Uniport Journal of Engineering and Scientific Research (UJESR)

Vol. 1, Issue 1, October/2016
ISSN: 2616-1192

(www.ujesr.org)

Optimum Conditions for the Removal of Lead from Aqueous Solution with Bamboo Activated Carbon

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Abstract

*The optimum conditions for the adsorption of lead from aqueous solution onto two varieties of bamboo activated carbon prepared by chemical activation method with $ZnCl_2$ were evaluated through batch adsorption studies. CABCW was washed after activation while UCABC was not washed after activation. The effects of adsorbent dose, initial concentration of adsorbate, agitation time, adsorbate pH and, particle size were used as variables to obtain the optimum conditions. Results showed increase in lead adsorption at smaller adsorbent dosage indicating more active sites were utilized at smaller adsorbent dose. However, percentage removal rate (%) increased with lead concentration due to availability of more metal ions at higher concentration. Thus, UCABC and CABCW achieved up to 96.45% and 92.55% removal, respectively at initial lead concentration of 50mg/l, at optimum pH of 11. Equilibrium was attained in 60mins and 150mins respectively for CABCW and UCABC while effects of particle size showed that larger particle sizes (425*μm*) favoured lead adsorption.*

Keywords: *Bamboo Activated Carbon, Chemical Activation, Lead, Adsorption.*

1. Introduction

Lead poisoning has been a major concern globally. It rarely occurs in nature, but it is usually found in ore with zinc, silver and copper and is extracted together with these metals. It is a soft, malleable poor metal, which is used as industrial raw material in the manufacture of wide variety of products including pigments for paints, ceramics, pipes, aluminum products, bullets, storage batteries, leaded glass, steel products, photographic materials, devices to shield X-rays and many others (Nadeem et al., 2006). Lead can be found in dust, air, water, soil and in some products used in and around our homes.

Lead is highly toxic and has no known beneficial effects in the human body. The maximum level of lead in drinking water is 10ug/l (WHO, 1993). At certain exposure levels, lead is poisonous to human being and animals. In short, all lead compounds are considered cumulative poisons (Patrick, 2006). Acute lead poisoning can affect nervous system and gastrointestinal track. It can damage the nervous connections (especially in young children) and can cause blood and brain disorders. Long term exposure can cause abdominal pains. Lead can harm young children’s growth, behavior and their ability to learn. Children under the age of six are more likely to get lead poisoning than the other age groups. Lead can also be passed from mother to baby during pregnancy. Severe lead poisoning can cause encephalopathy, with permanent damage, while moderate lead poisoning result in neurobehavioral and intelligent deficit (Patrick, 2006). The presence of lead in drinking water, even in low concentrations may cause anaemia, hepatitis and nephritic syndrome (Zulkali et al., 2006). Lead poisoning in humans causes severe damage to kidney, nervous system, reproductive system, liver and brain (Ozer, 2007).

Exposure to lead and lead compounds can occur through inhalation, ingestion and dermal contact. Lead poisoning typically results from ingestion of contaminated food and water. However, its effects are the same whether it enters the body through breathing or swallowing. Lead can affect almost every organ and system in the body even in very low concentrations. Thus, its removal from waste streams should be paramount.

2. Materials and methods

2.1. Preparation of Bamboo Activated Carbon

The dominant bamboo found in Nigeria could be referred to as Indian bamboo and this was the bamboo used for this study. Activated carbon was prepared from fully matured Bamboo sticks using the method as reported by Udeh and Agunwamba, 2016. The bamboo sticks were cut into smaller sizes (2- 4cm) and then washed, air dried. Zinc Chloride ($ZnCl_2$) of about 80% purity was used to chemically activate the bamboo sample at impregnation ratio of 1:2, carbonized in a muffle furnace at 500^{o}C for 3hrs and then grinded into powder. Part of the grinded activated bamboo carbon were washed with distilled water to a pH of 6 (to remove the activating chemical) and then dried in an oven at a temperature of 110^{o}C for a period of 6 hrs while the other part was not washed. The washed bamboo samples were named chemical activated bamboo carbon washed (CABCW) while the unwashed samples were named unwashed chemical activated bamboo carbon (UCABC). This nomenclature was used to identify the two variations of bamboo activated carbons prepared.

2.2. Batch Adsorption Studies

Batch adsorption method was used to investigate the removal of lead (Pb) ions from aqueous solution. Wastewater samples were simulated in the laboratory by mixing lead nitrate salt ($Pb(NO_3)_2$) in distilled water to obtain the desired initial concentrations. All the chemicals used were of analytical grade. Adsorption studies were conducted to obtain the effect of adsorbent dose, initial adsorbate concentration, initial adsorbate pH, agitation time and particle size on the adsorption of lead onto CABCW and UCABC. The adsorption efficiency of the test carbons was used as criterion for determining optimum conditions for lead removal.

