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Removal of Heavy Metals from Industrial Wastewater using Carbide Ash Waste

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ABSTRACT

Improper disposal of wastewater is one of the major problems our societies are facing today. The high cost of treating waste produced by industries every day is very high, which makes it difficult for industries to treat their wastewater effectively before disposal or reuse. The aim of this research work is to characterize the adsorbent (carbide ash) and use it to remove the four different heavy metals (Cadmium, nickel, cobalt, and manganese) present in wastewater. The drying method was used for the carbide ash waste while the adsorption method was used for the wastewater treatment. The moisture content of the ash was determined, and analytical techniques was used to characterize the ash are Fourier transform infrared spectroscopy (FTIR), scanning electron microscopy (SEM), X-ray diffraction (XRD), thermogravimetric analysis (TGA) Brunauer-Emmett-Teller (BET) and atomic absorption spectroscopy (AAS) for the quantification of the untreated and treated wastewater. FTIR results showed the spectrum at 3218cm^{-1} (stretching vibration hydroxyl group), 1375.cm^{-1} (bending vibration of methyl group), 764.1 cm^{-1} (presence of calcium oxide), scanning electron microscope (SEM) which shows the smooth morphology of carbide, X-ray diffraction (XRD) identified mineral composition (Portlandite Syn=65%, Lime = 24%, Osumilite = 3.9%, Quartz Syn=2.8%, Graphite-3R=1% and Anhydrite Syn=3.1%) of carbide ash sample, thermogravimetric analysis (TGA) which shows the stability of carbide ash at decreased mass of 20 g when its temperature increased reaches 470°C and Brunauer-Emmett-Teller (BET) analysis which shows the pore sizes of 5.0783g. The quantitative analysis of the adsorption treatment was carried out by the optimization of (dosage, time and pH). The result of the moisture content was (4.5 %). The results for the analysis for the optimized dosage for the four metals (Cd, Mn, Ni, and Co) are (80.71, 79.9, 99.89, and 80.29) % respectively. The pH optimization for the four metals (Cd, Mn, Ni, and Co) are (81.09, 97.56, 75.58, and 85.47) % respectively and for the time optimization of the four metals (Cd, Mn, Ni, and Co) are (81.09, 81.0, 73.41, and 72.06) % respectively. In conclusion, this study proves that carbide ash is effective for the removal of heavy metals from industrial wastewater, with removal efficiency of 99.8%.

1.0 Introduction

Water is omnipresent and fundamental to life. Water is used in household may contain high level of natural pollutants from human and animal wastes, as well as artificial pollutants in the form of naturally derived materials discharged to the environment by human activity, and synthetic chemicals produced solely by human activity [1]. Pollutants in wastewater and runoff from human activity may exceed the environment's natural detoxifying capacity. As a result, such wastewater is frequently required to be classified and treated for prior reuse or safe disposal to the environment [2]. Water pollution was primarily confined to tiny, isolated areas up until the middle of the 18th century when the industrial revolution commenced, and the chemical industry escalated because of petroleum. With the quick growth of several industries, a significant volume of fresh water is used as raw materials, intermediate products, and wastes are introduced into the water [3]. Improperly treated waste from municipalities and factories. Water effluent is released into the water body to degrades the quality of the water causing contamination in the body of the environment specifically in the case of oceans and rivers. Industrial wastewater produced by coal and steel industries, nonmetallic minerals industries, commercial business and industries for metal surface processing generates many heavy metals that are detrimental to human health [4]. Heavy metals in wastewater and industries effluent are major sources of contamination in the environment. Heavy metals are metals with densities more than 5g per cubic centimeter. Most of the elements in this groups are highly water soluble, well-known toxicants, and

