

Comparative Study of *Lophiraalata* Sawdust and Activated-Carbonized Sawdust in Surface Assimilation of Heavy Metals Contaminated Water

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ABSTRACT

Environmental pollution predominantly from heavy metals and minerals in the waste water is the paramount challenge in developing countries. Due to widespread anthropogenic activities such as industrial actions particularly mining, agricultural processes and disposal of industrial effluents; their absorption has increased to unsafe height. These heavy metals (Nickel and Cadmium), largely found in industrial effluents were adsorbed using *Lophiraalata* wood sawdust in its unmodified and modified form which it is very economical, effectual and most preferred methods for the removal heavy metals from contaminated water. The *lophiraalata* wood sawdust was acquired and washed with purified water, dried, and split into two portions. The earliest portion was used as unmodified sawdust sample while the other portion was first carbonized at a temperature of 600⁰C for 4 hours and thereafter activated using 2 Moles of KOH at room temperature for 24 hours. The two samples were used equally used as adsorbent to adsorb Nickel and Cadmium ions from aqueous solution. The effect of sawdust dosage, pH, and the contact time of heavy metal ions elimination has been carefully studied. The physiochemical properties of the two adsorbents used have also been worked out. The results gotten demonstrates that an increment in sawdust dosage. Contact time and the pH, all resulted to an increase in the adsorption rate. The results obtained showed that the activated –carbonized sawdust adsorbs more than the unmodified sawdust. The selectivity sequence of absorption rate is : Activated-Carbonized sawdust> Unmodified sawdust. Based on these results established, it is concluded that *lophiraalata* wood sawdust is a very good and effectual low-cost adsorbent for the elimination of heavy metal ions from polluted water and the activated-carbonized form of this sawdust is best recommended for eliminating poisonous pollutants from waste water.

Keywords: Environmental pollution, heavy metal, wastewater, *lophiraalata*, physiochemical.

INTRODUCTION

1.1 Background Study

The *Lophiraalata* sawdust which is also known as “Red-iron wood sawdust” is specie of plant in the Ochnaceae family. Its natural habitat is sub-tropical or tropical moist lowland forests. The timber is extremely hard and used for rail road ties and bridge planking. (Tih *et al.*, 2006 Murakami *et al.*, 1992)

The *Lophiraalata* has some unique sorptive properties which are very useful for adsorption. For

example, the timber is strong and resistant thereby making it useful for demanding construction outdoors. (Tih *et al.*, 2006). The timbers also have better electrical properties than other wood making it possible to use it in poles for electric fences without separate insulators. The colour is reddish brown and the wood is abrasive, dulling tools rapidly.

Because of its hardness and resistant properties, the *Lophiraalata* wood is well appreciated for heavy construction work for extreme conditions

including hydraulic works, marine construction, bridges, decks, ship building, industrial floors, staircase, wooden frame houses, and railway sleepers. (Tihetal., 2006; Murakami et al., 1992).

It also has a high energy value. It is a good fuel wood and yields excellent charcoal. The wood is very heavy with a density of 1010-1150kg/m³ at 12% moisture content, and very hard. It also has excellent mechanical properties, being both flexible and resistant to bending and very resistant to shock and abrasion.

I would like to state too that the *Lophiraalata* wood is very difficult to work with hand tools because of its hardness and high density. It is normally processed by sawing and is not suitable for peeling or slicing for veneer. But with appropriate heavy-duty machine tool, it saws well. The blunting effect on saw teeth and cutting edges is relatively small as it does not contain silica.

1.2 Statement of the Research Problems

The quality of water from industrial effluents .sewage sludge, copper water heater, etc. is contaminated with heavy metals. This is as a result of discharges from refineries and industrial activities like batteries, plating, pigments and plastics.

However, industrial effluents discharged into rivers will be highly polluted with heavy metals which affect the colour, odour and quality of the water. Moreover, the effluents will also affect human activities in their daily life such as drinking, cooking, washing and so on. Evaluation of these problems makes available approaches for the removal of heavy metals from contaminated water using *Lophiraalata*sawdust in its unmodified and activated-carbonized form of sawdust.

1.3 Objectives of the Study (Main and Specific Objectives)

The main objective of this study is to adsorb heavy metals from contaminated water.

The specific objectives of this research study are to:

- i. Use the *Lophiraalata* wood sawdust and the activated-carbonized form of this sawdust to adsorb heavy metals from contaminated water and compare which form of this sawdust adsorbs more heavy metal ion from contaminated water.

- ii. Determine the adsorption rate of the unmodified sawdust and the activated-carbonized sawdust.
- iii. Find out the optimum condition for removing Nickel and Cadmium from aqueous solution through adsorption of sawdust.

1.4 Significance of the Study

This study will help to find out the prevalence means of removing heavy metals from contaminated water which directly or indirectly discharged into water bodies without adequate treatment to remove the harmful sediments.

This study will be significant as:

- i. It will reduce the annual death rate of people caused by drinking contaminated water. The heavy metals present in the water are dangerous for health of humans and can lead to problems like asthma, cancer, skin disorders and even death.
- ii. It helps to ensure that water is not wasted. This *lophiraalata* sawdust in its unmodified and modified form can be used to treat heavy metals contaminated water discharged from industries which may be used by households for domestic purposes mainly in rural areas.
- iii. It helps to solve problems of water shortage and areas with limited access to safe water will be benefited. The water treated can be used for numerous purposes like drinking, household use, agriculture, irrigation and even industrial application.

1.5 Scope and Limitations of the Study

In view of the unique adsorptive properties of the *Lophiraalata* wood, its sawdust form shall be used as a low-cost adsorbent for the removal of Heavy metals from solutions. Using this particular sawdust in adsorption of Heavy metals appreciates the enhanced effectiveness of a low cost adsorbent in the removal of toxic metals.

Nevertheless, the scope of this dissertation work is limited to:

- i. Removal of heavy metals from contaminated water using *Lophiraalata* sawdust in its unmodified and modified form

- ii. Physiochemical properties of *lophiralata* sawdust and its activated-carbonized form of sawdust.

REVIEW OF RELATED LITERATURE

2.1 Heavy Metals

Heavy metals are elements having atomic weight between 63.5 and 200.6 and a specific gravity that is greater than 5.0 (Suciu *et al.*, 2008). They can also be chemical elements with a density that is greater than 4g/cm and is found in all kinds of soil, rocks, and water in fresh water and terrestrial ecosystem (Adelekan and Abegunde, 2011). Heavy metals can also refer to any element that has a relatively high density and is toxic or very poisonous even at a low concentration (Lenntech, 2010). Therefore, Heavy metals are at least five times the specific gravity of water. The specific gravity of water is 1 atm. Another school of thought puts Heavy metals as having a density of 60g or more (much higher than the average particle density of soil which is 2.65) and they occur naturally in rocks, but concentrations are frequently elevated as a result of contamination (Asio, 2009). They can also be said to be intrinsic, natural constituents of our environment (Aderinola *et al.*, 2009). Therefore, they can be said to be a group of metals and metalloids with atomic density greater than 4g/cm or five times greater than water (Obodai *et al.*, 2011).

2.2 Sources of Heavy Metals

Heavy metals are the major pollutants in marine, ground, industrial, and even treated water. These heavy metals are often discharged by a number of industries, such as metal plating facilities, mining operations and tanneries, and this led into contamination of fresh water and the marine environment (Low and Lee, 2000; Bailey *et al.*, 1999).

Heavy metals exist naturally in the soil forming processes of disintegration of parent resources at rare levels ($<1000 \text{ mg.kg}^{-1}$) and frequently poisonous (Kabata-Pendias and Pendias, 2001; Pierzynskiet *al.*, 2000). Heavy metals come from man-made sources trying to be more moveable in the soil, thereafter biologically available than soil

forming phenomenon (Kue *et al.*, 1983; Kaasalainen and Yli-Halla, 2003). Metal-containing solids at polluted laces can originate from an extensive variation of man-made sources in terms of metal mine stake outs, Lead (Pb) gasoline and paints tat are Lead (pb) based, application of fertilizers, discarding high metal wastes in inappropriately protected landfills, animal manures, bio solids (sewage sludge), coal combustion remainders, compost, petrochemicals, pesticides, and decomposition in atmosphere (Khan *et al.*, 2008; Zhang *et al.*, 2011; Basta *et al.*, 2005).

2.3 Effects of Toxic Heavy Metals_

Heavy metals are not bio-degradable and can lead to accumulation in living organisms thereby causing various diseases and disorders (Bailey *et al.*, 1999). Some metals are severely harmful to life. Examples of such metals are chromium, copper, lead, manganese, mercury, cadmium, nickel, etc., and they are significantly toxic to human beings and ecological environments (Yu, B *et al.*, 2000). Most of the heavy metals that are discharged into the waste water are found to be toxic and carcinogenic and they cause a serious threat to the human health (Srivastava *et al.*, 2006). The release of large quantities of these hazardous materials into the environment has resulted in a number of environmental problems and because these hazardous materials are not biodegradable and are persistent, they accumulate in the environment elements such as food chain, and this poses a significant danger to the human health. The table at the next page highlights the sources and toxic effect of some heavy metals. These metals have been extensively studied and their effects on human are regularly reviewed by international bodies such as the World Health Organization (WHO)

Table 2.1 shows the sources and toxicological effects of some heavy metals in the contaminated water.

