iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 14 Issue: III Month of publication: March 2026

DOI: https://doi.org/10.22214/ijraset.2026.79041

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 14 Issue III Mar 2026- Available at www.ijraset.com

Cement Kiln Dust Based Low-Cost Adsorbents for COD Removal From Domestic Wastewater

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Abstract: Wastewater contains a variety of physical, chemical, and biological impurities that must be effectively removed to ensure safe disposal or reuse. One widely employed chemical method in water and wastewater treatment is the coagulation-flocculation process, which plays a crucial role in eliminating colloidal and fine suspended solids. Traditionally, both synthetic and natural coagulants have been used in such treatments; however, increasing focus on sustainable and cost-effective solutions has led researchers to explore alternative materials. Cement kiln dust (CKD), a byproduct of cement manufacturing, is typically considered an industrial waste and poses significant disposal challenges. Numerous studies in the literature have demonstrated the potential of CKD as a coagulant for treating various industrial effluents due to its chemical composition. This study investigates the application of cement kiln dust in the coagulation-flocculation treatment of domestic wastewater. The experimental analysis aims to evaluate the effectiveness of CKD in reducing key effluent parameters such as pH, Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Dissolved Solids (TDS), and Total Suspended Solids (TSS). The results of this study could contribute to the development of a low-cost and eco-friendly treatment method for domestic wastewater, while simultaneously addressing the disposal issue of CKD from cement industries.
Keywords: Cement Kiln Dust (CKD), Domestic Wastewater, Coagulation-Flocculation, BOD, COD, TDS, TSS, pH, Industrial Waste Utilization, Wastewater Treatment.

I. INTRODUCTION

Coagulation is a fundamental physicochemical process employed extensively in water and wastewater treatment systems for the removal of fine suspended particles and colloidal matter that are not easily eliminated by sedimentation or filtration alone. The effectiveness of this process largely depends on several factors including the type and dosage of coagulant used, mixing conditions, pH, and alkalinity of the water. Conventional coagulants such as aluminium sulfate (alum), ferric chloride, and ferric sulfate are widely applied; however, these chemicals often present challenges related to cost, sludge production, and environmental impact. The optimal dosage of coagulants is essential for ensuring efficient removal of turbidity, suspended solids, and other contaminants from wastewater, as overdosing or underdosing can lead to inefficient treatment or secondary pollution. In recent years, increasing environmental awareness and industrial sustainability goals have driven researchers to investigate alternative, low-cost, and eco-friendly coagulants. Cement kiln dust (CKD), a fine, powdery by-product generated during the production of Portland cement, has emerged as a promising candidate. CKD is produced during the calcination process in cement kilns and is typically collected using air pollution control devices such as bag house filters and electrostatic precipitators. Disposing of CKD is a major challenge for cement industries due to its large volume and potential environmental hazards; however, its high calcium oxide (CaO) content provides a unique advantage. Quicklime (CaO), which is the principal component in CKD, offers strong alkaline properties, making CKD a potential substitute for lime in various environmental applications, particularly in wastewater treatment. The presence of calcium carbonate ($CaCO_3$) in CKD enhances its function as a ballasting agent, contributing to the coagulation of organic and inorganic particles by promoting floc formation and improving settling characteristics. When introduced into wastewater, CKD can neutralize acidity and form large, dense flocs through chemical reactions with dissolved and particulate contaminants, thereby aiding in their efficient removal. Its fine particle distribution and chemical composition enable it to function effectively under suitable alkalinity conditions. The use of CKD as a coagulant not only presents a sustainable approach to wastewater treatment but also addresses the issue of CKD disposal from cement manufacturing plants, aligning with principles of circular economy and waste valorization. Therefore, this study explores the feasibility and performance of using cement kiln dust as a coagulant in the treatment of municipal or domestic wastewater, focusing on its ability to reduce common effluent parameters such as turbidity, biochemical oxygen demand (BOD), chemical oxygen demand (COD), total dissolved solids (TDS), and total suspended solids (TSS), thereby offering an innovative and cost-effective alternative to traditional chemical coagulants.

II. LITERATURE REVIEW

Several researchers have extensively investigated the potential use of Cement Kiln Dust (CKD) in wastewater treatment, recognizing it as a promising low-cost and sustainable alternative to conventional chemical coagulants. CKD, a by-product of the cement manufacturing process, is primarily composed of calcium oxide (CaO), calcium carbonate ($CaCO_3$), and other alkaline constituents, making it highly effective in neutralizing acidic wastewater and promoting the coagulation of suspended particles. Numerous studies have highlighted its coagulative and flocculative capabilities, particularly in the treatment of both domestic and industrial effluents.

[1] “Utilizing Cement Kiln Dust as an Efficient Adsorbent for Heavy Metal Removal in Wastewater Treatment", Elmaadawy et al. (2025) have extensively explored the potential of CKD as a low-cost, sustainable, and highly effective adsorbent material for the removal of heavy metals from contaminated water sources. The research team, designed a comprehensive parametric study by varying key operational parameters such as solution pH (ranging from 6 to 9), contact time, adsorbent dose, and initial concentrations of metal ions. The findings revealed that CKD exhibited remarkably high adsorption efficiencies, with removal rates reaching up to 98% for lead (Pb), 94% for zinc (Zn), 92% for copper (Cu), and 90% for cadmium (Cd), all within a relatively short contact time of four hours. Such high efficiencies indicate the strong affinity between CKD and heavy metal ions, which is further corroborated by the adsorption data fitting well with the Langmuir isotherm model—implying monolayer adsorption on a homogeneous surface.

