

Coconut coir activated carbon: an adsorbent for removal of lead from aqueous solution

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Abstract

The purpose of this study was to prepare activated carbon from an agricultural solid waste and assess its effectiveness in adsorptive removal of lead from aqueous solution. Activated carbon was prepared from coconut coir and its characteristics were compared with that of a commercial bituminous coal-based activated carbon. The coconut coir activated carbon possessed higher surface and micropore areas, micropore volume and average pore diameter, and well developed meso- and micropores. Adsorption of lead from aqueous solution by the coconut coir activated carbon was examined. Batch adsorption test showed that extent of adsorption was dependent on lead concentration, contact time, pH and activated carbon dose. Adsorption was low at acidic pH and increased up to pH 5, with marginal increase up to pH 6. Equilibrium adsorption was attained in 2.5 h. Lead adsorption followed pseudo-second order kinetics. Equilibrium lead adsorption data for the coconut coir activated carbon and commercial activated carbon were described by the Langmuir and Freundlich isotherm models. Coconut coir activated carbon showed higher lead adsorption capacity [7.75 (Langmuir) and 3.63 (Freundlich)] compared with the commercial activated carbon [7.55 (Langmuir) and 1.87 (Freundlich)]. Coconut coir activated carbon is a suitable substitute for commercial activated carbon in the adsorptive removal of lead from water.

Keywords: adsorption, activated carbon, coconut coir, heavy metal, lead.

1 Introduction

Toxic heavy metals have become an ecotoxicological hazard of prime interest and increasing significance owing to their tendency to accumulate in living



organisms [1]. Lead is found in wastewater from industries such as battery, ceramic and glass manufacturing, metal plating and finishing, printing and tanning, and production of lead additives from gasoline [2]. The techniques to remove lead from water include ion exchange, chemical precipitation, reverse osmosis, evaporation, membrane filtration and adsorption [3]. Adsorption by activated carbon is a promising technique as it enables the removal of trace amount of lead. However, high cost of commercial activated carbon limits its use in developing countries and there is a growing need to prepare activated carbon from locally available waste materials.

Coconut coir is a residue in the processing of coconut and is an agricultural solid waste. It is rich in lignin (16-45%), hemicellulose (24-47%) and pectin (2%) content [4, 5]. The carboxylate and phenolic groups of lignin, hemicellulose and pectin are known as the main sites of metal binding [5]. In this study, activated carbon was prepared from coconut coir and its characteristics were compared with that of a commercial bituminous coal-based activated carbon. Adsorption of lead from aqueous solution by the coconut coir activated carbon was examined and its lead adsorption capacity was compared with that of the commercial activated carbon.

2 Materials and methods

2.1 Activated carbon

Coconut coir activated carbon (CCAC) was prepared by soaking washed and dried coconut coir overnight in 10% potassium hydroxide solution followed by washing with distilled water to remove free potassium hydroxide and drying at $105 \pm 5^\circ\text{C}$ for 24 h. It was then subjected to activation at 900°C for 30 min in an atmosphere of nitrogen. The carbon obtained was washed with distilled water and then with 10% hydrochloric acid. The carbon was washed further with distilled water to remove the free acid and dried at $105 \pm 5^\circ\text{C}$ for 24 h. The carbon was ground to a finer size of 212-500 μm and used in adsorption test.

A commercial bituminous coal-based activated carbon was obtained from the Calgon Carbon Corporation, Pittsburgh, PA. It was ground to a size of 212-500 μm and used in adsorption test.

2.2 Adsorption test

Batch adsorption test was carried out by shaking 25 mL of lead nitrate [$\text{Pb}(\text{NO}_3)_2$] solution with 0.1 g of activated carbon in a stoppered glass bottle placed on an orbital shaker at 150 rpm and room temperature (22°C). After a predetermined contact time, the bottle was removed from the shaker and the supernatant was filtered through Whatman No. 1 filter paper and analysed for lead concentration by Method 3111 B of Standard Methods [6]. The effect of pH (1-6), contact time (0-180 min), lead concentration (20-60 mg Pb/L), and activated carbon dose (2-10 g/L) on adsorption was evaluated. Adsorption isotherm was determined by batch equilibrium test at the optimum pH and

contact time for adsorption with 25 mL of 10-100 mg Pb/L lead solution and 0.1 g activated carbon.

