



## Research Article

# Adsorption of Hg(II) Ions from Aqueous Solution Using Doum Palm Shell: Desorption and Effluent Treatment

<sup>1</sup>Alkali, M. I. and <sup>2</sup>Kyari, A.U.

<sup>1</sup>Department of Chemistry, Kashim Ibrahim University, Maiduguri, Borno State, Nigeria

<sup>2</sup>Department of Geography, Kashim Ibrahim University, Maiduguri, Borno State, Nigeria

\*Corresponding author's Email: [ibrambnanabe@gmail.com](mailto:ibrambnanabe@gmail.com), [doi.org/10.55639/607.020100114](https://doi.org/10.55639/607.020100114)

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### ABSTRACT

The contamination of water bodies by heavy metals, particularly mercury (Hg<sup>2+</sup>), poses significant environmental and public health challenges due to their toxicity, persistence, and bioaccumulative nature. This research investigates the potential of carbonized Doum palm shell (DPS) (*Hyphaene thebaica*) as a low-cost for the adsorption of Hg(II) ions from aqueous solutions and real industrial effluent. The adsorbent was prepared via pyrolysis under controlled conditions and characterized using physicochemical and advanced analytical techniques such as FTIR, XRD, SEM-EDX, and BET surface area analysis. Batch adsorption experiments were conducted to evaluate the effects of operational parameters including initial metal ion concentration, pH, contact time, temperature and adsorbent dosage. The results revealed that adsorption efficiency was highly dependent on pH 7 with optimal Hg(II) ions removal. The maximum adsorption capacity observed was 254.63 mg/g at 45 mg/L. The BET analysis showed a high surface area 960.650 m<sup>2</sup>/g, confirming the mesoporous nature of the material, while SEM analysis revealed a well-developed porous structure suitable for adsorption. Application of the adsorbent to real textile effluent demonstrated an outstanding removal efficiency of 99.68 %, reducing mercury concentration close to permissible limits. Desorption studies using dilute acids (HCl and HNO<sub>3</sub>) indicated that the adsorbent could be regenerated and reused, with HCl showing superior desorption efficiency. The adsorption mechanism was predominantly governed by ion-exchange processes. The findings demonstrate that Doum palm shell-derived activated carbon is effective, eco-friendly, and economically viable material for mercury removal from contaminated water, offering promising potential for wastewater treatment applications in developing regions.

**Corresponding author:** Alkali, M. I, **Email:** [ibrambnanabe@gmail.com](mailto:ibrambnanabe@gmail.com)

Department of Chemistry, Kashim Ibrahim University, Maiduguri, Borno State, Nigeria

## 1.0 INTRODUCTION

The origin of the large quantities of aqueous effluents that contain high level of heavy metals is as a result of the extended use of metals and chemicals in the process industries and agricultural activities, which tends to pose difficult environmental disposal challenges (Abdus-Salam *et al.*, 2021). Heavy metals, which are not biodegradable (Adegoke *et al.*, 2023) are therefore of great concern because they are being added to water, soil and air in increasing amounts. They are toxic to human health when consumed at relatively high amounts and may cause serious health problems upon long term exposures. This makes their effective removal from water sources within a reasonable cost, an important issue (Abdullahi and Alkali, 2023). Existing technologies for metal ion removal from water are expensive; some of which include ion exchange resin, solvent extraction, electrolytic and precipitation processes, electro-dialysis and membrane technology (Alkali *et al.*, 2022). Other conventional technologies which have also been used ranged from granular activated carbon to reverse osmosis. These processes are however, not economically feasible for small scale industries prevalent in developing economies due to large capital investment (Godwin *et al.*, 2022). Since most conventional methods are neither effective nor economical, especially when used for the reduction of heavy metal ions to low concentrations, new separation methods are required to reduce heavy metal concentrations to environmentally acceptable levels at affordable cost. Bio-removal has the potential to contribute to the achievement of this goal (Adebayo *et al.*, 2015).

Because of the demand for products and the increase in industries, the exploitation and use of heavy metals have intensified exponentially, generating an increase in the metal ion production that, at high concentrations, are toxic to ecosystems such as Hg(II), As(III), Cd(II) and Pb(II) among others (Naharro *et al.*, 2020). The high demand for products, especially certain metals such gold, extracted by mining, has caused serious damage to ecosystems because of the release of heavy metals such as mercury (Vareda *et al.*, 2019).

Mercury and its compounds, especially organomercuric species, are related to various diseases and cause damage to organisms where they accumulate, from bacteria and small organisms to mammals and humans. As a result, organic compounds such as methylmercury have the highest levels of toxicity (Morton-Bermea *et al.*, 2015). Thus, in fish and other mammals, mercury more precisely in its methylated form ( $\text{CH}_3\text{Hg}^+$ ) tends to pass through the intestinal wall when ingested, and accumulates in the muscle tissue, thus generating the phenomenon of biomagnification. In humans, methylmercury is associated with different biological damage such as a congenital lesion, teratogenic and carcinogenic effects, gastroenteritis, ataxia, loss of vision, and it directly affects fetal development in humans (Vareda *et al.*, 2019).