[2] “Cement kiln dust as an alternative technique for wastewater treatment”, Hasaballah, Hegazy, Ibrahim, and El-Emam (2021) delves into the application of CKD as an environmentally friendly alternative coagulant for the treatment of low to moderately polluted wastewater. This research aimed to evaluate CKD’s pollutant removal potential by assessing various physicochemical parameters before and after treatment. Utilizing a controlled jar test setup, the optimal operating conditions for effective pollutant removal were established: pH of 8.1, a CKD dosage of 1.9 g, and a particle grain size of 0.1 mm, with a contact time of 30 minutes at a mixing speed of 150 rpm. The findings demonstrated remarkable removal efficiencies for a broad spectrum of contaminants. Specifically, CKD was able to remove 85.3% of biological oxygen demand (BOD), 81.6% of chemical oxygen demand (COD), 97.1% of total phosphorus (TP), 86.8% of total nitrogen (TN), 36% of total dissolved solids (TDS), 74% of salinity, 61.2% of electrical conductivity, and 94.6% of turbidity, along with an 84% increase in dissolved oxygen (DO) concentration. In terms of heavy metal removal, CKD proved equally impressive, with removal percentages of 88.4% for Pb, 90.9% for Cd, 88.5% for Zn, 97.2% for Fe, 94.2% for Co, 70% for Ni, and 79.9% for Cu. To validate its performance, the results were benchmarked against those obtained using alum, a conventional coagulant widely employed in water treatment. Alum achieved comparable but slightly varied removal efficiencies: 86.6% for BOD, 79.6% for COD, 96.6% for TP, 59.9% for TN, 39.7% for TDS, 65% for salinity, 59% for conductivity, 95.2% for turbidity, and 85.3% for DO increase.

[3] “Effect of water treatment residuals and cement kiln dust on COD adsorption and heavy metals from textile wastewater”, Mahmoud, Hammad, and Hakami (2020) investigated the potential of CKD and WTR to remove pollutants such as chemical oxygen demand (COD), heavy metals, and color from textile wastewater through a batch adsorption technique. WTR, a by-product from drinking water treatment plants where alum is used to remove suspended solids and colloids, has typically been discarded as waste. However, its high aluminum and iron content renders it a promising candidate for pollutant removal from industrial effluents. Similarly, CKD, generated as a fine particulate by-product in cement manufacturing, is rich in calcium oxides and alkaline compounds, making it an effective adsorbent for acidic and metal-laden waste streams. The experimental design in this study included the application of both CKD and WTR at varying doses, evaluating their individual and combined performances in adsorbing COD and removing heavy metals. Remarkably, the COD adsorption increased with both CKD and WTR addition, peaking after 2 hours of contact time. The adsorption behavior of COD on CKD aligned well with both Langmuir and Freundlich isotherm models, indicating the occurrence of monolayer as well as multilayer adsorption. Notably, the Langmuir maximum adsorption capacity for WTR (100 mg/g) significantly outperformed that of CKD (14.3 mg/g), underscoring WTR's superior adsorption potential. Furthermore, the heavy metal concentrations in the treated textile wastewater samples fell below permissible levels set by both the Egyptian and United States Environmental Protection Agency standards for irrigation use.

[4] “Feasibility Study of Using Cement Kiln Dust for COD Reduction in the Treatment of Municipal wastewater”, Galagali and Salunkhe (2015) explored the feasibility of using CKD as a chemical coagulant for the treatment of municipal wastewater, particularly focusing on its capacity to reduce chemical oxygen demand (COD) levels. Municipal wastewater is often rich in both organic and inorganic contaminants, which must be effectively removed before discharge to prevent eutrophication and other forms of environmental degradation. The authors conducted a series of bench-scale experiments to assess CKD’s coagulant efficiency at varying dosages ranging from 0.5 g/L to 3.0 g/L, under controlled pH and mixing conditions.

The findings revealed that CKD could significantly reduce COD concentrations, with the optimal dosage identified at 2.0 g/L, where the most efficient coagulation and flocculation occurred. Beyond this dose, the removal efficiency plateaued or slightly declined, possibly due to particle restabilization or overdosing effects. The study strongly highlighted the dual benefits of CKD use: not only does it offer a cost-effective, easily available substitute for traditional chemical coagulants like alum or ferric chloride, but it also provides an environmentally sound disposal route for a solid waste stream from the cement industry.

[5] "Review of beneficial uses of cement kiln dust (CKD), fly ash (FA) and their mixture", Elbaz, Aboulfotoh, Dohdoh, and Wahba (2019), from Zagazig University, critically examined the beneficial applications of CKD, fly ash (FA), and their combined use across multiple environmental and industrial sectors. The authors begin by highlighting the massive global scale of CKD generation, noting that approximately 0.06–0.07 tons of CKD are produced per ton of cement, with global estimates predicting over 220 million tons of CKD discarded annually. Traditionally destined for landfills, CKD comprises calcite ($CaCO_3$), quartz (SiO_2), calcium sulfate ($CaSO_4$), and trace amounts of potentially toxic heavy metals such as cadmium, lead, and selenium. Although generally regarded as non-hazardous due to its low leachability, prolonged atmospheric exposure can significantly impact air quality and human health. The review thoroughly discusses the emission sources in cement manufacturing, such as the kiln system, raw mills, and clinker cooler, all of which contribute to the dispersion of CKD into the atmosphere and cause environmental problems ranging from local air pollution to global climate change impacts including greenhouse gas emissions, acid rain, and biodiversity loss.