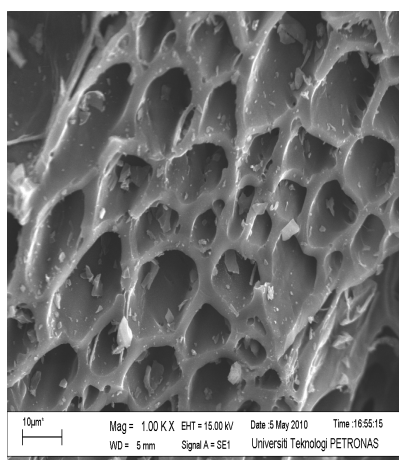
3 Results and discussion

3.1 Activated carbon characteristics

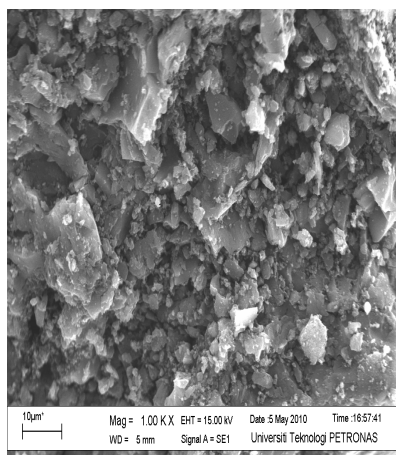
The coconut coir activated carbon (CCAC) and commercial activated carbon (CAC) were characterised for various physical and chemical parameters, as shown in table 1. The CCAC possessed higher surface and micropore areas, micropore volume and average pore diameter than those of CAC. According to scanning electron micrograph, as shown in fig.1, the CCAC contained well-developed meso- and micropores compared to CAC.

Table 1: Characteristics of CCAC and CAC.

Parameter	CCAC	CAC
Surface Area (m^2/g)	826	626
Micropore Area (m^2/g)	551	509
Micropore Volume (mL/g)	0.25	0.23
Average Pore Diameter (\AA)	24	15
Ash Content (%)	14	22
Bulk Density (g/mL)	0.31	0.52
pH	4.3	5.6



CCAC



CAC

Figure 1: Scanning electron micrograph of CCAC and CAC.

3.2 Effect of pH on adsorption

Effect of pH on lead adsorption by CCAC from a 20 mg Pb/L lead solution in 24 h is shown in fig. 2. It is observed that adsorption was low at low acidic pH and increased (39.6%) up to pH 5, with marginal increase up to pH 6. Above pH 6, lead hydroxyl complexes and lead hydroxide form and hence was not considered. For adsorption of lead by CAC, maximum adsorption (33.2%) also occurred at pH 5 (data not shown). At low acidic pH, lead adsorption was hindered possibly as a result of competition between hydrogen and lead ions for adsorption sites, with an apparent preponderance of hydrogen ions. As pH increased, negative charge density on the activated carbon surface increased due to deprotonation of adsorption sites, thus lead adsorption increased. Similar observations have been reported for adsorption of lead by activated carbon prepared from palm shell [7], *Militia ferruginea* plant leave [8], sugar cane bagasse and eucalyptus sawdust [9] and coconut shell and palm seed hull [10], and activated biochar prepared from pinewood and rice husk [11]. All subsequent adsorption tests were conducted at pH 5.

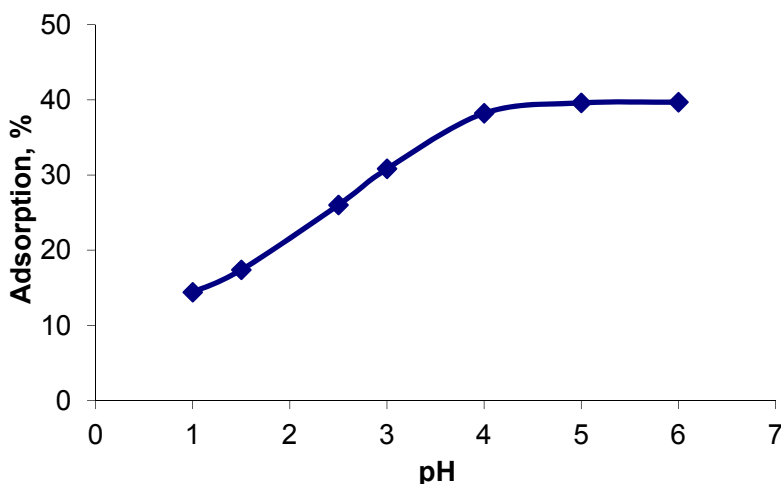


Figure 2: Effect of pH on lead adsorption by CCAC.

