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Synthesis of Zeolite a From Kaolin and Its Adsorption Potential for the Removal of Pb, Cr, and Cd from Refinery Wastewater

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ABSTRACT

This study investigated the synthesis of Zeolite A from kaolin and evaluated its adsorption potential for the removal of heavy metals such as lead (Pb), chromium (Cr), and cadmium (Cd) from refinery wastewater. Kaolin was subjected to a series of chemical treatments, followed by hydrothermal synthesis to produce Zeolite A, which was then characterized using X-ray diffraction (XRD) which showed its crystallinity nature with a visible sharp peak at 2θ, Fourier-transform infrared spectroscopy (FTIR) showing peaks at varying wavelengths at 3384, 3236, 2868, 1628 and 1560 cm⁻¹ respectively and Brunauer–Emmett–Teller (BET) surface area analysis showing 370.497 m²/g and a pore diameter at 2.94 nm with smooth well-formed crystalline faces seen from the scanning electron microscope analysis. The adsorption efficiency of the synthesized zeolite was tested under various conditions, including initial metal concentration. The results showed that the synthesized Zeolite A exhibited a high surface area and well-defined mesoporosity, making it highly effective in adsorbing Pb, Cr, and Cd ions, the Si /Al ratio of the as-synthesized zeolite nanoparticles was 1.33 with percentage removal of Pb as 28.43%, Cd as 5.54% and Cr was 100% from the refinery wastewater.

INTRODUCTION

Zeolites are crystalline, three-dimensional structures composed of aluminum silicate and are characterized by their microporous nature. Due to their small, fixed-size pores that allow the passage of smaller molecules while restricting larger ones, they are often called molecular sieves (Castro-Muñoz *et al.*, 2020). The term "zeolite" was introduced in 1756 by the Swedish mineralogist Axel Fredrik Cronsted (Faraj *et al.*, 2024). Zeolites have special properties that make them useful in a variety of chemical and environmental processes. These include the ability to modify their structure, tune acidic and basic sites, and incorporate additional elements into their framework. As members of the well-known crystalline aluminosilicate family, zeolites exhibit a unique set of characteristics that have not been seen before, including high surface area, distinct microporosity, high (hydro)-thermal stability, intrinsic activity, and the capacity to contain active metal species in their pores (Kumari, 2023; Y. Li *et al.*, 2021; Serati-Nouri *et al.*, 2020). Because of its adsorptive qualities, zeolitic acidity has been researched extensively. Protonic sites absorb the majority of hydrocarbon processes and many transformations of functionalized compounds. Aluminosilicate zeolitic solids are crystalline compounds consisting of a three-dimensional network of SiO₄ and AlO₄ tetrahedra, with an extremely regular and open microporous structure (Kordala & Wyszowski, 2024; Nzodom Djozing *et al.*, 2024; Vasconcelos *et al.*, 2023). Zeolitic materials' exceptional adsorption, catalysis, and

ion exchange capabilities have produced a wide range of bulk powder applications in both industry and research (Gholamiyan *et al.*, 2020; Grela *et al.*, 2023; Torabian *et al.*, 2010). When compared to micron-sized zeolites, the performance of the materials as adsorbative and separative is affected by the significant changes in characteristics that occur when particle size is reduced from the micrometre to the nanometre scale. The exterior surface area will rise as the particle size decreases. As a result, there is a notable rise in the ratio of external to internal atom counts, leading to increased surface activity. The acidity of the outer surface plays a significant role when using zeolitic materials for large-molecule absorption. Six more cavities that are comparable to this core cavity are joined by an 8-ring window that has an opening diameter of 4.2°Å. The production of Lynde Type A (LTA) nanocrystalline zeolite has already been documented by a number of writers (Novembre *et al.*, 2021, 2024; Reschetilowski, 2024). But since fundamental adsorption starts to matter in a lot of processes, such as heavy metal removal, a greater understanding of the subject is now needed. In zeolitic materials, anions like O²⁻, AlO₄⁻, or OH⁻ correlate to the basicity of the framework. The negative charge in Si–Al zeolites is carried by the framework oxygen. When low electronegativity cations, such as alkali cations, balance this charge, the charge can rise to the point where basic characteristics are created. The oxygen atoms in the related framework therefore function as Lewis bases and the cation as a Lewis acid. As a result, the negative charges of

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the framework oxygen atoms in zeolites may also be used to describe the base strength. In general, basic zeolites should be anticipated to exhibit a significant separation between basic sites with varying strengths. It is commonly known that the charge on the framework oxygen changes in tandem with the Si-O-Al angle and the distance, with the charge growing as the distance shrinks. It was determined by theoretical and experimental methods of the framework Si/Al ratio effect on the acidity/basicity that the existence of neighbours affects the strength of zeolites' sites (Romero *et al.*, 2007). Zeolites are utilised to adsorb a wide range of compounds due to their extremely high adsorbing ability, they are widely used in the fields of drying, separation, and purification, a wide range of materials can be adsorbed by zeolites. Applications in drying, purification, and separation fall within this category (Jagaba *et al.*, 2021). With a capacity of up to more than 25% of their weight in water, they are highly efficient desiccants and can remove water to very low partial pressures, they are capable of separating isomers and gas mixtures, as well as eliminating volatile organic compounds from air streams, gas separation is a frequently utilised zeolites' characteristic, it is possible to "sieve" molecules with certain dimensions and let them pass through the holes in zeolites thanks to their porous structure (Vasconcelos *et al.*, 2023). By adjusting the size and quantity of cations around the pores, one may modify the structure and fine-tune this feature, additional uses for the pore include conducting polymers and the polymerisation of semi-conducting materials to create materials with unique electrical and physical properties (X. Li *et al.*, 2023). Previous research has shown that zeolites synthesized from kaolin are highly effective in removing heavy metals. Zeolite-A produced from low-cost Egyptian kaolin achieved removal efficiencies of 33 mg/g for copper and 20 mg/g for nickel from waste solutions (X. Li *et al.*, 2023). Moreover, Zeolite-A derived from Kalabsha kaolin was reported to completely eliminate zinc and copper from waste solutions (Romanos *et al.*, 2017). Similarly, Zeolite-A synthesized from Jordanian kaolin was used to remove lead from waste solutions, exhibiting an adsorption capacity of 100 mg/g (Castro-Muñoz *et al.*, 2020; El-Eswed *et al.*, 2009).