Table 2.1: Sources and toxicological effects of some heavy metals

S/N	Heavy Metal	Sources	Effect
1.	Copper	Water pipes; copper water heaters; Frozen greens and canned greens using copper to produce an ultra-green color' Alcoholic beverages from copper brewery equipment; Instant gas hot water heaters; Hormone pills' pesticides, Insecticides, fungicides; copper Jewelry; copper cooking pots.	Mental disorders; Anemia; Arthritis/rheumatoid arthritis; Hypertension; Nausea/vomiting; hyperactivity; Schizophrenia; Insomnia; Autism; Stuttering; Postpartum Psychosis; Inflammation and Enlargement of Liver, Heart problem, cystic fibrosis. Hormone pills' Insecticides, fungicides; copper Jewelry; copper cooking pots.
2.	Chromium	Steel and Textile Industry	Skin Rashes; respiratory problems; Hemolysis, Acute Renal Failure; Weakened Immune systems; Kidney and Liver damage; Alteration of Genetic material; Lung cancer; pulmonary fibrosis.
3.	Nickel	Effluents of silver refineries; Electroplating Zinc Base. Casting and storage battery industries.	Dermatitis; Myocarditis; Encephalopathy; Pulmonary Fibrosis; cancer of lungs, nose and bone; headache; dizziness; nausea and vomiting; chest pain; rapid respiration.
4.	Lead	Industries such as Mining, Steel, Automobile, Batteries and Paints. Pollutants arising from increasing industrialization.	Nausea; Encephalopathy; Headache and vomiting; learning difficulties; mental retardation; Hyperactivity; vertigo; kidney Damage; birth defects; muscle weakness; anorexia; cirrhosis of the liver; thyroid dysfunction; Insomnia; Fatigue; degeneration of motor Neurons; Schizophrenic-like behaviour.

5.	Cadmium	Phosphate fertilizer; Sewage sludge; Industrial uses like batteries, plating, pigments and plastics.	Chills, fever, muscle aches (cadmium blues); trachea-bronchitis; pneumonitis; pulmonary edema; Respiratory Tract and kidney problems; Damage to liver and kidneys
6.	Mercury	Industries like Chloro alkali, paints, pulp and paper. Oil Refining, rubber processing and fertilizer, dental fillings, adhesives, fabric softeners rugs, thermometers, fluorescent light tubes and high intensity street lamps, pesticides, cosmetics and pharmaceuticals.	Tremors; birth defects; kidney damage; Nausea; loss of hearing or vision; gingivitis; chromosome damage; Mental retardation Tooth loss; seizures; cerebral palsy; blindness and deafness; hypertonia; muscle rigidity; Minamata diseases

Sources: *Alluri et al, (2007)*

To avoid the aforementioned health hazards, it is therefore essential to remove these toxic heavy metals from waste water before they are disposed. The various techniques used for removing heavy metals includes precipitation, ion-exchange, filtration, electro dialysis, adsorption, reverse osmosis (Rao *et al.*, 2000).

However, most of these techniques do not give a satisfactory depollution, especially when you consider the operational costs (Marchetti *et al.*, 2000). Precipitation methods, for example, are particularly reliable but they require large settling tanks for the precipitation of voluminous alkaline sludge and a subsequent treatment is needed. In addition, the effluents after such a treatment usually have an unacceptably high total dissolved solid and when applied to dilute metal waste or lower concentrations, these processes are either ineffective or not cost-effective and they require high level of expertise, hence, they are not used by many end-users. Ion-exchange has the advantage of allowing the recovery of metallic ions, but the problem with this method is that it is very expensive and sophisticated.

For these reasons, Adsorption technology has gained a wider application due to its inherent low cost, simplicity, versatility, and robustness.

Adsorption is operative in most natural, physical, biological, and chemical systems, and is widely used in industrial application such as activated charcoal, synthetic resins, and water purification. Adsorption is also currently considered to be very suitable for waste water treatment because of its simplicity, and cost of effectiveness (Yadabaparthiet *al*, 2009; Kwon *et al*, 2010). Adsorption is a commonly used technique for the removal of metallic ions from various industrial effluents (Gottipati, and Mishra, 2012).

2.4 Various Conventional Methods for the Removal of Heavy Metal

2.4.1 Chemical Precipitation

Chemical precipitation processes involve the addition of chemical reagents, followed by the separation of the precipitated solids from the cleaned water. Precipitation of Metals is achieved by the addition of coagulants such as alum, lime, iron salts and other organic polymers. Gopalratnamet *al.*, (1988) found 80% removal of Zn, Cu, and Pb, and up to 96.2% removal of oil from industrial waste water by using a joint hydroxide precipitation and air floatation system.

2.4.2 Electro Dialysis (ED)

Electro Dialysis (ED) is a membrane process whereby ions are transported through semi-permeable membrane but under the influence of an electric potential. The membrane are cat ion- or anion-selective, which basically means that either positive ions are negative ions will flow through.-selective membranes are polyelectrolyte with negatively charged matter, which rejects the negatively charged ions and allows only the positively charged ions to flow through.

2.4.3 Coagulation/Flocculation

Coagulation and flocculation are an essential part of deinking water treatment as well as wastewater treatment. Coagulation is the chemical reaction which occurs when a chemical or coagulant is added to the water. The coagulant encourages the colloidal material in the water to join together into small aggregates called “flocs” suspended matter is then attracted to these flocs. Flocculation is a slow gentle mixing of the water to encourage the flocs to form and grow to a size which will easily settle out.

Randtke et al., (1997) reviews the basic mechanics involved in the removal of organic contaminants by coagulation. Kuo *et al.*, (2001) studied the effects of initial pH and adsorption of Heavy metals and reviewed turbidity, alum and pre-ozonation doses, and flocculation time on the removal of dissolved organic matter during alum coagulation’

2.4.4 Ultra-Filtration

Ultra-filtration is a separation process which involves using membranes with pore sizes in the range of 0.1 to 0.001 microns. Typically, ultra-filtration will remove high molecular weight substances, colloidal materials, and organic and inorganic polymeric molecules. It is a pressure driven purification process in which water and low molecular weight substance permeate a membrane while particles, colloids, and macromolecules are retained. The primary removal mechanism is size exclusion, although the electrical charge and surface chemistry of the particles or membrane may affect the purification efficiency.

2.4.5 Reverse Osmosis

Reverse Osmosis is when a pressure is applied to the concentrated side of the membrane forcing purified water into the dilute side, the rejected impurities from the concentrated side being washed away in the reject water. Applications that have been reported for Reverse Osmosis processes include the treatment of organic containing waste water, waste water from electroplating and metal finishing. pulp and paper, mining and petrochemical, textile, and food processing industries, radioactive wastewater, municipal wastewater, and contaminated groundwater (Slater *et al.*, 1983; Cartwright, 1985; Ghabriset *al.*, 1989; Williams et al., 1990).

2.5 Adsorption

Adsorption is a process whereby a gas or liquid solute accumulates on the surface of a solid or a liquid (called the adsorbent). (Piero, 2005) It is the capability of all solid molecules to attract to their surfaces, molecules of gases or dissolved substances are called adsorbents, while the adsorbed molecules are usually referred to collectively as the adsorbent. It should be noted that adsorption is quite different from absorption. Adsorption is the process through which a substance, originally present in one

phase is removed from that phase by dissolution in another (typically a liquid), as opposed to the accumulation at the interface as in the case of adsorption. (Piero, 2005). Adsorption can either be physical adsorption (physio-sorption) or chemical adsorption (chemo-sorption).

2.5.1 Physisorption

This type of adsorption depends mainly on the physical or Van der Waals forces of attraction between the solid adsorbent and the adsorbent molecules. There is no chemical specificity in physical adsorption.

2.5.2 Chemisorption

This is the type of adsorption which involves a chemical reaction between the surface and the adsorbate. In chemisorptions, gases are held to a solid surface by chemical forces that are specific for each surface and each gas. Chemical adsorption usually occurs at a higher temperature than those at which physical adsorption occurs, and like most chemical reactions, it usually involves energy of activation.