Several natural and synthetic adsorbent materials have been tested for adsorbing toxic contaminants from aqueous media. Adsorbent efficiency of various low-cost organic materials and agricultural waste products has been optimized for Cr(VI) removal using Desert Date Seeds (Alkali *et al.*, 2022), Comparative adsorption studies of Cr(VI), Pb(II) and Cd(II) ions onto Tiger-nut activated carbon-zeolite composite by Ojo *et al.*, (2025) among many others.

Therefore, this research worked on the adsorption of Hg(II) ions from aqueous solution using doum palm shell: desorption and effluent treatment.

### 1.1 Doum palm (*Hyphaene thebaica*)

Doum palm (*Hyphaene thebaica*) Hyphaene is derived from the Greek word 'hyphaino' referring to the fibres from the leaves, which are used for weaving. Its common names are Dom (Arabic), doum palm, Egyptian doum palm, gingerbread palm (English) and Goruba (Hausa) (Alkali *et al.*, 2022). Doum palm (*Hyphaene thebaica*) is one of the most beneficial plants in the world (Islam *et al.*, 2022). This plant is also distributed in desert and subtropical regions of the world (Mansur, 2021). *Hyphaene thebaica* as a common palm tree with edible fruit belongs to the family called Arecaceae. It also grows very well in the northern part of Nigeria. The oval, apple-sized bright orange fruit has a reddish shell, a dense, spongy, delicious, fibers rich fruit flesh with a gingerbread-like flavor, and a big

kernel and the fruit's coating is eatable and may be crushed into powder or sliced into pieces. The fruit has a sweet taste (Islam *et al.*, 2022; Sabre *et al.*, 2022).

Doum fruit is an excellent source of carbohydrate, micronutrients such as vitamins especially niacin, folic acid, pyridoxine, riboflavin, and thiamin and important minerals like potassium, sodium, calcium, magnesium, as well as phosphorus (Inuwa *et al.*, 2023). Doum is considered to contain higher moisture content, crude fiber, ash content, protein, fat, and vitamins (Islam *et al.*, 2022). Doum fruits are rich in fibers, antioxidants, B-complex vitamins, essential minerals in the epicarp and mesocarp, and have a considerable content of



**Fig. 1.1:** Doum palm (*Hyphaene thebaica*) shells

### 1.2 Preparation of the Adsorbent

The edible parts of the Doum palm (*Hyphaene thebaica*) were removed leaving behind the shell as waste, which was thoroughly washed with distilled water to remove the impurities according to the method adopted by Abdus-Salam and Ikudayisi (2017). The samples were dried at a room temperature. A 20 g of the sample was weighed and transferred into clean a porcelain crucible and was carbonized at 500 °C for 1 hr in a pyrolyser under inert environment by slight method of Adebayo *et al.*, (2014). The carbonized material was allowed to cool in a desiccator. After cooling, the carbonized materials were weighed to determine the percentage carbon yield according to the method adopted from ((Etong *et al.*, 2024).

$$\% \text{ Carbon Yield (CY)} = \frac{\text{weight of the product}}{\text{weight of the starting material}} \times 100 \quad (1)$$

monosaccharides such as glucose and fructose (Shady *et al.*, 2021).

It is used in different countries particularly here in Maiduguri for the treatment of diabetes, obesity, hypertension, dyslipidemias and to reduce cardiovascular diseases (Shamandy & Saad, 2022). The fruits are transformed in traditional beverages, juice, jelly or puree and usually used to prepare nutritive diets, and other food products. The fruit has been a popular component of tea preparation consumed for refreshment, regulation of body weight and blood glucose (Kolla *et al.*, 2021). However, after removing the flesh part the shell has no or less economic value.

Thereafter, the material was pulverised using mortar and pestle to reduce the size to 0.1 mm particle sizes. Thereafter, the fine carbonized sample was labelled appropriately and kept in polyethylene bottles for adsorption experiment according to the method adopted from Abdus-Salam and Buhari (2016). The extent of adsorption was calculated using the formula in equation (1.2).

## 2.0 MATERIALS AND METHODS

### 2.1 Adsorbent Preparation and Analysis

Doum Palm Shells were purchased from custom market Maiduguri, Borno State. The adsorbent was successfully prepared and carbonized using pyrolyzer under nitrogen condition at 500 °C for 2 hrs. The activated carbon was allowed to cooled in a desiccator and used for physico-chemical analysis, characterization as well as adsorption studies. All reagents used in this

work were of analytical grade. The stock solution of mercury was prepared from  $\text{HgCl}_2$  (Sigma-Aldrich, 99%),  $\text{HCl}$  (Merck),  $\text{HNO}_3$  (Merck)  $\text{NaCl}$  (Sigma-Aldrich, 99%) were also used in the research. All glassware and polyethylene materials were previously treated for 24 hrs in 10% (v:v) nitric acid and rinsed with deionized water (Milli-Q  $18.2\text{M}\Omega\text{ cm}^{-1}$  resistivity).

The adsorption efficiencies of the adsorbent were prepared in the laboratory has been studied in the laboratory. The prepared adsorbents were characterized by some physicochemical and spectroscopic methods such as Fourier Transform Infrared (FTIR) for surface functional group, X-ray Diffraction (XRD) for crystallinity, Scanning Electron Microscopy coupled with energy dispersive X-ray (SEM-EDX) structural morphology and elemental analysis and Bruner Emit Teller (BET) for surface area analysis.