The effectiveness of low-cost, locally sourced materials for environmental remediation has been widely demonstrated in Nigerian studies, particularly in relation to water quality improvement and contaminant control, underscoring the relevance of developing indigenous adsorbents for heavy-metal removal from polluted water systems (Umar *et al.*, 2024).

Access to reliable water sources remains a critical global challenge, with groundwater playing an indispensable role by supplying more than half of global drinking water demand and over 40% of irrigated agricultural land, particularly in water-scarce and semi-arid regions (Yusuf & Abdi, 2025).

The earth's crust naturally contains metals, and the amounts of these elements in the environment might

change geographically depending on the location. According to (Ibrahim *et al.*, 2010; Ndatsu *et al.*, 2020), the characteristics of the metal and the effects of external variables determine its dispersion in the environment.

Refinery Wastewater

Wastewater treatment is a crucial supporting procedure for safe operation in refineries, given the large volumes of water they utilise. There are several kinds of wastewater, contaminants found in wastewater streams, and large refinery units that produce large volumes of wastewater (Rashid *et al.*, 2021). Cooling water, process water and steam, storm water, and sanitary sewage water are the four categories of effluent from refineries. Process water and steam that are in direct touch with petroleum fractions are the most severely contaminated wastewater streams among them and need immediate treatment. Accidental spills and unintentional exposure to pollution sources on refinery surfaces can pollute storm water (Lellis *et al.*, 2019). Before being supplied to public water treatment facilities, cooling water and sanitary sewage water might not need much treatment. To lessen the strain on the treatment units, it is generally advised to avoid combining different kinds of wastewater streams (Azeez *et al.*, 2020). Both man-made and natural processes release heavy metals into the environment. The earth's crust naturally eroding, mining, soil erosion, industrial discharge, urban runoff, sewage effluents, pesticides or disease control agents applied to plants, fallout from air pollution, and a host of other factors are examples of these sources (Oliveira *et al.*, 2018). While occupational exposure is a major source of exposure for certain individuals, the majority of people are mostly exposed to these harmful substances through their diet, which includes food and water. The essential elements cobalt (Co), copper (Cu), chromium (Cr), iron (Fe), magnesium (Mg), manganese (Mn), molybdenum (Mo), nickel (Ni), selenium (Se), and zinc (Zn) play significant roles in various biochemical and physiological processes. A deficiency in these micronutrients can lead to numerous illnesses or deficiency syndromes (Abdel-mohsien & Mahmoud, 2015). Due to their presence in trace amounts (from parts per billion to less than 10 parts per million) in different environmental matrices, heavy metals are also classified as trace elements (Taylor *et al.*, n.d.). Their bioavailability is influenced by physical factors such as temperature, phase association, adsorption, and sequestration, as well as by complexation kinetics, lipid solubility, octanol/water partition coefficients, and chemical properties affecting speciation at thermodynamic equilibrium. Moreover, biological factors such as trophic interactions, species characteristics, and physiological and biochemical adaptability are also crucial determinants (Rashid *et al.*, 2021).

Cadmium

Occurrence in the Environment, Its Production(Industrial) And Uses

One heavy metal that presents serious risks to

occupational and environmental health is cadmium. In an average of 0.1 mg/kg, it is found naturally in the Earth's crust in a rather high concentration. While marine phosphates can have cadmium concentrations of up to 15 mg/kg, sedimentary rocks typically contain the greatest quantities of cadmium compounds among different geological formations. Cadmium is frequently used in many industrial applications because of its characteristics. Batteries, pigments, and alloys are the main products made with it (Hunt, 2003).

Potential and Risk associated with Exposure to Humans

Cadmium, even though not needed for human health, can be very harmful in small amounts. Exposure to cadmium, especially in children, has been linked to behavioral problems like hyperactivity and learning difficulties (Gonz *et al.*, 2023). Cadmium can enter the body through eating contaminated food or breathing in cigarette smoke. Some foods, like leafy greens, potatoes, cereals, and seafood, naturally have small amounts of cadmium, eating too much of these foods can increase cadmium levels in the body, breathing in cadmium particles for a long time can lead to respiratory problems, similar to emphysema, and weakened lung function (Okoro *et al.*, 2023; Tolkou & Toubanaki, 2023).

Occurrence in the Environment, Its Production (Industrial) And Uses

Chromium is a naturally occurring element found in the Earth's crust that can exist in different forms (oxidation states). While it's released into the environment through both natural and human activities, industrial processes are the main contributors. Industries like metal processing, tannery operations, and stainless-steel welding release significant amounts of chromium (Singhal, 2021). Trivalent chromium is essential for human and animal health, aiding in glucose, lipid, and protein metabolism. However, hexavalent chromium is toxic and has been classified as a carcinogen. The health risks associated with chromium depend on its form. While metallic chromium is less harmful, hexavalent chromium can cause serious health problems. It was once thought that hexavalent chromium was only produced through human activities, but recent studies have shown that it can also occur naturally in water (Abdel-mohsien & Mahmoud, 2015). However, naturally occurring Cr (VI) has recently been discovered at levels in ground and surface waters that are higher than the 50 µg/liter World Health Organisation drinking water standard. Because chromium is extensively utilised in so many industrial processes, is found in many environmental systems as a pollutant. Commercial applications for chromium compounds include wood preservation, leather tanning, dyes and pigments, industrial welding, and chrome plating. Boilers and cookery systems both employ chromium as an anticorrosive (Badeenezhad *et al.*, 2023; Silva *et al.*, 2025).

