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

Udeh, N. U[1]. , Agunwamba, J.C[2]
[1]*Department of Environmental Engineering, University of Port Harcourt, Rivers, Nigeria.*
[2]*Department of Civil and Environmental Engineering, University of Nigeria Nuskka, Nigeria.*

ABSTRACT
The performance of two varieties of Bamboo activated carbon (CABC washed and CABC unwashed), produced by chemical activation with $ZnCl_2$, was evaluated through batch adsorption studies for the removal of Cadmium from aqueous solution. The effects of adsorbent dose, initial concentration of cadmium, agitation time, adsorbate p and, particle size were used as variables to obtain the optimum conditions for the removal of cadmium. Results obtained revealed that as the adsorbent dose increased, the amount adsorbed per unit mass decreased indicating that more active sites were utilized at smaller adsorbent dose. Also, the effects of initial cadmium concentration showed that percentage removal rate increased with increase in cadmium concentration due to availability of more metal ions at higher concentrations. Thus, all the carbons achieved at least 82.62% removal at initial Cadmium concentration of 50mg/l. The optimum pH was 5 and 7 for CABC unwashed and CABC washed respectively while the optimum particle size was 50μm for all the carbon tested. Furthermore, CABC unwashed performed better as an adsorbent because it achieved 71.48% removal of Cadmium in 60 minutes, while CABC washed achieved 69.46% removal in 120mins.

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I. INTRODUCTION

Heavy metal pollution has been a major concern globally. Sources of heavy metal pollution come from discharges of various industries such as petroleum-refining, pesticides, smelting, mining, electroplating, tanning, glass, herbicides and ceramic manufacturing industries [1]. The wastewater from these industries can contain heavy metals such as chromium, lead, cadmium, aluminium, arsenic, copper, iron, manganese, vanadium, nickel, mercury, cobalt and among others. These metals are toxic both in chemically combined forms as well as in their elemental forms and their excessive intake by man may result in severe health hazards including prenatal and developmental defects [2]. In particular, Cadmium is a contaminant that is a known mutagen, teratogen and carcinogen. The excessive intake of cadmium can cause severe mucosal irritation, widespread capillary damage, hepatic and renal damage, central nervous problems followed by depression, gastrointestinal irritation and possible necrotic changes in the liver and kidney.

Adsorption techniques are widely used for the removal of diverse contaminants and commercial activated carbon is the preferred adsorbent but its use is restricted due to high cost [3]. Thus, non- conventional low cost adsorbents have been investigated. Bamboo can be converted into charcoal and activated carbon by carbonization and the activation [4][5] and [3]. The conversion of Bamboo, an abundant natural renewable resource, into activated carbon will help to solve part of wastewater treatment problem [3]. The focus of this research is to evaluate the optimum conditions for the removal of cadmium ions from aqueous solution using bamboo based activated carbon.

II. MATERIALS AND METHODS

2.1 Preparation of Bamboo Activated Carbon

The Bamboo sticks used for this study could be referred to as Indian bamboo which is the dominant bamboo in Nigeria found in the rain forest belt [6]. Fully matured Bamboo sticks were cut into smaller sizes (2- 4cm) and then washed, air dried and then taken to the laboratory for further processing. Zinc Chloride ($ZnCl_2$) of about 80% purity was used as the activating agent. The bamboo samples were chemically activated using ($ZnCl_2$) at impregnation ratio of 1:2, carbonized in a muffle furnace at 500^oC for 3hours 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^oC for a period of 6 hours while the other part was not washed. The washed bamboo samples were named Chemical Activated Bamboo Carbon (CABC washed) while the unwashed samples were named CABC unwashed. This nomenclature was used to identify the two variations of bamboo activated carbons prepared.

