

Comparative Analysis of the Adsorption of Heavy Metals in Wastewater Using *Borassus Aethiopium* and *Cocos Nucifera*

Adie D.B

Okuofu C.A.

Osakwe C.

Department of Water Resources and Environmental Engineering
Ahmadu Bello University, Zaria, Nigeria

Abstract

*In the study, the adsorption of heavy metal ions (Pb^{2+} and Cd^{2+}) using activated carbon from *Borassus aethiopum* (seed shells) and *Cocos nucifera* (shells) was carried out, so as to comparatively evaluate the effectiveness of both adsorbents for the purpose of removing Pb^{2+} and Cd^{2+} from wastewater. *Borassus aethiopum* seed shells (BASS) and *Cocos nucifera* shells (CONS) collected within Zaria and its environs were crushed into particle size of about 300-450 μ m and the physico-chemical as well as the adsorption properties of the activated BASS/CONS were studied. Effects of various process parameters have been investigated in this study as well by following batch adsorption technique at $30\pm 2^{\circ}C$. Percentage removal of Pb^{2+} and Cd^{2+} was found to increase with decrease in initial concentration of metal ion, and increased with increase in contact time and adsorbent dose. The monolayer adsorption capacity, Q_o for Pb (II) was found to be 12.19 mg/g and 24.39 mg/g for activated BASS and CONS respectively. In the same vein, the monolayer adsorption capacity, Q_o for Cd (II) was found to be 10.20 mg/g and 25.797 mg/g for activated BASS and CONS respectively. In conclusion, it was established that activated CONS had a higher monolayer adsorption capacity for Pb^{2+}/Cd^{2+} than activated BASS.*

Key Words: *Cocos nucifera*, *Borassus aethiopium*, Lead, Cadmium and wastewater

Introduction

Water pollution due to the presence of heavy metals in water and wastewaters has been a major cause of concern for environmental engineers. Several episodes of heavy metal contamination in aquatic environment have increased the awareness about heavy metal toxicity (Upendra, 2006). Among these, Minamata tragedy due to Mercury poisoning and "Itai-Itai" disease in Japan due to cadmium toxicity are well known (Upendra, 2006). More recently cases of lead poisoning were reported in Zamfara State, Nigeria; which led to the death of several people and animals as a result of lead contamination of water bodies (streams and rivers) and the environment (Sadeeq, 2010 and Isah, 2010). The presence of heavy metals in the environment is thus of major concern because of their extreme toxicity and tendency for bioaccumulation in the food chain even in relatively low concentration (Okuo and Ozioko (2001); Malakul, et.al, 2002; Mohan and Singh, 2002).

Many efforts have been made recently to find cheaper pollution control methods and materials (Panday. et.al., 1985; Ali and Bishtawi, 1997; Acemioglu and Alma, 2001).

The importance of adsorption in environmental pollution control has been well highlighted in literature. Khashimova et.al., (2008), reported that the use of adsorption for separation of pollutants from mixtures has been continuously increasing and that the main advantages of adsorption are its high selectivity compared with other separation techniques and relatively high capacity of the adsorbent for pollutants even at low concentration. Ho (2007), reported that about 9,058 articles on adsorption have been published on adsorption materials. Among these are; Johnson (1990), Youssef (1993), Raji et.al (1997), Izanloo and Nasserri (2005); Otun et.al (2007); Oke et.al, (2008); even more recently, Ismail et.al (2009), Jagaba (2010), Adie et.al.(2010) and Omeiza (2011).

In recent years, a number of adsorptive materials such as aquatic plants, agricultural by-products and residues, industrial by-products, saw dust, clay, Zeolite, and micro organisms have been used for the removal of heavy metals from wastewaters.

Agricultural residual materials being economical and eco-friendly due to their unique chemical composition, availability, renewability, and low cost seem to be a viable option for heavy metal removal from wastewaters. Hence, this study is to evaluate the removal of Pb (II) and Cd (II) from synthetic wastewaters by using activated carbon sourced from BASS and CONS, which are both bioresource materials.

As far as known to the researcher, removal of metal ions onto activated carbon from BASS is rare in literature; however, removal using activated carbon from CONS is documented in some literature. This therefore calls for the need for documentation of heavy metal removal using activated carbon from BASS and a comparative analysis with activated carbon from CONS, considering effect of some of these heavy metal ions on human health and the environment. Furthermore, being agricultural residues, BASS could serve as a viable, eco-friendly and economic option (adsorbent) for heavy metal remediation.