Potential for Human Exposure to Heavy Metals

Chromium is essential for the metabolism of cholesterol, fats, and glucose in the human body. A deficiency in chromium can lead to conditions such as hyperglycemia, increased body fat, and reduced sperm count. However, at high concentrations, chromium becomes toxic (Dagne, 2020). Chromium pollution is mainly caused by emissions from industries such as metallurgy, refractory materials, and chemicals. These industries release chromium into the air and water, leading to increased levels in the environment (Dagne, 2020; Dagne *et al.*, 2019).

Occurrence in the Environment, Its Production(Industrial) And Uses

Lead a bluish-gray natural metal with occurrence found or seen in small quantities in the earth's crust. While some lead is naturally present in the environment, human activities such as the burning of fossil fuels, mining, and manufacturing have led to significantly higher levels. Lead has a variety of industrial, agricultural, and domestic applications and is commonly used in the production of lead-acid batteries, ammunition, metal products (such as solder and pipes), and X-ray shielding devices (Ali Khan *et al.*, 2011).

Human Exposure to Lead

Lead in the human body is primarily stored in the kidney, liver, and other soft tissues. However, the skeleton holds the most lead. The nervous system is especially sensitive to lead poisoning. Early symptoms of lead exposure to the central nervous system (CNS) include headache, poor attention span, irritability, memory loss, and lethargy (Abubakar *et al.*, 2015; Ali Khan *et al.*, 2011). There is growing concern globally, especially in developed countries, regarding human exposure to heavy metals, as well as their intake and absorption. Populations are increasingly advocating for a cleaner environment and a reduction in contaminants caused by human activities. This has led to stricter regulations being implemented in developed nations (Collin *et al.*, 2022).

Zeolites have demonstrated efficacy in removing radioactive particles from nuclear waste and can be used to treat water or soil contaminated with heavy metals such as iron (Fe), chromium (Cr), and lead (Pb), among others (Romero *et al.*, 2005, 2007).

This study focuses on synthesizing Zeolite A from kaolin to evaluate its adsorption potential for the removal of Pb, Cr, and Cd ions from refinery wastewater. The synthesized Zeolite A will be characterized using techniques such as SEM, FT-IR, XRD, EDX, and BET. The study will also investigate the adsorption efficiency of the zeolite in removing heavy metals from petroleum refinery wastewater and determine the percentage removal of these contaminants.

MATERIALS AND METHODS

Apparatus and Equipment

The apparatus and equipment used in this study include 250 mL beakers, crucibles, a digital balance, volumetric flasks, conical flasks, spatulas, stirrers, sieves of mesh sizes 350 μm and $\leq 100 \mu\text{m}$, measuring cylinders, and sample bottles.

Chemicals and Reagents

The chemicals and reagents used are sodium hydroxide (NaOH), kaolin, and nitric acid (HNO_3).

Sample Collection

The kaolin sample was obtained from Darazo, Bauchi State, Nigeria, for use in the synthesis of Zeolite A.

Sample Treatment

The collected kaolin sample was first washed with distilled water to remove impurities, then air-dried at room temperature in the laboratory. The washed sample was subjected to metakaolinization to enhance its reactivity.

Synthesis of Zeolite A

To synthesize Zeolite A, 600 g of the purified kaolin was soaked in 2 L of water for 24 hours to form a slurry. After removing the water that remained at the surface, a slurry of the materials was then sieved with a mesh of size 350 μm , for the second time also dried, then pulverized, and sieving was carried out again so as to achieve a particle size $\leq 100 \mu\text{m}$. Then metakaolin phase process was then done and achieved by raising temperature and heating the kaolin sample at a temperature from 600°C to 900°C range for 2 hours using a muffle furnace Model SXL. Zeolite A synthesis was then achieved with the use of metakaolin samples that was calcined at temperature of 700°C and 900°C, while using NaOH as source of the Na_2O . A 5g solution of NaOH was then made to dissolve in a 72 deionized water sample with continuous stirring for a period of 10 minutes. 4.1g of produced metakaolin was then weighed and added gradually so as to achieve and form an aluminosilicate gel. The aluminosilicate gel

was stirred rigorously and continuously while maintaining room temperature for 24 hours to age.

A hydrothermal treatment was then performed by placing the mixture in an oven maintained at 120°C for 6 hours. Then the resulting reaction after that was washed and filtered using deionized water, until a neutral pH of approximately 7 was achieved. The resulting product was dried in an oven at 100°C for 4 hours.

Digestion of Wastewater Samples

The industrial wastewater sample was collected from a refinery. The collected wastewater was transferred into a beaker, and 12.676 mL of concentrated HNO_3 was added and boiled to digest the sample, ensuring complete dissolution of metal ions.

Batch Adsorption Experiment

The batch adsorption experiments were conducted by varying the dosage of the synthesized Zeolite A from 0.2 to 1.0 g per liter for Pb(II), Cd(II), and Cr(II) ions. The samples were mechanically agitated at 250 rpm at room temperature. After adsorption, the solutions were filtered using Whatman No.1 filter paper, and the filtrates were analyzed for the presence and concentration of the metal ions using an Atomic Absorption Spectrophotometer (AAS), Model PG 990.

Determination of Adsorption Efficiency

The percentage removal (%R) of Pb, Cd, and Cr was calculated to evaluate the adsorption efficiency of the synthesized Zeolite A. The percentage removal was determined using the following equation:

Equation

$$\%R = (C_0 - C_1) / C_0 \times 100$$

Where: C_0 = Initial concentration of the Heavy metal ion in the solution

C_1 = Final concentration of the Heavy metal ion in the solution

%R = Percentage removal of Heavy metal from the solution.