2.2 Batch Adsorption Studies

The adsorption of Cadmium (Cd) (II) ions from aqueous solution was investigated by batch method. All the chemicals used were of analytical grade. Wastewater samples were simulated in the laboratory by mixing anhydrous Cadmium compounds in distilled water to obtain the desired initial concentrations. Adsorption studies were conducted to obtain the effect of adsorbent dose, initial adsorbate concentration, initial adsorbate pH, agitation time, particle size and agitation speed on the adsorption of Cadmium onto CABC washed and CABC unwashed. The adsorption efficiency of the test carbons for Cadmium removal was used as criterion for determining optimum conditions.

To investigate the effect of adsorbent dose, 50ml of simulated wastewater samples of pH 7 and initial cadmium concentration of 20mg/l were mixed with specified adsorbent doses of 1, 2, 3, 4 and 5g into plastic containers and then attached to a mechanical shaker and then agitated for one hour. After the end of agitation period, the containers were removed slowly from the shaker and the contents were then filtered through no. 542 Whatman filter paper. The filtrates were then separately analysed for residual concentrations of cadmium using Atomic adsorption spectrometer (AAS). The optimum adsorbent dosage for cadmium was noted and adopted for the next experiment while other test conditions and experimental procedure remained same.

A study on the effect of initial concentrations of cadmium was conducted by adjusting the initial concentration of the adsorbates via dilution of the simulated wastewater samples. Different initial concentration of cadmium (10, 20, 30, 40 and 50mg/l) were prepared while the optimum condition of adsorbent dosage was adopted. The experimental procedure remained the same and the optimum initial concentration of cadmium was noted.

The effect of agitation time on the adsorption of cadmium was conducted by varying the agitation time but adopting the optimum adsorbent dose and optimum initial concentration of cadmium. 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 cadmium was analyzed and the optimum agitation time for adsorption of cadmium was noted.

To investigate the effect of adsorbate pH on the adsorption of cadmium, the pH of the adsorbates 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 for cadmium were adopted while other test conditions and experimental procedure remained same. The optimum adsorbate pH for the adsorption of cadmium was noted.

The effect of particle size of the adsorbent on the adsorption of cadmium was investigated. Sieve analysis was carried out on the bamboo activated carbon and four particle sizes of 425µm, 250µm, 150µm and 50µm were investigated using the optimum values of agitation time, adsorbent dose, initial concentration of adsorbates and pH, while other test procedure remained the same.

III. RESULTS AND DISCUSSION

The results of the batch adsorption studies conducted with two different samples of bamboo activated carbon namely CABC washed and CABC unwashed for the removal of Cadmium in aqueous solutions were shown in Figs. 1 to 5.

3.1 Effect of Adsorbent dose on Cadmium Removal

The effect of different adsorbent doses (1g, 2g, 3g, 4g, and 5g) of CABC washed and CABC unwashed on cadmium removal from aqueous solution was shown in Fig 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 [7]. 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 Cadmium ions at higher adsorbent dose, leading to lower adsorption efficiency [8]. Thus, the optimum adsorbent dosage for the removal of Cadmium was 1g at removal efficiency of 67.71 and 71.31% for CABC washed and CABC unwashed respectively. This observation confirms the adsorptive capacity of bamboo activated carbon thus; carbon dosage of 1g was taken as the optimum dosage.