## 2.2 Characterization of the Adsorbent

The Doum Palm Shell (DPS) adsorbent was characterized by physico-chemical methods such as bulk density, pH, point of zero charge, micropore volume and surface area. The pH of the DPS suspension in water was determined using 1:10 mass/volume mixture ratio with a pH meter (pHS-25 model) (Adegoke *et al.*, 2017). The bulk density of the DPS was determined by Archimedes' principle (Adebayo *et al.*, 2020). The point of zero charge (pzc) of the adsorbent was determined by using mass titration Abdus-Salam and Buhari, (2014) and potentiometric methods. Surface area, micropore volume and micropore area of the adsorbent was determined by BET Nitrogen adsorption and desorption isotherms at liquid nitrogen temperature (77K) using TRISTAR 3000 Surface area analyzer. A 0.3 g of sample was degassed in  $\text{N}_2$  at 77 K for 18 hrs prior to measurements. The adsorbent was further characterized using X-ray diffraction (PW3050/60 Goniometer), Infra-red (Perkin Elmer FT-IR Spectrometer 1000) and Scanning Electron Microscopy (Leo 1430VP and FEI Nova NanoSEM 230) coupled with EDX.

## 2.3 Batch Adsorption Experiment

The influences of initial adsorbate concentration (0–50 mg/L), contact time (0–90 min), pH (2–10), adsorbent dosage (2–50 mg), speed (0–600 rpm) and temperature (20–80 °C) on the

adsorption processes were successfully investigated. The batch mode adsorption experiment was conducted by bringing into contact the 25 mL of  $\text{Hg}$  (II) ion solution with a specified quantity of the adsorbents in a set of each 250 mL conical flasks as prescribed by (Alkali *et al.*, 2022). The concentration of residual of the metal ions was determined by an Atomic Absorption Spectrophotometer (Bulk Scientific 210VP). The equilibrium amount of the metal ion adsorbed,  $q_e$ , (mg/g) and removal efficiency,  $R$  (%) will be calculated each by Equations (2) and (3) respectively:

$$q_e = \frac{v(c_i - c_e)}{M} \quad (2)$$

where  $q_e$  = the amount of solute adsorbed from solution (mg/g),  $V$  = volume of the adsorbate (L),  $c_i$  = the concentration before adsorption (mg/L),  $c_e$  = the concentration after adsorption (mg/L) and  $M$  = the mass of the adsorbent (g) (Alkali *et al.*, 2022b). The extent of adsorption will be calculated using the equation (3) (Abdus-Salam *et al.*, 2021b).

$$\% \text{ Adsorption} = \frac{c_i - c_e}{c_i} \times \frac{100}{1} \quad (3)$$

## 2.4 Real Effluent Analysis

The Effluent samples were collected mainly from Tie-dyeing area, Shehuri North, Maiduguri, Borno State. Effluents were digested by Gaya *et al.*, (2015) method as follows; concentrated  $\text{HNO}_3$  (5 ml) was added to 100 ml of effluent in a beaker which was covered. Equal volume of the  $\text{HNO}_3$  (5 ml) was added to the mixture and heated gently, until a light, clear solution was obtained. The cadmium, chromium and lead concentration of the raw effluent sample was determined using 210S12051104 atomic absorption spectrophotometer (AAS). The effluent was later subjected to adsorption with the Doum Palm Shell (DPS) adsorbent. A 0.01 g of the adsorbent are agitated with 20 ml of the effluent in a water bath shaker at 230 rpm for 5 hr. The analysis was performed in duplicates. The samples were filtered and filtrates were analysed using AAS. The percentage removal of the metals (Mercury) was calculated using the equation (3).

## 2.5 Desorption Experiment of the Adsorbents

Desorption studies create opportunity to investigate the regeneration and reusability of loaded precursors and composites used as

adsorbents in this study. The viability of adsorbents in practical applications is depending on their evaluation for the reusability due to the reduced cost of adsorption by the successful use of the adsorbent (Tahoon *et al.*, 2020). The basic

desorption mechanisms are ion-exchange, complexation and precipitation depending on the most effective desorbing agent (Dada *et al.*, 2018).

### 3.0 RESULTS AND DISCUSSION

#### 3.1 Point of Zero Charge

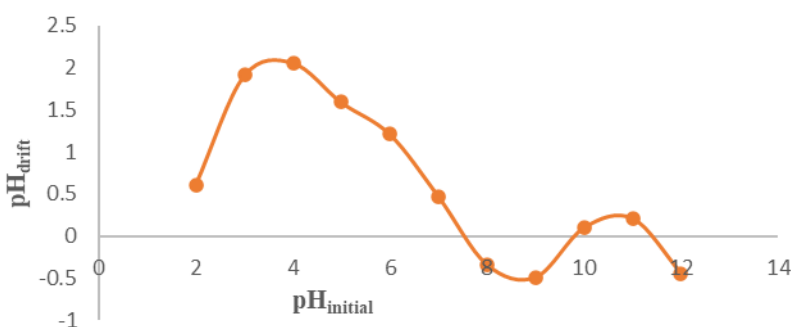


Fig. 3.1: Graph of pH<sub>pzc</sub> of DPS

The point of zero charge (pH<sub>pzc</sub>) is the pH at which the total number of positive and negative charges on the surface of the adsorbents becomes zero (Abdus-Salam and Adekola, 2005). This parameter is very important in the adsorption phenomena, especially when electrostatic forces are involved in the mechanisms (Sulejmanović *et al.*, 2019). The pH<sub>pzc</sub> is the point where the curve of pH final versus pH initial intersects (Nguyen *et al.*,