2.5.3 Low-Cost Adsorbent

As earlier noted, adsorption technology has gained a wider application for the removal of Heavy metals due to its inherent low cost, simplicity, versatility, and robustness. Other conventional methods for heavy metals removal are either very costly or require high level of expertise. Low cost adsorbents used in adsorption are derived from agricultural by-products and industrial wastes and are exploited to remove recalcitrant wastes from synthetic wastewater. Conversion of these materials into adsorbents for wastewater treatment helps to reduce the cost of waste disposal. The adsorption of toxic wastes from industrial wastewater using agricultural waste and industrial by-products has been massively investigated (Basuet *al.*, 2006; Srivastavaet *al.*, 2006). The technical feasibility of the various low-cost adsorbents for heavy metal removal from contaminated water has been reviewed (Babel et al., 2003). Instead of using very expensive materials as adsorbents for heavy metals removal, wood sawdust which is considered largely as wastes and is locally available, is an inexpensive material and an effective low-cost adsorbent for the removal of heavy metals from waste water.

2.5.4 Factors Affecting Adsorption

The most important factors affecting adsorption are:

- i. **Surface Area of Adsorbent:** The larger the size of the surface area of the adsorbent, the greater the adsorption capacity. (Piero, 2005) In this research work, the surface area of the sawdust will be increased by carbonizing the sawdust and then activating the carbonized sawdust. Activating the adsorbent will cause it to have a very high degree of micro porosity which is a useful property in adsorption.
- ii. **The Particle Size of Adsorbent:** Smaller particle size reduces internal diffusion and mass transfer limitation to the penetration of the adsorbate inside the adsorbent. In other words, equilibrium is more easily achieved and nearly full adsorption capability can be attained. However, waste water drops across columns packed with powdered materials are too high for use of this material in packed beds. Addition of powdered adsorbent must be followed by their removal. (Piero, 2005)
- iii. **Contact Time:** The longer the time, the more complete the adsorption will be. However, the equipment will be larger. (Piero 2005)
- iv. **pH:** The degree of ionization of specie is affected by the pH (e.g. a weak acid or a weak base). This in turn affects adsorption. (Piero, 2005)
- v. **Degree of Ionization of the Adsorbent Molecule:** More highly ion molecules are adsorbed to a smaller degree than neutral molecules. (Piero, 2005)
- vi. **Solubility of the Solute (Adsorbent) in Liquid:** Substances that are slightly soluble in water will be more easily removed from water that is, adsorbed than substances with high solubility. In addition, non-polar substances will be more easily removed than polar substances since the latter possesses a great affinity for water. (Piero, 2005)
- vii. **Number of Carbon atoms:** For substances in the same homologous series, a larger number of carbon atoms are generally

associated with a lower polarity and therefore a greater potential for being adsorbed (e.g. the degree of adsorption increases in the sequence: Formic- Acetic- Propionic -Butyric acid) (Piero, 2005)

viii. Size of the Molecule with Respect to Sizes of the Pores: Large molecules may be too large to enter small pores and this may reduce adsorption independently of other causes. (Piero, 2005)

ix. Affinity of the solute of the Adsorbent (Carbon): The surfaces of the activated carbon is only slightly polar. Hence, non-polar substances will be more easily picked up by the carbon than polar ones. (Piero, 2005)

2.5.5 Adsorption Equilibrium

Upon contacting an amount of the unmodified sawdust and the activated –carbonized sawdust with waste water containing an adsorbent substance, adsorption will take place. Adsorption will continue until equilibrium will be established between the substance in solution and the same substance in the adsorbed state. At equilibrium a relationship exists between the concentration of the species in solution and the concentration of the same species in the adsorbed state (that is, the amount of species adsorbed per unit mass of the adsorbent), (Piero, 2005).

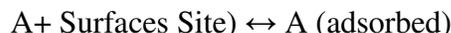
2.6 Theoretical Models

There are several models for predicting the equilibrium distribution. However, the following four models are most commonly observed:

- i. Linear Isotherm
- ii. Langmuir Isotherm
- iii. Freundlich Isotherm
- iv. Brunauer, Emmet, and Teller (BET) Isotherm

However, for the application of activated-carbon in water and waste water treatment, the most commonly used isotherms are the Freundlich and Langmuir adsorption isotherm.

Langmuir Isotherm: Langmuir was the first to point out that in the chemical adsorption of a gas on a solid surface, a layer single molecule in thickness is formed (Sharma and Forster, 2004). This theory assumes the process:



$$\text{Equation 2.1}$$

We assume that only a single layer of molecules (a monolayer) can be adsorbed on the surface sites (Robert, 2008). The Langmuir Isotherm assumes

- i. Monolayer coverage,
- ii. Equilibrium model,
- iii. All adsorption sites are equally probable,
- iv. A second order reaction

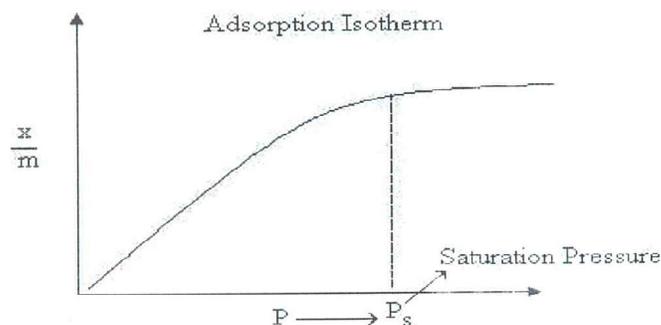


Figure 2.1: Langmuir Adsorption Isotherm
Source: Gawande *et al.*, (2017).

Freundlich Isotherm: To show the variation of the amount of gas absorbed per unit mass of the adsorbent with pressure at constant temperature, Freundlich suggested an empirical equation (Sharma and Forster, 2004). Equation 2.2 shows Freundlich isotherm which is commonly used:

$$q_e = k_f c_e^{\frac{1}{n}} \quad \text{Equation 2.2}$$

Where k_f = Freundlich constant, indicating the adsorption capacity, n = A constant characterizing the affinity of the metal ions towards adsorbent q_e = Amount of heavy metal ions adsorbed per weigh unit of heavy metal, C = Heavy metal concentrations at equilibrium.

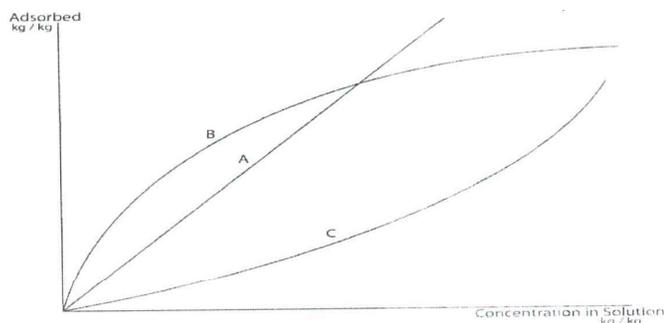


Figure 2.2: Freundlich Adsorption Isotherm

Source: Gawande *et al.*, (2017).

MATERIALS AND METHODS

3.1 Materials

3.1.1 Apparatus

- i. Beaker
- ii. Conical flask
- iii. Measuring cylinder
- iv. sieve (53 μ m)
- v. Sample bottles
- vi. Pipette
- vii. Volumetric flask
- viii. Spatula
- ix. Funnel
- x. Filter paper
- xi. Glass stirrer
- xii. Clay pot

3.1.2 Reagents

- i. Distilled water
- ii. 2 Mol potassium hydroxide (KOH)
- iii. Nickel sulphate (NiSO₄)
- iv. Cadmium sulphate (CdSO₄)
- v. Buffer solution
- vi. Unmodified Lophiraalata sawdust sample
- vii. Activated-carbonised Lophiraalata sawdust sample

3.1.3 Equipment

- i. Atomic Adsorption Spectrophotometer (AAS)
- ii. pH meter
- iii. Mechanical Shaker
- iv. Oven

- v. Weigh balance
- vi. Desiccator

3.2 Methodology

3.2.1 Collection of Samples

The *Lophiraalata* wood sawdust was obtained at a local sawmill located at Itam Timber Market, Itu Local Government Area, Uyo capital city, Akwa Ibom state. The fine particles of this sawdust were collected in large quantity. The salts of the heavy metals to be adsorbed were collected at the Chemistry Department Laboratory. Nickel Sulphate (NiSO₄) and Cadmium sulphate (CdSO₄) were collected.

3.2.2 Preparation of Samples

The sawdust was dried under the sun until there was no trace of water found in it. The sawdust sample was then filtered with a sieve mesh size of 53 μ m so that the very fine particles are filtered. The sawdust sample was then divided into two portions. The first portion was used as the unmodified sawdust sample while the second portion was carbonized and thereafter activated and was used as the activated-carbonized sawdust sample.

3.2.3 Preparation of the Carbonized Sawdust

The other part of sawdust to be carbonized was poured into clay pot and was heated in an oven at 600⁰C for 4 hours. This was done batch-wise until all sawdust samples were carbonized.

3.2.4 Activation of the Carbonized Sawdust

The carbonized sawdust was then activated by using 2 Mol potassium hydroxide (KOH). The production of activated carbon using sawdust was carried out using chemical activation that is, the thermal decomposition of the raw material impregnated with the activating agent (2Mol KOH). Potassium Hydroxide is a strong dehydrating agent which could alter the structure of carbon to form the porous structure.