[6] "Removal of Copper from Wastewater using Low-Cost Adsorbents", Nalkund, Pai, and Thanushree (2015) investigated the effectiveness of CKD, alongside pulp and paper mill sludge (PMS), in removing copper (Cu) from industrial wastewater through a batch adsorption process. The researchers conducted a series of experiments under controlled laboratory conditions (27 ± 3°C), focusing on two critical operational parameters: adsorbent dosage and contact time. Their findings revealed that equilibrium for copper adsorption was achieved at a dosage of 2 g/L of CKD with a contact time of 40 minutes, yielding a high removal efficiency of 98%, significantly outperforming PMS, which showed only 65% removal efficiency at a dosage of 4 g/L in 20 minutes.

[7] "The effective treatment of dye-containing simulated wastewater by using the cement kiln dust as an industrial waste adsorbent", Syala, Sadik, El-Demerdash, Mekhamer, and El-Rafey (2024), the adsorption behavior of CKD was investigated for two common industrial dyes—Methylene Blue (MB) and Congo Red (CR)—from simulated dye-contaminated wastewater. This research adds to the growing body of evidence supporting CKD as a viable industrial waste adsorbent that addresses both waste valorization and wastewater remediation challenges. To understand the surface characteristics and adsorptive potential of CKD, a suite of advanced characterization techniques was applied, including X-ray Fluorescence (XRF) for elemental composition, X-ray Diffraction (XRD) for crystalline structure analysis, Fourier Transform Infrared Spectroscopy (FTIR) for identifying functional groups, Brunauer–Emmett–Teller (BET) for surface area analysis, and Scanning Electron Microscopy (SEM) for morphological assessment. Batch adsorption experiments were systematically conducted under various parameters—contact time, pH, temperature, initial dye concentration, and adsorbent dose—to optimize the operational conditions. The experimental data was subjected to kinetic modeling using pseudo-first-order, pseudo-second-order, and intraparticle diffusion models, with the pseudo-second-order model providing the best fit, indicating chemisorption as the governing mechanism. Thermodynamic evaluations revealed that the adsorption was endothermic, suggesting increased efficiency at higher temperatures, which aligns with industrial effluent temperatures in many sectors.

[8] "Treatment of Domestic Waste Water by Filtration Operation Using Low-Cost Natural Adsorbents", Islamuddin and Ahmad (2016), emphasize the importance of using natural, low-cost adsorbents in filtration operations for the treatment of domestic wastewater. Traditional wastewater disposal practices such as land spreading are fraught with environmental risks including eutrophication of surface and groundwater bodies, and also demand considerable labor input, especially in rural settings. The authors advocate for the use of filtration-based treatment technologies, which offer an energy-efficient and environmentally friendly solution tailored to both rural and urban areas with limited infrastructure. These systems rely on physical and physico-chemical principles for contaminant removal and are particularly effective in reducing parameters such as color, odor, BOD, COD, hardness, and suspended solids, all of which are typical of untreated domestic effluents. The study specifically promotes the application of multimedia filtration systems, often composed of layers of natural materials such as sand, gravel, charcoal, and locally available biomass, which collectively enable mechanical straining, adsorption, and microbial degradation. The advantage of such systems lies in their ability to sustain high microbial populations, thereby facilitating effective biological degradation of organic pollutants even under low-energy, intermittent flow conditions. The low cost, ease of maintenance, and adaptability to varying load conditions make these filters particularly valuable for point-of-use or household-level treatment, especially in water-stressed and economically disadvantaged communities.

The authors point out that these filters are not only capable of removing pathogens and reducing turbidity, but also present a promising solution for reclaiming wastewater for non-potable uses such as irrigation, toilet flushing, car washing, gardening, and even fire-fighting. The decentralized nature of this technology aligns with the principles of sustainable water management and resource recovery, making it especially relevant in the context of integrated water and sanitation strategies in remote or underdeveloped regions.

[9] “Effectiveness of using cement kiln dust as a coagulant in wastewater treatment”, Pavithra and Rajkumar (2021), a waste material generated during cement manufacturing, was examined for its effectiveness as a chemical coagulant in treating domestic wastewater. The study was motivated by two environmental imperatives: the urgent need to manage and repurpose CKD, which poses serious disposal challenges, and the requirement for more sustainable alternatives to conventional coagulants like alum and ferric salts that are not only costly but also raise concerns over sludge handling and residual toxicity. The researchers emphasized that CKD, due to its alkaline nature and fine particle size, has a significant potential to destabilize colloidal particles and reduce various pollutant concentrations in wastewater. Through laboratory-scale experiments, the performance of CKD in coagulation-flocculation was systematically studied. The authors observed notable reductions in key physicochemical parameters such as pH, biochemical oxygen demand (BOD), chemical oxygen demand (COD), total dissolved solids (TDS), and total suspended solids (TSS). These findings are consistent with earlier studies that highlighted CKD's capacity to serve not only as a pH neutralizer but also as a multifunctional agent capable of binding organic and inorganic particles due to its high content of lime (CaO) and other reactive oxides. The study also utilized analytical techniques such as Scanning Electron Microscopy (SEM) and Energy Dispersive X-Ray Diffraction (EDX) to analyze the surface morphology and elemental composition of CKD before and after treatment, revealing morphological changes and active surface interactions during the coagulation process.