2019). The pH at zero-point charge in the DPS result obtained was above 7.0 as shown in Fig. 3.1. The results from Table 3.1 shows that at pH > pH<sub>pzc</sub> the surface is negatively charged which favours the adsorption of positively charged species such as Hg (II) ion (Nwosu *et al.*, 2018). A carbon of pH 6-8 is acceptable for most application such as for sugar decolourization, water treatment among other factors (Buhari *et al.*, 2020).

#### 3.2 Physico-chemical Results

Table 3.1: Summary of Physico-chemical Parameters of the DPS

Properties	Results
pH <sub>pzc</sub>	7.9
Ph	8.73
Carbon Yield (%)	73.48
Bulk Density (g/ml)	0.68
Iodine Number (mg/g)	540.89
Moisture Content (%)	4.09
Ash Content (%)	0.92
Volatile Matter (%)	1.05

It can be observed from Table 3.1 that the carbon yield was found to be high in the DPS (73.48 %). This could be attributed to the release of volatiles during carbonization to eliminate non-carbon species (Adegoke *et al.*, 2017). The pH of the adsorbent is the degree of acidity or basicity of that adsorbent and depends on number of factors which include method of

preparation, inorganic matter content, chemically active oxygen groups on its surface as well as the kind of treatment to which the adsorbent was subjected to (Gan *et al.*, 2004). The pH of the DPS is 8.73 which basic in nature. The bulk density was found to be 0.68 g/mL. Similarly, high bulk density is very important in packaging and transportation and is desirable as

it can significantly reduce cost (Adebayo *et al.*, 2016). Also, the sample might be of great potential for waste water treatment as their bulk density was high.

Iodine number is a widely used parameter for activated carbon testing for its simplicity and a rapid assessment of adsorbent quality. It gives an estimate of its surface area and porosity (Ekpete and Horsfall, 2011). The result of iodine number as shown in Table 3.1 was 540.89 mg/g. Moisture content of the DPS was determined and it was observed that the moisture content was 4.09 %. The ability of a sample to absorb moisture when placed in humid environment suggests good applicability of the sample to adsorption processes (Falah *et al.*, 2015). The values obtained were higher than 3.88 % of Saygili and Guzel, (2017). The low moisture content shows that the particle density is relatively low and the material could be best for adsorption process (Buhari *et al.*, 2020).

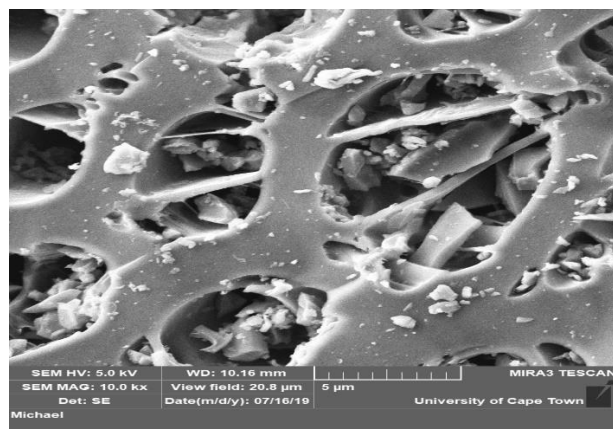
Ash content can also affect activated carbon in the reduction of overall activity of activated carbon and result obtained was 0.92 %. The lower the ash value therefore the better the activated carbon in adsorption environment. It predicts the exact surface area and porosity of an

adsorbent (Magaji *et al.*, 2020). Similarly, the volatile matter is one of the most common parameters measured in adsorbent sample. It is measured as a weight percent of gas emissions from a sample that is released during heating to 950 °C in an oxygen free environment (Viena and Nizar, 2019). The volatile matter revealed 1.05 % as shown in Table 3.1. The value obtained was lower than the value reported by Ekpete *et al.*, (2017).

### 3.3 Characterization of Results of DPS

#### 3.3.1 SEM/EDX Analysis

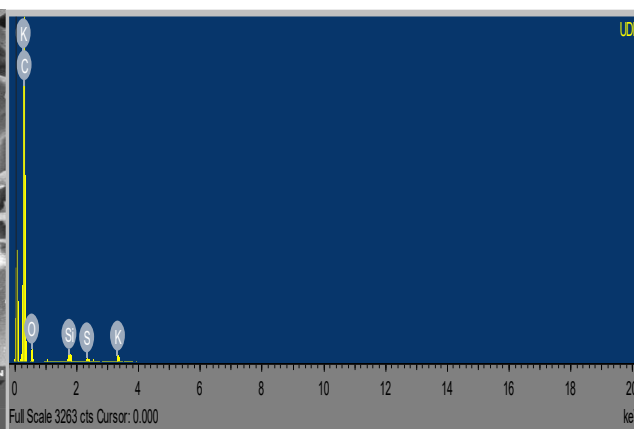
Scanning electron microscope is an important analytical technique used for visual confirmation of surface morphology of an adsorbents (Abdus-Salam and Ikudiyisi, 2016). The results of DPS was obtained from the analysis at 10.00 kx magnification and presented in Figs. 3.2. The result indicated that the pore structure was made up of cylinder like tubes. The result was in agreement with the previous observation reported by the researchers on preparation of modified Desert Date peels (Alkali *et al.*, 2022a). Similarly, EDX confirmed carbon 86.63 % and oxygen 12.17 % as major elements in the sample. Others are 0.71 % (K), 0.18 % (S) and 0.32 % (Si) respectively.