The samples were treated with excess 2 Mol KOH chlorides for 24 hours at room temperature. It should be noted that an increase in the activating agent promotes the contact area between the material and the activating agent increases the surface area and the porosity of carbon. After the activation step, the samples were washed thoroughly with distilled water until the residual

activating agent on the surface of the activated carbon was completely removed. This was achieved by regularly checking the pH of the filtrate after each washing until the filtrate was brought to neutrality (pH 7). After which the samples were oven dried for 30 minutes at 100°C for 2 hours.

3.3 Characterization of the unmodified sawdust and the Activated-Carbonized Sawdust

The unmodified sawdust and the prepared activated-carbon were characterized by physical properties and chemical properties. Physical properties of the unmodified sawdust and the activated carbon are moisture content, ash content, and the bulk density, while the chemical properties include the pH, contact time, and the sawdust dosage.

3.3.1 Moisture Content

Moisture content is the quality of water contained in a material. It can also be expressed as the amount of water physically bound on the activated carbon under normal condition. The moisture content of the unmodified sawdust and the activated carbon are often required to define and express its properties in relation to the net weight of the carbon. In this research project, the moisture content of the unmodified sawdust and the prepared activated carbon were determined using the oven drying method.

Moreover, 2g of the dried unmodified sawdust and the activated carbon were weighed and placed into a pre-dried crucible and placed in an oven at 100°C to constant weight for 2 hours respectively. After drying, the crucible was removed, cooled in a desiccator and then weighed.

The moisture content was calculated in by:

$$\% \text{ Moisture content} = \frac{w_2 - w_1}{w_2} \times 100$$

Equation 3.1

Where W_1 = Weight of the wet sawdust, W_2 = Weight of the dry sawdust

3.3.2 Ash Content

Ash is the inorganic residue remaining after the water and the inorganic matter have been removed by heating, which provides a measure of the total minerals within the sample. Ash content is

a measurement of the materials left behind from the carbonization and activation of the carbon material.

In this research project, 2g of the dried activated carbon was weighed into a preheated porcelain crucible with a known weight. The crucible and the dried activated carbon were reweighed together; it was then transferred into a muffle furnace and heated at 60°C for 2 hours till no further reweighed to obtain the weight of ash. The weight of the remaining ash which is expressed as a percentage of the original weight of the activated carbon was the ash content of the activated carbon.

The ash content in percentage was calculated by the formula: $\% \text{ Ash Content} = \frac{\text{Weight of Ash}}{\text{Weight of Sample}} \times 100$

Equation 3.2

3.3.3 Bulk Density

The bulk density of a powder is the weight of the powder divided by the volume it occupies and it is normally expressed in g/ml. This test can provide a gross measure of particle size and dispersion which can affect material flow consistency and reflect packaging quantity. The bulk density of activated carbon depends on the shape, size and the density of individual particles.

In this research project, the bulk density of the samples was determined by filling a graduated cylinder (10mL) with dry unmodified sawdust and the activated carbonized sawdust to the top graduation by gently tapping on the table and weighing the cylinder along with the sample and finally dividing the weight of the sample by the volume of the cylinder respectively.

The formula is given a:

$$\text{Bulk Density} = \frac{W_{MAT}}{V_{MAT}}$$

Equation 3.3

Where W_{MAT} = Weight of the sample (g), V_{MAT} = Volume of the cylinder (mL³)

3.3.4 pH

The pH value of the activated carbon is a measure of whether it is acidic or basic. Activated carbon when coming out of the kiln tends to be a bit basic with pH around 8. A pH that is too high indicates too much contaminants and a too low pH especially for acid washed activates carbon means that the acid has not been properly rinsed away.

Most activated carbons are specified for a pH range of 6-8.

In this research project, 1 g of the sample was weighed and transferred into a beaker. 100 mL of distilled water was added into the samples and stirred for one hour. The samples were allowed to stabilize before the pH was measured using a pH meter.

3.3.5 Contact Time

The effect of contact time on adsorption of Ni ions and Cd ions were investigated. 1.0g each of the adsorbents (unmodified sawdust and activated-carbonized sawdust) was taken into 5 beakers containing 100 mL solution at an initial concentration of 20mg/∴. The solutions were agitated at a fixed stirring speed of 180 rpm for varying time period ranging from 20 to 120 minutes at a fixed pH value of 6. The final concentration of each solution was determined by Atomic adsorption spectrophotometer (AAS) and the percentage Ni²⁺ and Cd²⁺ was then determined.

3.3.6 Sawdust Dosage

The effect of sawdust dosage on the percentage removal of metallic ions was investigated by varying adsorbent dose in the range of 0.1 to 0.4g. Separate of adsorbents (ranging from 0.1 to 0.4g of unmodified sawdust and the activated-carbonized sawdust) were each taken into 4 sample bottle containing 100mL of metal solution of initial concentration of 20 ppm. The solutions were agitated at a fixed stirring speed of 180 rpm for a predetermined contact time of 120 minutes and a fixed pH value of 6.0. The final concentration of solutions was then determined by Atomic Adsorption spectrophotometer (AAS), and the percentage removal of Ni²⁺ and Cd²⁺ were determined.

3.4 Preparation of the Stock Solution

In the preparation of stock solution of Nickel and Cadmium, specifically a known mass (2.64g) of Nickel Sulphate was dissolved in 200mL of distilled water. The resulting solution was diluted to 100mL mark using distilled water to give a stock solution of 1000 ppm. Similarly, Cadmium Sulphate solution was prepared by dissolving a known mass (1.85) of Cadmium Sulphate was dissolved 200 mL of distilled water and the solution diluted to

1000mL mark using distilled water to give a stock solution of 1000ppm.

3.5 Adsorption Experiment

The experimental procedure for the adsorption experiment basically involves adding a specified amount of the prepared adsorbent, that is, the unmodified sawdust and the activated carbonized sawdust, with the already diluted solutions of the heavy metals (Nickel and Cadmium respectively). The given set-ups were prepared in batches and were subjected to varying conditions and agitated with a mechanical shaker at 120 rpm for 1 hour. After which, filtration of the adsorbent from the solution was carried out. The concentration of the heavy metals left in the various solution was then determined using an Atomic Adsorption Spectrophotometer (AAS), model AA500. The varying conditions at which the batch experiments were carried out was recorded.

3.6 Water Treatment Units

Water treatment is essentially a process of water purification and it is often very necessary because water naturally occurs in contaminated form. Portable water must be free of pathogenic organisms, toxic substances and excess of mineral and organic materials. Impurities in water must be below certain limits or be removed before using the water for domestic or industrial purposes. This means that with the exception of unusual situations, water must be treated. To be attractive to consumers, water should be free from heavy metals (Nickel and Cadmium), colour, turbidity and odour, it should contain sufficient oxygen and be acceptable in taste.

Provision of well treated supply free from heavy metals at sufficient level to meet the daily needs of consumers will greatly help decrease the incidence of skin and eye infections and may also reduce diarrheal disease and most worm infections.

Table 3.1: Water treatment units and applications

S/N	Unit of process	Applications
1.	Screen	Removal of floating water.
2	Plain sedimentation	Removal of fine discrete particles which are allowed to settle under gravity and then be removed.
3.	Coagulation and flocculation	Addition of some chemicals to coagulate the finer and lighter flocculent materials which cannot settle under the process of plain sedimentation by allowing them to form a larger mass called flocs and can settle under gravity
4.	Secondary sedimentation	This is the settling tank with short detention time where the flocculent materials that have come together in process of coagulation and flocculation settle down and are then removed.
5	Filtration	This is employed to remove very fine particles and colloidal matters which might have escaped from the sedimentation tank. Some micro-organisms are also removed from filtration.
6.	Disinfection	The effluent from the filter may still contain some bacterial. For this reason, disinfection is necessary. Disinfection may be achieved by chlorination, ozonation or son-ozone process.
7	Aeration	Water, which has been treated by adsorbent, sedimentation, filtration and disinfection, will be safe but not necessarily attractive. Aeration unit removes odour and colour (iron and manganese) by mixing the exposing water to air. Aeration can be created through hydraulic jump.
8	Chemical precipitation	Remove such chemicals in water like iron, manganese and hardness.
9	Ion exchange	By exchange of ion, this process also achieves the removal of hardness.

Source: Agunwamba, J.C., (2008)

There are also other treatment processes that might be applied; for example, fluoridation

(addition of fluorides in solution) for each tooth care.

The unit operation design is aimed at successively removing smaller suspended matters from heavy metal contaminated water using *Lophiraalata* sawdust and activated-carbonized sawdust, leaves, sawdust and other sizeable clogging substances are removed by screening.

