

Comparative study of the Bioadsorption of Cadmium and lead from industrial waste water using melon (*Citrullus colocynthis*) husk activated with sulphuric acid

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Abstract: Melon (*Citrullus colocynthis*) husk (Lloyd, 1898), a readily available agricultural waste product was used as a low-cost potential adsorbent to remove cadmium and Lead from industrial effluents. Adsorption studies were carried out on melon husks activated with sulphuric acid as a function of parameters such as contact time, adsorbent dosage and adsorbate concentration. Cadmium removal was found to be dependent on the three parameters with maximum removal attained at 70min with 0.6g for sulphuric acid (H₂SO₄) activated melon husk. Both metals were mostly removed at low adsorbate concentration. Lead removal did not show strict dependency on these parameters with maximum removal attained within the first minute with H₂SO₄ activated melon husks with records of 100% adsorption. Adsorption isotherms correlated well with both Langmuir and Freundlich isotherm models and their R² values ranges from 0.911- 1. Experimental data were also evaluated to find out kinetic characteristics of the adsorption process. Adsorption process for the two target heavy metal ions were found to follow pseudo-second order adsorption kinetics while their r² values ranges from 0.797- 0.999. The r² values and the pairwise t- test showed that lead is better adsorbed than cadmium. Activated melon husk, a readily available adsorbent was found to be efficient in the uptake of Cd(II) and Pb(II) ions in industrial effluents, thus, predisposing it as an excellent alternative for the removal of heavy metals from water and waste water.

Keywords: Bioadsorption, Waste Water, Melon Husk, Sulphuric Acid

1. Introduction

Contamination of the environment; Land, atmosphere and water which include streams, lakes, underground water, bays, or oceans by substances harmful to living things has become a serious issue of concern. The contamination of water seems to be more serious due to the place and importance of water to life. Water is necessary to life on earth. All organisms contain it; some live in it; some consume it. Plants and animals require water that is moderately pure and they cannot survive if their water is loaded with toxic chemicals or harmful microorganisms. If severe, water pollution can kill large numbers of fish, birds, and other animals in some cases killing all members of a species in an affected area, (Encarta, 2009).

Industrial effluents are one of the major causes of

environmental pollutions. Effluents discharged from dyeing industries are highly coloured, of low biological oxygen demand (BOD) and high chemical oxygen demand (COD). Disposal of this coloured water into receiving waters can be toxic to aquatic life (Lee *et al.*, 1999). They also pose a problem because they may be mutagenic and carcinogenic (Pacic *et al.*, 2000) and can cause severe damage to human beings such as dysfunction of kidney, reproductive system, liver, brain and central nervous system (Menahan, 1994)

Industrial activities like mining, painting, car manufacturing, metal plating, tanneries and agricultural activities like intensive use of fertilizers and fungicides are the main sources of wastes containing heavy metals. The term heavy metal refers to any metallic chemical element that has a relatively high density and is toxic or poisonous even at low concentrations. Heavy metals include mercury

(Hg), cadmium (Cd), arsenic (As), Chromium (Cr), Thallium (Tl) and Lead (Pb) (Lenntech, 2004). Among these toxic heavy metals, mercury, lead and cadmium have been called “the big three” and are in the lime light due to their major impact on the environment (Volesky, 1994; Volesky and Holan, 1995).

Heavy metals are considered to be one of the most hazardous water contaminants. According to the World Health Organization (WHO, 2006) among the most toxic heavy metals are cadmium, chromium, copper, lead, mercury and nickel. They cannot be degraded or destroyed. To a small extent they enter our bodies via food, drinking water and air, Heavy metals are dangerous because they tend to bioaccumulate. Bioaccumulation means an increase in the concentration of a chemical in a biological organism over time, compared to the concentration in the environment. Heavy metals can enter a water supply by industrial and consumer waste, or even from acidic rain breaking down soils and releasing heavy metals into streams, lakes, rivers and groundwater (Encarta, 2009).