**Fig. 3.2a:** SEM Micrograph of DPS

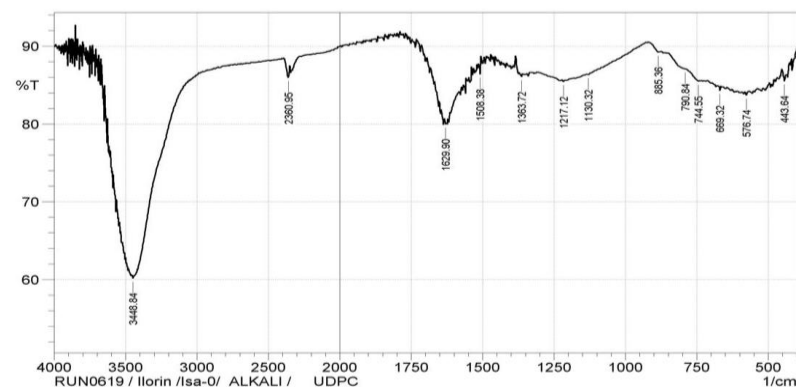
#### 3.3.2 FT-IR Result

The spectrum of DPS revealed broad bands at 3448.84 and 1622.19  $\text{cm}^{-1}$ ; these can be attributed to the  $\text{-OH}$  stretching vibration and  $\text{C=O}$  bending vibration. The major peaks obtained were in agreement with the literature (Jimoh *et al.*, 2026). Other peaks were also



**Fig. 3.2b:** EDX Spectrum of DPS

noted at 2359.02 and 746.48  $\text{cm}^{-1}$  which can be related to  $\text{C}\equiv\text{C}$  stretching vibrations in alkyne groups (Azeez *et al.*, 2022) and vibrations of aromatic substitution by aliphatic groups (Alkali *et al.*, 2025).



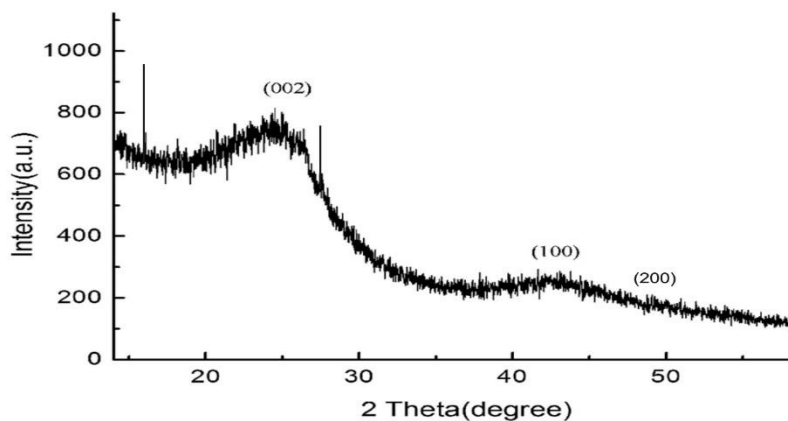
**Fig. 3.3:** FT-IR Spectrum of DPS

### 3.4 XRD Result

It can be observed from the information of XRD that the diffraction peaks at  $2\theta = 34.85^\circ$  is related to graphene structure of the DPS and the value obtained was in agreement with literature reported by Altalhi *et al.*, (2021). The prominent diffraction peaks in the DPS adsorbent was in the range of  $20^\circ < 2\theta < 80^\circ$  which is common to all activated carbon powders, and corresponds to the  $sp^3$  lattice reflections (Iijima, 1991). The

positions of all maxima coincided with the peaks characteristics of crystalline structure of cellulose and all the peaks obtained were in agreement with literature reported by (Ayob *et al.*, 2021). Obviously, the peaks obtained are in accordance with the International Centre for Diffraction Database (ICDD) and Joint Committee on Powder Diffraction System (JCPD) respectively.