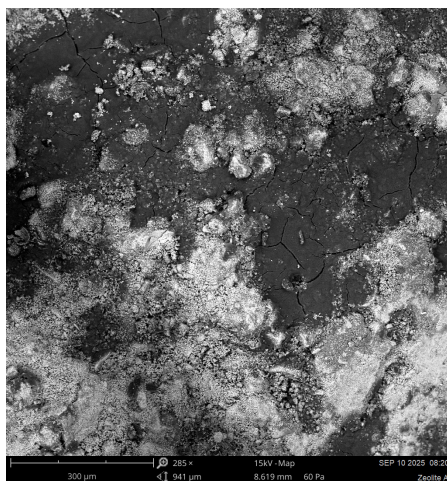


Figure 1: Morphology showing the occurrence of Zeolite A associated phases obtained by hydrothermal synthesis.

RESULTS AND DISCUSSION

Scanning Electron Characterization

Scanning electron microscope (Q150 R Phenom-World FEI Company, Eindhoven Netherland). SEM was used by directing a focused beam of high-energy electrons onto the Synthesized Zeolite A.

A scanning electron microscope (SEM) of the sample in Figure 1.0 showed the morphology of zeolite A to be very clear and cubic crystals at magnification 100X, as

this is a key feature of zeolite A, the surface of Zeolite A also appeared smooth with well-formed crystalline faces, showing little to no amorphous material. This indicates good crystallization and the absence of impurities or unreacted kaolin (Tawatwachoom & Rungrojchaipon, 2015).

X-ray Diffraction Characterization

X-ray diffraction (Rigaku, D/Max, 2500 V, Cu-K α radiation: 1.54056 Å) experiments were carried out

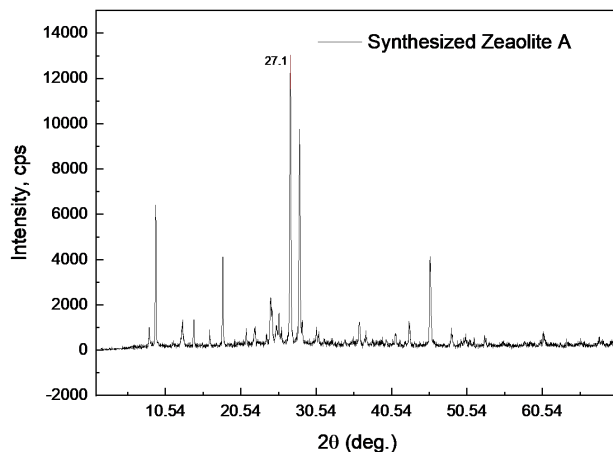


Figure 2: X- ray Diffraction pattern of synthesized Zeolite A

on graphene, Wide-angle X-ray diffractograms were recorded in the range of 0–80° (2θ) angle keeping the sample at temperature 30°C. In figure below the XRD pattern of synthesized Zeolite A

This peak suggests the presence of a well-crystallized phase of zeolite A. In XRD analysis, the intensity and sharpness of the peak at 27.1° can be used to assess the crystallinity of the material. A sharp peak indicates a high degree of crystallinity, Zeolites are crystalline, porous aluminosilicate molecular sieves with uniform pores of molecular dimensions that are widely used in industrial

applications such as catalysis, adsorption, membrane separation and ion exchange.(X. Li *et al.*, 2023), the higher peaks is visible at 2theta Braggs angle signifying Crystalline form of Zeolite A which is mainly quartz (SiO₂) with the highest peak which is very common as shown in fig.2.The result suggest that the synthesized product contain Zeolite A (Rios *et al.*, 2007).

Brunner Emmett Teller characterization

The surface area is determined through BET analysis (Quantachrome, NOVA 4200e, USA). The BET utilises

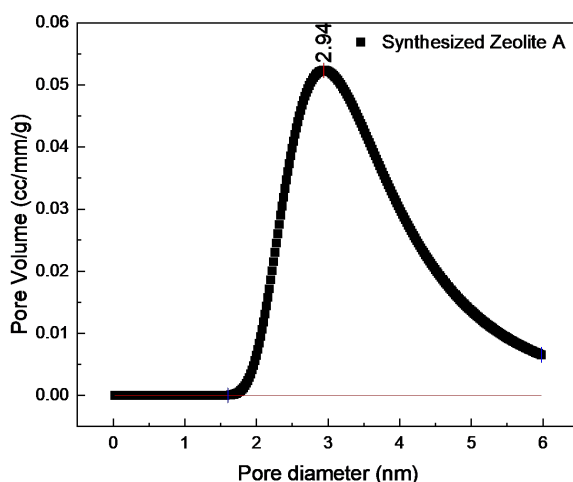


Figure 3: Pore Diameter of synthesized Zeolite A

nitrogen adsorption at varying pressures to accurately measure the specific surface area of materials. Calculating the amount of adsorbate gas that corresponds to a monomolecular layer on the plasma exfoliated graphene's surface to determine its surface area.

The pore diameter of 2.94 nm (or 29.4 Å) falls within the mesoporous range, according to the IUPAC classification.

Mesopores are defined as pores with diameters between 2 nm and 50 nm. This size is larger than the typical micropores of zeolite A, which usually have a pore size of around 0.4 nm (4 Å). Therefore, the measured pore diameter suggests the presence of additional mesopores in the structure, possibly due to inter-crystallite porosity or modifications to the material during synthesis. The