2.2.1. Effects of Adsorbent Dosage

The effect of adsorbent dose was investigated by mixing 50ml of simulated wastewater samples of pH 7 and a fixed initial adsorbate conc. of 20mg/l stock solution of lead with different adsorbent doses of 1, 2, 3, 4 and 5g and then agitated for one hour using a mechanical shaker. The contents were then filtered and the filtrates analysed for residual concentration of lead using Atomic adsorption spectrometer (AAS). The optimum adsorbent dosage for lead removal was noted and adopted for the next experiment.

2.2.2. Effects of Initial Ion Concentration

Effect of different initial concentration of lead (10, 20, 30, 40 and 50mg/l) were investigated by adjusting the initial concentration of lead via dilution of the simulated wastewater sample while the optimum condition of adsorbent dosage was adopted. The experimental procedure remained the same and the residual concentration of lead was analyzed. The optimum initial lead concentration was noted.

2.2.3. Effects of Agitation Time

The effect of different agitation time (30min, 60min, 90min, 120min, 150mins and 180mins) on the adsorption of lead was conducted by varying the agitation time but adopting the optimum adsorbent dose and optimum initial concentrations. The experimental procedure and other test conditions remained the same except that the plastic containers were removed from the shaker at specified time intervals of 30min, 60min, 90min, 120min, 150mins and 180mins. The residual concentration of lead was analyzed and their optimum agitation time for adsorption was noted.

2.2.4. Effects of Adsorbate pH

To investigate the effect of adsorbate pH on the adsorption of lead, the pH of the adsorbate were adjusted to 3, 5, 7, 9 and 11 by adding 0.1M (NaOH) or HCl solutions as the case may be. The optimum adsorbent dosage, initial concentration and agitation time were adopted while other test conditions and experimental procedure remained same. The optimum adsorbate pH for the adsorption was noted.

2.2.5. Effects of Particle Size

The effect of different particle sizes of the adsorbent on the adsorption of lead was investigated by carrying out sieve analysis on the bamboo activated carbon. Four different particle sizes (425µm, 250µm, 150µm and 50µm) were investigated using the optimum values of agitation time, adsorbent dose, initial concentration and pH, while other test procedure remained the same. The optimum adsorbent particle size was noted.

3. Results and discussion

3.1. Effect of Adsorbent dose on Lead Removal

The effects of different adsorbent doses of CABCW and UCABC on lead removal from aqueous solution were shown in Figure 1. Results revealed that as the adsorbent dosage increased, the amount adsorbed per unit mass of the adsorbent decreased. This decrease in unit adsorption may be due to adsorption sites remaining unsaturated during adsorption (Li et al, 2010). This reveals that more active sites are utilized at lower adsorbent dose, producing higher adsorption efficiency, while only part of active sites were occupied by lead ions at higher adsorbent dose, leading to lower adsorption efficiency (Okure et al 2010). Thus, the optimum adsorbent dosage for the removal of lead was 1g with removal efficiency of 79.29% and 81.36% for CABCW and UCABC respectively.

3.2. Effect of Initial Ion Concentration on Lead Removal

Results on the effect of initial concentration on the adsorption of lead onto CABCW and UCABC were presented in Figure 2. The results showed that percentage removal rate increased with increase in lead concentrations. This may be due to the fact that as the concentration is increased, more metal ions were available in the solution for the adsorption (Nwabanne and Mordi, 2009). This increase revealed that optimum removal efficiency of 87.15% and 92.82% were achieved with CABCW and UCABC, respectively at 50mg/l. Thus, lead removal was highly concentration dependent and this might also be due to high driving force for mass transfer (Okuo and Ozioko, 2001).