Sample : UDP	File : Sg2~1.ASC	Date : Apr 08 7:55:40	Operator :
Comment : Qualitative	Memo		
Method : 2nd differential	Typical width : 0.065 deg.	Min. Height	800:00 c p s



**Fig. 3.4:** XRD Spectrum of DPS

**Table 3.2:** Summary of BET Analysis

BET Parameters	DPS
<b>Surface Area (<math>m^2/g</math>)</b>	960.650
Single point surface area at P/P <sub>0</sub>	998.90
t-Plot micro-pore area	670.550
t-Plot external surface area	580.520
Langmuir Surface Area	710.24
BJH Adsorption cumulative surface area of pores	640.250
BJH Desorption cumulative surface area of pores	650.460
<b>Pore volume (<math>cm^3/g</math>)</b>	
Single point adsorption total pores volume	0.604460

t-Plot micro-pore volume	0.050050
BJH Desorption cumulative volume of pores	0.451203
<b>Pore size (nm)</b>	
Adsorption average pore width (4V/A by BET)	3.25350
Desorption average pore width (4V/A by BET)	3.26750
BJH Adsorption average pore width (4 V/A)	4.4450
BJH Desorption average pore width (4V/A)L	5.0855

The surface area result obtained was 950.650 m<sup>2</sup>/g. However, the was higher than value report for Jujube pit adsorbent by Gao *et al.*, (2020). The value obtained from this research is within the minimum range of 500 to 1500 m<sup>2</sup>/g needed for industrial application and removal of small molecules from aqueous solution (Nwosu *et al.*, 2015). Similarly, the N<sub>2</sub> adsorption-desorption isotherms results showed that all the adsorbents

belong to type IV isotherms with values in the range of 2 to 5 nm according to IUPAC classification of adsorption isotherm (Ayob *et al.*, 2021). The pore volume and pore area distributions of the adsorbents determined from the BET were shown in Table 3.2 indicating mesoporous nanomaterial with capillary condensation (Alkali and Fatima, 2024).



**Fig. 3.5:** BET Plot of DPS

### 3.5 Adsorption Results

#### 3.5.1 Initial Concentration

The plots of the amount of Hg (II) ion adsorbed on the adsorbents (0.01 g each) from 25 ml solutions for different initial concentrations (5-50ppm) of Hg (II) ion is shown in fig. 3.6. The initial concentration of adsorbate plays an important role as a given mass of the adsorbent can adsorb only a fixed amount of the solute (Abdus-Salam *et al.*, 2021a). The more concentrated the solution, the lower the amount of metal ion that a given mass of adsorbent can adsorb (Ferda and Serin, 2012). Consequently, as concentration increases, the adsorption of

Hg<sup>2+</sup> ions onto the adsorbent was observed to decrease. However, an optimum concentration whereby there was no significant decrease in Hg adsorption was observed at 45ppm with 254.63 mg/g maximum quantity adsorbed. The quantity adsorbed increased with an increase in the initial metal ions concentration as a result of available and accessible active sites on adsorbents and increase concentration of adsorbate ions in the bulk solution which then enhanced the adsorption process (Ayodele and Adekola, 2016).

### 3.5.2 Effect of pH

One of the most important analytical factors in the chemistry of adsorption is the pH value, which owing to its effect on solubility of metal ions, surface charge of the adsorbent and the degree of protonation of binding sites of the chelating molecules on adsorbate during the reaction (Alkali *et al.*, 2025). The result of adsorption of Hg (II) was presented in Fig. 3.7. The maximum adsorption capacity obtained at pH 7. At low pH value, the surface of adsorbents are closely associated with hydroxonium  $H_3O^+$  and hold the protonated active sites and maintained a net positive charge, as a result adsorption capacity is low (Jimoh *et al.*, 2026). Moreover, as pH value increases, the surface of the adsorbent becomes more charged negatively resulting in increasing adsorption of metal ions from the aqueous medium during adsorption (Farghali *et al.*, 2017). It could be concluded that cationic metal ion adsorption increases with increase in pH values in this study. The result obtained were higher than  $Cr^{6+}$  adsorption from paper mill sludge by Gorzin and Abadi, (2017) with 11 mg/g obtained between pH of 4-6.

### 3.5.3 Effect of Contact Time

Primarily, the efficiency of adsorption strongly depends upon time of adsorption (Ugbe and Abdus-Salam, 2020). The result of the contact time on the adsorption of Hg (II) ion from aqueous solutions onto DPS was shown in Fig. 3.8. The adsorption was studied between 10 to 60 min contact time while other parameters were kept constant. The maximum quantity adsorbed

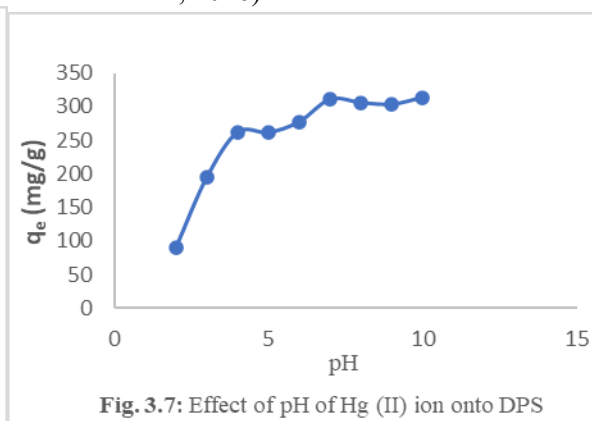
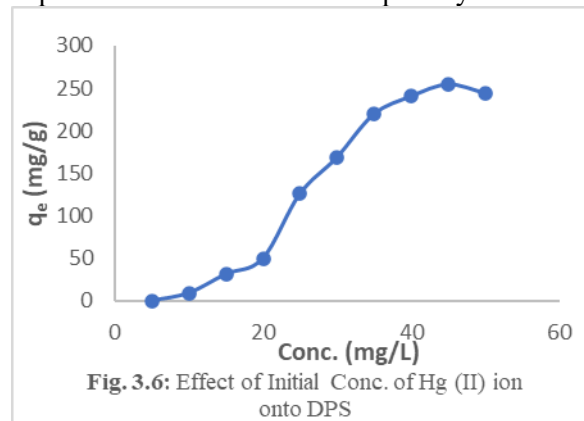
by DPS 55.07 mg/g. The optimum contact time was obtained within 60 min. Thereafter, the adsorption capacity decreased with increase in contact time for adsorbents which suggested that a substantial number of vacant sites on adsorbent surface was occupied by adsorbate molecules (Ephraim *et al.*, 2017). This is generally in agreement with the findings reported by Danbature *et al.*, (2017).