The discharge of these waste containing heavy metals and other discharges which includes plastic wastes, such as polyethylene terephthalate (PET) and Polyvinyle Chloride (PVC), industrial wastes, such as oil combustion residues and fabrics, as well as the discharge of tires, sewages, sludges, fertilizer etc, constitutes a serious challenge in waste management strategies. It is therefore of main relevance to find alternatives by which such materials can be handled in a more environmentally friendly or acceptable procedures (Hayashi, 2005).

Many conventional methods such as chemical precipitation, chemical coagulation, chemical oxidation and biological techniques, solidification, electrolytic recovery, ion exchange have been used for removal of dyes and metal ions. The application of such method however, is sometimes restricted because of technical or economical constraints, (Bossrez *et al.*, 1997 Yu and Kaewsarn, 1999). Hence, more economical means such as biosorption for the removal of metals have been sought for. It is non-polluting, and it can be highly selective, more efficient, easy to operate and hence cost effective. Also, adsorption using activated carbon have been reported (Ouki and Neufeld, 1997; Shim *et al.*, 2001; Monser and Adhoum, 2001). The removal of heavy metals by Activated carbon (AC) is economically favourable and technically easy (Khezami and Capart, 2005). Other advantage of AC over other methods of remediation of heavy metals from waste water is that, it is sludge-free. ACs, therefore, are widely used to treat waters contaminated with heavy metals.

The use of such non-conventional wastes as carbon source for the production of AC might be an efficient alternative for both, adoption of effective waste management practice, and production of low-cost AC. Plastic wastes, various industrials wastes like fly ashes, pitch, polymer residues, sawdust (Raji and Anirudhan, 1997; Igwe *et al.*, 2005), old newspaper, tires and sewage sludges have been raw materials for AC production.

Several agricultural wastes products have also been found useful in AC production, like coconut shell, rice husk, groundnut husk, cassava peel, maize cob (Abia *et al.*, 2003), banana pith, medicago sativa (Alfalfa), sphagnum moss peat, sunflower stalks, fungal, bacteria, algae (Gardea-Torresdey *et al.*, 1995; Sun and Shi, 1998; Kapoor and Viraraghavan, 1995) and others.

Commercially available activated carbons are expensive. In a developing economy like Nigeria, it is better to find low-cost adsorbent to be used in this field. There is therefore, a need to search for an effective adsorbent for environmentally friendly and economically waste water treatment. This work therefore focuses on the use of activated carbon (AC) from melon (*Citrullus colocynthis*) husk as low-cost adsorbent materials for the removal of cadmium and lead from waste water that is discharged into water bodies. The objective of the study is to convert the waste melon husk into usable material and use same in effecting the treatment of the industrial effluents containing cadmium and lead. The study also aims to assess the efficiency of waste melon husk as an environmentally friendly material for metal remediation.

2. Materials and Methods

2.1. Collection of Adsorbent

The melon husks were collected from the melon sellers at the main market in Ogbomoso town of Oyo State, Nigeria.

2.2. Preparation of Adsorbent

Debris and stones were separated from the melon husks by hand-picking. The husks were washed thoroughly with tap water and rinsed with distilled water before being sun-dried. The husks were grounded at the market using the miller's machine. The grounded husks were sieved with Ordinary kitchen sieve to achieve a more uniform particle sizes. The husk was now ready for modification.

2.3. Modification with Concentrated H_2SO_4

The grounded husk was treated with H_2SO_4 in the ratio 1:1 (w/v), and was dried. It was then wash with distilled water, after which it was soaked in 1% $NaHCO_3$ overnight to remove residual acid. It was oven-dried at $150^{\circ}C$ for 24 hours. The activated husk was then grounded further and sieved Particle size of 250-500 μm was collected and stored in an air-tight container for use. Aghar *et al.* (2005) and Raghuvanshi *et al.* (2004) modification method.

2.4. Adsorption Procedure

The modified melon husks were used to treat Lead (II) and Cadmium (II) simulated waste water. The equilibrium time (contact time), adsorbent dosage effect and concentration effect of the adsorbates were studies.