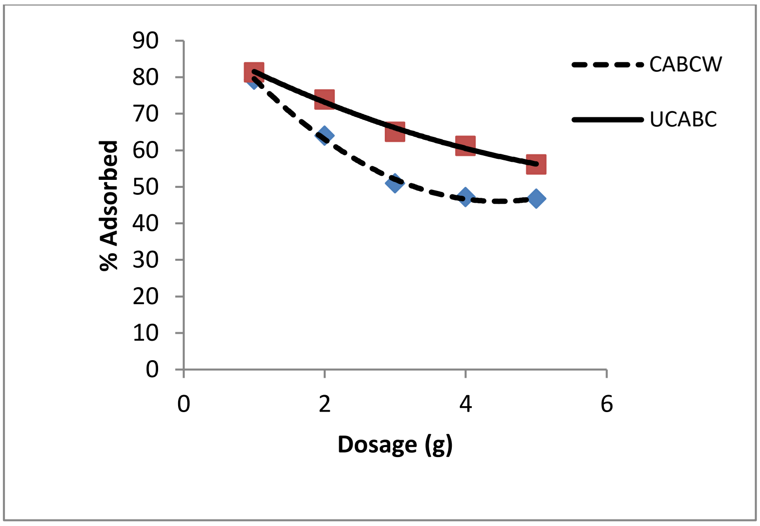

Figure 1: Lead removal as function of adsorbent dosage

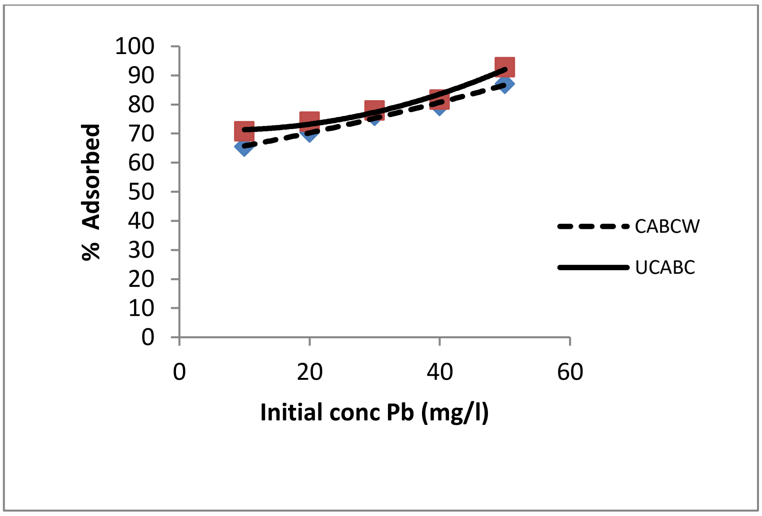

Figure 2: Lead removal as a function of initial concentration

3.3. Effect of Agitation Time

The equilibrium time required for the maximum adsorption of lead ions onto CABCW and UCABC was studied. The results, as shown in Figure 3, revealed an increase in adsorption of lead ions with increase in agitation time. This may be due to the decrease in boundary layer resistance to mass transfer in the bulk solution and an increase in kinetic energy of the hydrated metal ions (Baes and Mesmer, 1976). The removal efficiency increased with time and attained equilibrium at 60mins (85.45%) for CABCW and 150mins (90.15%) for UCABC.

3.4. Effect of Adsorbate pH

Results on the effects of adsorbate pH on the removal of lead onto CABCW and UCABC were shown in Figure 4. The percentage removal efficiency for lead adsorption increased as the pH moves from the acidic pH 3 to alkaline pH 11. Thus, alkaline medium tend to support adsorption of Pb more than acidic medium. High removal efficiency of lead was observed at pH of 11 for CABCW (92.55%) and UCABC (96.45%). This showed that pH was an important controlling parameter for adsorption of lead ions because it affects the solubility of the metal ions, concentration of the counter ions on the functional group of the adsorbent and the degree of ionization of the adsorbate during reaction (Badmus et al, 2007; Israel et al, 2010). Studies showed that heavy metal cations are completely released in extreme acidic condition (Gundogdu et al, 2009) while at lower pH values, the H+ ions compete with the metal cation for the adsorption sites in the system (Ahmed et al; Demirbas et al, 2004).

3.5. Effects of Particle size

Results on the effect of different particle sizes of CABCW and UCABC on the removal of lead from aqueous solution was shown in Figure 5. The removal rate increased with larger particle sizes indicating an increase in the diffusion path occasioned by the larger diameter particles. Similar trends were reported by Demirbas et al, 2004; Akpen et al, 2013. High removal efficiency of 90.48% and 88.33% for CABCW and UCABC, respectively was observed at particle size 425µm.