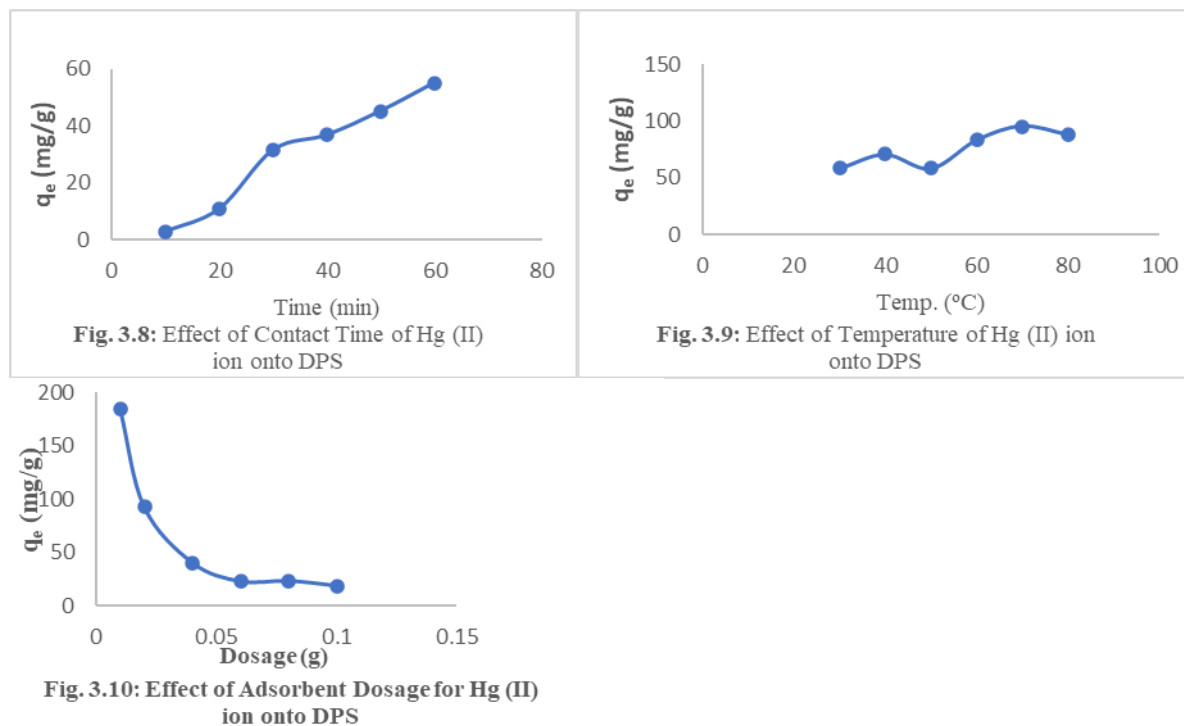
### 3.5.4 Effect of Temperature

The impact of temperature on the quantity of Hg (II) ion onto adsorbed DPS as shown in Fig. 3.9. The result of Hg (II) ion adsorption on DPS at 70 °C was 95.41 mg/g. Similarly, there was a decrease in adsorption capacity as the temperature increased in the adsorption from 20-70 °C pointing towards exothermic process (Adebayo *et al.*, 2020; Tahoon *et al.*, 2020). The results obtained are higher than 16.56 mg/g on desert date seed shell adsorption for the removal of Pb (II) ion reported (Alkali *et al.*, 2022b).

### 3.5.5 Effect of Adsorbent Dosage

The adsorbent dosage for the maximum adsorption for DPS was presented in Fig. 3.10. The amount of metal ion adsorbed,  $q_e$  decreased with increase in the amount of dosage for Hg (II) ion. The maximum quantity adsorbed  $q_e$  (mg/g) for Hg (II) was 185.11 (mg/g) at 0.01 g of DPS. The result have the same trends with literature reported by Buhari *et al.*, (2020). Analytically, such a behavior could be attributed to the accessibility of active binding exchangeable sites and large surface areas (Abdus-Salam and Buhari, 2016).