2.5. Preparation of Stimulated Wastewater (Stock Solution)

All the experimental containers were properly washed and rinsed with distilled water to avoid, any contamination. The stock solutions were prepared by measuring out 1000ml of distilled water into two different 2-litre containers. One gram (1g) of the Cadmium (II) was added to one Container containing 1000ml of distilled water and 1g of Lead (II) was also added to the other container. Proper mixture was ensured. Two stock solutions were prepared. 1000mg/L of Cadmium and 1000mg/L of Lead, respectively.

2.6. Treatment of the Wastewater with the Adsorbent

250ml of the stock solution was drawn and poured into 250ml Erlenmeyer flask. 3g of the adsorbent was measured out using Electronic weighing balance. It was added into the 250ml of the stock sample and was thoroughly shaken together for proper mixing. 20ml each of this mixture (adsorbent and adsorbate) were immediately drawn and poured into eleven different 100-ml Erlenmeyer flasks. The first 20ml sample was immediately filtered at zero minute into a sample container using Whatman filter paper. The other 20ml samples were placed on different magnetic stirrers and were stirred at different magnetic stirrers and were stirred at different time between 0 and 100 minutes using standard methods recommended for examination of water and waste water (Clesceri *et al.*, 1998). The stirring was to make adsorption more effective. The heavy metal ion concentration (Pb and Cd) of the treated wastewater were analyzed at the time interval of 10 minutes, between 0 and 100 minutes.

Subsequent adsorption experiments were carried out by using optimized parameters. Using 20ml of the stock solutions at 20 minutes for Pb(II) and 50-70 minutes for Cd(II) depending on the particular modified melon husk use. The dosages of the adsorbents were varied between 0.2g to 1.0 at 0.2g interval, while the time and adsorbate concentration were kept constant.

Considering the effect of adsorbate concentration, the concentrations of the adsorbate were varied using distilled water at constant time and adsorbent dosage. Concentration of adsorbed metal ions (Pb(II) and Cd(II)) at any of these experiments were determined spectrophotometrically by using standard method of Clesceri *et al.* (1998).

The concentrations of the stock solutions were determined to serve as control sample or initial concentrations. Residual metal ion concentrations in the filtrate (after adsorption) were measured by atomic adsorption spectrophotometry (AAS) model 9100 x Philips, England). The amount of lead(II) and cadmium(II) adsorbed q_t , (mg/l) at time (t) were calculated by using the following equation:

$$q_t(\text{mg/L}) = \frac{(C_o - C_e) V}{m}$$

Where C_o and C_e are the metal ion concentration in

mg/L initially and at given time, t respectively, V, is the volume of the adsorbate and M, the mass of the adsorbent in gram.

$$\text{While } q_t(\text{mg/g}) = \frac{(C_o - C_e) X (V/1000)}{m}$$

The percentage of the metal ion removed ($R_{\text{metal}} \%$) from solution was calculated by using the following equation.

$$R_{\text{cd(ii)}} (\%) = \frac{C_o - C_e}{C_o} \times 100$$

$$R_{\text{pb(iv)}} (\%) = \frac{C_o - C_e}{C_o} \times 100$$

$$q_e = C_o - C_e$$

2.7. Sorption Isotherms

Adsorption is usually described through isotherms, that is, the amount of adsorbate on the adsorbent as a function of its pressure (if gas) or concentration (if liquid) at constant temperature. The quantity adsorbed is nearly always normalized by the mass of the adsorbent to allow comparison of different materials. Equilibrium studies that give the capacity of the adsorbent and equilibrium relationships between adsorbent and adsorbate are described by adsorption isotherms which are usually the ratio between the quantity adsorbed and the remaining in solution at fixed temperature at equilibrium. Langmuir and Freundlich isotherms are the earliest and simplest known relationships describing the adsorption equation (Muhamad *et al.*, 1998; jalali *et al.*, 2002). These two isotherm models were used to assess the different isotherms and their ability to correlate experimental data.