3.7 Ethical Issues

The major ethical issue of concern during this dissertation was ensuring that *Lophiraalata* sawdust was completely examined. Furthermore, the investigation report used during this study were obtained after following the due processes and ensuring that they would be used strictly for the purpose within the confine of this dissertation. Similarly, adequate care was taken to ensure that parts of the report that were carried out in this dissertation were done under close supervision and that they were by no means left in the care or taken by those who were not supposed to be in possession of them. Moreover, only papers whose labels attest to the fact that they were produced from sustainable and environmentally friendly processes were used in printing this work.

3.7.1 Ethical Clearance

Ethical approval for the study was obtained from the department of Civil Engineering, University of Uyo, Uyo, Akwalbom State before commencement.

3.7.2 Funding

The study was sponsored by the researcher. There was no financial involvement of the subjects

RESULTS AND DISCUSSION

4.1 Physiochemical Properties of Unmodified Sawdust

From the unmodified sawdust, the following were the physiochemical properties obtained:

Table 4.1: Physiochemical Properties of Unmodified Sawdust

Physiochemical Properties	Proportion
Moisture content (%)	2.64
Ash content (%)	1.20
Bulk Density (g.mL ⁻³)	0.89
pH	7.02

Source: Field data (2019)

4.2 Physiochemical Properties of Activated Carbonized Sawdust

From the activated-carbonized sawdust, the following were the Physiochemical Properties obtained:

Table 4.2: Physiochemical Properties of Activated Carbonized Sawdust

	Proportion
	1.05
Physiochemical Properties	1.40
Moisture content (%)	0.835
pH	7.02

Source: Field data (2019)

4.3 Results for the Adsorption of Nickel ion by Unmodified Sawdust and the Activated Carbonized Sawdust

The following tables below were obtained from the results obtained from Atomic Adsorption Spectrophotometer (AAS) analysis that was carried out on the various filtrates obtained from the experimentation using unmodified sawdust and activated carbonized sawdust to adsorb Nickel ions.

Table 4.3: Effect of unmodified sawdust dosage on adsorption of Nickel ion

S/N	Sawdust Dosage (g)	Initial concentration (Mg/g)	Equilibrium concentration (Mg/g)	Amount Adsorbed (%)
1	0.1	100	2.24	97.76
2	0.2	100	1.11	98.89
3	0.3	100	0.74	99.26
4	0.4	100	0.54	99.46

Source: Field data (2019)

Effect of Unmodified Sawdust Dosage for Nickel ion

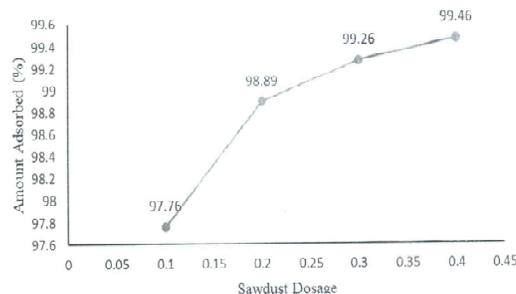


Figure 4.1: Amount of Nickel ion adsorbed by unmodified sawdust as a function of sawdust dosage. Source: Field data.

Table 4.4: Effect of activated-carbonized sawdust dosage on adsorption of Nickel ion

S/N	Sawdust Dosage (g)	Initial concentration (Mg/g)	Equilibrium concentration (Mg/g)	Amount Adsorbed (%)
1	0.1	100	0.25	99.75
2	0.2	100	0.09	99.91
3	0.3	100	0.05	99.95
4	0.4	100	0.03	99.97

Source: Field data (2019)

Effect of activated-carbonized sawdust dosage for Nickel ion

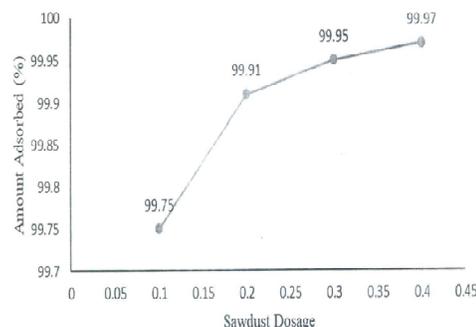


Figure 4.2: Amount of Nickel ion adsorbed by activated-carbonized sawdust as a function of sawdust dosage. Source: Field data.

Table 4.5: Effect of pH of unmodified sawdust on adsorption of Nickel ion

S/N	pH	Initial concentration (Mg/g)	Equilibrium concentration (Mg/g)	Amount Adsorbed (%)
1	3	100	6.48	93.52
2	4	100	1.62	98.38
3	5	100	0.81	99.19
4	6	100	0.58	99.42

Source: Field data (2019)

Effect of pH of unmodified sawdust of Nickel ion

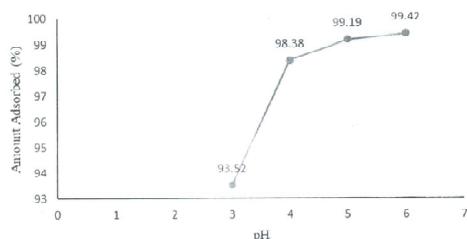


Figure 4.3: Amount of Nickel ion adsorbed by unmodified sawdust as a function of pH. Source: Field data.

Table 4.6: Effect of pH of activated-carbonized sawdust on adsorption of Nickel ion

S/N	pH	Initial concentration (Mg/g)	Equilibrium concentration (Mg/g)	Amount Adsorbed (%)
1	3	100	3.20	96.80
2	4	100	0.65	99.35
3	5	100	0.37	99.63
4	6	100	0.27	99.73

Source: Field data (2019)

Effect of pH of activated-carbonized for Nickel ions

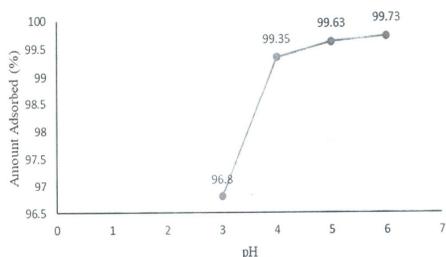


Figure 4.4: Amount of Nickel ion adsorbed by the activated-carbonized sawdust as a function of pH. Source: Field data.

Table 4.7: Effect of contact time of unmodified sawdust on adsorption of Nickel ion

S/N	Contact Time (Min)	Initial concentration (Mg/g)	Equilibrium concentration (Mg/g)	Amount Adsorbed (%)
1	20	100	2.744	97.26
2	40	100	1.27	98.73
3	80	100	0.84	99.16
4	100	100	0.60	99.40
5	120	100	0.46	99.54

Source: Field data (2019)

Effect of Contact Time for unmodified sawdust for Nickel ion

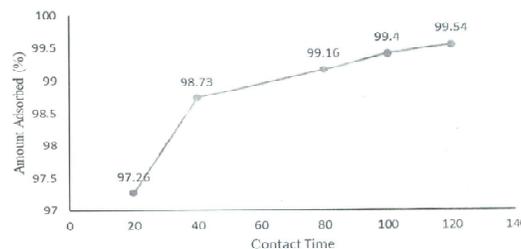


Figure 4.5: Amount of nickel ion adsorbed by unmodified sawdust as a function of contact time. Source: Field data.

Table 4.8: Effect of contact time of activated-carbonized sawdust on adsorption of Nickel ion

S/N	Contact Time (Min)	Initial concentration (Mg/g)	Equilibrium concentration (Mg/g)	Amount Adsorbed (%)
1	20	100	1.14	98.86
2	40	100	0.53	99.47
3	80	100	0.35	99.65
4	100	100	0.26	99.74
5	120	100	0.15	99.85

Source: Field data (2019)

Effect of contact time for Activated-Carbonized Sawdust for Nickel ion

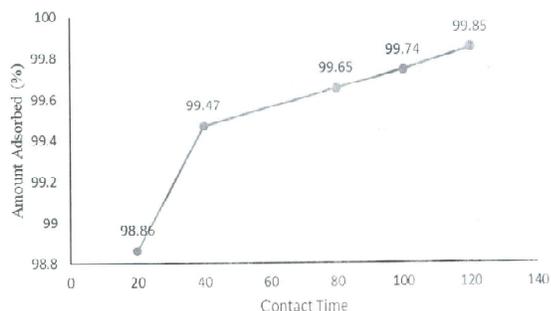


Figure 4.6: Amount of Nickel ion adsorbed by activated-carbonized sawdust as a function of contact time. Source: Field data.

4.4 Results for Adsorption of Cadmium Ion by Unmodified Sawdust and Activated-Carbonized Sawdust

The following tables below were obtained from the results obtained from AAS analysis that was carried out on the various filtrates obtained from the experimentation using unmodified sawdust and the activated-carbonized sawdust to adsorb cadmium ions.