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carcinogenic agents. They include copper, silver, zinc, cadmium, gold, mercury, lead, chromium, iron, nickel, tin, mercury, arsenic, selenium, molybdenum, cobalt, manganese, and aluminum [5]. The existence of these heavy metals in our wastewater disposal could result in acute health issues to living organisms and causes pollution in the environment therefore different ways have been introduced for the removal of these heavy metals in industrial wastewater before disposal to the water bodies which can be accomplished through variety of treatment options, including chemical precipitation, coagulation, complexation, activated carbon adsorption, ion exchange, solvent extraction, foam flotation, electro-deposition, cementation, and membrane operations [6]. The methods of removal of the removal of heavy metals from wastewater can be classified into three groups which are namely, physical methods such as ultrafiltration, coagulation, membrane filtration. Biological methods such as bioaccumulation in which plants and microorganisms are being used. Chemical methods are chemical precipitation, hydroxide precipitation, adsorption, and ion exchange. Most of the elements in this group are highly water soluble, well-known toxic substances and cancer-causing agents. Heavy metals include the elements copper, silver, zinc, cadmium, gold, mercury, lead, chromium, iron, nickel, tin, arsenic, selenium, molybdenum, cobalt, manganese, and aluminum [8].

They pose major hazards to the human population as well as the aquatic life of the receiving water bodies. They can be absorbed and deposited in the human body, causing major health effects such as cancer, organ damage, nervous system impairment, and, in extreme circumstances, death. It also has a negative impact on growth and development. Heavy metals in wastewater and industrial effluent are a major source of pollution in the environment, and industrial wastewater streams containing heavy metals are produced by different companies [9].

Heavy metals are comprised of around 50 elements, 17 of which are the most dangerous. Heavy metals include antimony, arsenic, bismuth, cadmium, cerium, chromium, cobalt, copper, gallium, gold, iron, lead, manganese, mercury, nickel, platinum, silver, tellurium, thallium, tin, uranium, vanadium, and zinc [10]. Heavy metals can either be essential or non-essential. Essential metal ions are non-toxic that are harmless to organisms if only a small quantity is present but can be harmful to the body if concentrations surpass a threshold level [11]. Non-essential metals have no biological role and are hazardous to the organism in even small quantity or trace amount. Essential or non-essential, excessive exposure to either type of metals can have major negative health consequences. [12]

Industrial Wastewater

Industrial wastewater is one of the most significant pollutants of the water environment. A significant volume of industrial effluent was released into rivers, lakes, and coastal areas throughout the last century [13]. This produced severe pollution in the water environment and had a significant impact on the ecosystem and human life. Industrial wastewater is the aqueous waste generated because of compounds are being dissolved or suspended in water, often during the use of water in an industrial production process or the cleaning activities that occur in conjunction with that process.

Sources of Industrial Wastewater

Battery manufacturing, chemical manufacturing, electric power plants, food manufacturing, iron and steel industry, metal working, mines and quarries, nuclear industry, oil and gas extraction, petroleum refining and petrochemicals, pharmaceutical manufacturing, pulp and paper industry, smelters, textile mills, industrial oil contamination, water treatment, and wood preserving are all sources of industrial wastewater [14].

Types of Industrial Wastewater

There are various types of industrial wastewater based on industry and contaminants. Metal-working industries release chromium, nickel, zinc, cadmium, lead, iron, and titanium compounds, with the electroplating industry being a major polluter [15]. Silver is produced in photo processing shops, solvent waste is produced in dry cleaning and car repair shops, and inks and dyes are released in printing companies. As a result of the pulp and paper industry's reliance on chlorine-based compounds, pulp and paper mill effluents contain organic chloride and dioxins, as well as suspended particles and organic wastes [16]. The petrochemical sector emits a significant number of phenols and mineral oils [17]. Furthermore, wastewater from food processing industries contains a high concentration of suspended particles and organic materials. In general, industrial effluent is classified as either inorganic or organic.

Health Effect of Industrial Wastewater

Increased discharge of contaminated wastewater from point and non-point/diffuse sources endangers human health and aquatic ecosystem. Heavy metals, dyes, pesticides, antibiotics, endocrine disrupting substances, and micro-plastics are major contaminants that endanger aquatic and human life [18]. Severe adverse effects in humans include neurotoxicity, mutations, cancer, and problems of the endocrine and reproductive systems. Irrigation with contaminated water has several detrimental consequences, particularly for soil qualities such as low carbon mineralization, low microbial biomass, low enzyme activities, and changes in soil pH and cation exchange capacity (CEC) [19].