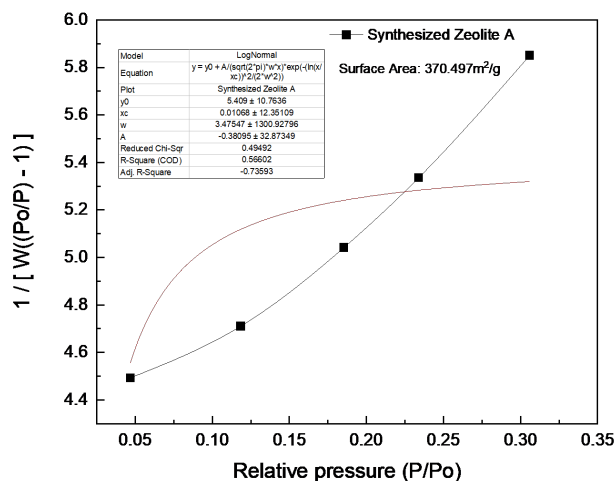


Figure 4: Surface Area of synthesized Zeolite A

presence of mesopores can enhance the diffusion of larger molecules and facilitate better mass transfer within the material, making the zeolite more versatile for applications that require the adsorption of larger species. A surface area of 370.498 m²/g is typical for high-quality zeolites. It indicates a well-developed porous structure and suggests that the material has a high density of accessible pores, this value is within the expected range for zeolite A (generally 300–700 m²/g), confirming that the sample has good crystallinity and a minimal number of defects, a large surface area like this is beneficial for adsorption processes, as it provides more active sites for interaction with adsorbates such as heavy metals or organic compounds. The combination of high surface area and a pore diameter of 2.94 nm allows the zeolite to adsorb a wide range of molecules, from small metal ions like Pb, Cr, and Cd to larger organic molecules, making it highly effective for removing heavy metals from solutions due to numerous active sites and channels for metal ion interaction and transport within the porous network; this specific combination of properties makes the material suitable for refinery wastewater treatment by ensuring efficient diffusion of metal ions and maximizing adsorption capacity, while the presence of mesopores along with the microporous framework shows that the zeolite can also be used in catalysis applications where larger reactants need to access active sites or in separations where different sizes of molecules need to be accommodated; the observed larger pores (2.94 nm) indicate modifications during synthesis, such as acid or base treatment, which can create mesoporosity by removing structural units or introducing defects, and, ultimately,

the BET analysis results confirm that the zeolite has a high surface area and a mesoporous structure, making it versatile and effective for adsorption (particularly heavy metal removal), catalysis, and separation processes, as the combination of micropores and mesopores enhances its ability to handle complex adsorbates and reactions.

Fourier Transform Infrared Characterization

The Cary 630 FTIR, (Agilent Technology, USA), utilises advanced Fourier transform infrared (FTIR) spectroscopy technology, which is widely recognised as the most advanced method for identifying and quantifying molecular compounds. FTIR utilises an infrared light source to pass

The FTIR analysis of Zeolite A, with peaks at 3384.1 cm⁻¹ and 3236 cm⁻¹ corresponding to the O-H stretching vibrations of hydroxyl groups and hydrogen-bonded water molecules respectively, indicates the presence of adsorbed water or surface hydroxyl groups, suggesting a hydrophilic nature beneficial for applications involving adsorption of polar molecules or water-soluble contaminants, while the peak at 2868 cm⁻¹, attributed to C-H stretching vibrations, suggests possible organic residues or impurities, and the peak at 1628 cm⁻¹, corresponding to the H-O-H bending vibration, further confirms the presence of water molecules within the porous structure, making this sample suitable for adsorption applications due to its well-developed porous structure and active sites for interactions with various molecules.

The result of Zeolite synthesized from Kaolin was characterized as shown in figures below and also the

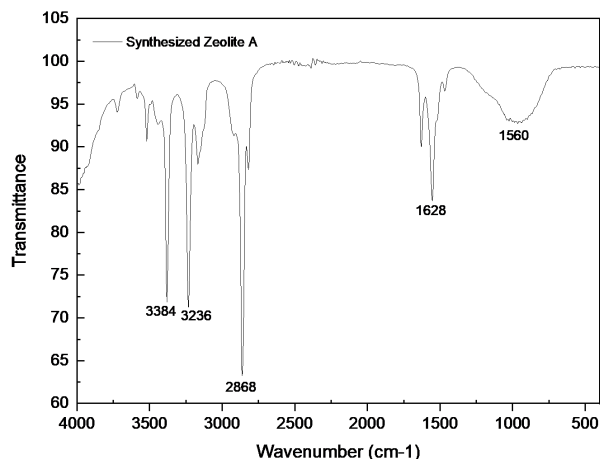


Figure 5: FTIR of synthesized Zeolite A

results explained both the percentage composition of the element as well as the table of percentage removal of heavy metal in the refinery waste water.

Energy Dispersive Spectroscopy Characterization

A scanning electron microscope and energy dispersive spectroscopy (Q150 R Phenom-World FEI Company,

Eindhoven, Netherlands) were used. The data generated by EDX analysis consisted of spectra with peaks corresponding to all the different elements present in the sample. Every element had characteristic peaks of unique energy, all of which were extensively documented. Furthermore, EDX was used for both qualitative (the

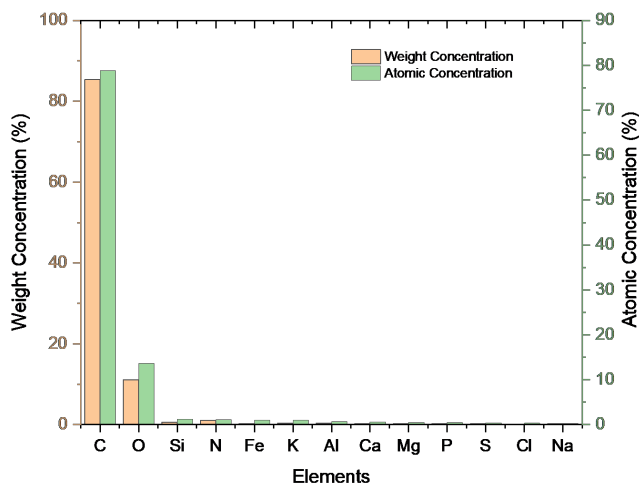


Figure 6: EDX of synthesized Zeolite A

type of elements) and quantitative (the percentage concentration of each element in the sample) analysis. The Energy Dispersive X-ray (EDX) which depict the Zeolite at elemental level before adsorption, it was

observed from the percentage weight concentration composition that Carbon has the highest elemental percentage of 78.8% which signifies that a carbonated Zeolite was formed as shown in figure 6.0.

Table 1: Showing the decrease in concentration of Heavy metal from refinery.