2.8. Sorption Kinetics

The rate of adsorption of a molecule unto a surface is an essential parameter when designing batch sorption systems, consequently it is essential to establish the time dependence of such systems under various process conditions. In an attempt to describe the sorption rate and confirm the reaction mechanism of Cd^{2+} and Pb^{2+} onto melon husk, two kinetic models were applied to the experimental data. The first model was based on the assumption that sorption of metal ions onto the melon husk was reversible and followed a first order rate kinetics (Vinod and Anirudhan, 2002). The experimental data were further evaluated based on the pseudo-second order kinetic rate model proposed by Ho *et al.* (1995).

3. Result

The results of the effects of contact time on cadmium and Lead Sorption by the adsorbent is presented in Figures 1 and 2. There was rapid adsorption of Cd(II) by H_2SO_4 modified melon husks and the adsorption of Lead with H_2SO_4

recorded 100% removal except at 100 minute at which point the percentage adsorption dropped to 87.626% (Figure, 2).

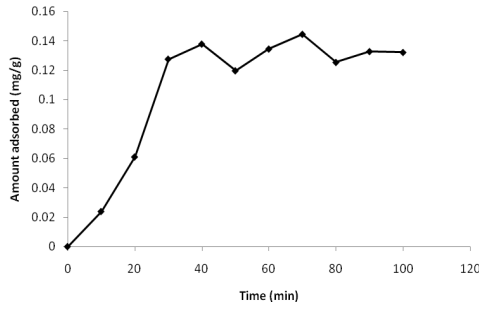


Fig 1. Effect of contact time on adsorption of Cd²⁺; H₂SO₄ (Volume 250mL, adsorbent dose 3g)

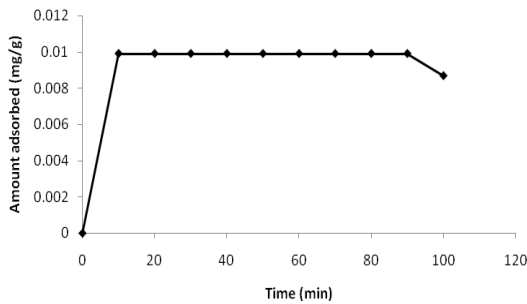


Fig 2. Effect of contact time on adsorption of Cd²⁺; H₂SO₄ (Volume 250mL, adsorbent dose 3g)

The results of the effects of the adsorbent dosage on Cd(II) and Pb(II) sorption is presented in Figure 3 and 4 and shows that both cadmium and lead adsorption is adsorbent dosage dependant. The percentage removal of cadmium increased with increasing adsorbent dosage up to a dosage of 0.6g of the adsorbent (H₂SO₄ modified melon husk), at which point the maximum adsorption was attained. After this, any other additional dose did not have any effect, the sorption decreased. For lead adsorption (Fig.4), it was also the same effect with maximum adsorption attained with 0.4g of the adsorbent (H₂SO₄ modified melon husk). Further increase in dosage amount did not show any positive effect again. In fact the adsorption dropped and remained relatively constant.

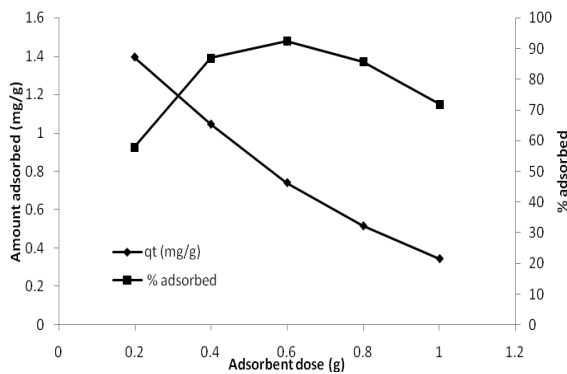


Fig 3. Effect of adsorbent dose on adsorption of Cd²⁺; H₂SO₄ (Volume 250mL)

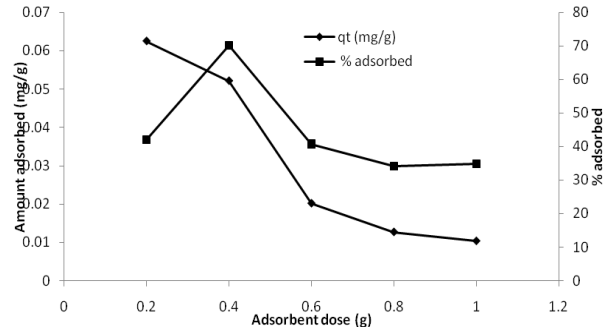


Fig 4. Effect of adsorbent dose on adsorption of Pb²⁺; H₂SO₄ (Volume 250mL)