[10] “Current and Emerging Adsorbent Technologies for Wastewater Treatment: Trends, Limitations, and Environmental Implications”, Younas et al. (2021), the authors provide a critical evaluation of current and emerging adsorbent technologies used in wastewater treatment, with a focus on material efficiency, environmental implications, and future prospects. The study emphasizes that while traditional methods like activated carbon and ion exchange resins are effective, their high cost and disposal-related limitations have led researchers to explore a wide array of low-cost, eco-friendly adsorbents, especially those derived from agricultural, industrial, and natural sources. Materials such as biochar, agricultural residues, clay minerals, zeolites, and even cement kiln dust (CKD) are highlighted for their potential in removing a variety of pollutants including heavy metals, dyes, organic compounds, and nutrients. A key strength of this review lies in its systematic comparison of sorbent types, categorized into agricultural waste-based, non-agricultural natural, and synthetic/modified adsorbents, with a detailed explanation of their removal mechanisms. These include ion exchange, surface complexation, electrostatic attraction, precipitation, and hydrogen bonding, which govern the adsorption dynamics based on the pollutant type and water chemistry. The review also explores biosorption, a subset of adsorption that leverages biological materials—often dead microbial biomass or plant-based materials—for pollutant uptake, due to their inherent functional groups (e.g., hydroxyl, carboxyl, amine). The modification of raw adsorbents through thermal treatment, chemical activation, and impregnation with metal oxides is presented as a promising strategy to enhance surface area, porosity, and functionalization, thereby improving adsorption capacity and selectivity.

III. PROPOSED METHODOLOGY

A. METHODOLOGY

In the study to evaluate the effectiveness of Cement Kiln Dust (CKD) as a coagulant for domestic wastewater treatment. The process begins with the sampling of CKD, followed by its characterization using Scanning Electron Microscopy (SEM) and Energy Dispersive X-ray (EDX) spectroscopy to understand its surface structure and elemental composition. Simultaneously, domestic wastewater samples are collected and subjected to preliminary analysis for key effluent parameters such as pH, Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Dissolved Solids (TDS), and Total Suspended Solids (TSS) using standard laboratory methods. After this initial assessment, the jar test experiment is conducted using a standard bench-scale setup to simulate the coagulation-flocculation process, where CKD is applied at different dosages to determine its performance in removing pollutants from wastewater. The treated samples are then analyzed to measure the removal efficiency of the CKD in terms of the same effluent parameters. Finally, based on the results, the optimum dosage of CKD is determined, reflecting the most effective concentration for achieving maximum pollutant reduction. This methodology not only evaluates the potential of CKD as an alternative coagulant but also helps in optimizing its practical application for real-world wastewater treatment scenarios.

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 14 Issue III Mar 2026- Available at www.ijraset.com

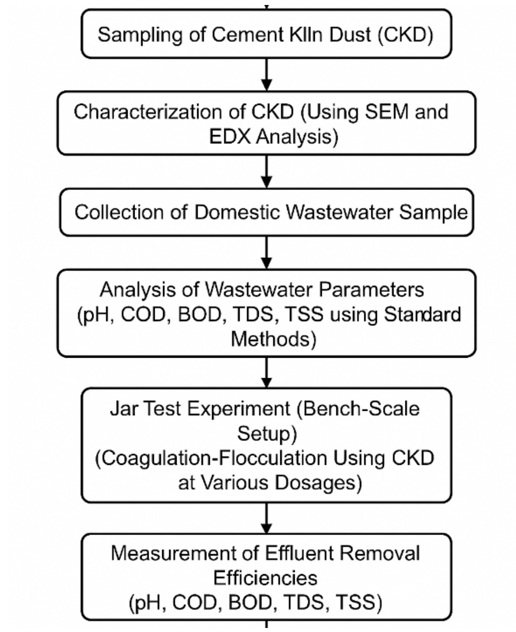

Fig.3.1: Flowchart of Proposed Methodology

B. TESTS PERFORMED

To determine the chemical characteristics and microstructural properties of Cement Kiln Dust (CKD), two highly advanced analytical techniques were employed: Scanning Electron Microscopy (SEM) and Energy Dispersive X-ray Spectroscopy (EDX or EDS). These tests were critical in understanding the surface morphology, elemental composition, and physical behavior of CKD particles, which directly influence their performance as a coagulant in wastewater treatment processes.

(a) (b) (c)

Fig.3.2: Cement Kiln Dust

1) Scanning Electron Microscopy (SEM)

Scanning Electron Microscopy (SEM) is a powerful imaging technique that provides highly magnified, detailed, and high-resolution images of the surface topography of solid materials. In this study, SEM was used to examine the surface structure of the CKD particles, which are typically fine and powdery in nature. Through SEM analysis, researchers could observe the shape, texture, and size distribution of the CKD particles, as well as detect any agglomerations, porosity, or irregularities. This morphological information is crucial because the surface area, porosity, and particle size of CKD directly affect its reactivity, settling properties, and floc formation behavior during coagulation-flocculation processes. SEM imaging typically involves bombarding the CKD sample with a focused beam of high-energy electrons, which interact with the atoms on the surface of the material to produce various signals. These signals are then detected and converted into images that reveal the microstructural features of the material in great detail, typically at magnifications ranging from hundreds to tens of thousands of times.