S/N	Element	Sample	Concentration (Mg/L)	Dosage
1	Pb	1	65.736	0.00g
		2	51.822	0.2g of zeolite-A
		3	51.177	0.4g of zeolite-A
		4	49.526	0.6g of zeolite-A
		5	48.068	0.8g of zeolite-A
		6	47.047	1.0g of zeolite-A

2	Cr	1	0.029	0.00g
		2	0.022	0.2g of zeolite-A
		3	0.004	0.4g of zeolite-A
		4	0.002	0.6g of zeolite-A
		5	0.000	0.8g of zeolite-A
		6	0.000	1.0g of zeolite-A
3	Cd	1	23.792	0.00g
		2	23.525	0.2g of zeolite-A
		3	23.409	0.4g of zeolite-A
		4	23.313	0.6g of zeolite-A
		5	23.271	0.8g of zeolite-A
		6	22414	1.0g of zeolite-A

Adsorption Studies of Zeolite A In Waste Water

The distribution of heavy metals (Cr, Cd, Pb) in wastewater samples from refinery has been investigated. Cadmium (Cd), the untreated wastewater (that is before addition of zeolite A in g dosage) has the highest concentration to be about 23.792, after adding 0.2g dosage of zeolite-A, the concentration reduces to 23.525. Then 0.4, 0.6, 0.8 and 1.0g Zeolite A dosage was added and the concentration reduces to 23.409, 23.312, 23.271 and 22.414 respectively which was the lowest. The percentage removal at 0.2g of zeolite A was 0.860% and at 1.0g, the percentage removal increased to 5.542%.

Chromium (Cr), the untreated wastewater (that is before addition of zeolite A) has the highest concentration to be about 0,027, after adding 0.2g of zeolite-A, the concentration reduces to 0022. Then 0.4, 0.6, 0.8 and 1.0g was added and the concentration reduces to 0.004, 0.002, 0.000 and 0.000 respectively which was the lowest. The percentage removal at 0.2g of zeolite A was 24.138% and at 1.0g, the percentage removal increased to 100%.

Lead (Pb), the untreated wastewater (that is before addition of zeolite A) has the highest concentration to be about 65.736, after adding 0.2g of zeolite-A, the concentration reduces to 51.822 Then 0.4, 0.6, 0.8 and 1.0g was added and the concentration reduces to 51.177, 49.526, 48.068. and 47.047 respectively which was the lowest. The percentage removal at 0.2g of zeolite A was 21.166% and at 1.0g, the percentage removal increased to 28.430%.

CONCLUSION

The synthesis of Zeolite A from kaolin proved to be an efficient and sustainable approach for producing a high-quality adsorbent with remarkable adsorption capabilities for heavy metals. The synthesized zeolite exhibited a high surface area and well-developed porosity, which contributed to its excellent adsorption performance for Pb, Cr, and Cd ions from refinery wastewater. The adsorption studies confirmed that the zeolite's adsorption capacity was influenced by various factors such as pH, contact time, and metal ion concentration. The kinetic

and isotherm analyses revealed that the adsorption process followed a pseudo-second-order kinetic model and fit well with the Langmuir isotherm model. Overall, the results demonstrated that kaolin-derived Zeolite A could serve as an effective and low-cost adsorbent for treating heavy metal-contaminated industrial wastewater, thereby offering a sustainable solution for environmental remediation.

REFERENCES

- Abdel-mohsien, H. S., & Mahmoud, M. A. M. (2015). Accumulation of Some Heavy Metals in Oreochromis niloticus from the Nile in Egypt : Potential Hazards to Fish and Consumers. *September*, 1003–1013.
- Abubakar, A., Uzairu, A., Ekwumemgbo, P. A., & Okunola, O. J. (2015). Risk Assessment of Heavy Metals in Imported Frozen Fish Scomber scombrus Species Sold in Nigeria: A Case Study in Zaria Metropolis. *Advances in Toxicology*, 2015, 1–11. <https://doi.org/10.1155/2015/303245>
- Ali Khan, F., Hussain, I., Ahmed Chishti, K., Ur Rehman Khattak, M., Muhammad Hassan Shah, S., Asif Khan, M., & Muhammad Mukarram Shah, S. (2011). Evaluation of Heavy Metals in Blue and White Flowering Silybum marianum, Collected from Differnet Districts of KPK, Pakistan. *J. Agric. & Environ. Sci*, 10(3), 434–439.
- Azeez, T. O., Onukwuli, D. O., Nwabanne, J. T., & Banigo, A. T. (2020). Cissus Populnea Fiber - Unsaturated Polyester Composites: Mechanical Properties and Interfacial Adhesion. *Journal of Natural Fibers*, 17(9), 1281–1294. <https://doi.org/10.1080/15440478.2018.1558159>
- Badeenezhad, A., Soleimani, H., Shahsavani, S., Parseh, I., Mohammadpour, A., Azadbakht, O., Javanmardi, P., Faraji, H., & Babakrpur Nalosi, K. (2023). Comprehensive health risk analysis of heavy metal pollution using water quality indices and Monte Carlo simulation in R software. *Scientific Reports*, 13(1), 1–18. <https://doi.org/10.1038/s41598-023-43161-3>
- Castro-Muñoz, R., Ahmad, M. Z., & Fila, V. (2020). Tuning of Nano-Based Materials for Embedding