The adsorption of cadmium by H₂SO₄ modified melon husk did not show strict dependency on the concentration of the adsorbate, (Fig 5). This was attributed to the high efficiency of H₂SO₄ modified melon husk in removing both cadmium and lead. This high efficiency of H₂SO₄ activated melon husk has been shown throughout this study. The adsorption of lead showed dependency on adsorbate concentration with the lowest removal of 42.1% attained at the highest concentration and 100% removal was maintained for the subsequent lesser concentrations of the adsorbate (Fig 6).

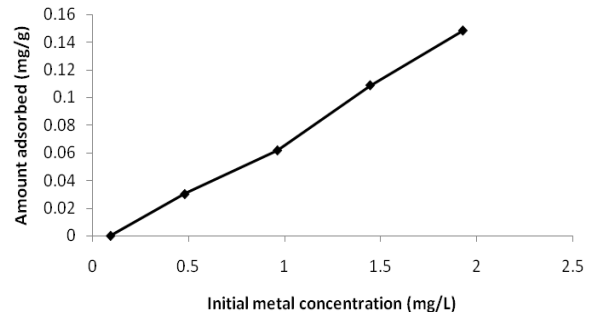


Fig 5. Effect of initial metal concentration on adsorption of Cd²⁺; H₂SO₄ (Adsorbent Dose 3g, Volume 250mL)

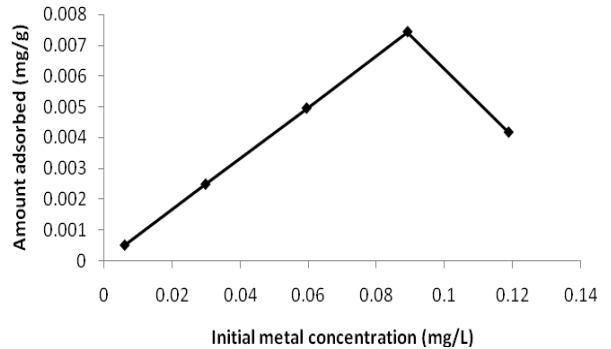


Fig 6. Effect of initial metal concentration on adsorption of Pb²⁺; H₂SO₄ (Adsorbent Dose 3g, Volume 250mL)

Adsorption isotherm model for sorption of cadmium and lead is presented in fig 7 and 8 respectively.

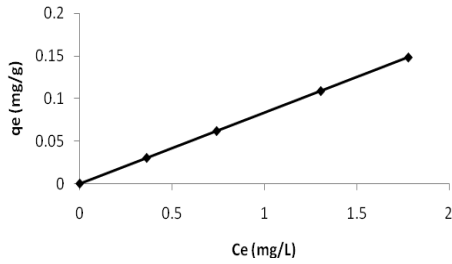


Fig 7. Adsorption isotherm model for sorption of Cd^{2+} (H_2SO_4)

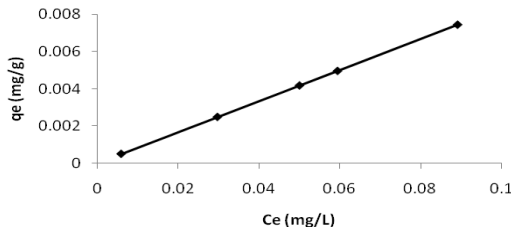


Fig 8. Adsorption isotherm model for sorption of Pb^{2+} (H_2SO_4)

A plot of q_e against C_e (Fig. 7 and 8) yielded straight lines and indicates a good fit of the isotherm to the experimental data. The linear plots of $1/q_e$ against $1/C_e$ show that adsorption followed the Langmuir model (Fig. 9 and 10). The correlation coefficient R^2 is 0.999 for sorption of lead by urea modified melon husk, while R^2 for others is one (1).