The aim of this research work is to remove heavy metal ions from industrial wastewater using carbide ash waste.

Objective

- Collection of carbide ash waste and industrial wastewater from the sampling point.
- Preparation of the collected carbide ash waste for treatment and storing of the obtained industrial wastewater in the fridge
- Characterization of the carbide ash using analytical instruments. Such as, Fourier-infrared spectroscopy (FTIR), Brunauer-emmett-teller (BET), Scanning electron microscope (SEM), Thermobalance for thermogravimetric analysis (TGA), X-ray diffraction (XRD)
- Treatment of heavy metals from industrial wastewater using the dried carbide ash.

2.0 Experimental

2.1 Sampling techniques

Wastewater was obtained from Agbara industrial estate at the estate central waste reservoir. The obtained industrial wastewater was stored in the fridge till usage. The carbide ash was obtained from a mechanic shop at Ijora Olopa, Lagos. State, and subjected to oven drying for four days to remove and determine the moisture content in the carbide ash. After drying the carbide ash, it was pulverized, sieved using 1 mm mesh and stored in a closed container for usage.

2.2 Sampling Areas

1.0g of dried powdered carbide ash powder was introduced into 100 mL of industrial wastewater sample for the optimization of dosage and for the pH. 0.1 M HCl and 0.1 M NaOH were used to adjust the pH to desired range using pH meter. The mixture was transferred to a H - Y vibrator shaker with adjustable speed multiple usage function by search tech instruments British standard. For 90 min, and was filtered using a whatman No 1 filter paper and the filtrate was analyzed for heavy metal ion concentration using Inductively coupled plasma optical emission spectroscopy.

3.0 Results and Discussion

3.1 Characterization

3.1.1 X-Ray Diffraction (XRD) Spectrum

The X-Ray Diffraction (XRD) was used to analyze the crystal structure of a material or sample of intensity of diffraction. XRD peak intensity with respect to angles showed different mineral phases with the abundance of minerals present in the sample presented in Figure 2. In this XRD analysis of the carbide ash sample, Portlandite Syn has the highest peak intensity of 270 and other peaks at 70, 80 and 170. Portlandite Syn has some adsorption capabilities and the presence of high peak of portlandite may not necessarily be good or bad because adsorption sustainability for adsorption process depends on the specific adsorbent properties for a particular substance. Graphite Syn has the lowest intensity peak of 21 in the XRD spectrum. Figure 3 revealed the % mineral composition of the CAW: Portlandite (65%), Lime (24%), Osumilite (3.9%), Quartz (2.8%), Graphite 3R (1%), and Anhydrite (3.1%). The presence of graphite Syn in the carbide ash sample is small compared to other minerals present but its presence is good and worthy because graphite is known for its superb adsorption properties, especially for adsorption of organic compounds. Graphite Syn has a high surface area which makes it effective for adsorption. It is widely used in gas separation, water treatment, etc. Other minerals present in the XRD spectrum of the carbide ash waste are Lime, Osumilite, Quartz HP Syn, and Anhydrite Syn. Generally, these minerals have their own properties and effectiveness in the adsorption process.