- Into Low-Permeability Polyimides for a Featured Gas Separation. *Frontiers in Chemistry*, 7(January), 1–14. <https://doi.org/10.3389/fchem.2019.00897>
- Collin, M. S., Venkatraman, S. K., Vijayakumar, N., Kanimozhi, V., Arbaaz, S. M., Stacey, R. G. S., Anusha, J., Choudhary, R., Lvov, V., Tovar, G. I., Senatov, F., Koppala, S., & Swamiappan, S. (2022). Bioaccumulation of lead (Pb) and its effects on human: A review. *Journal of Hazardous Materials Advances*, 7(May), 100094. <https://doi.org/10.1016/j.hazadv.2022.100094>
- Dagne, B. B. (2020). Determination of Heavy Metals in Wastewater and Their Toxicological Implications around Eastern Industrial Zone, Central Ethiopia. *Journal of Environmental Chemistry and Ecotoxicology*, 12(2), 72–79. <https://doi.org/10.5897/jece2019.0453>
- Dagne, B. B., Endale, T., Tesfahun, K., & Negash, D. (2019). Levels of some toxic heavy metals (Cr, Cd and Pb) in selected vegetables and soil around eastern industry zone, central Ethiopia. *African Journal of Agricultural Research*, 14(2), 92–101. <https://doi.org/10.5897/ajar2018.13324>
- El-Eswed, B., Yousef, R. I., Alshaaer, M., Khalili, F., & Khoury, H. (2009). Alkali solid-state conversion of kaolin and zeolite to effective adsorbents for removal of lead from aqueous solution. *Desalination and Water Treatment*, 8(1–3), 124–130. <https://doi.org/10.5004/dwt.2009.672>
- Faraj, H., Jamrah, A., Al-Omari, S., & Al-Zghoul, T. M. (2024). Optimization of an electrocoagulation-assisted adsorption treatment system for dairy wastewater. *Case Studies in Chemical and Environmental Engineering*, 9(December), 100574. <https://doi.org/10.1016/j.cscee.2023.100574>
- Gholamiyan, S., Hamzehloo, M., & Farrokhnia, A. (2020). RSM optimized adsorptive removal of erythromycin using magnetic activated carbon: Adsorption isotherm, kinetic modeling and thermodynamic studies. *Sustainable Chemistry and Pharmacy*, 17(July), 100309. <https://doi.org/10.1016/j.scp.2020.100309>
- Gonz, P., Puentes, J. G., Moya, A. J., & Rubia, M. D. La. (2023). applied sciences Comparative Study of the Presence of Heavy Metals in Edible Vegetable Oils.
- Grela, A., Kuc, J., Klimek, A., Matusik, J., Pamula, J., Franus, W., Urbański, K., & Bajda, T. (2023). Erythromycin Scavenging from Aqueous Solutions by Zeolitic Materials Derived from Fly Ash. *Molecules*, 28(2). <https://doi.org/10.3390/molecules28020798>
- Hunt, J. R. (2003). Bioavailability of iron, zinc, and other trace minerals from vegetarian diets. *American Journal of Clinical Nutrition*, 78(3 SUPPL.). <https://doi.org/10.1093/ajcn/78.3.633s>
- Ibrahim, H. S., Jamil, T. S., & Hegazy, E. Z. (2010). Application of zeolite prepared from Egyptian kaolin for the removal of heavy metals: II. Isotherm models. *Journal of Hazardous Materials*, 182(1–3), 842–847. <https://doi.org/10.1016/j.jhazmat.2010.06.118>
- Jagaba, A. H., Kutty, S. R. M., Hayder, G., Baloo, L., Ghaleb, A. A. S., Lawal, I. M., Abubakar, S., Al-dhawi, B. N. S., Almabhashi, N. M. Y., & Umaru, I. (2021). Degradation of Cd, Cu, Fe, Mn, Pb and Zn by Moringa-oleifera, zeolite, ferric-chloride, chitosan and alum in an industrial effluent. *Ain Shams Engineering Journal*, 12(1), 57–64. <https://doi.org/10.1016/j.asej.2020.06.016>
- Kordala, N., & Wyszowski, M. (2024). Zeolite Properties, Methods of Synthesis, and Selected Applications. *Molecules*, 29(5). <https://doi.org/10.3390/molecules29051069>
- Kumari, M. (2023). Role of nanomaterials in environmental remediation. Adsorption through Advanced Nanoscale Materials: Applications in Environmental Remediation, 83–99. <https://doi.org/10.1016/B978-0-443-18456-7.00005-5>
- Lellis, B., Fávoro-Polonio, C. Z., Pamphile, J. A., & Polonio, J. C. (2019). Effects of textile dyes on health and the environment and bioremediation potential of living organisms. *Biotechnology Research and Innovation*, 3(2), 275–290. <https://doi.org/10.1016/j.biori.2019.09.001>
- Li, X., Han, H., Evangelou, N., Wichrowski, N. J., Lu, P., Xu, W., Hwang, S. J., Zhao, W., Song, C., Guo, X., Bhan, A., Kevrekidis, I. G., & Tsapatsis, M. (2023). Machine learning-assisted crystal engineering of a zeolite. *Nature Communications*, 14(1), 1–12. <https://doi.org/10.1038/s41467-023-38738-5>
- Li, Y., Zhu, G., Wang, Y., Chai, Y., & Liu, C. (2021). Preparation, mechanism and applications of oriented MFI zeolite membranes: A review. *Microporous and Mesoporous Materials*, 312, 110790. <https://doi.org/10.1016/j.micromeso.2020.110790>
- Ndatsu, Y., Ibrahim, A., Abubakar, H., Mohammed, A. O. A. H., & Usman, H. B. (2020). Phytochemical , Heavy Metal Analysis and Phytotoxic Activities of Crude Extract of Annona senegalensis Stem Bark. 5(1), 94–102.
- Novembre, D., Gimeno, D., & Del Vecchio, A. (2021). Synthesis and characterization of Na-P1 (GIS) zeolite using a kaolinitic rock. *Scientific Reports*, 11(1), 1–13. <https://doi.org/10.1038/s41598-021-84383-7>
- Novembre, D., Gimeno, D., Marinangeli, L., Tangari, A. C., Rosatelli, G., Ciulla, M., & di Profio, P. (2024). Rice Husk as Raw Material in Synthesis of NaA (LTA) Zeolite. *Molecules*, 29(18). <https://doi.org/10.3390/molecules29184396>
- Nzodom Djozing, W., Valange, S., Nikitenko, S. I., & Chave, T. (2024). Sonohydrothermal synthesis of zeolite A and its phase transformation into sodalite. *Dalton Transactions*, 1, 3–6. <https://doi.org/10.1039/d4dt01943a>
- Okoro, H. K., Orosun, M. M., Oriade, F. A., Momoh-Salami, T. M., Ogunkunle, C. O., Adeniyi, A. G., Zvinowanda, C., & Ngila, J. C. (2023). Potentially Toxic Elements in Pharmaceutical Industrial Effluents: A Review on Risk Assessment, Treatment, and Management for Human Health. Sustainability