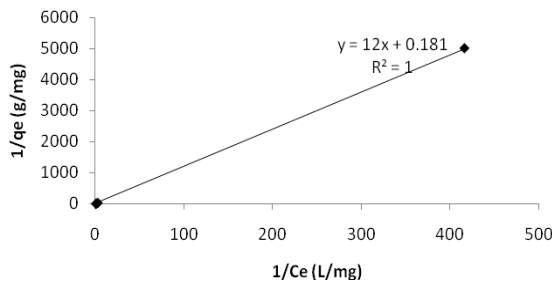


Fig 9. Langmuir equilibrium isotherm model for sorption of Cd^{2+} (H_2SO_4)

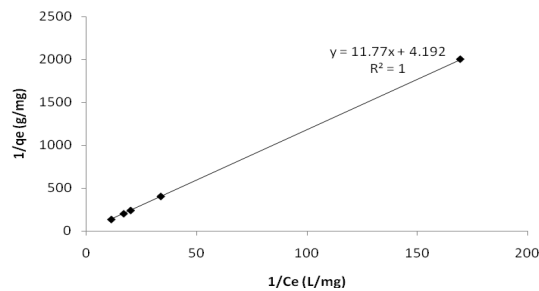


Fig 10. Langmuir equilibrium isotherm model for sorption of Pb^{2+} (H_2SO_4)

The rate of adsorptions of Cd(II) and Pb(II) onto H_2SO_4 were fitted into pseudo-second order adsorption kinetics. The data showed that, modified melon husk enhanced the equilibrium sorption capacity of the melon husk towards both metal ions. The r^2 values (coefficient of determination) ranges between 0.025 and 0.602 (Fig.11 and 12).

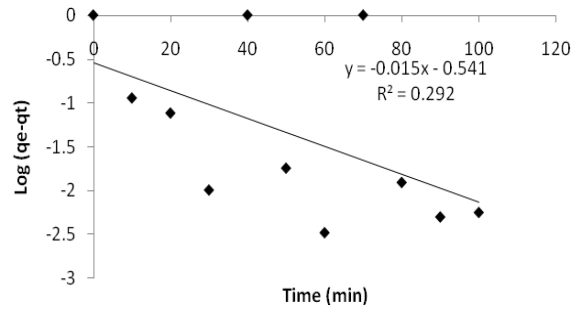


Fig 11. Pseudo-first order sorption kinetics of Cd^{2+} (H_2SO_4)

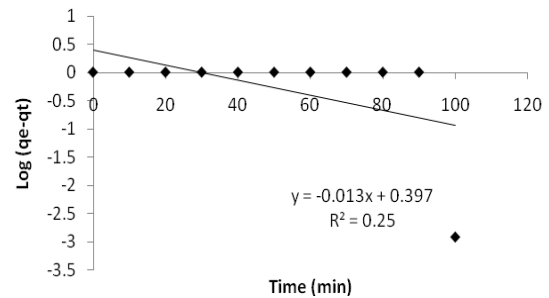


Fig 12. Pseudo-first order sorption kinetics of Pb^{2+} (H_2SO_4)

4. Discussion

The result of the experiments showed that modified or activated melon husk has the potential of removing cadmium and lead from waste water-like many other agricultural waste products. Nasim *et al.* (2004) in their review showed that agricultural waste products like sugarcane bagasse, rice husk, coconut husk, oil palm shell, neem bark e.t.c have a great potential for the elimination of heavy metals from waste water.

Results obtained from the analysis of filtrates while varying the contact time of the adsorbent with the adsorbate showed that the removal of cadmium and lead from waste water increased with increasing contact time. According to Iyagba and Opete (2009), the results obtained from varying the contact time of the adsorbent with the adsorbate showed that the removal of chromium and lead from drill cutting extract increased with increasing contact time and attained equilibrium at 90 and 120 min for both activated palm kernel shell (APKS) and activated palm kernel husk (APKH), respectively.