Table 4.9: Effect of unmodified sawdust dosage on adsorption of Cadmium ion

S/N	Sawdust Dosage (g)	Initial concentration (Mg/g)	Equilibrium concentration (Mg/g)	Amount Adsorbed (%)
1	0.1	100	1.04	98.96
2	0.2	100	0.51	99.49
3	0.3	100	0.32	99.68
4	0.4	100	0.26	99.74

Source: Field data (2019)

Effect of unmodified sawdust dosage for Cadmium ion

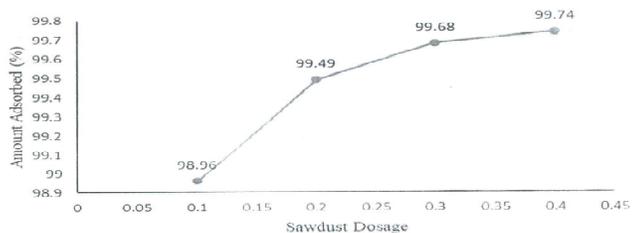


Figure 4.7: Amount of Cadmium ion adsorbed by unmodified sawdust as a function of sawdust dosage. Source: Field data.

Table 4.10: Effect of activated carbonized sawdust dosage on adsorption of Cadmium ion

S/N	Sawdust Dosage (g)	Initial concentration (Mg/g)	Equilibrium concentration (Mg/g)	Amount Adsorbed (%)
1	0.1	100	0.16	99.84
2	0.2	100	0.07	99.93
3	0.3	100	0.05	99.95
4	0.4	100	0.03	99.97

Source: Field data (2019)

Effect of Activated Carbonized Sawdust Dosage for Cadmium ion

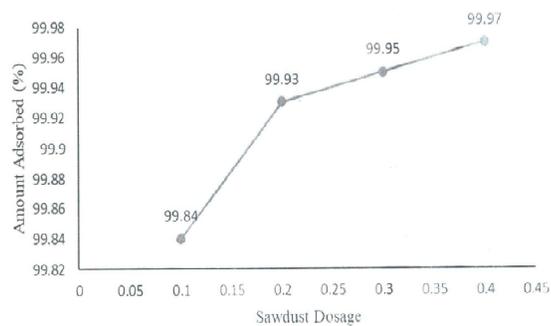


Figure 4.8: Amount of Cadmium ion adsorbed by activated-carbonized sawdust as a function of sawdust dosage. Source: Field data.

Table 4.11: Effect of pH unmodified sawdust on adsorption of Cadmium ion

S/N	pH	Initial concentration (Mg/g)	Equilibrium concentration (Mg/g)	Amount Adsorbed (%)
1	3	100	0.21	99.97
2	4	100	0.09	99.91
3	5	100	0.06	99.94
4	6	100	0.04	99.96

Source: Field data (2019)

Effect of pH Unmodified Sawdust for Cadmium ion

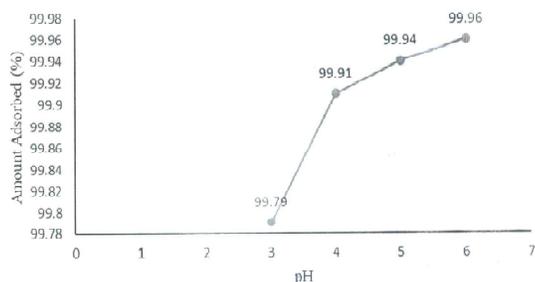


Figure 4.9: Amount of Cadmium ion adsorbed by unmodified sawdust as a function of pH. Source: Field data.

Table 4.13: Effect of contact time of unmodified sawdust on adsorption of Cadmium ion

S/N	Contact time	Initial concentration (Mg/g)	Equilib
1	20	100	
2	40	100	
3	80	100	
4	100	100	
5	120	100	

Source: Field data (2019)

Effect of Contact Time of Unmodified Sawdust for Cadmium ion

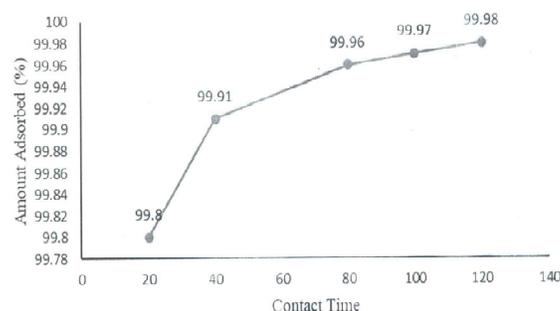


Figure 4.11: Amount of Cadmium ion adsorbed by unmodified sawdust as a function of contact time. Source: Field data.

Table 4.12: Effect of pH activated-carbonized sawdust on adsorption of Cadmium ion

S/N	pH	Initial concentration (Mg/g)	Equilib
1	3	100	
2	4	100	
3	5	100	0.01
4	6	100	0.0025

Source: Field data (2019)

Effect of pH Activated-Carbonized Sawdust for Cadmium ion

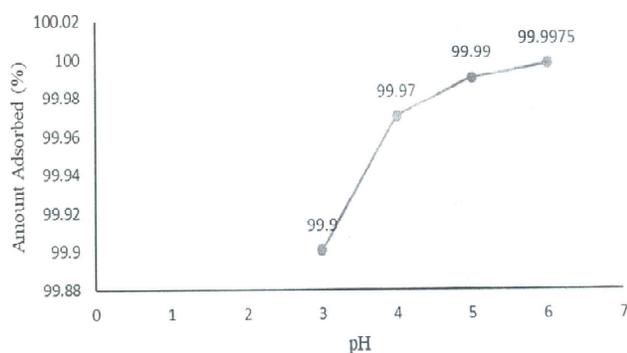


Figure 4.10: Amount of Cadmium ion adsorbed by activated-carbonized sawdust as a function of pH. Source: Field data.

Table 4.14: Effect of contact time of activated-carbonized sawdust on adsorption of Cadmium ion

S/N	Contact time	Initial concentration (Mg/g)	Equilib
1	20	100	
2	40	100	
3	80	100	
4	100	100	
5	120	100	

Source: Field data (2019)

Effect of contact time of Activated Carbonized Sawdust for Cadmium ion

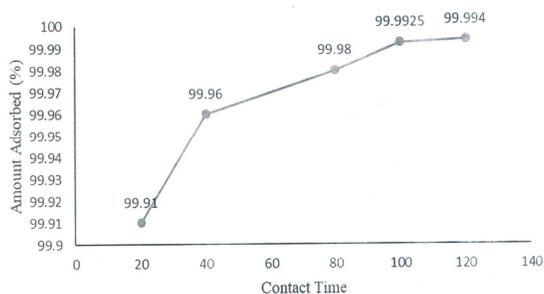


Figure 4.12: Amount of Cadmium ion adsorbed by activated-carbonized sawdust as a function of Contact Time.
Source: Field data

4.5 Discussion

The results obtained shows that the higher the sawdust dosage for both Nickel and Cadmium ions, the higher the adsorption rate but in comparison with the graphs, it was noticed that the activated-carbonized sawdust adsorbed more heavy metal ions than the unmodified sawdust samples. A careful examination of the pH of unmodified sawdust sample indicates that at pH 3, about 93.52 mg/kg Nickel ions was absorbed while for Cadmium, at the same pH, 99.79 mg/kg was adsorbed. At pH4, 98.38 mg/kg Nickel ions was adsorbed while 99.91 mg/kg Cadmium ions was adsorbed. At pH5, 99.19 mg/kg Nickel ions was adsorbed while 99.94 mg/kg Cadmium ions was adsorbed. At pH6, 99.42 mg/kg Nickel ions was adsorbed while 99.96 mg/kg of Cadmium ions was adsorbed. Therefore, it follows the sequence that as the pH increases, the amount of toxic metals adsorbed by the adsorbent increases. The same phenomenon is applicable to the pH of the activated-carbonized sawdust only that in its case it absorbs more toxic metals than the unmodified sawdust sample. As an example, at pH3, the activated-carbonized sawdust adsorbs 96.82 mg/kg Nickel ions and 99.90 mg/kg mg/kg Cadmium ions respectively. At pH4, it adsorbs 99.35 mg/kg ions and 99.97 mg/kg Cadmium ions. At pH5, 99.63 mg/kg of Nickel ions and 99.99 mg/kg of Cadmium ions. At pH6, 99.73 mg/kg of Nickel ions was adsorbed by the activated-carbonized sawdust while 99.9975 mg/kg of Cadmium ions was adsorbed; thereby indicating that the activated

carbonized sawdust adsorbs more in comparison with the unmodified sawdust. The effect of contact time for Nickel and Cadmium ions respectively, shows that as the time is increased from about 20 minutes to 120 minutes, the adsorption rate is also increasing.

Therefore, the result obtained indicates that an increase in sawdust dosage, contact time, and the pH, for both the Nickel ions and the Cadmium ions, resulted in an increase in the adsorption rate.

Consequently, we can rightly say that adsorption rate increases with an increase in adsorbent dosage, the contact time, and the pH.

From the graph and the results, it was observed that the activated-carbonized Sawdust adsorbed more than the unmodified sawdust and this is because activation of the adsorbent increases the surface area and the porosity of the carbon structure thereby causing the activated adsorbent to adsorb more toxic metals in comparison with the unmodified sawdust. The selectivity order for adsorption in terms of an increase in adsorption rate is: Activated-carbonized Sawdust > Unmodified Sawdust Sample.