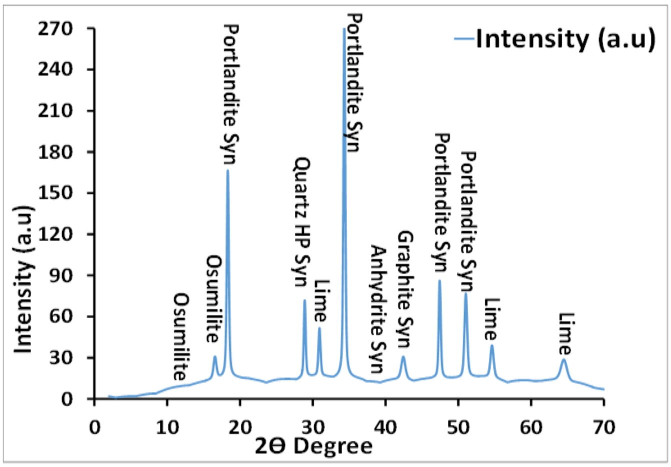

Figure 2: XRD spectra of carbide ash waste sample

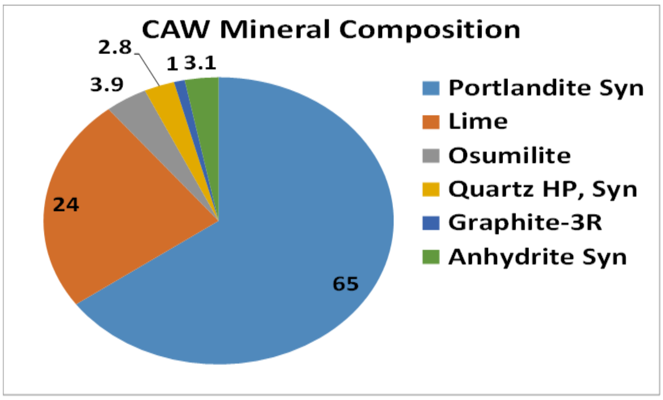

Figure 3. XRD mineral phases of carbide ash waste sample

3.1.2 Scanning Electron Microscopy (SEM) Images of Carbide Ash Waste

The scanning electron microscope (SEM) presented in Figure 4 showed the surface morphology and composition of the carbide ash sample. SEM shows the high-resolution images of the carbide ash sample by giving closer insights to the sample morphology and features. A represent magnification of (x 1000) and B represent magnification of (x 2000).

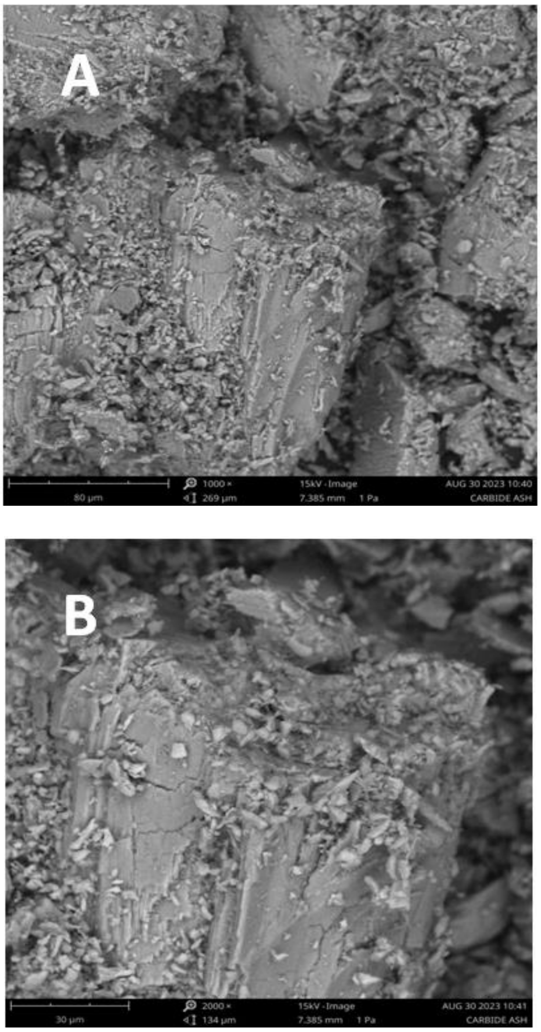

Figure 4: SEM images of carbide ash sample at magnifications x1000 (A) and x2000 (B)