Fig.3.3: Scanning Electron Microscopy (SEM)

2) Energy Dispersive X-ray Spectroscopy (EDX)

Energy Dispersive X-ray Spectroscopy (EDX), often integrated with SEM, is an elemental analysis technique used to determine the chemical composition of the sample under investigation. While SEM provides physical imagery, EDX complements it by offering qualitative and quantitative insights into the elements present in the CKD sample. The principle behind EDX is based on the interaction between X-rays and the elements within a sample. When the CKD sample is bombarded with the electron beam during SEM, the atoms within the sample emit characteristic X-rays that are specific to each element. The EDX detector captures these X-rays and identifies the elements by analyzing their energy signatures. This information is presented in the form of spectra and tables, indicating the presence and relative abundance of elements such as calcium (Ca), oxygen (O), silicon (Si), magnesium (Mg), aluminium (Al), potassium (K), and sulfur (S), among others. These elements, especially calcium in the form of calcium oxide (CaO) and calcium carbonate ($CaCO_3$), play a major role in CKD's ability to act as a coagulant. The presence of alkaline elements further supports its pH neutralizing capacity and floc-forming potential.By combining SEM and EDX analysis, a comprehensive understanding of CKD's microstructure and elemental makeup was obtained, which is essential for evaluating its suitability and efficiency as a coagulant in wastewater treatment. These advanced techniques thus provided the foundational data required for selecting CKD dosage, predicting its behavior in the treatment process, and interpreting the performance results during coagulation and flocculation experiments.

Fig.3.4: Energy Dispersive X-ray Spectroscopy (EDX)

C. RAW WASTEWATER (DOMESTIC)

The sample collected for this study was obtained from the Sewage Treatment Plant (STP) located in Bhandewadi, Nagpur, which primarily receives raw domestic wastewater.

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Volume 14 Issue III Mar 2026- Available at www.ijraset.com

To assess the quality of the influent entering the treatment system, a series of tests were conducted to determine key characteristics of the raw wastewater. These tests provide critical information regarding the pollution load and are essential for designing and evaluating the treatment process.

The parameters considered in this study included:

- pH, which indicates the acidity or alkalinity of the wastewater;
- Biological Oxygen Demand (BOD), a measure of the amount of biodegradable organic matter;
- Chemical Oxygen Demand (COD), representing the total quantity of chemicals (both biodegradable and non-biodegradable) that can oxidize in the sample;
- Total Suspended Solids (TSS), indicating the presence of particulate matter; and
- Total Dissolved Solids (TDS), representing the concentration of dissolved substances in the water.

Fig.3.5: Bhandewadi STP, Nagpur

IV. RESULTS & DISCUSSION

A. *CHARACTERISTICS OF CEMENT KILN DUST*

Cement Kiln Dust (CKD) is a by-product obtained from the manufacturing process of Portland cement in rotary kilns. It is a fine, greyish powder that possesses both physical and chemical properties which make it suitable for various applications, particularly in the field of environmental and construction engineering. Physically, CKD is characterized by its very fine particle size and lightweight nature. The dust particles are highly porous and have a relatively large surface area, which contributes to their high reactivity and sorption capacity. These features make CKD potentially useful in pollutant removal from wastewater, soil stabilization, and even partial replacement in concrete mixes.Chemically, CKD contains a mixture of compounds including calcium oxide (CaO), silicon dioxide (SiO_2), aluminum oxide (Al_2O_3), iron oxide (Fe_2O_3), magnesium oxide (MgO), potassium oxide (K_2O), and sodium oxide (Na_2O), among others. The exact composition can vary depending on the type of raw materials used and the operating conditions of the kiln. These oxides contribute to the alkaline nature of CKD, which is beneficial in neutralizing acidic contaminants and enhancing coagulation processes in water treatment.

Microscopic and elemental analysis of CKD reveals important insights into its structure and composition. Scanning Electron Microscopy (SEM) images show that CKD particles possess irregular shapes and a porous morphology, indicating a high surface area and good potential for adsorption. Furthermore, Energy Dispersive X-ray Spectroscopy (EDS) confirms the presence of various elements within CKD, supporting its utility in environmental applications. Overall, the unique physical, chemical, and morphological characteristics of cement kiln dust make it a promising material for beneficial reuse in sustainable engineering practices.

1) *Scanning Electron Microscopy*

Scanning Electron Microscopy (SEM) is a powerful analytical technique used to obtain detailed information about the surface topography and composition of materials at the micro to nanoscale. In the present study, SEM was employed to investigate the textural and morphological characteristics of cement kiln dust (CKD) samples.

The SEM images, as shown in Figure 4.1, clearly reveal that the CKD particles exhibit a fine-grained structure with a highly porous surface morphology. These features are significant, as they suggest that CKD has a high surface area, which plays a crucial role in enhancing its sorption properties. The porous and fine-textured nature of the particles indicates their potential effectiveness in adsorbing contaminants, making CKD a promising low-cost adsorbent material in wastewater treatment. Furthermore, the morphological observations support the conclusion that CKD can function effectively as a coagulant, contributing to the removal of suspended solids and pollutants from water. These findings underline the importance of SEM analysis in characterizing waste-derived materials and evaluating their suitability for environmental applications.