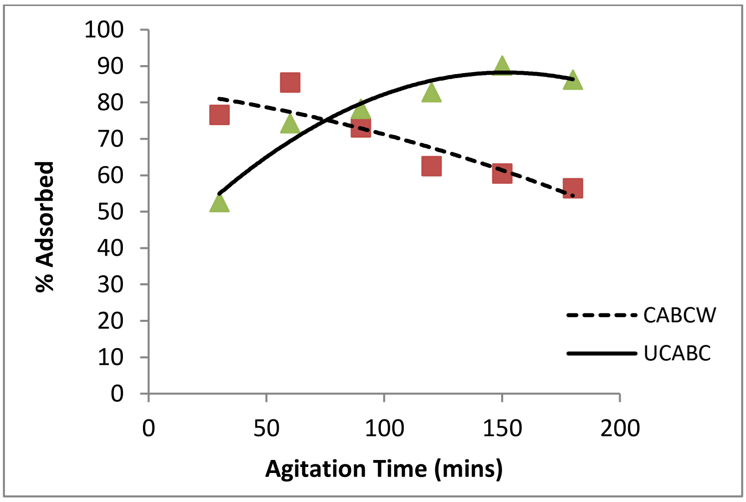

Figure 3: Lead removal as a function of agitation time

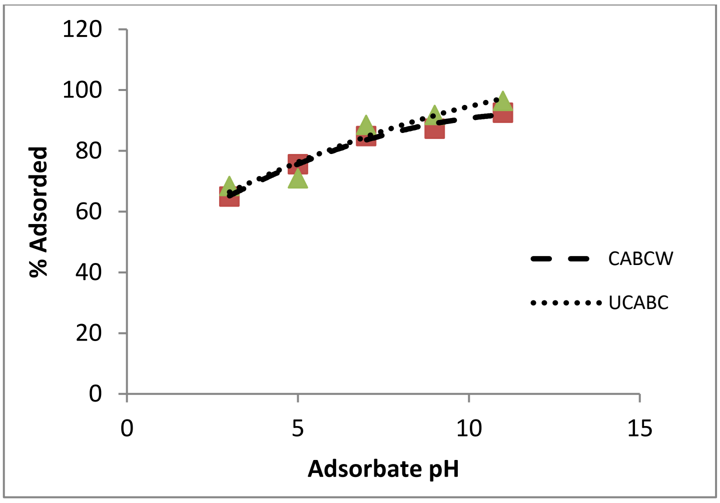

Figure 4: Lead removal as a function of adsorbate pH

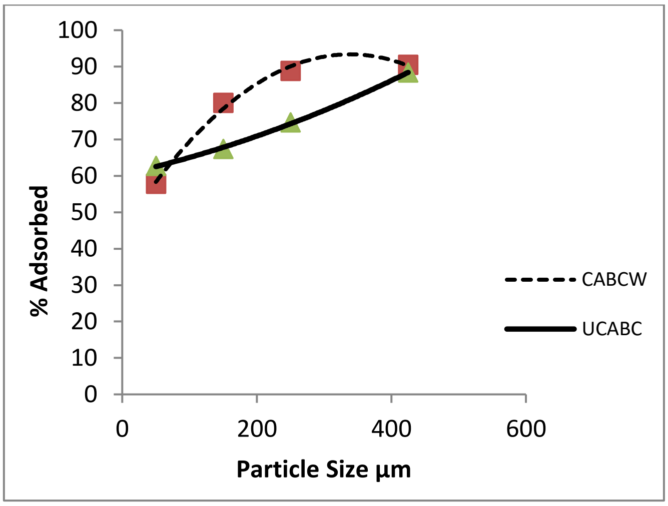

Figure 5: Lead removal as a function of particle size

4. Conclusions

This study revealed the optimum conditions for the removal of lead from aqueous solution using chemically activated bamboo carbon. The amount of leads adsorbed was found to vary with adsorbent doses, initial adsorbate concentration, agitation time, adsorbate pH and adsorbent particle size. The rate of removal increased with smaller adsorbent dosage while the amount adsorbed per unit mass increased with increase in initial lead concentrations for both CABCW and UCABC. In general all the carbons achieved at least 87% removal at initial lead concentration of 50mg/l with larger particle size (425µm). Lead removal were pH dependent (pH 11) tending towards alkalinity. Also, there was increase in adsorption of lead ions with increase in agitation time due to increase in kinetic energy of the metal. CABCW attained equilibrium in 60mins while UCABC attained equilibrium in 150mins.

In conclusion, chemically activated bamboo carbon can be used for the removal of lead from aqueous solution. The UCABC (unwashed chemically activated bamboo carbon) could effectively remove lead from aqueous medium and might be a better adsorbent compared to CABCW to avoid generating additional wastewater. The optimum conditions for the adsorption of lead from aqueous solution for the various bamboo activated carbons were summarised in Table 1.

Table 1: Optimum Conditions for Adsorption of Lead from Aqueous Solution onto CABCW and UCABC

Variables	**Optimum Conditions**	
	CABCW	**UCABC**
Adsorbent dose (g)	1	1
Initial Adsorbate conc. (mg/l)	50	50
Adsorbate pH	11	11
Agitation Time (mins)	60	150
Particle size (µm)	425	425

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