For the adsorption of cadmium in the present work, equilibrium were attained at 70 min for H_2SO_4 activated melon husk. But for the adsorption of lead, equilibrium were attained within the first 10 minute for H_2SO_4 activated melon husks. Amuda *et al.* (2007) reported that the adsorption of lead by the seed of *chrysophyllum albidum* increased with contact time and equilibrium was attained at 30 min. The results of the adsorption of cadmium by *Platanus orientalis* leaf (POL) indicates that cadmium adsorption increased with increasing time and became almost constant after 60 min for POL and 60 min for its ash (Mahvi *et al.*, 2007a). Similar results showed that

adsorption of cadmium increase with increased in contact time and became almost constant after 45min for rice husk and 30 min for its ash (Mahvi *et al.*, 2005b). Wong *et al.* (2003), Kiff and little (1986) reported that adsorption of Cd(II) is dependent on contact time. These findings are in agreement with the result of the present work.

The amount of adsorbent employed was found to influence the efficiency of the adsorption process most especially on the sorption process of cadmium. The percentage removal of cadmium increased with increasing carbon, dosage up to the doses of 0.8g, 1g and 0.6g for H₂SO₄. With these dosages maximum adsorption were attained. Once the maximum adsorption sets in, even with no further increase in the dose of adsorbent there was no further adsorption. This was in agreement with Ajmal *et al.* (2003) who reported that adsorption of Cd(II) was dependent on contact time, concentration, temperature, adsorbent doses and pH of the solution.

According to Iyagba and Opete (2009) the percentage removal of lead and chromium increases with increased carbon dosage. The performance of the adsorbent was evaluated by Amuda *et al.* (2007) for the removal of lead. The dose of the adsorbent was varied between 1.0 and 3.0g/100ml. Percentage lead removal increased significantly as the amount of adsorbent added increased. Adsorbent dosage of 2.0g/100ml was required to remove 99% of lead in aqueous solution. This showed that as the dose of adsorbent increased, there was increase in the available exchangeable sites for lead. Peternele *et al.* (1999) confirmed that Cd(II) and Pb(II) removal were dependent on adsorbent dosage.

The absorption of Lead did not show consistent increase in adsorption process with increased adsorbent dosage. For H₂SO₄ MMH, increase in adsorbent dosage (0.2 – 0.4g) increased percentage adsorption at which point the maximum adsorption was attained. The amount of ions bound to the adsorbent and amount of free ions remained almost constant even with further addition of dose of the adsorbent. It was evident from the results obtained that the removal capacity was low at high dose rate and vice versa due to the decrease in the amount of free ion left for adsorption. Nasim *et al.* (2004) reported that the sorption capacity is dependent on the type of the adsorbent investigated and the nature of the wastewater treated.

The percentage removal of cadmium and Lead by the adsorbent increased with decreasing adsorbate concentration. At lower concentration, cadmium and Lead ions in the solution interacted with the binding sites and higher percentage adsorption was facilitated. At higher concentration, more cadmium and Lead ions were left unabsorbed in solution due to the saturation of the binding site. Boucher *et al.* (2008) reported the sorption efficiency of Copper decreased with increase in adsorbate concentration.

Wong *et al.* (2008) reports that adsorption of Cd(II) on phosphate treated rice is dependent on adsorbate concentration. The studies of Chand *et al.* (1994) on the removal of Chromium (VI) from aqueous waste showed

that the removal was generally most effective at low concentration. Amuda *et al.* (2007) in their work on removal of lead from industrial wastewater using *chrysophyllum albidum* seed shell agreed that the removal of lead is most effective at low adsorbate concentration.

The percentage removal of Cd(II) from the least C₀ (initial concentration) of 0.09632 was 73.5% while that of Pb(II) at the least concentration of 0.00594 or even before was 100%. This difference in rate of adsorption is because adsorption of metal cation on adsorbent depends upon the nature of adsorbent surface and species distribution of the metal cations (Namasivayam and Ranganthan, 1995). Mahvi *et al.* (2005a) agreed with this from the results of their work on removal of Cadmium from wastewater using tea waste. Mahvi *et al.* (2005a) in another study to find out the effect of metal type on adsorption, concluded that the adsorption efficiency is also dependent upon the type of metal. Not more than 76% removal of Ni ions achieved with the same conditions that gave rise to 94 and 60 % removal of Pb and Cd respectively.