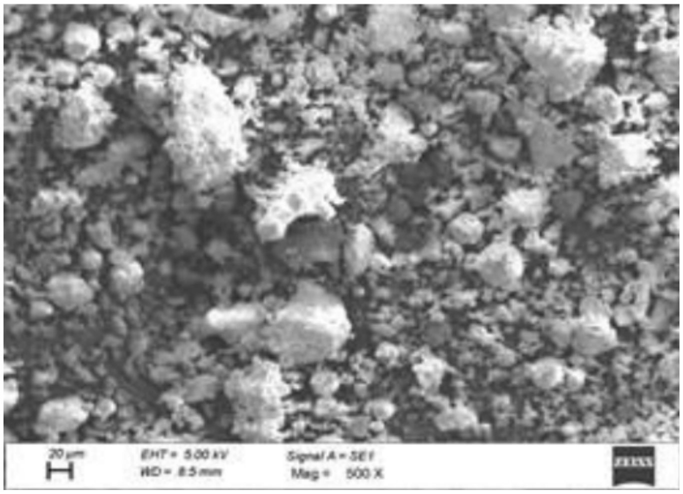


Fig.4.1: Scanning Electron Microscopy image of Cement Kiln Dust sample 1

2) Energy Dispersive X-ray Spectroscopy

Energy Dispersive X-ray Spectroscopy (EDS or EDX) is an analytical technique commonly used for the elemental analysis or chemical characterization of a sample. It works in conjunction with Scanning Electron Microscopy (SEM) and enables the identification and quantification of the elemental composition present in a material. In this study, EDS analysis was performed on cement kiln dust (CKD) to determine its chemical constituents. The results of the EDS analysis, as illustrated in Figure 4.2, revealed the presence of various elements in the CKD sample, providing valuable insights into its composition. This elemental information is crucial in assessing the suitability of CKD for environmental applications, such as its effectiveness in adsorption and coagulation processes during wastewater treatment. The chemical makeup identified through EDS supports the findings from the SEM analysis, further confirming that CKD possesses characteristics favorable for use as a low-cost treatment material.

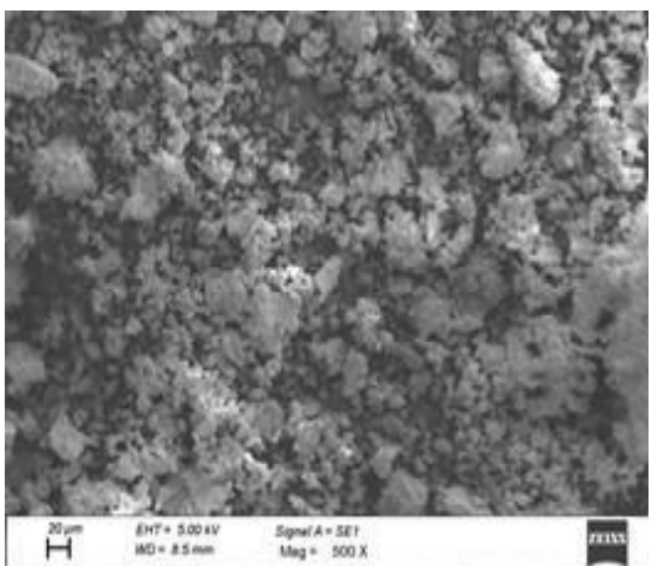


Fig.4.2: Scanning Electron Microscopy image of Cement Kiln Dust sample 2

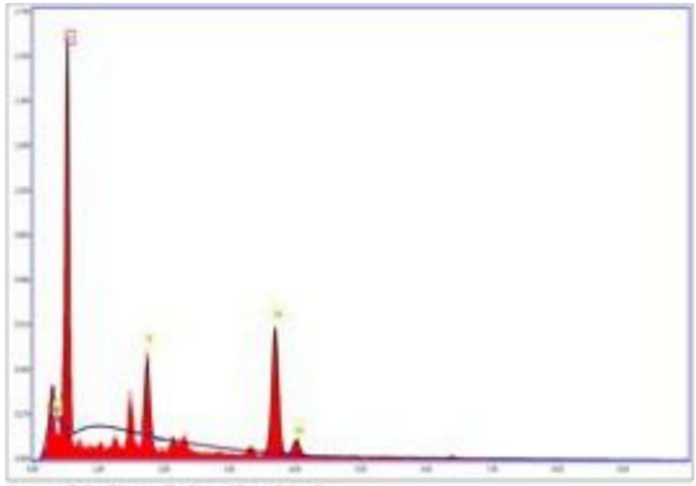


Fig.4.3: Energy dispersive X-ray spectroscopy image of Cement Kiln Dust sample 1

Table 4.1: Elemental composition of CKD sample 1

Element	Weight %	Atomic %	Error %
O	64.80	80.90	9.50
Si	6.50	4.60	7.40
Ca	28.70	14.50	3.60

Table 4.2: Elemental composition of CKD sample 2

Element	Weight %	Atomic %	Error %
C	10.85	17.20	11.90
O	53.40	63.80	10.20
Al	2.10	1.50	12.80
Si	6.60	4.50	6.50
Ca	27.05	13.70	3.60

B. INFLUENT CHARACTERISTICS

Before initiating the coagulation process, the influent characteristics of the wastewater were thoroughly analyzed using standard methods as prescribed by APHA (American Public Health Association). This preliminary testing is essential to understand the nature and concentration of pollutants present in the raw sewage, which directly influences the selection and efficiency of the treatment process. Key parameters such as pH, Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), and Total Dissolved Solids (TDS) were measured to determine the pollution load and treatment needs. The detailed results of the influent wastewater characteristics are presented in Table 4.3. These values serve as baseline data for evaluating the performance of the coagulant used and the overall effectiveness of the treatment process.