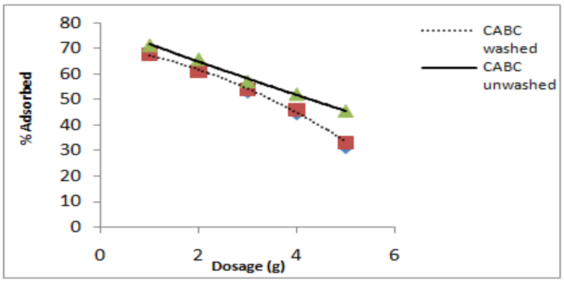

Fig. 1: Cadmium Removal as a function of Adsorbent Dose

3.2 Effect of Initial Ion Concentration on Cadmium Removal

The effect of different initial concentration of cadmium (10, 20, 30, 40 and 50mg/l) on adsorption with CABC washed and CABC unwashed were presented in Fig. 2. Results showed that percentage removal rate increased with increase in cadmium concentration. This may be due to the fact that as the concentration is increased, more metal ions are available in the solution for the adsorption process [9]. With increase of initial ions concentration, the removal efficiency of CABC washed increase from 50.75% to 84.35% while CABC unwashed increased from 61.05% to 82.62%. Thus, cadmium removal was highly concentration dependent and this might also be due to high driving force for mass transfer [10]. Optimum removal efficiency of 84.35% and 82.62% at 50mg/l were observed for CABC washed and CABC unwashed respectively and this was taken as the optimum concentration.

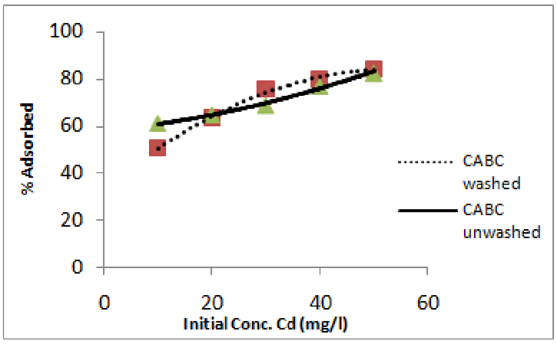

Fig. 2: Cadmium Removal as a function of Initial Conc.

3.3 Effect of Agitation Time

The adsorption of cadmium ions onto CABC washed and CABC unwashed was studied as a function of time in order to find out the equilibrium time required for maximum adsorption of metallic ions and this was shown in Fig. 3. There was an increase in adsorption of the cadmium ion with increase in agitation time which 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 [11]. In general, the removal efficiency increased with time and attained equilibrium in 120 minutes for CABC washed while CABC unwashed took 60 minutes to attain equilibrium. These observations indicate that CABC unwashed would require less residence time to remove cadmium from aqueous medium. Thus, the results indicated 69.46% removal efficiency at 120mins for CABC washed and 71.48% at 60mins for CABC unwashed. These contact times were chosen as the optimum contact time.

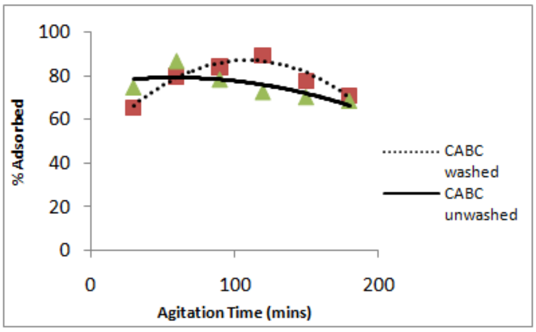

Fig. 3: Cadmium Removal as a function of Agitation Time

3.4 Effect of Adsorbate pH

The effect of different cadmium pH (3, 5, 7, 9 and 11) on adsorption with CABC washed and CABC unwashed was presented in Fig. 4. pH is an important controlling parameter for adsorption of metal 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 [12] [13]. Heavy metal cations are completely released in extreme acidic condition [14] while at lower pH values, the H+ ions compete with the metal cation for the adsorption sites in the system [15] [16].

The effect of pH on the adsorption of cadmium ions from solutions, it was evident that the percentage removal efficiency decrease with increase in pH for CABC unwashed but was neutral for CABC washed. This implies that cadmium removal was pH dependent and was better at acidic – neutral pH for CABC unwashed and CABC washed respectively. High removal efficiency of 89.73% was achieved for CABC unwashed at pH 5 while 87.81% removal efficiency was observed at pH of 7 for CABC washed. Thus pH of 7 and 5 were taken as the optimum pH for CABC washed and CABC unwashed respectively.