Borassus aethiopum is a specie of the Genus; *Borassus* (*Borassus* palm). In English, it is referred to as either of; African palm, African Palmyra, toddy palm, black rhun palm etc. It also has names in other indigenous African languages, like “*giginya*” in Hausa language. Male plants produce flowers that are small and inconspicuous; whereas female plants grow large flowers which produce yellow to brown fruits resembling coconut, and containing up to 3 seeds in them, (Barot and Gignoux, 1999).

Cocos nucifera, commonly known as coconut palm belongs to the palm family *Arecaceae*. Coconut is the common name for the fruit of this palm tree which is widely distributed in tropical regions. The tree has a cylindrical trunk of about 45 cm in diameter and can grow up to 30 m high, with many rings marking the places of former leaves. The general objective of the study is to use BASS and CONS as source of activated carbon for heavy metals removal from wastewaters.

Materials and Methods

Materials

To be able to carryout the experiment, Mortar, Pestle, Sieves (British Standard; 150-300 μ m), Muffle furnace (S30 2AU), pH meter (CRISON micro pH 2000), Orbital shaker (Scigenics Biotech Orbitech), weighing balance (Mettler H31), Electric oven, Atomic Absorption Spectrophotometer (Shimadzu AA6800), and Desiccators are required. Other apparatuses used were Test tubes, watch glasses, polythene bags, crucible, measuring cylinders, spatula, conical flask, volumetric flask and plastic containers. Reactions were carried out using Standard methods (APHA, 1995).

Methods

Sample Collection: Samples of *Borassus aethiopum* shell (obtained after the edible outer fibrous pulp and albumen or seed found inside the kernel have been removed) were collected from Samaru, Sabon Gari, and other areas within Zaria and its environs. Samples of *Borassus aethiopum* seed shells (BASS) were recovered from the fruits after removing its fibrous outer husk. Shells of CONS were collected from different market locations in Samaru, Sabon Gari, and other areas within Zaria and its environs.

Sample Analysis: Tests and analysis of the samples (BASS and CONS) were carried out at the National Research Institute for Chemical Technology Laboratory (NARICT), Zaria; Soil Science Departmental Laboratory, A.B.U, Zaria; Postgraduate Analytical Laboratory, Department of Chemistry, A.B.U, Zaria and Hydrobiology Laboratory, Dept of Biological Sciences A.B.U, Zaria.

Processing of Samples: Dried shell (BASS) were crushed to remove the dried kernel inside it, after which, the crushed seed shells were washed clean with water and air dried to obtain fiber-free and soil free shells samples. Similarly, the CONS shell samples were crushed into small chips and air-dried. The air dried shells (BASS/CONS) were then ground separately into small particles sizes with a mortar and pestle. Ground samples (BASS/CONS) were then sieved into sizes of range of 300-4500 μ m.

Activation and Carbonization of Sample: The samples of BASS/CONS were activated and carbonized thus: 2.0g of ground fiber-free BASS/CONS was weighed into a crucible and mixed thoroughly with 2cm³ each of 0.1M Phosphoric acid (H₃PO₄) at an impregnation ratio of 1.0 (impregnation ratio here, defined as; the ratio of the weight of H₃PO₄ to the weight of the BASS/CONS sample).

Soaking time was set at 12hrs, after which the crucible and its content was heated at a temperature of about 500°C, for an activation time period of 15 minutes in a muffle furnace. This procedure was repeated in batches for the two samples (BASS/CONS) until the required mass of each sample was achieved. The activated samples (BASS/CONS) were washed separately with 0.5M NaHCO₃. The acidity of the washed liquor was repeatedly monitored until the pH reading was within the range of about 6-7. Finally the activated carbon of each sample was dried in an oven with temperature set at 105°C.

Preparation of Stock Solutions: Activating solution of H₃PO₄ in addition to heavy metal solutions (divalent cations of Pb²⁺ and Cd²⁺) for the adsorption test were prepared in stock solutions of up to 1000mg/L.