3.1.3 Thermogravimetric Analysis (TGA)

The thermogravimetric analysis (TGA) curve presented in Figure 5 showed the weight loss % with respect to the temperature. The TGA revealed that as the mass (g) was decreasing, as there was increase in temperature. This weight loss changes continuously due to the thermal treatment of the CAW sample. Mass of 100 g having temperature of 100 °C dropped to mass of 94 g with an increase temperature of 300 °C. The TGA analysis shows that it continued to drop till mass of 20 g is reached with an increase in temperature of 470 °C. After the mass (g) decreased to 20 g, it became stable, but the temperature continued to increase till 900 °C is reached. The Thermogravimetric analysis (TGA) study reveals the carbide ash is stable at 470 °C, it shows that the carbide ash sample is appropriate for applications including adsorption at a very high temperature of 470 °C above which shows the stability of the sample. Generally, TGA is a characterization technique that is used to analyze the composition of materials and thermal stability. It involves heating of sample and measuring its weight loss with respect to temperature. TGA provides information about the degradation, volatilization and decomposition of a material.

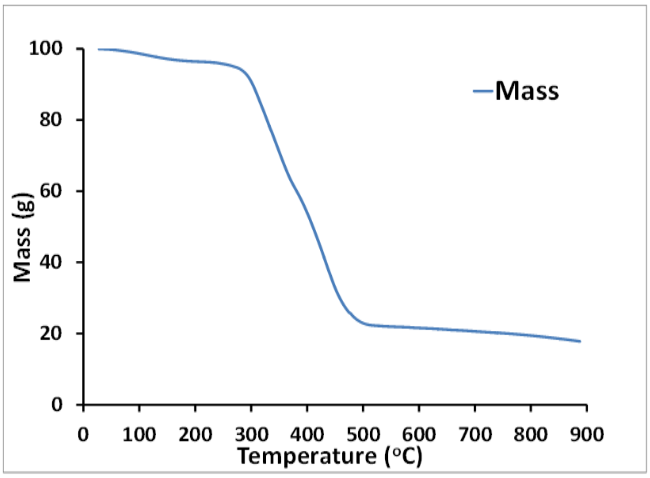

Figure 5: Thermogravimetric Analysis (TGA) of carbide ash waste.

3.1.4 Fourier Infrared Transform (FTIR) Spectroscopy

The Fourier transform infrared spectroscopy (FTIR) is an analytical method that provides information about the functional groups and chemical bonds that are present in a sample. The FTIR helps to identify the types of functional groups present in the CAW sample, which is done by measuring the absorption of infrared light by sample. FTIR spectra of CAW sample is presented in Fig 6. The CAW sample produced a broad bands and distinct peaks at around 3218 cm-1, 2046.7 cm-1, 1856.2 cm-1, 1647 cm-1, 1166 cm-1, which were attributed to the stretching vibrations of hydroxyl group (OH) group due to the presence of water, carbonyl group (C=O), C-O bond respectively, and the distinct peaks at 764.1cm-1 revealed the presence of CaO. These peaks and broad band indicate the functional groups present in the CAW sample and they also provide insights into the adsorption process as it implies that they have some adsorption properties.