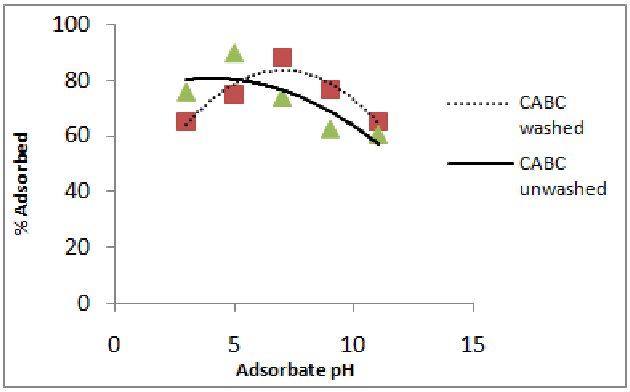

Fig. 4: Cadmium Removal as a function of Adsorbate pH

3.5 Effects of Particle size

The effect of different particle sizes (50, 150, 250 and 425µm) of CABC washed and CABC unwashed on the removal of Cadmium from aqueous solution was shown in Figure 5. The removal rate of Cadmium increased with smaller particle sizes thereby producing shorter time to equilibrium. This may be attributed to the increase in the diffusion path occasioned by the smaller particles. Similar trends were reported by [17] [18]. High removal efficiency of 87.37% and 89.68% for CABC washed and CABC unwashed respectively was observed at particle size 50µm. Thus, 50µm was noted as the optimum particle size.

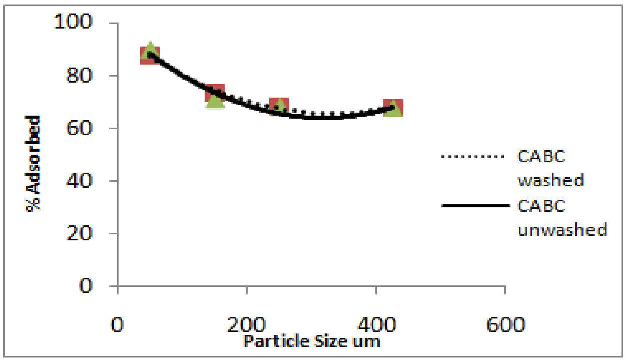

Fig. 5: Cadmium removal as a function of Particle size

IV. CONCLUSIONS

This study investigated that bamboo activated carbon can be effectively used as an adsorbent for the removal of cadmium from aqueous solution at some optimum conditions. The amount of cadmium adsorbed was found to vary with adsorbent dose, initial cadmium concentration, agitation time, adsorbate pH and adsorbent particle size.

The optimum conditions for the adsorption of cadmium from aqueous solution for the various bamboo activated carbons were summarised in Table 1.

Table 1: Optimum conditions for adsorption of Cadmium from aqueous solution on bamboo activated carbon

Variables	Optimum Conditions	
	CABC washed	CABC unwashed
Adsorbent dose (g)	1	1
Initial Cadmium conc. (mg/l)	50	50
Adsorbate pH	7	5
Agitation Time (mins)	120	60
Particle size (µm)	50	50

The rate of cadmium removal increased with smaller quantities of adsorbent dose while the amount adsorbed per unit mass increased with increase in initial cadmium concentrations for both CABC washed and CABC unwashed. In general all the carbons achieved at least 82.62% removal at initial cadmium concentration of 50mg/l with smaller particle size of 50 µm and cadmium removal was pH dependent. Furthermore, there was increase in adsorption of cadmium ions with increase in agitation time, for CABC washed, due to increase in kinetic energy of the metal while CABC unwashed attained equilibrium in lesser time.

In conclusion, bamboo activated carbon can be used for the removal of cadmium from aqueous solution and the results revealed that CABC unwashed might be a better adsorbent compared to CABC washed due to shorter contact time to attain equilibrium and also the fact that there may be no need to wash off the chemical used for activation to avoid generating additional wastewater that need to be treated.

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