Preparation of Standard Solutions of Pb²⁺ and Cd²⁺ (Synthetic Wastewaters): In the preparation of stock solution of Lead ions, procedures specified in Standard Method for the Examination of Water and Wastewater (APHA, 1998) was followed. Specifically a known mass (1.599g) of Lead nitrate (Pb(NO₃)₂) was dissolved in 200mL of distilled water, 10ml of concentrated HNO₃ was then added and the resulting solution was diluted to 1000mL mark using deionized water. Working solution was then prepared from the stock solution by diluting 20mL of the stock solution to 1000mL with deionized water. Similarly, synthetic Cadmium ion solution was prepared by dissolving a known mass of Cadmium salt (Cd(NO₃)₂ .4H₂O) in distilled water (APHA, 1998). 1.599g of Cadmium nitrate was dissolved in distilled water, 10mL of concentrated HNO₃ was then added, and the solution diluted to 1000mL mark using deionized water. Working solution was then prepared as described in the procedure for Lead.

Determination of Physico-chemical Characteristics of BASS/ CONS: This was achieved by determining *Moisture Content, Volatile solid and Ash content, Water and acid solubility, pH and Bulk density.*

Investigation of Adsorption Potentials of Activated Carbon from BASS/CONS: In investigating the adsorption potentials of activated carbon from BASS/CONS, the effects of adsorbent dose, contact time, and initial metal ion concentration on the percentage removal of Pb(II) and Cd(II) was examined.

- a. *Effect of adsorbent dose on the adsorption of Pb(II) and Cd(II) onto Adsorbents:* Effect of adsorbent dose on percentage removal of metal ions was investigated by varying adsorbent dose in the range of 0.5 to 2.5g. Separate masses of adsorbents (ranging from 0.5-2.5g of BASS/CONS) were each taken into 5 beakers containing 50mL of metal solution of initial concentration of 20mg/L. The solutions were agitated at a fixed stirring speed of 180rpm for a predetermined contact time of 150 minutes and a fixed p^H value of 6.0. The final concentration of solutions was then determined by Atomic Absorption spectrophotometer, and the percentage removal of Pb²⁺/Cd²⁺ determined.
- b. *Effect of contact time on the adsorption of Pb(II) and Cd(II) onto Adsorbents:* The effect of contact time on adsorption of Pb(II) and Cd(II) was investigated. 1.0g each of the adsorbents (activated BASS/CONS) was taken into 5 beakers containing 50mL of metal solution at an initial concentration of 20mg/L. The solutions were agitated at a fixed stirring speed of 180rpm for varying time period ranging from 30 - 150 minutes at a fixed p^H value of 6. The final concentration of each solution was determined by Atomic Absorption Spectrophotometer, and the percentage Pb²⁺/Cd²⁺ was then determined.
- c. *Effect of Initial Metal Ion Concentration on the adsorption of Pb(II) and Cd(II) onto Adsorbents:* Effect of initial metal ion concentration on percentage removal of metal ions (adsorption) was investigated by varying concentration of the metal ions (Pb²⁺/Cd²⁺) in the range of 2.5 to 20mg/L. 50mL of separate concentrations of metal ions (ranging from 2.5-20mg/L) were each taken into 5 beakers containing a fixed mass (1.0g) of the adsorbents (activated BASS/CONS). The solutions were agitated at a fixed stirring speed of 180rpm for a predetermined contact time of 150 minutes and fixed p^H value of 6.0. The final concentration of each solution was determined by Atomic Absorption spectrophotometer.

Adsorption Capacity Test

In the determination of adsorption capacity of the adsorbent for Pb²⁺, 50ml of the working solution of Lead ions containing 20mg/L of Pb²⁺ each was taken into five different beakers and known masses (0.5, 1.0, 1.5, 2.0, 2.5g) of the adsorbent was each added to the solution (specifically at the same and controlled initial p^H of solution fixed at 6.0). The mixture was stirred at 180 revolutions per minute (rpm) for a predetermined time (for which equilibrium was attained). The supernatant of the mixture was then filtered through Whatman filter paper (number 40). Determination of Lead ion concentration was done by Atomic Absorption Spectrophotometer.

The same procedure was followed in the determination of the adsorption capacity of the adsorbent for Cd²⁺. The amount of solute (Pb²⁺ and Cd²⁺) removed (adsorbed) at equilibrium was computed thus;

$$q_e = \frac{(C_o - C_e)V}{M} \quad (1)$$

the amount of solute (Pb²⁺ and Cd²⁺) removed at a given time was computed using equation (2). The percentage of Pb²⁺ and Cd²⁺ removed, R (%) from the solution was calculated using equation (3);

$$q_t = \frac{(C_o - C_t)V}{M} \quad (2) \quad R = 100 \frac{(C_o - C_t)}{C_o}$$

(3)

Where, C_o, C_t, and C_e are initial liquid-phase concentration of sorbate, experimental concentration (mg/L) in time t and equilibrium liquid-phase of sorbate respectively.