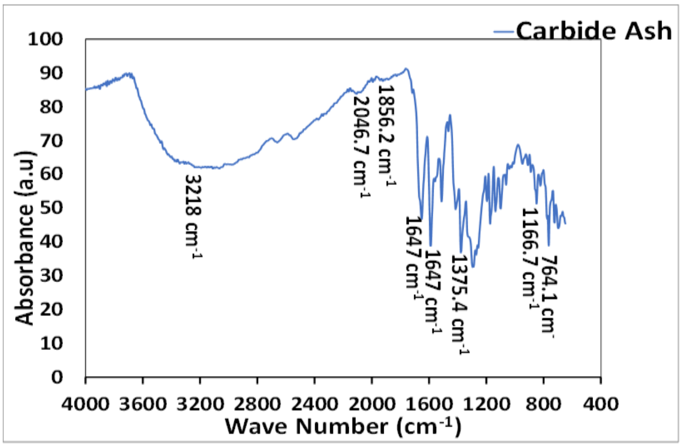

Figure 6: Fourier Transform Infrared spectroscopy (FTIR) of carbide ash sample

3.2 Adsorption Treatment

3.2.1 Dosage Optimization

The dosage optimizations results were carried out between 0.5 g - 2.5 g for the removal of Mn, Co, Ni, and Cd from the industrial wastewater using the CAW sample. Dosage optimization graphs for the four metals are presented in Figure 7. The graphs showed the effect of dosage plotted against percentage of removal for Mn, Co, Ni, and Cd with the following extraction efficiency (79.80, 80.29, 99.82 and 80.71) % at the optimized at constant time of 240 min. The dosage optimization showed the four adsorbed heavy metals had their highest percentage removal at the dosage of 2.5 g, proving that 2.5 g is the most effective dosage for adsorption of Mn, Co, Ni, and Cd of the industrial wastewater.

3.2.2 Contact Time Optimization

Effect of Contact Time

Contact time optimizations were studied between 60 minutes and 240 minutes for the removal of four (4) different heavy metals. The contact time optimization graphs show the removal of four 4 different heavy metals present in the wastewater. The graphs showing contact time plotted against percentage (%) extraction. The contact time optimization shows, Mn, Co, Ni, and Cd (81.00, 72.06, 73.74 and 81.09) % extraction of efficiency respectively at the optimized contact time of 240 minutes.

3.2.3 pH Optimization

The study of pH in industrial wastewater is one of the important factors needed for the adsorption of metal ions from aqueous media. pH optimizations were studied between pH 2 – pH 10 for the removal of Mn, Co, Ni, and Cd with the extraction efficiency (97.56, 85.47, 75.58 and 83.50) % using the optimized dosage of 2.5 g and 240 min. All the absorbed heavy metals had their highest percentage (%) removal at pH 4, except cadmium (Cd) at pH 2 due to the occurrence of precipitation. This proves that pH 4 is the most effective pH for adsorption treatment of water using carbide ash.

4.0 Conclusion

The adsorption removal of Mn, Co, Ni, and Cd metals by carbide ash has shown to be significantly effective and also the pH dependent shows that the absorbed heavy metals had their highest percentage (%) removal at pH 4, except for cadmium (Cd) which is at pH 2 due to the occurrence of precipitation. The carbide ash proves that pH 4 is the most effective pH for adsorption treatment of Mn, Co and Ni (97.56, 85.47, 75. 58)% and pH2 for Cd with 83.50% removal from industrial wastewater using carbide ash.

Figure 1: Map of the sampling site where the wastewater was obtained in Agbara industrial estate, Ogun State.