Table 4.3: Influent Characteristics of Wastewater

Influent Characteristics	Value
pH	6.80
Biological Oxygen Demand	610 mg/l
Chemical Oxygen Demand	750 mg/l
Total Suspended Solids	245 mg/l
Total Dissolved Solids	1320 mg/l

Table 4.4: Effluent characteristics of wastewater corresponding to dosage of CKD (trial 1)

Dosage of Cement Kiln Dust (g/l)	pH	BOD (mg/l)	COD (mg/l)	TSS (mg/l)	TDS (mg/l)
0	6.95	615	755	248	1325
1	7.02	518	620	245	1055
1.5	7.08	335	430	230	1145
2	7.09	248	370	238	1215
2.5	7.11	295	535	233	1115
3	7.20	230	335	215	1105
3.5	7.28	295	540	232	1125

Table 4.5: Effluent characteristics of wastewater corresponding to dosage of CKD (trial 2)

Dosage of Cement Kiln Dust (g/l)	pH	BOD (mg/l)	COD (mg/l)	TSS (mg/l)	TDS (mg/l)
0	6.68	300	618	285	1675
1	7.00	245	538	248	1340
1.5	7.10	230	430	230	1210
2	7.18	155	318	215	1115
2.5	7.26	115	215	205	1055
3	7.30	130	335	233	1120
3.5	7.38	150	370	245	1250

Table 4.6: Effluent characteristics of wastewater corresponding to dosage of CKD (trial 3)

Dosage of Cement Kiln Dust (g/l)	pH	BOD (mg/l)	COD (mg/l)	TSS (mg/l)	TDS (mg/l)
0.0	6.88	590	650	378	1545
2.4	7.08	265	378	334	1325
2.6	7.09	265	370	324	1315
2.8	7.10	245	348	315	1278
3.0	7.10	248	365	327	1290
3.2	7.11	268	388	338	1320

Table 4.7: Removal efficiencies of effluent characteristics corresponding to dosage of CKD (trial 1)

Dosage (g/l)	BOD Removal (%)	COD Removal (%)	TSS Removal (%)	TDS Removal (%)
1.0	15.00	17.20	1.00	13.50
1.5	44.80	42.00	6.50	19.80
2.0	58.90	49.80	3.80	7.85
2.5	50.90	28.60	5.80	15.10
3.0	61.80	54.80	13.00	16.00
3.5	50.80	27.50	6.20	14.90

Table 4.8: Removal efficiencies of effluent characteristics corresponding to dosage of CKD (trial 2)

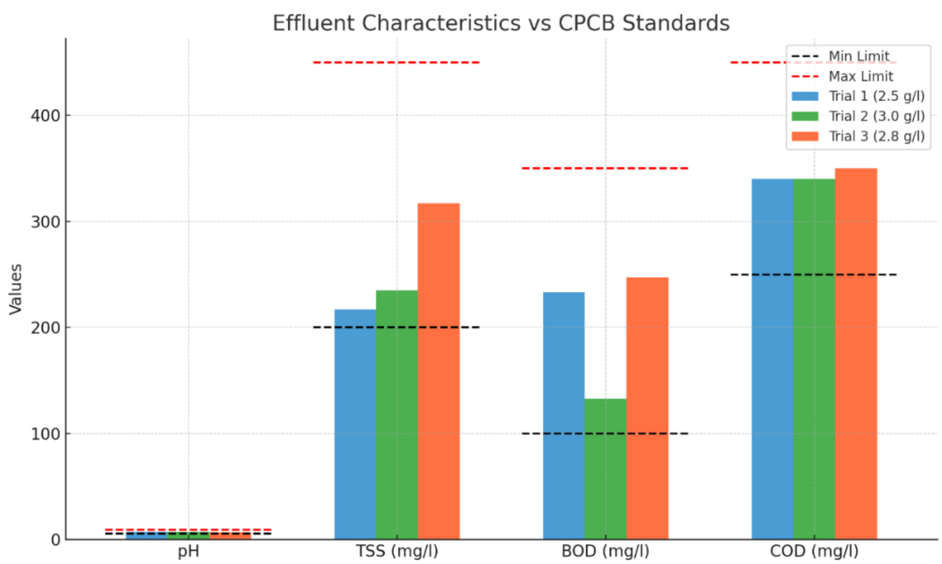
Dosage (g/l)	BOD Removal (%)	COD Removal (%)	TSS Removal (%)	TDS Removal (%)
1.0	18.00	12.50	13.00	19.50
1.5	23.50	29.80	18.90	27.10
2.0	47.90	47.90	24.40	32.90
2.5	61.50	64.20	28.00	36.50
3.0	56.20	45.00	18.20	32.50
3.5	48.70	39.50	14.00	25.10

Table 4.9: Removal efficiencies of effluent characteristics corresponding to dosage of CKD (trial 3)

Dosage (g/l)	BOD Removal (%)	COD Removal (%)	TSS Removal (%)	TDS Removal (%)
2.4	54.50	41.50	11.40	13.90
2.6	54.40	42.70	14.00	14.40
2.8	58.00	46.00	16.40	17.10
3.0	57.50	43.30	13.20	16.10
3.2	54.10	40.00	10.40	14.10

Table 4.10: Standards for sewage discharge (as per Central Pollution Control Board)

Effluent Characteristic	Discharge Limits (CPCB Standards)	Trial 1 (2.5 g/l)	Trial 2 (3.0 g/l)	Trial 3 (2.8 g/l)
pH	5.5 – 9.0	7.30	7.40	7.10
TSS (mg/l)	200 – 450	217	235	317
BOD (mg/l)	100 – 350	233	133	247
COD (mg/l)	250 – 450	340	340	350



Graph 4.1: Comparing Effluent Characteristics from Trials 1, 2, And 3 Against CPCB Discharge Standards