While M, V and R are the adsorbent mass, volume of solution (50mL) and the percent metal ion adsorbed respectively.

Results and Discussion

Results: The results of the study of adsorption of heavy metal ions (Pb²⁺, Cd²⁺) using activated carbon from BASS & CONS are presented and discussed under four categories as follows:

- (a) **Physicochemical characteristics of BASS and CONS:** These involved determination of moisture content, volatile solids ash content, bulk density, and the pH of raw and carbonized samples. In addition, raw samples (of BASS and CONS) were digested (by wet digestion) to determine concentration of some specific metals in the samples. The summary of the results are as shown in Table 1.

Table 1: Physicochemical Properties of Raw and carbonized (BASS/CONS) samples

PARAMETER	BASS	CONS
Physical		
Moisture (%)	9.20	7.01
Volatile solid (%)	86.70	90.10
Ash Content (%)	4.10	2.90
pH		
(i) Raw	6.28	6.33
(ii) Carbonized	5.92	5.98
Bulk density (g/cm³)		
(i) Raw		0.43
(ii) Carbonized	0.45	0.53
Chemical	0.55	
Solubility in water (%)	0.98	1.20
Solubility in 0.25M HCl (%)	5.20	7.30
Calcium (mg/g)	0.18	0.15
Iron (mg/g)	3.18	1.02
Aluminum (mg/g)	0.01	0.03
Cadmium (mg/g)	-	-
Lead (mg/g)	-	-

- (b) **Moisture Content (%):** From Table 1, the moisture content of BASS and CONS were found to be 9.2 and 7.01% respectively. Generally, the yield and quality of activated carbon produced can be improved by removal of moisture, UN FAO, (1985). The lower the percentage (%) moisture, the better the yield and quality of the activated carbon. These values (values for CONS and BASS) are both generally lower than values obtained from powdered corn cobs (Adie et.al, 2010) and activated carbon from *Carica papaya* seeds, (Omeiza, 2011).
- (c) **Ash Content (%):** According to Allen (1974), the Ash content gives an idea of the measure of mineral content of the samples. In a study by OMRI (2002), it was found that the amount of ash depends on the carbon source. The ash content from this study was found to be 4.1 and 2.9% for BASS and CONS respectively. This is favourable because the ash serves as interference during the adsorption process. The lower the ash content, the better the material (OMRI, 2002). Both values (for CON and BASS) are slightly higher compared with the value obtained for powdered corn cobs (Adie, et al, 2010). However, the value for CONS is comparable with the value obtained for *Carica papaya* seeds (Omeiza, 2011).

(d) Volatile Solids: From Table 1, volatile solids was found to constitute about 90.1% of the mass of CONS, while that of BASS was found to be about 86.7%. These values are comparable with values obtained for powdered corn cobs Adie, et al (2010). The high percentage(%) of volatile solids in CONS and BASS is indicative of the fact that both adsorbents can be destroyed easily and metal recovery can be effectively employed for the recovery of metal ions from adsorbents (CONS and BASS) after they have been used for adsorption of such metals.

(e) Water and Acid Solubility: Table 1 indicated that the solubility of BASS and CONS in water was 0.98 and 1.2% respectively, while the acid solubility was found to be 5.2 and 7.3% for BASS and CONS respectively. This shows that BASS will be more stable in neutral aqueous medium as well as acidic medium than CONS. The water and acid solubility values obtained for BASS and CONS were both observed to be higher when compared to values obtained from carbonized apricot stones (Kobyta et. al, 2004) and powdered corn cobs, (Adie, et.al, 2010). This difference is attributable to the nature of the adsorbent as well as the nature of chemical activation and carbonization process carried out in producing the activated carbon adsorbents (BASS and CONS).

(e) pH: The for pH raw BASS and CONS from Table 1 are 6.28 and 6.33 respectively, whereas, that of carbonized BASS and CONS are 5.92 and 5.98 respectively (after several washings).The pH of activated carbon depends on the nature of the activating process and the activating agent used. pH can be modified by washing (Abram 1973), and that of carbon in suspension can vary in range from 4 to 12.