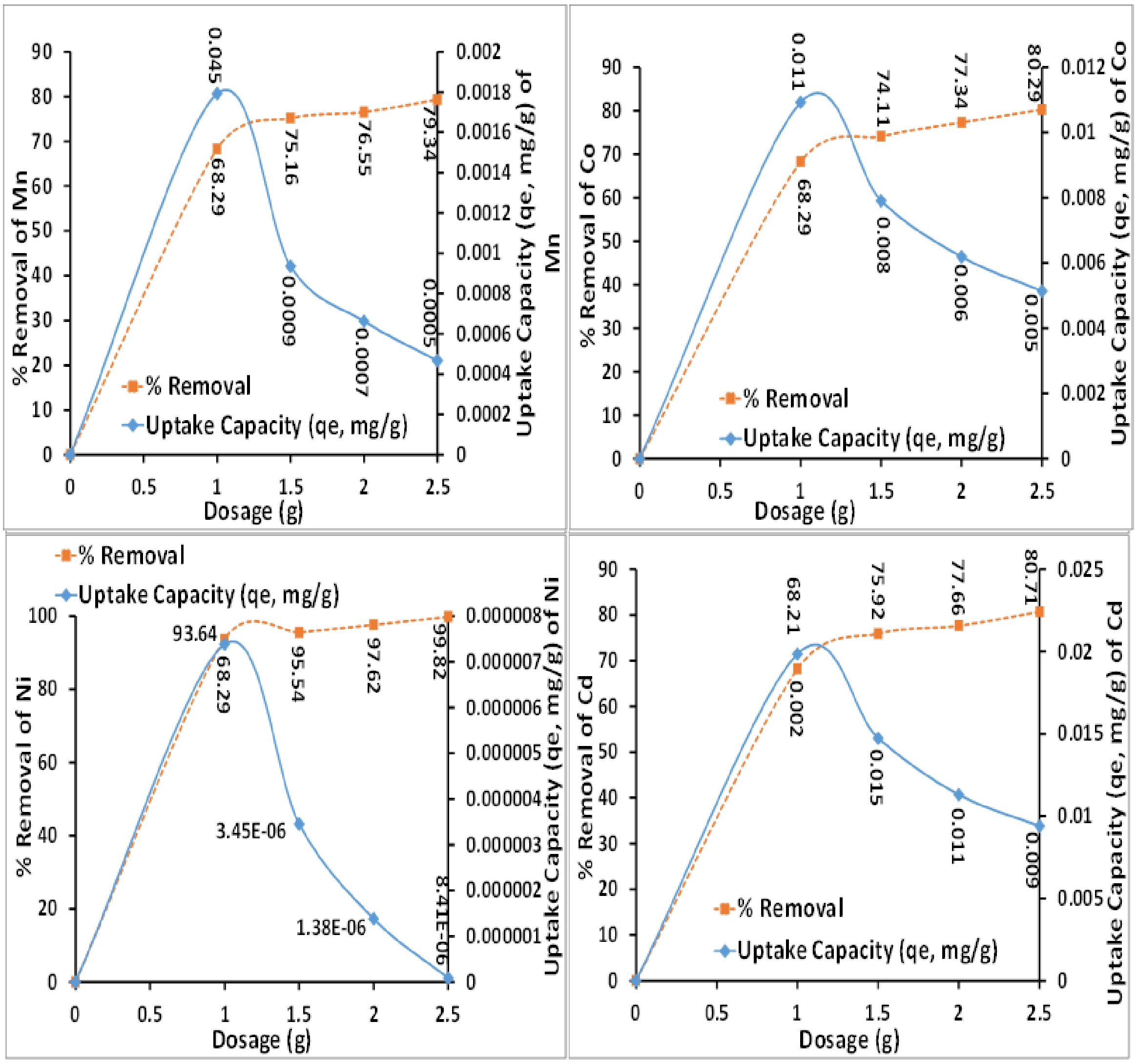

Figure 7: Dosage optimization of adsorption treatment of wastewater

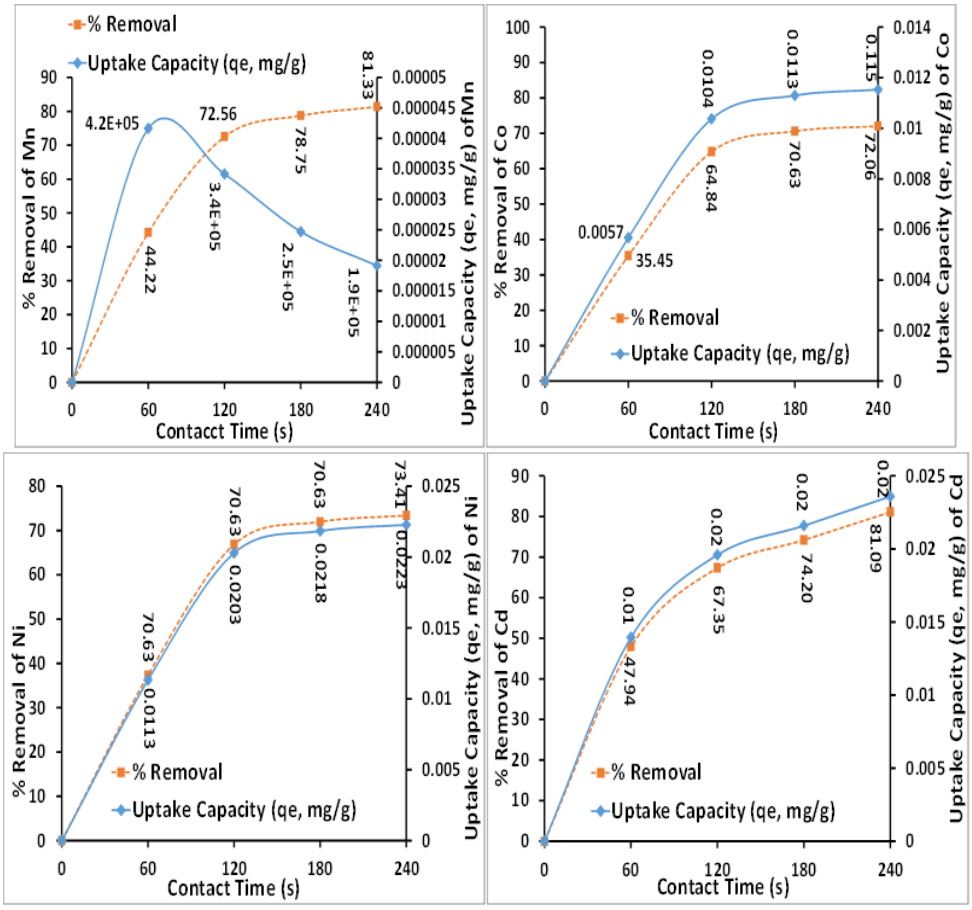

Figure 8: Contact time optimization of