Fig.4.4: Dried Flocs After Coagulation-Flocculation Process

IV. CONCLUSION

1) Optimum Dosage for Maximum Efficiency: Based on the experimental analysis conducted in this study, it was found that the maximum removal efficiency of key effluent characteristics such as BOD, COD, TSS, and TDS was achieved when the dosage of Cement Kiln Dust (CKD) ranged between 2.5 to 3.0 g/l. This dosage range provided the most effective balance between pollutant reduction and chemical usage, making it a practical choice for treatment applications.
2) Removal Efficiency Range: The study demonstrated that the removal efficiencies of effluents ranged between 30% and 70% depending on the dosage and the pollutant type. CKD showed significant potential in removing BOD and COD, while also contributing moderately to the reduction of TSS and TDS. This indicates that CKD can act as a reliable and effective coagulant in wastewater treatment processes.
3) Suitability for Irrigation Use: After treatment with CKD, the water quality of the effluent was found to be within the permissible limits prescribed by CPCB (Central Pollution Control Board) for discharge on land for irrigation purposes. The treated water exhibited acceptable pH levels and reduced pollutant loads, indicating that it can be safely reused for agricultural irrigation, thereby promoting wastewater reuse and sustainable water management practices.
4) Need for Additional Treatment Stages: While the coagulation–flocculation process using CKD showed considerable improvement in effluent quality, the results also indicate that further advanced treatment processes (such as filtration, disinfection, or biological treatments) may be required for complete treatment, especially if the water is to be reused for more sensitive applications such as domestic or industrial use.
5) Potential for Low-Cost Wastewater Treatment: The use of Cement Kiln Dust, which is an industrial by-product, offers an economically viable and environmentally sustainable solution for wastewater treatment. Its availability, low cost, and satisfactory performance in pollutant removal make it a promising material for large-scale and decentralized wastewater treatment, especially in developing regions. The study supports the idea of reusing CKD, thus promoting circular economy principles and reducing environmental waste from the cement industry.

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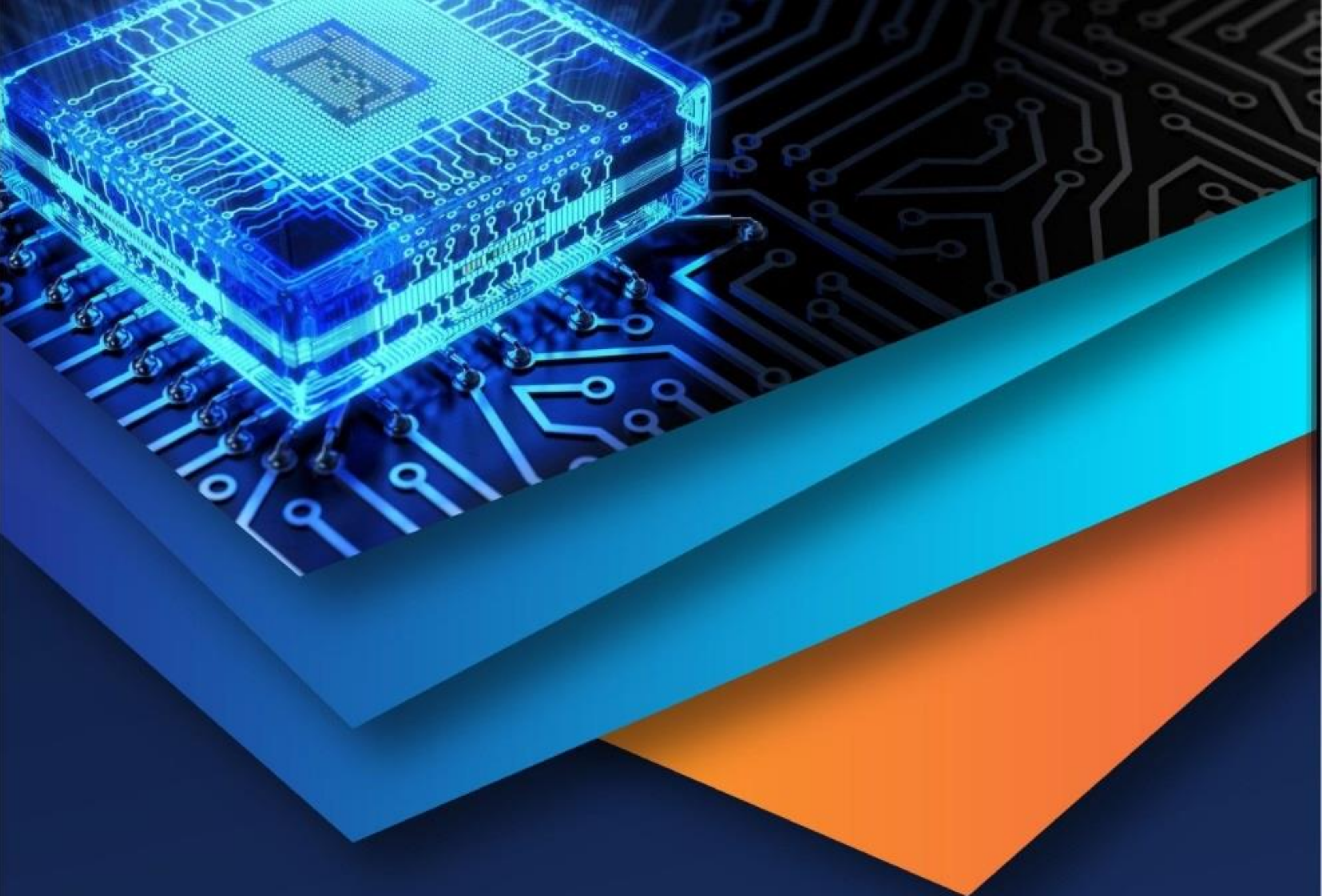

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