(f) Metal Concentrations: From Table 1, results of digestion (wet digestion method) of the samples (BASS and CONS), shows that, 1g of BASS contains 0.18mg of Calcium (Ca^{2+}), 3.81mg of Iron (Fe^{2+}), and 0.01mg of Aluminum (Al^{3+}). Whereas 1g of CONS contains 0.15mg/g of Calcium (Ca^{2+}), 3.81mg of Iron (Fe^{2+}), and 0.03mg of Aluminum (Al^{3+}). Basically, it has been postulated that in the presence of water, Calcium salts undergo displacement reaction (Oke et.al, 2008). This shows that BASS and CONS underwent reactions with Lead/Cadmium ions, which reduced the p^{H} to a region that supports the removal of these metal ions by the adsorbents. Furthermore, the end product reacted with Lead/Cadmium ions to precipitate the metal ions (pollutants). This indicates that, apart from the volatile portions (of BASS/CONS),which can adsorb these ions (Lead/Cadmium ions),the presence of these important coagulant (Ca^{2+} , Fe^{2+} and Al^{3+}) in the adsorbents (BASS/CONS) helped formed flocs, increasing the attractive force (between the adsorbent and the metal ions) leading to precipitation of these metal ions (Lead/Cadmium ions).

Batch Adsorption Studies

a. *Effect of contact time:* The experimental runs measuring the effect of contact time on the batch adsorption of Pb^{2+} and Cd^{2+} (initial metal ion concentration of 20mg/L, pH; 6, at a temperature of $30 \pm 2^\circ\text{C}$, and agitation speed of 180rpm) is as shown in Figs. 1 and 2.

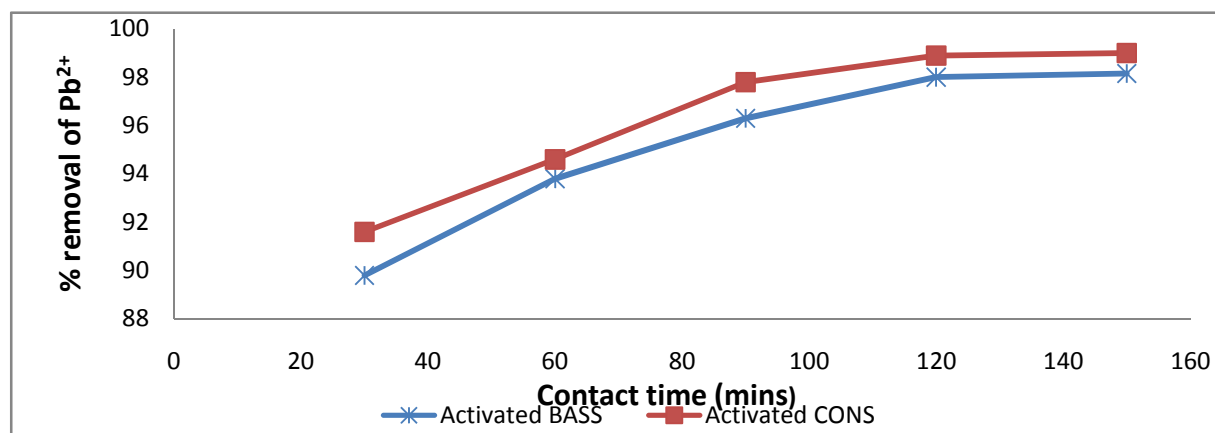


Fig.1: Effect of Contact time on Pb^{2+} Removal using Activated Carbon from CONS and BASS

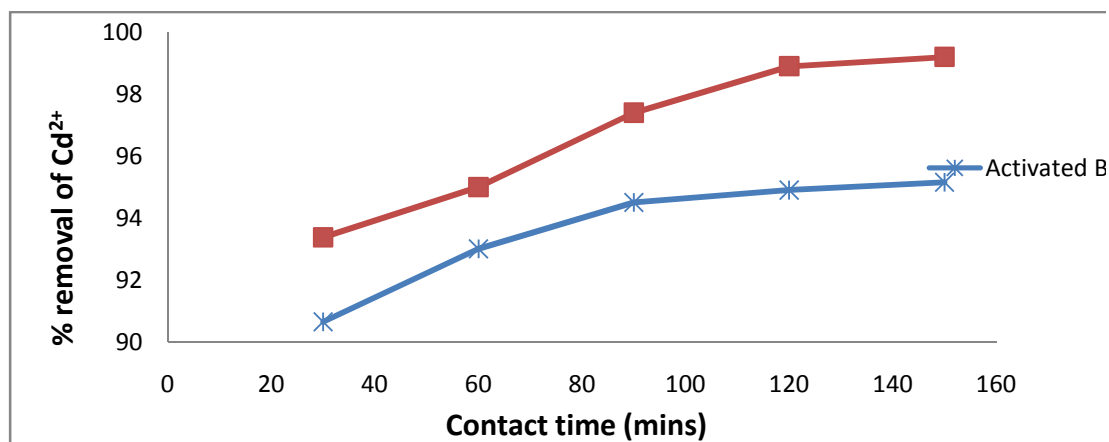


Fig. 2: Effects of Contact time on Cd²⁺ Removal using Activated Carbon from CONS and BASS