adsorption treatment of wastewater

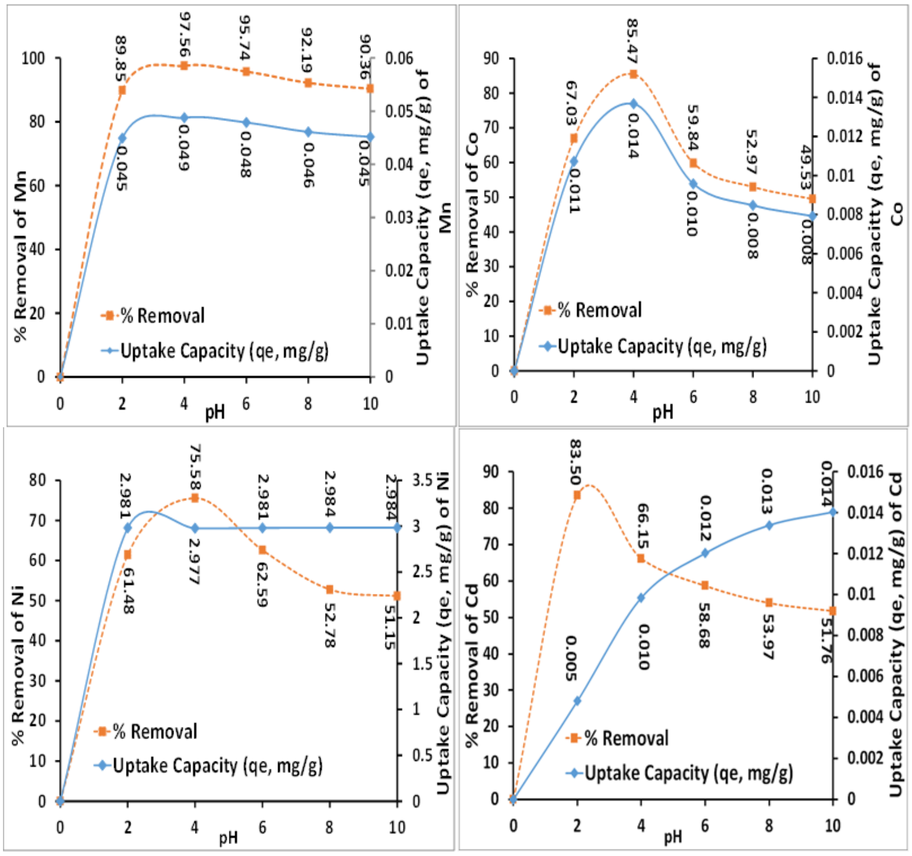

Figure 9: pH optimization of adsorption treatment of wastewater

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