3.3 Effect of contact time and lead concentration on adsorption

Effect of contact time and lead concentration on lead adsorption by CCAC are shown in fig. 3. Extent of adsorption increased with decrease in lead concentration and increase in contact time. Equilibrium adsorption was attained in 150 min (2.5 h). For lead adsorption by CAC, equilibrium adsorption was also attained in 2.5 h (data not shown). A contact time of 2.5 h was used in all subsequent adsorption tests.

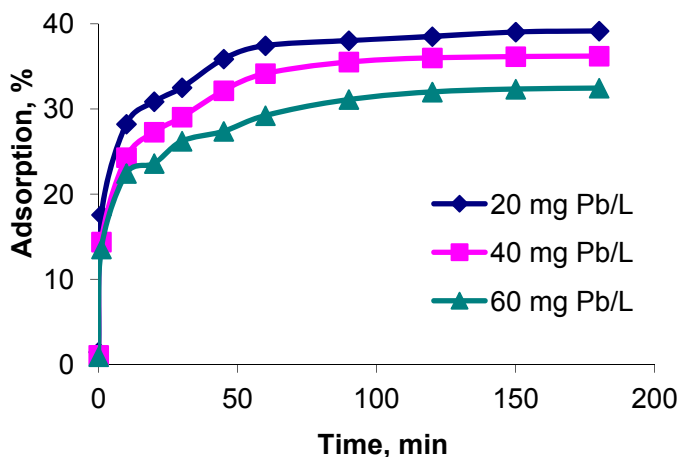


Figure 3: Effect of contact time and lead concentration on lead adsorption by CCAC.

3.4 Effect of activated carbon dose on adsorption

Effect of activated carbon dose on lead adsorption from a 20 mg Pb/L lead solution by CCAC is shown in fig. 4. Adsorption increased with activated carbon dose and attained maximum adsorption (ca 100%) at 8 g/L activated carbon dose.

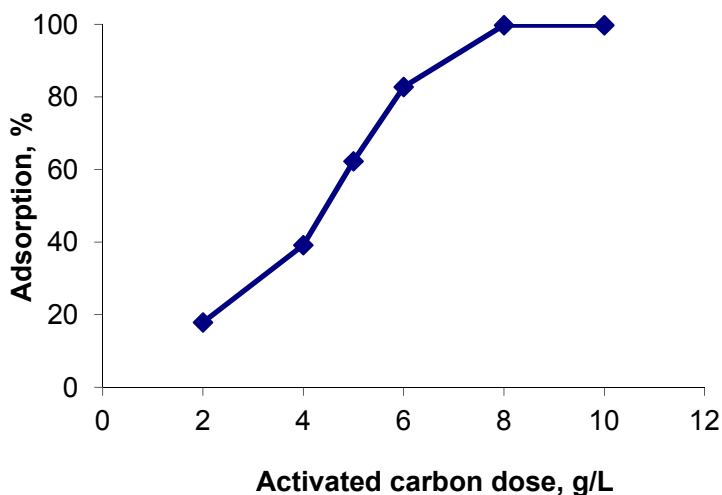


Figure 4: Effect of activated carbon dose on lead adsorption by CCAC.

3.5 Adsorption kinetics

To identify the kinetics of lead adsorption by CCAC, two commonly used kinetic models i.e. pseudo first-order and pseudo second-order [12] were employed.

$$\frac{dq}{dt} = k_1(q_e - q) \quad (1)$$

$$\frac{dq}{dt} = k_2(q_e - q)^2 \quad (2)$$

where, q_e is the amount of solute adsorbed at equilibrium per unit weight of adsorbent (mg/g), q is the amount of solute adsorbed at time t per unit weight of adsorbent (mg/g), and k_1 and k_2 are reaction rate constants. The following linearised time dependent functions were obtained by integrating and rearranging eqns. (1) and (2) for the boundary conditions $t = 0$ to > 0 and $q = 0$ to > 0 .

$$\log(q_e - q) = \ln q_e - \frac{k_1 t}{2.303} \quad (3)$$

$$\frac{t}{q} = \frac{1}{k_2 q_e^2} + \frac{t}{q_e} \quad (4)$$

For pseudo first-order and pseudo second-order kinetic models, the reaction rate constants calculated from eqns. (3) and (4) are shown in table 2 and the kinetic plots are shown in fig. 5 and 6. R^2 values as well as figs. 5 and 6 indicate that kinetics of lead adsorption by CCAC is better expressed by the pseudo second-order kinetic model. Compliance to the pseudo second-order kinetic model strongly suggests chemical adsorption or chemisorption between lead and CCAC.