It was observed that, increase in contact time from 30 to 150 minutes significantly enhanced the percentage (%) removal of Pb²⁺/Cd²⁺ from the synthetic wastewater using the adsorbents (BASS and CONS). As observed from both graphs, the initially rapid adsorption gradually gave way to adsorption at a slow rate; indicative of the fact that the process tended to approach equilibrium state between 120-150 minutes (for both adsorbents). The maximum percentage (%) removal of Pb²⁺ using activated CONS was found to be about 99% while activated BASS was found to be about 98.15%, whereas the maximum % removal of Cd²⁺ using activated CONS was found to be about 99.2% while activated BASS was 95.2%. For both metal ions, activated CONS was found to have a higher removal percent.

Thus, it was observed from the study that the removal of Pb²⁺/Cd²⁺ by adsorption onto activated CONS/BASS increased rapidly in the beginning and then slowly until equilibrium time was reached. This is in agreement with findings of Ho and McKay (1998). The nature of the adsorbent and its available sorption sites affected the time needed to reach equilibrium. This may be explained by the fact that; initially, a large number vacant sites were available and as the adsorption process continued, much of the available sites were used up which slowed the process down later due to exhaustion of remaining surface sites and repulsive forces developed between solute molecules and bulk phase as expounded by Saravanane, et al (2002).

b. *Effect of Adsorbent Dose:* The effect of adsorbent (type) and dosage is depicted in figs 4.3 and 4.4. Both adsorbents were used at dose/dosage ranging from 0.5g (10g/L) to 2.5g (50g/L) in a batch adsorption technique.

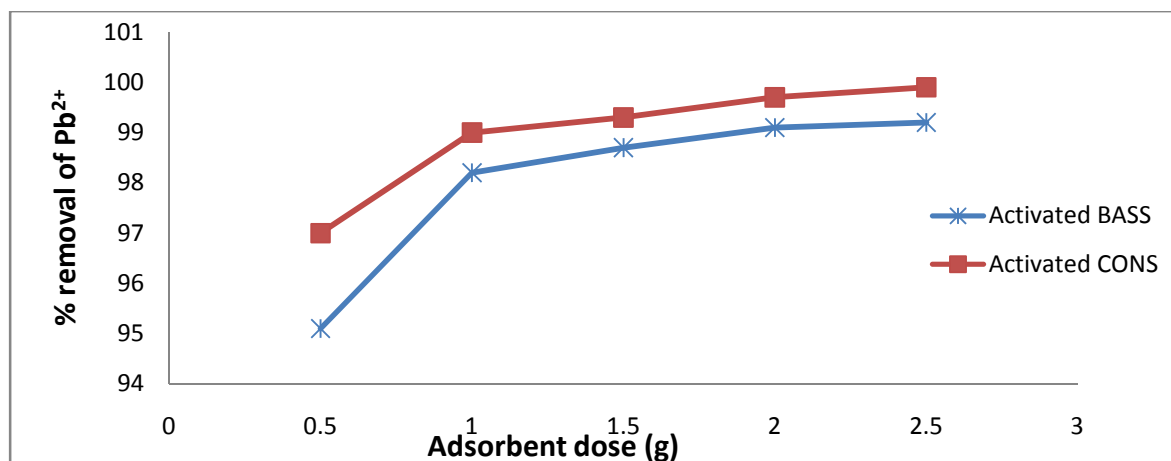


Fig. 3: Effect of adsorbent dose on Pb²⁺ Removal using Activated Carbon from CONS and BASS

