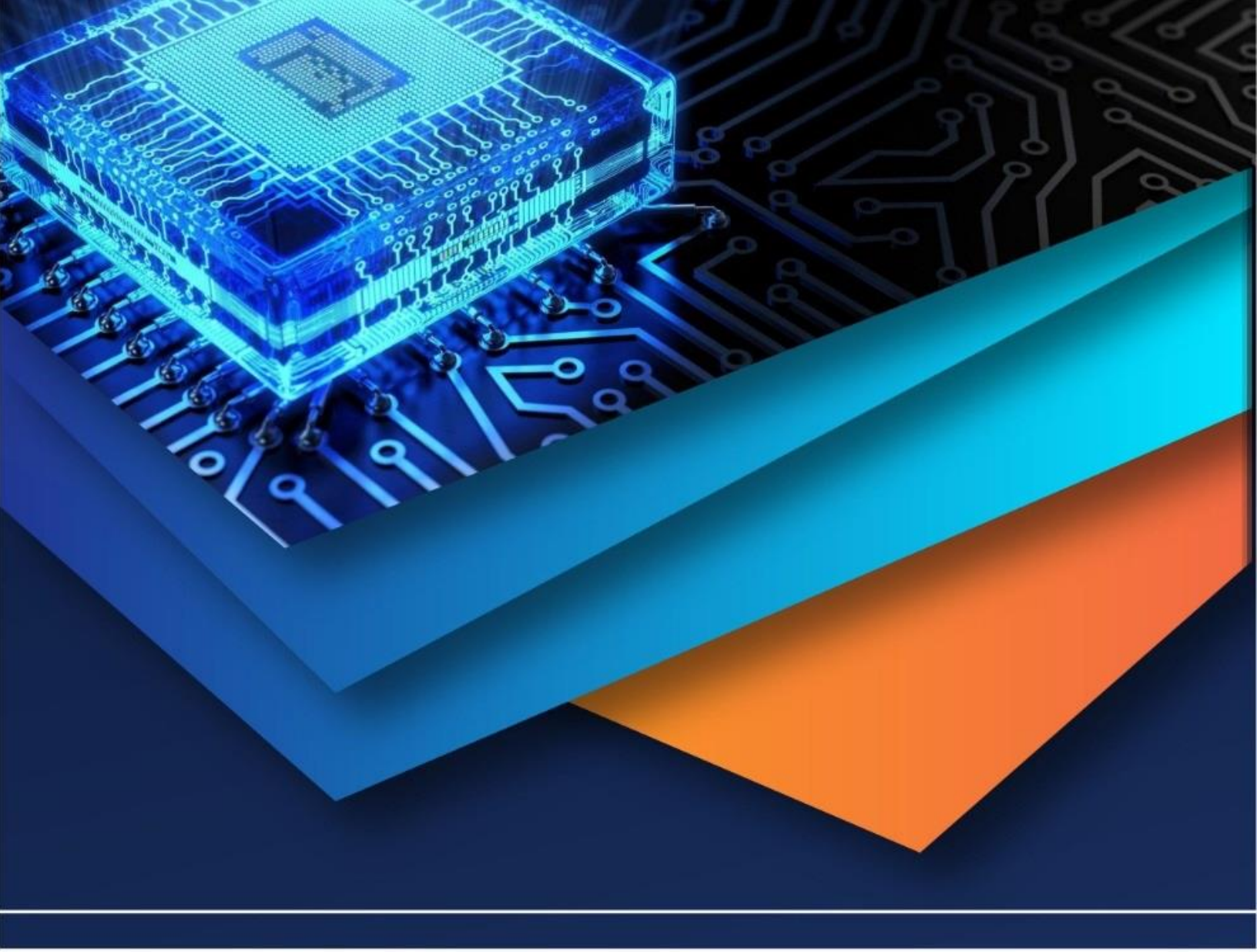
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