Table 2: Pseudo first-order and pseudo second-order reaction rate constants for lead adsorption by CCAC.

Lead concentration (mg Pb/L)	Pseudo first-order		Pseudo second-order	
	k_1 (h ⁻¹)	R^2	k_2 (g/mg·h)	R^2
20	0.033	0.9561	0.027	0.9991
40	0.026	0.9327	0.022	0.9984
60	0.027	0.9571	0.023	0.9978

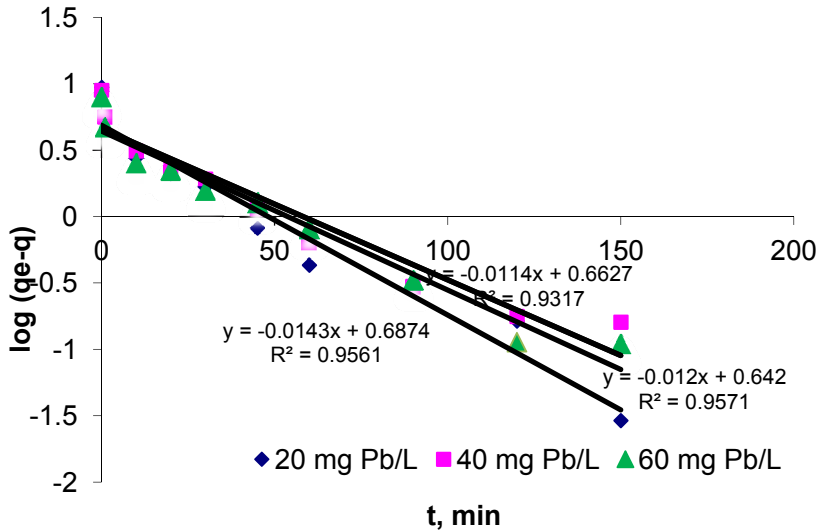


Figure 5: Pseudo first-order kinetic plot for lead adsorption by CCAC.

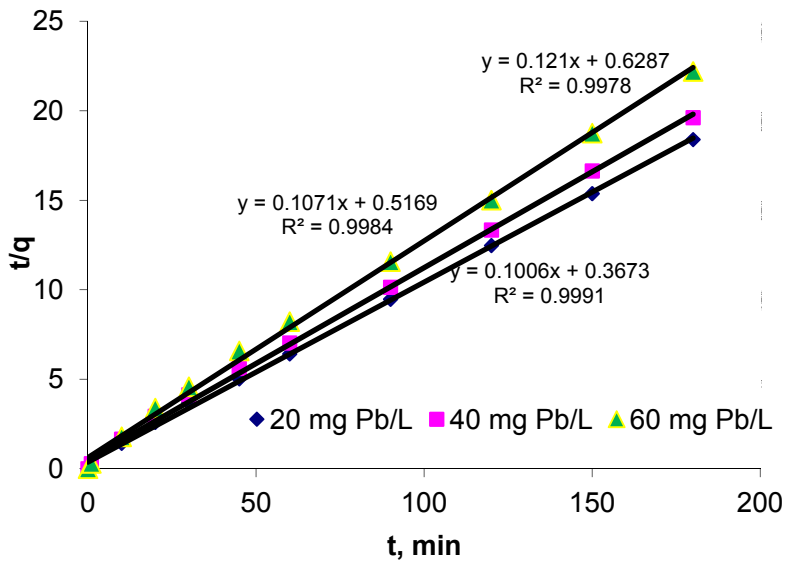


Figure 6: Pseudo second-order kinetic plot for lead adsorption by CCAC.

3.6 Adsorption isotherm

In adsorption in a solid-liquid system, the distribution ratio of the solute between the liquid and the solid phase is a measure of the position of equilibrium. The preferred form of depicting this distribution is to express the quantity q_e as a function of C_e at a fixed temperature, the quantity q_e being the amount of solute adsorbed per unit weight of the solid adsorbent, and C_e the concentration of solute remaining in the solution at equilibrium. An expression of this type is termed an *adsorption isotherm* [13].