5.1 SUMMARY

This section summarizes the findings of the study. The synopsis of this research ascertains that:

- i. *Lophiraalata* wood sawdust is a good adsorbent for the removal of heavy metals from contaminated water.
- ii. The activated carbonized form of *Lophiraalata* sawdust is most preferable for the removal of toxic contaminants from industrial sludge.
- iii. An increase in sawdust dosage, contact time and pH results in a resultant increase in the adsorption rate.

5.2 Conclusion

The following conclusions can be drawn based on the comparative study of heavy metals ion removal by the *Lophiraalata* wood sawdust adsorption. First of all, the *Lophiraalata* is a very good and effective low-cost adsorbent for the removal of heavy metal ions from waste water. Secondly, the activated-carbonized Sawdust is most

effective for heavy metal removal in aqueous solutions.

5.3 Engineering Implications Of Findings

From the analysis carried out, it is deduced that industrial sludge is heavily contaminated with heavy metals. The contaminants can be reduced using a low-cost adsorbent (*Lophiraalata* sawdust and its activated carbonized form of sawdust) at optimum. Consequently, justified remedial steps in sludge treatment would result to eliminate the heavy metals from industrial waste. This could be achieved through proper engineering master plan.

5.4 Contribution to Knowledge

This study has been able to contribute as other scholars that heavy metals can be removed from water using *Lophiraalata* sawdust in its unmodified and activated carbonized form. This *Lophiraalata* has some unique soptive properties which makes them very useful for adsorption.

Furthermore, because of its hardness and resistance properties, *Lophiraalata* wood is well appreciated in construction works for extreme conditions including hydraulic works, marine construction, bridges, etc.

Ultimately, *Lophiraalata* sawdust has a high energy value. It is a good source of fuel.

5.5 Recommendations

Heavy metals are non-biodegradable and can lead to accumulation of heavy organisms thereby causing various diseases and disorders. For this note, this finding is recommending for:

- i. Communities that lack access to well treated water and purification. By improving household water and purification access will impact household finances and ultimately the economy at large.
- ii. Areas where industrial effluents have negative effects on the water quality which may turn to affect the end users.
- iii. Rural areas with limited or no access to basic amenity like pipe borne water.
- iv. The Federal Government Agency, Multinational companies and Non-governmental organizations (National and International) to fund this research work to

ensure that heavy metals contaminated water is treated in larger volume as the demand of water for domestic and industrial use is high.

- v. The Standard Organization of Nigeria (SAN) to approve and certify this finding.

5.6 Suggestions for Further studies

The following propositions are hereby made for more studies:

- i. Transportation and building Engineers have to consider *Lophoraalata* wood because of its hardness and resistant properties. It can be used as roof beams, supports in building structures and likewise in setting-up wooden bridges particularly in rural areas, and so forth.
- ii. Additional studies should be carried out to ascertain the use of *Lophiraalata* sawdust in its unmodified and modified form to eliminate calcium and magnesium in hard water.
- iii. Other methodical tools not used throughout this data examination process should be used to further determine the degree of dissimilarities in *Lophiraalata* sawdust in cooperation with its unmodified and modified form to eliminate heavy metal contaminated water.

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Unmodified sawdust	1.04	1.03	0.96	0.95
Activated carbonized sawdust	0.16	0.15	0.15	0.14

APPENDICES

APPENDIX 1: PREPARATION OF STOCK SOLUTION

Relative Molecular Mass of the Salt Compound

Atomic Mass of the Salt

Appendix 1.1: Stock Solution for Nickel

$$\frac{\text{NiSO}_4}{\text{Ni}} = \frac{154.756}{58.6934} = 2.64\text{g/mol}$$

Therefore, 2.64g/mol of NiSO⁴ was diluted in 1000 ml of distilled water to give a shock solution of 1000ppm.

Appendix 1.2: Stock Solution for Cadmium

$$\frac{\text{cdSO}_4}{\text{cd}} = \frac{208.4736}{112.411} = 1.85\text{g/mol}$$

Therefore, 1.85g/mol of cdSO₄ was diluted in 1000 ml of distilled water to give a shock solution of 1000ppm.

APPENDIX 2: SERIAL DILUTION

$$C_1 V_1 = C_2 V_2$$

Where C₁ = Concentration of stock solution, V₁ = volume of Aliquot taken from stock solution

C₂ = Final concentration, V₂ = Volume of flask used for serial dilution

APPENDIX 3: RESULTS FROM ATOMIC ADSORPTION SPECTROPHOTOMETE R (AAS) ANALYSIS

The following results were the results obtained directly from the Atomic Adsorption Spectrophotometer (AAS) machine before calculations and graphs were plotted:

Appendix 3.1: Sawdust Dosage for Nickel

SAWDUST DOSAGE	0.1	0.2	0.3	0.4
Unmodified sawdust	2.24	2.22	2.21	2.18
Activated carbonized sawdust	0.25	0.19	0.14	0.13

Appendix 3.2: Sawdust Dosage for Cadmium

SAWDUST DOSAGE	0.1	0.2	0.3	0.4
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Appendix 3.3: Effect of pH on Nickel

PH	3	4	5	6
Unmodified sawdust	6.48	3.24	2.42	2.32
Activated carbonized sawdust	3.20	1.30	1.10	1.09

Appendix 3.4: Effect of pH on Cadmium

PH	3	4	5	6
Unmodified sawdust	0.21	0.18	0.17	0.17
Activated carbonized sawdust	0.10	0.06	0.03	0.01

Appendix 3.5: Effect of Contact Time on Nickel

CONTACT TIME	20	40	80	100	120
Unmodified Sawdust	2.74	2.54	2.51	2.24	2.30
Activated carbonized sawdust	1.14	1.06	1.05	1.04	0.77

Appendix 3.5: Effect of Contact Time on Cadmium

CONTACT TIME	20	40	80	100	120
Unmodified Sawdust	0.20	0.17	0.13	0.10	0.10
Activated carbonized sawdust	0.09	0.07	0.05	0.03	0.03

APPENDIX 4: CALCULATION FROM AAS ANALYSIS

(Machine Reading – Blank) x Aliquot Digest

Weight of the Adsorbent

$$\frac{\text{MgL}^{-1}}{\text{g}} = \text{Mg/g} = \text{ppm}$$

Where Blank = 0, Aliquot Digest = 100ml = 0.1l.

Weight of the Adsorbent = Adsorbent dosage (0.1, 0.2, 0.3, 0.4)

Appendix 4.1: Effect of Unmodified Sawdust Dosage on Nickel and Cadmium

S/N	NICKEL	CADMIUM
1.	$\frac{2.24 \times 0.1}{0.1} = 2.24 \text{ Mg/g}$	$\frac{1.04 \times 0.1}{0.1} = 1.04 \text{ Mg/g}$
2.	$\frac{2.22 \times 0.1}{0.2} = 1.11 \text{ Mg/g}$	$\frac{1.03 \times 0.1}{0.2} = 0.51 \text{ Mg/g}$
3.	$\frac{2.21 \times 0.1}{0.3} = 0.74 \text{ Mg/g}$	$\frac{0.96 \times 0.1}{0.3} = 0.32 \text{ Mg/g}$
4.	$\frac{2.18 \times 0.1}{0.4} = 0.54 \text{ Mg/g}$	$\frac{0.95 \times 0.1}{0.4} = 0.26 \text{ Mg/g}$

Appendix 4.2: Effect of Activated-Carbonized Sawdust Dosage on Nickel and Cadmium

S/N	NICKEL	CADMIUM
1.	$\frac{2.25 \times 0.1}{0.1} = 0.25 \text{ Mg/g}$	$\frac{0.16 \times 0.1}{0.1} = 0.16 \text{ Mg/g}$
2.	$\frac{0.19 \times 0.1}{0.2} = 0.09 \text{ Mg/g}$	$\frac{0.15 \times 0.1}{0.2} = 0.07 \text{ Mg/g}$
3.	$\frac{0.14 \times 0.1}{0.3} = 0.05 \text{ Mg/g}$	$\frac{0.15 \times 0.1}{0.3} = 0.05 \text{ Mg/g}$
4.	$\frac{0.13 \times 0.1}{0.4} = 0.03 \text{ Mg/g}$	$\frac{0.14 \times 0.1}{0.4} = 0.03 \text{ Mg/g}$