- (Switzerland), 15(8). <https://doi.org/10.3390/su15086974>
- Oliveira, G., Calisto, V., Santos, S. M., Otero, M., & Esteves, V. I. (2018). Paper pulp-based adsorbents for the removal of pharmaceuticals from wastewater: A novel approach towards diversification. *Science of the Total Environment*, 631–632, 1018–1028. <https://doi.org/10.1016/j.scitotenv.2018.03.072>
- Rashid, R., Shafiq, I., Akhter, P., Iqbal, M. J., & Hussain, M. (2021). A state-of-the-art review on wastewater treatment techniques: the effectiveness of adsorption method. *Environmental Science and Pollution Research*, 28(8), 9050–9066. <https://doi.org/10.1007/s11356-021-12395-x>
- Reschetilowski, W. (2024). Catalysis on Zeolites and Zeolite-like Materials II. *Catalysts*, 14(7). <https://doi.org/10.3390/catal14070460>
- Rios, C. a., Williams, C. D., & Maple, M. J. (2007). Synthesis of Zeolites and Zeotypes by Hydrothermal transformation of Kaolinite and Metakaolinite. *Bistua*, 5(1), 15–26. <http://wlv.openrepository.com/wlv/handle/2436/30311>
- Romanos, J., Rash, T., Abou Dargham, S., Prosniewski, M., Barakat, F., & Pfeifer, P. (2017). Cycling and Regeneration of Adsorbed Natural Gas in Microporous Materials. *Energy and Fuels*, 31(12), 14332–14337. <https://doi.org/10.1021/acs.energyfuels.7b03119>
- Romero, M. D., Ovejero, G., Rodríguez, A., & Gómez, J. M. (2005). Enhancement of the basic properties in FAU zeolites by impregnation with cesium hydroxide. *Microporous and Mesoporous Materials*, 81(1–3), 313–320. <https://doi.org/10.1016/j.micromeso.2005.02.013>
- Romero, M. D., Ovejero, G., Uguina, M. A., Rodríguez, A., & Gómez, J. M. (2007). Fast tailoring of the acid-base properties in the NaX zeolite by cesium-exchange under microwave heating. *Microporous and Mesoporous Materials*, 98(1–3), 317–322. <https://doi.org/10.1016/j.micromeso.2006.09.024>
- Serati-Nouri, H., Jafari, A., Roshangar, L., Dadashpour, M., Pilehvar-Soltanahmadi, Y., & Zarghami, N. (2020). Biomedical applications of zeolite-based materials: A review. *Materials Science and Engineering C*, 116(February), 111225. <https://doi.org/10.1016/j.msec.2020.111225>
- Silva, J. R., de Carvalho, M. H., Dantas de Jesus, A. M., & Fiore, F. A. (2025). Effect of thermal drying on the physico-chemical and microbiological characteristics of drinking water treatment sludge. *Cleaner Engineering and Technology*, 26(August 2024). <https://doi.org/10.1016/j.clet.2025.100947>
- Singhal, A. (2021). Heavy metals in drinking water and their impact on human health. *Asian Journal of Research in Social Sciences and Humanities*, 11(11), 586–591. <https://doi.org/10.5958/2249-7315.2021.00270.7>
- Tawatwachoom, T., & Rungrojchaipon, P. (2015). in-Situ Synthesis of Zeolite a , Zeolite P and Zeolite Y / Carbon in-Situ Synthesis of Zeolite a , Zeolite P and Zeolite Y / Carbon Composite With Carbonaceous Rice Husk Ash. *Pure and Applied Chemistry International Conference*, June, 0–5.
- Taylor, P., Eletta, O. A. A., Adekola, F. A., & Omotosho, J. S. (n.d.). Toxicological & Environmental Chemistry Determination of concentration of heavy metals in two common fish species from asa river , ilorin , nigeria. December 2014, 37–41. <https://doi.org/10.1080/0277224031000106654>
- Tolkou, A. K., & Toubanaki, D. K. (2023). Detection of Arsenic , Chromium , Cadmium , Lead , and Mercury in Fish : Effects on the Sustainable and Healthy Development of Aquatic Life and Human Consumers (Cu) are necessary for fish at very low levels (for their enzyme processes), they can becom.
- Torabian, A., Kazemian, H., Seifi, L., Bidhendi, G. N., Azimi, A. A., & Ghadiri, S. K. (2010). Removal of petroleum aromatic hydrocarbons by surfactant-modified natural zeolite: The effect of surfactant. *Clean - Soil, Air, Water*, 38(1), 77–83. <https://doi.org/10.1002/clen.200900157>
- Umar, A., Olorunsola, K., Hassan, U. M., & Yusuf, Y. Y. (2024). An Assessment of Groundwater Potential for Water Supply in Misau and Dambam Local Government Areas of Bauchi State , Nigeria. *Applied Research and Innovation (ARI)*, 2(2), 13–22. <https://doi.org/https://doi.org/10.54536/ari.v2i2.1812>
- Vasconcelos, A. A., Len, T., Nazar, A. De, Oliveira, D., Alice, A., Rodrigo, A., Emmerson, C., & Luque, R. (2023). applied sciences Zeolites : A Theoretical and Practical Approach with Uses in (Bio) Chemical Processes where. *Applied Science*.
- Yusuf, M. O., & Abdi, D. Y. (2025). Factors influencing the Utilization of Hand-Dug Shallow Wells for Agricultural and Domestic Water Supply in Harawa District , Somali Region , Ethiopia. *Applied Research and Innovation (ARI)*, 3(2), 28–35. <https://doi.org/https://doi.org/10.54536/ari.v3i2.5198>