Samarghandi *et al.* (2006) studied the percentage removal of Cd, Pb and Phenol at the same conditions. Pb was found to attain above 99 % removal both at minimal and optimal conditions. For Cd it was 26 and 94.5 % respectively. Phenol was 51% for minimal and 76% for optimal conditions. These results agreed with the current work, that lead removal is almost 100% without much dependency on various factors which affect metal sorption. This is due to the nature of lead ion which makes it better adsorbed than cadmium ion as shown in the results.

The equilibrium sorption data were represented by Langmuir and Freundlich isotherm models. According to Igwe and Abia (2007), in the equilibrium sorption isotherm studies of Cd(II), Pb(II) and Zn(II) ions detoxification from waste water using unmodified and EDTA-modified maize. The data fitted to Langmuir, Freundlich and Dubinin-Radushkevich isotherm. The linearized plot of both Langmuir and Freundlich produced R² values that ranges from 0.911 to 1. This shows that H₂SO₄ is an efficient adsorbent in the removal of Cd and Pb.

Isotherm studies for heavy metal adsorption on rice husk by Mohan *et al.* (2008) showed that adsorption data fitted better with Freundlich than Langmuir model. Adsorption characteristics of heavy metal ions onto a low cost biopolymeric sorbent from aqueous solutions by Unlu and Ersoz (2005) fitted to Freundlich type isotherm model. While Langmuir model fitted better in the biosorption of lead from industrial wastewater using *Chrysophyllum albidum* seed shell, Amuda *et al.* (2007). Boucher *et al.* (2008) and Saikaew *et al.* (2009), in their separate work on heavy metal adsorption using various agricultural wastes reported that the data fitted better to Langmuir isotherm model.

The positive linear plots of the sorption kinetics of both Cd(II) and Pb(II) showed that the experimental data were fitted into pseudo-second order sorption kinetics. Ho *et al.* (1995) in the sorption kinetics of Pb²⁺ and Cu²⁺ ions, reported that the experimental data were fitted into pseudo-

second order kinetics. The coefficient of determination, r^2 , from the pseudo-second order rate model showed that, r^2 values are greater than 0.990 for both metals with or without modification. The r^2 values of the pseudo-second order rate for the present work ranges from 0.797-0.999 which is similar to that obtained by Ho et al. (1995). The r^2 values for Cd^{2+} are 0.830, 0.848 and 0.797, while those of Pb^{2+} are 0.999, 0.869 and 0.989 with Urea, NaOH and H_2SO_4 MMHs, respectively. Unlu and Ersoz (2006) reported that the experimental data of the adsorption characteristics of heavy metal ions onto a low cost biopolymeric sorbent from aqueous solutions, followed pseudo-second order adsorption kinetics. Saikaew et al. (2009) also reported a similar result of pseudo-second order sorption kinetics on the biosorption of cadmium ions from aqueous solution using pomelo peel, an agricultural waste. The coefficient of determination values indicates that the modified melon husk is an excellent biomaterial for the removal of metal ion from industrial waste water.

The r^2 values for the pseudo-second order kinetics showed that Pb(II) was better adsorbed than Cd(II).

Using the pairwise t-test, the result also showed significant difference in the adsorption of Cd(II) and Pb(IV) ions since the significance value (2-tailed) is less than α , were $\alpha = 0.05$. Lead was better adsorbed; this is in agreement with the studies of Samaghandi et al. (2006) and some researchers. There is significant difference ($p < 0.05$) in the adsorption of Cd(II) and Pb(IV), with Pb(IV) being better adsorbed from the paired sample test.

5. Conclusion

Based on the findings of this research, the study concludes that melon husk activated with sulphuric acid can be used effectively in the remediation of industrial waste water. The study also recommends that industries reduce their use of these heavy metals or better still find alternative material to it, since it is known that even though metals are adsorbed, they can still find their way into the environment.

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