**Table 3.3:** Level of Hg (II) ion in the Textile Effluent

Adsorbent	Raw Conc. (mg/L)	Conc. after adsorption (mg/L)	Amount removed (mg/L)	Permissible limit (WHO) (mg/L)	% Removal
DPS	0.625	0.002	0.623	0.001	99.68

The results obtained for the effluent analysis of Hg ion onto the DPS adsorbent is presented in Table 3.3. It could be observed from the Table that; the raw effluent has value before adsorption process: 0.625 mg/L on Hg (II) ions. The amount adsorbed after the DPS treatment was 0.623 mg/L and the percentage removal was 99.68 %. The raw effluent value obtained was higher than the maximum permissible limit of mercury concentration in aqueous medium: Hg = 0.001 mg/L (Akinyeye *et al.*, 2020). If the heavy metal concentration exceeds those recommended permissible limits as presented in Table 3.3, it could be major contribution to many life-threatening diseases in human, and

their bioaccumulation by aquatic organisms. Some these effects include; severe damage to kidney, brain, liver, reproductive and nervous systems as well as oxidative stress and impaired respiratory infections (Wang *et al.*, 2019). Therefore, there is need for continuously protection of the environment, human health and the aquatic life through the use adsorbents for the removal of heavy metal ions from wastewater (Hani *et al.*, 2019; Abdel-Ghani *et al.*, 2015). This novel result confirmed the great potentials of this adsorbent in the treatment of industrial textile effluent. Consequently, the results obtained are in conformity with literature reports (Gao *et al.*, 2020).

**Table 3.4:** Percentage Desorbed of Hg (II) ion on DPS

Adsorbents	0.05 M HCl			0.05 M HNO <sub>3</sub>		
	A1 (%)	A2 (%)	A3 (%)	B1 (%)	B2 (%)	B3 (%)
UDP	97.8	84.2	60.6	84.2	32	29.4

Desorption study is a process that can help to explain adsorption behavior, adsorbate recovery

from aqueous solutions, adsorbent recycling and practical applications of the treatment to industrial

effluents (Tahoon *et al.*, 2020). Therefore, mechanism of adsorption can be further probed by desorption studies of the adsorbate from the surface of the adsorbent in different solvent medium. The obtained results of adsorption-desorption studies of Hg (II) ion loaded on DPS showed that 95 % to 98.3 % first cycle; 82.4 % to 89 % second cycle; 57.4 % to 64.6 % and third cycle recoveries with 0.05 M HCl acid. Similarly, 0.05 M HNO<sub>3</sub> gave 82.4 % to 89 % first cycle, 32 % to 56.6 % second cycle and 22.4 % to 37.4 % third cycle recovery results respectively. It was observed that, the surface of the adsorbent was covered by H<sup>+</sup> ions of the stripping agent (HCl or HNO<sub>3</sub>) which displaced the Hg (II) ions into the solution. Therefore, the mechanism was proceeded by ion-exchange (Adekola *et al.*, 2012). The trend of results obtained were similar to the findings of Dada *et al.*, (2018).

In conclusion, the results of adsorption-desorption obtained could be due to the competition between protons and metal ions for binding available sites under acidic conditions, which allows desorption of cations (Abesekara *et al.*, 2020). The small loss of adsorption capacity or efficiency after each cycle of recovery may be due to non-desorbed adsorbate from the previous adsorption process. This could lead to coverage of some adsorption sites and changes in the surface chemistry and structure of the adsorbents (Vijayalakshmi *et al.*, 2017). According to results, it can be identified that, the use of acids as desorbing agent mostly yield higher desorption ability. Similarly, HCl performed better than HNO<sub>3</sub> acid in the adsorption-desorption studies of metal ions on the adsorbents which could be attributed to Cl<sup>-</sup> ions being more electronegative than NO<sub>3</sub><sup>-</sup> ions, hence, HCl is protonated with a greater desorption capacity than HNO<sub>3</sub>. Thus, this novel adsorbent is suitable for toxic metals removal with ease of reusability mainly controlled by ion-exchange.

#### CONCLUSION

This study successfully demonstrated the effectiveness of carbonized Doum palm shell (DPS) as a low-cost and efficient adsorbent for the removal of Hg(II) ions from aqueous solutions and industrial effluents. The physicochemical characterization confirmed that the adsorbent possesses desirable properties such as high surface area, appropriate pore structure, and functional groups that facilitate adsorption processes. The adsorption performance was significantly influenced by operational parameters, with optimal

conditions observed at neutral pH, moderate contact time, and low adsorbent dosage. The high adsorption capacity recorded highlights the strong interaction between Hg(II) ions and the active sites on the adsorbent surface. The experimental results further revealed that the adsorption process is exothermic and favors lower temperatures.

Importantly, the application of the adsorbent to real textile effluent resulted in a removal efficiency of 99.68%, demonstrating its practical relevance in wastewater treatment. Desorption and regeneration studies confirmed the reusability of the adsorbent, with hydrochloric acid proving to be more effective than nitric acid, indicating that ion-exchange is the dominant mechanism involved. In conclusion, Doum palm shell (DPS), an abundant agricultural waste, can be effectively converted into a high-performance adsorbent for mercury remediation. Its low cost, high efficiency, and reusability make it a promising candidate for large-scale environmental applications, particularly in resource-limited settings. Future studies may focus on scaling up the process, exploring multi-metal adsorption systems, and optimizing regeneration cycles for industrial deployment.

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#### DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

#### CONFLICT OF INTEREST

The authors declare no conflict of interest.

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