The Langmuir adsorption isotherm is

$$q_e = \frac{Q^\circ b C_e}{1 + b C_e} \quad (5)$$

where, Q° is the number of moles of solute adsorbed per unit weight of adsorbent in forming a monolayer on the surface (monolayer limiting adsorption capacity) and b is a constant related to the energy of adsorption.

The Freundlich adsorption isotherm is

$$q_e = K_f C_e^{1/n} \quad (6)$$

where, K_f is the Freundlich constant (adsorption capacity) and $1/n$ represents the adsorption intensity.

Adsorption isotherm for lead adsorption by CCAC and CAC were determined by batch equilibrium test using optimum contact time and pH (2.5 h and pH 5) for lead adsorption. The isotherms were fitted to the linear form of the Langmuir equation [$C_e/q_e = 1/(bQ^\circ) + C_e/Q^\circ$], fig. 7 and Freundlich equation [$\log q_e = \log K_f + (1/n) \log C_e$], fig. 8. The values of Langmuir constants Q° and b , and Freundlich constants K_f and $1/n$ are shown in table 3. Values of Q° and K_f indicated higher lead adsorption capacity of CCAC compared with CAC.

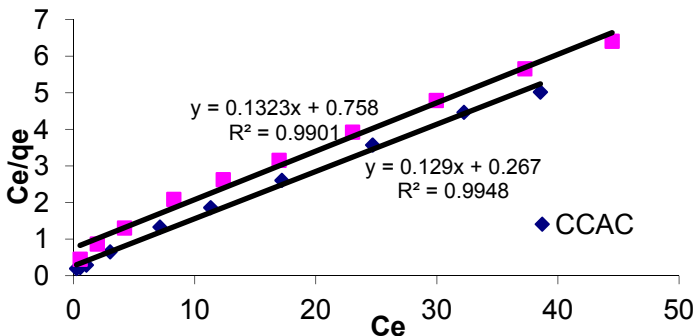


Figure 7: Langmuir adsorption isotherm for lead adsorption.

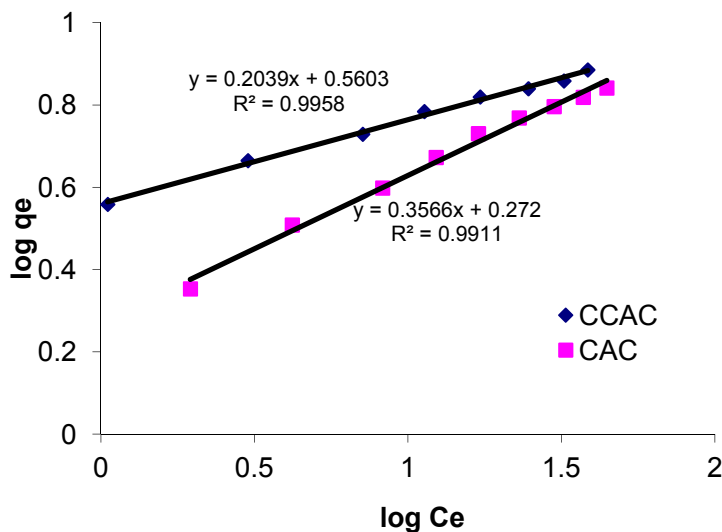


Figure 8: Freundlich adsorption isotherm for lead adsorption.

Table 3: Langmuir and Freundlich constants for lead adsorption.

Activated carbon	Langmuir constant		Freundlich constant	
	Q^o	b	K_f	$1/n$
CCAC	7.75	0.48	3.63	0.20
CAC	7.55	0.17	1.87	0.36

4 Conclusions

The coconut coir activated carbon (CCAC) possessed higher surface and micropore areas, micropore volume and average pore diameter, and well-developed meso- and micropores compared to those of a commercial bituminous coal-based activated carbon (CAC). Maximum lead adsorption occurred at pH 5 and equilibrium adsorption was attained in 2.5 h. Lead adsorption by CCAC followed pseudo second-order kinetics. The CCAC showed higher lead adsorption capacity compared with CAC. The CCAC is a suitable substitute for commercial activated carbon in the adsorptive removal of lead from water.

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