Appendix 4.3: Effect of pH Sawdust Dosage on Nickel and Cadmium

S/N	NICKEL	CADMIUM
1.	$\frac{6.48 \times 0.1}{0.1} = 6.48 \text{ Mg/g}$	$\frac{0.21 \times 0.1}{0.1} = 0.21 \text{ Mg/g}$
2.	$\frac{3.24 \times 0.1}{0.2} = 1.62 \text{ Mg/g}$	$\frac{0.18 \times 0.1}{0.2} = 0.09 \text{ Mg/g}$
3.	$\frac{2.42 \times 0.1}{0.3} = 0.81 \text{ Mg/g}$	$\frac{0.17 \times 0.1}{0.3} = 0.06 \text{ Mg/g}$
4.	$\frac{2.32 \times 0.1}{0.4} = 0.58 \text{ Mg/g}$	$\frac{0.17 \times 0.1}{0.4} = 0.04 \text{ Mg/g}$

Appendix 4.4: Effect of pH on Nickel and Cadmium for Activated-Carbonized Sawdust

S/N	NICKEL	CADMIUM
1.	$\frac{3.20 \times 0.1}{0.1} = 3.20 \text{ Mg/g}$	$\frac{0.10 \times 0.1}{0.1} = 0.10 \text{ Mg/g}$
2.	$\frac{1.30 \times 0.1}{0.2} = 0.65 \text{ Mg/g}$	$\frac{0.6 \times 0.1}{0.2} = 0.03 \text{ Mg/g}$
3.	$\frac{1.10 \times 0.1}{0.3} = 0.37 \text{ Mg/g}$	$\frac{0.03 \times 0.1}{0.3} = 0.01 \text{ Mg/g}$
4.	$\frac{1.09 \times 0.1}{0.4} = 0.27 \text{ Mg/g}$	$\frac{0.01 \times 0.1}{0.4} = 0.0025 \text{ Mg/g}$

Appendix 4.5: Effect of Contact Time on Nickel and Cadmium for Unmodified Sawdust

S/N	NICKEL	CADMIUM
1.	$\frac{2.74 \times 0.1}{0.1} = 2.74 \text{ Mg/g}$	$\frac{0.20 \times 0.1}{0.1} = 0.20 \text{ Mg/g}$
2.		

	$\frac{2.54 \times 0.1}{0.2} = 1.27 \text{ Mg/g}$	$\frac{0.17 \times 0.1}{0.2} = 0.085 \text{ Mg/g}$
3.	$\frac{2.51 \times 0.1}{0.3} = 0.84 \text{ Mg/g}$	$\frac{0.13 \times 0.1}{0.3} = 0.04 \text{ Mg/g}$
4.	$\frac{2.42 \times 0.1}{0.4} = 0.60 \text{ Mg/g}$	$\frac{0.10 \times 0.1}{0.4} = 0.025 \text{ Mg/g}$
5.	$\frac{2.30 \times 0.1}{0.5} = 0.46 \text{ Mg/g}$	$\frac{0.10 \times 0.1}{0.5} = 0.02 \text{ Mg/g}$

1.	$\frac{100-2.24}{100} \times 100 = 97.76\%$	$\frac{100-1.04}{100} \times 100 = 98.96\%$
2.	$\frac{100-1.11}{100} \times 100 = 98.89\%$	$\frac{100-0.51}{100} \times 100 = 99.49\%$
3.	$\frac{100-0.74}{100} \times 100 = 99.26\%$	$\frac{100-0.32}{100} \times 100 = 99.68\%$
4.	$\frac{100-0.54}{100} \times 100 = 99.46\%$	$\frac{100-0.26}{100} \times 100 = 99.74\%$

Appendix 4.6: Effect of Contact Time on Nickel and Cadmium for Activated Carbonized Sawdust

S/N	NICKEL	CADMIUM
1.	$\frac{1.14 \times 0.1}{0.1} = 1.14 \text{ Mg/g}$	$\frac{0.09 \times 0.1}{0.1} = 0.09 \text{ Mg/g}$
2.	$\frac{1.06 \times 0.1}{0.2} = 0.53 \text{ Mg/g}$	$\frac{0.00 \times 0.1}{0.2} = 0.035 \text{ Mg/g}$
3.	$\frac{1.05 \times 0.1}{0.3} = 0.35 \text{ Mg/g}$	$\frac{0.05 \times 0.1}{0.3} = 0.02 \text{ Mg/g}$
4.	$\frac{1.04 \times 0.1}{0.4} = 0.26 \text{ Mg/g}$	$\frac{0.03 \times 0.1}{0.4} = 0.075 \text{ Mg/g}$
5.	$\frac{0.77 \times 0.1}{0.5} = 0.15 \text{ Mg/g}$	$\frac{0.03 \times 0.1}{0.5} = 0.006 \text{ Mg/g}$

Appendix 5.2: Percentage Amount of Nickel and Cadmium Absorbed due to the Effect of Activated Carbonized Sawdust Dosage

S/N	NICKEL	CADMIUM
1.	$\frac{100-0.25}{100} \times 100 = 99.75\%$	$\frac{100-0.16}{100} \times 100 = 99.84\%$
2.	$\frac{100-0.09}{100} \times 100 = 99.91\%$	$\frac{100-0.07}{100} \times 100 = 99.93\%$
3.	$\frac{100-0.05}{100} \times 100 = 99.95\%$	$\frac{100-0.05}{100} \times 100 = 99.95\%$
4.	$\frac{100-0.03}{100} \times 100 = 99.97\%$	$\frac{100-0.03}{100} \times 100 = 99.97\%$

APPENDIX 5: CALCULATION OF PERCENTAGE AMOUNT ADSORBED

$$\frac{\text{Initial Concentration} - \text{Equilibrium Concentration}}{\text{Initial Concentration}} \times 100$$

Appendix 5.1: Percentage Amount of Nickel and Cadmium Absorbed due to the Effect of Unmodified Sawdust Dosage

S/N	NICKEL	CADMIUM
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Appendix 5.3: Percentage Amount of Nickel and Cadmium Absorbed due to the Effect of pH Unmodified Sawdust

S/N	NICKEL	CADMIUM
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1.	$\frac{100-6.48}{100} \times 100 = 93.52\%$	$\frac{100-0.21}{100} \times 100 = 99.97\%$
2.	$\frac{100-1.62}{100} \times 100 = 98.38\%$	$\frac{100-0.09}{100} \times 100 = 99.91\%$
3.	$\frac{100-0.81}{100} \times 100 = 99.91\%$	$\frac{100-0.06}{100} \times 100 = 99.94\%$
4.	$\frac{100-0.58}{100} \times 100 = 99.42\%$	$\frac{100-0.04}{100} \times 100 = 99.96\%$

Appendix 5.4: Percentage Amount of Nickel and Cadmium Absorbed due to the Effect of pH Activated Carbonized Sawdust

S/N	NICKEL	CADMIUM
1.	$\frac{100-3.20}{100} \times 100 = 96.80\%$	$\frac{100-0.10}{100} \times 100 = 99.90\%$
2.	$\frac{100-0.65}{100} \times 100 = 99.35\%$	$\frac{100-0.03}{100} \times 100 = 99.97\%$
3.	$\frac{100-0.37}{100} \times 100 = 99.63\%$	$\frac{100-0.01}{100} \times 100 = 99.99\%$
4.	$\frac{100-0.27}{100} \times 100 = 99.73\%$	$\frac{100-0.0025}{100} \times 100 = 99.9975\%$

Appendix 5.5: Percentage Amount of Nickel and Cadmium Absorbed due to the

Effect of Contact Time for unmodified Sawdust

S/N	NICKEL	CADMIUM
1.	$\frac{100-2.74}{100} \times 100 = 97.26\%$	$\frac{100-0.20}{100} \times 100 = 99.80\%$
2.	$\frac{100-1.27}{100} \times 100 = 98.73\%$	$\frac{100-0.085}{100} \times 100 = 99.91\%$
3.	$\frac{100-0.84}{100} \times 100 = 99.16\%$	$\frac{100-0.04}{100} \times 100 = 99.96\%$
4.	$\frac{100-0.60}{100} \times 100 = 99.40\%$	$\frac{100-0.025}{100} \times 100 = 99.97\%$
5.	$\frac{100-0.46}{100} \times 100 = 99.54\%$	$\frac{100-0.02}{100} \times 100 = 99.98\%$

Appendix 5.6: Percentage Amount of Nickel and Cadmium Absorbed due to the Effect of Contact Time for Activated Carbonized Sawdust

S/N	NICKEL	CADMIUM
1.	$\frac{100-1.14}{100} \times 100 = 98.86\%$	$\frac{100-0.09}{100} \times 100 = 99.91\%$
2.	$\frac{100-0.53}{100} \times 100 = 99.47\%$	$\frac{100-0.035}{100} \times 100 = 99.96\%$
3.	$\frac{100-0.35}{100} \times 100 = 99.65\%$	$\frac{100-0.02}{100} \times 100 = 99.98\%$
4.	$\frac{100-0.26}{100} \times 100 = 99.74\%$	$\frac{100-0.0075}{100} \times 100 = 99.9925\%$

5	$\frac{100-0.15}{100} \times 100 = 99.85\%$	$\frac{100-0.006}{100} \times 100 = 99.994\%$
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