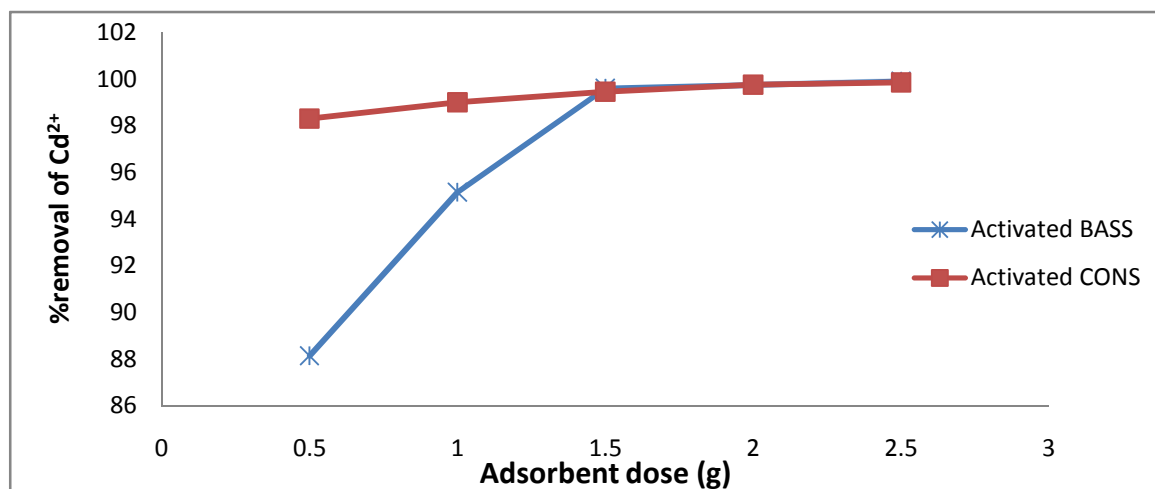


Fig. 4 Effect of Adsorbent dose on Cd²⁺ Removal using Activated Carbon from CONS/ BASS

The adsorbent (BASS and CONS) dose was in each case for each adsorbent varied between 0.5g to 2.5g in 50mL of aqueous solution of the metal ion (equivalent to dosage of 10g/L to 50g/L) in a batch adsorption technique. In each case, increase in adsorbent dose resulted to an increase in percentage (%) removal of Pb²⁺/Cd²⁺ for both adsorbents. However, it was observed that after a certain adsorbent dose of between 1-1.5g, the removal efficiency (%) did not increase so significantly.

The maximum percentage (%) removal of Pb²⁺ using activated BASS was found to be 99.75% at the maximum adsorbent dose of 2.5g (50g/L), while that activated CONS was 99.89% at the maximum adsorbent dose of 2.5g (50g/L). For Cd²⁺ however, the maximum percentage (%) removal for BASS was found to be 99.2%, while that for CONS, was 99.85% at the maximum adsorbent dose of 2.5g (50g/L). It is evident that for both metal ions, activated CONS had a higher % removal of these metal ions than activated BASS. Furthermore it was found that for both adsorbents (activated BASS/CONS) the optimum % removal of the metal ions was achieved with adsorbent dosage of between 1.0-1.5g (20-30 g/L). Beyond 1.5g (40g/L), the increase in % removal of the metal ions was found to be relatively small or insignificant. Hence optimum dose for both adsorbent was fixed at 1g (equivalent to 20g/L).

The variation in sorption capacities between various adsorbents could be related to the type and concentration of surface group responsible for the adsorption of metal ions from solution (Dakiky et.al, 2002). Thus, the phenomenon of increase in % removal of Pb²⁺/Cd²⁺ with increase in adsorbent dosage may be explained thus; with increase in the adsorbent dosage, more surface area is available for adsorption due to increase in active sites on the adsorbents or due to conglomeration of carbon at higher doses.

- c. *Effect of initial metal ion concentration:* Figs 4.5 and 4.6 show the effect of initial metal ion (Pb²⁺/Cd²⁺) concentration on the adsorption of these ions from synthetic wastewater of the metal ions using activated BASS/CONS as adsorbents

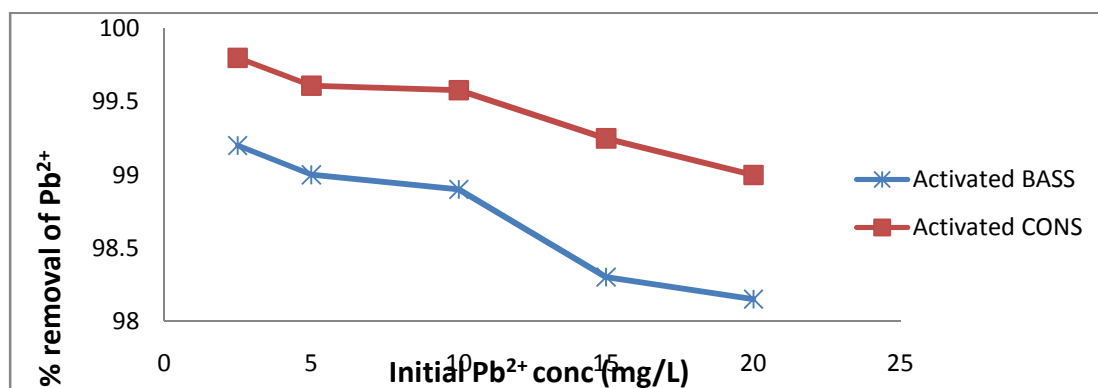


Fig 4.5: Effect of Initial Conc. of Metal ion on Percentage (%) Removal of Pb²⁺ using Activated Carbon from CONS and BASS

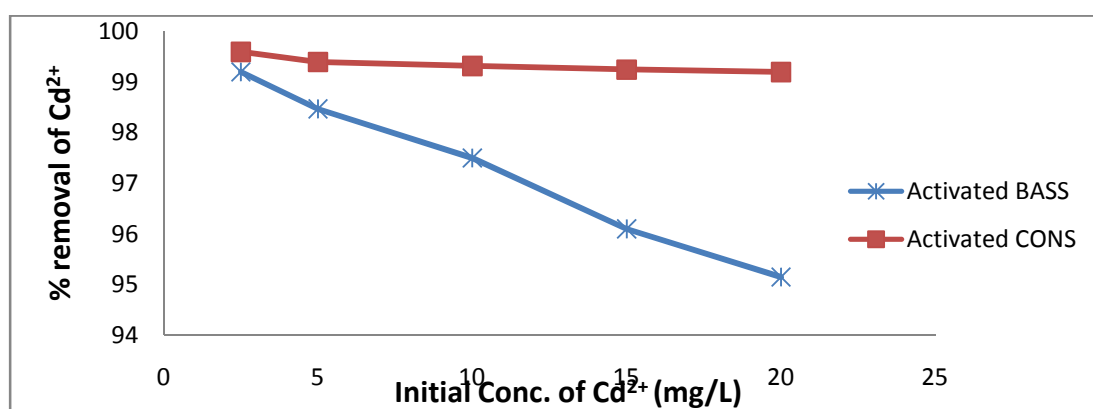


Fig. 6: Effect of Initial Conc. of Metal ion Percentage (%) Removal Cd²⁺ using Activated Carbon from CONS and BASS

It was observed that with increase in metal ion concentration from 2.5-20mg/L, there was an accompanying decrease in the percentage (%) removal of Pb²⁺/Cd²⁺ for both adsorbents. The % removal of Pb²⁺ decreased from 99.2 to 98.15% with increase in metal concentration from 2.5 to 20mg/L with activated BASS. For Cd²⁺ using activated BASS, the % removal decreased from 99.4% to 95.15% with an increase in metal concentration from 2.5-20mg/L. For activated CONS, the % removal of Pb²⁺ decreased from 99.8 to 92.0% and from 99.8 to 99% for Cd²⁺ with increase in metal concentration from 2.5-20mg/L. This is generally in agreement with findings of Gupta & Mohapatra (2003) and Zouboulis, et.al, (2002). This phenomenon can be explained thus; at higher concentration, most of the Pb²⁺/Cd²⁺ are left unabsorbed due to saturation of the adsorption sites. The ratio of sorptive surface to ion concentration decreased with increasing metal ion concentration and so ion removal reduced. At low initial concentration of metal ions, more binding sites are available, but as concentration increases the number of ions competing for available binding sites in the adsorbent increased.

Conclusion

This study (from experiment, observations and results) indicated the suitability of using activated BASS/CONS for the removal of Pb(II) and Cd(II) in aqueous solution through batch adsorption studies. The obtained experimental results showed that process parameters such as adsorbent dose, initial metal concentration, and contact time affected uptake of both adsorbents (for the uptake of Pb (II) and Cd (II)). The effect of various process parameters showed that percentage (%) adsorption decreased with increase in initial metal ion concentration, whereas with increase in contact time and adsorbent dose, there was increase in percentage (%) adsorption or removal of metal ions. Finally, this works shows that locally available materials such as *Borassus aethiopum* (seed shells) and *Cocos nucifera* (shells) could easily be sourced to produce activated carbon which can be used as efficient adsorbents for Lead and cadmium ion removal from wastewater, representing an environmentally effective means of utilizing these agricultural residues. However, it was established that activated CONS had a higher monolayer adsorption capacity for of Pb²⁺/Cd²⁺ than activated.

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