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Adsorptive Removal of Lead from Battery Wastewater by Coconut Coir

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The sorption behavior of lead ions on coconut coir has been investigated to decontaminate lead ions from aqueous solutions. Various physico-chemical parameters were optimized to simulate the best conditions in which this material can be used as an adsorbent. Maximum adsorption was observed at 0.0001 to 0.001 mol L^{-1} of acid solutions (HNO_3, HCl and $HClO_4$) using 0.4 g of adsorbent for 4.83×10^{-5} mol L^{-1} lead concentration in ten minutes equilibration time. The adsorption of lead was decreased with the increase in the concentrations of all the acids used. The kinetic data indicated an intraparticle diffusion process with sorption being pseudo-second order. The determined rate constant k_2 was 8.8912 g mg^{-1} min^{-1}. The adsorption data obeyed the Freundlich isotherm over the lead concentration range of 2.41×10^{-4} to 1.45×10^{-3} mol L^{-1}. The characteristic Freundlich constants i.e., $1/n = 0.44 \pm 0.02$ and $K = 0.184 \pm 0.0096$ m mol g^{-1} have been computed for the sorption system. The sorption mean free energy from the Dubinin-Radushkevich isotherm is 10.48 ± 0.72 kJ mol^{-1} indicating the ion-exchange mechanism of chemisorption. The uptake of lead increases with the rise in temperature (293–333 K). Thermodynamic quantities i.e., ΔG, ΔS, and ΔH have also been calculated for the system. The sorption process was found to be endothermic. The proposed procedure was successfully applied for the removal of lead from battery wastewater samples.

Keywords coconut coir; kinetics; lead adsorption; sorption isotherms; thermodynamics

INTRODUCTION

Rapid increase of industrialization and urbanization is affecting the environment significantly. Water is particularly vulnerable to contamination from discharge of waste waters from various industries. The heavy metal lead has toxic effects on living organisms including humans and particularly in children (1–3), and is among the common pollutants in industrial effluents. Lead is introduced into the environment through various industrial processes such as the formation of insecticides, storage battery, ammunition, soldering material, paint and petrochemicals, and metal plating and finishing industries, etc. All these sources contribute in making the water toxic beyond the suggested tolerable limit of 0.015 mg L^{-1} by the US Environmental Protection Agency (4). Therefore, there is a dire need to look into a cost-effective methodology for the effective removal of lead from industrial effluents prior to their safe disposal into water bodies.

Several treatment processes for the removal of lead ions from aqueous solutions have been reported, mainly precipitation (5,6), ferritization (7), flotation (8), solvent extraction (9,10), and adsorption. The adsorption of lead on various inorganic materials and organic compounds has been reported. The inorganic sorbents used for lead are oxides of manganese and titanium (11,12), bentonite (13), peat (14), activated carbon (15,16), silica gel (17), lateritic minerals (18), and limestone (19) whereas the organic sorbents include polycarbonate filters (20), polyacrylonitrile and acrylonitrile charcoal composite (21), fungus (22), and algal biomass (23). However, some of these procedures are either expensive, time consuming, or inefficient in reducing the metal ion concentration in the effluents to the desired/required level, hence there is a need to look into other inexpensive, rapid, and efficient methods for this purpose.

The present communication deals to assess the possibility of utilization of coconut coir as a sorbent for the removal of lead ions from aqueous solutions. The coconut coir is naturally occurring, readily available, and is cheaper material. The main constituents of coir are cellulose, lignin, hemicellulose and pectin, and related compounds (24,25) which are thought to have the potential to bind metal ions and therefore, could be used as adsorbents for the treatment of industrial effluent. It is also the continuation of our studies regarding the exploitation of cheaper agricultural by-products for the decontamination of lead from aqueous media (26,27).

EXPERIMENTAL PROCEDURE

Equipment

The absorption measurements were made with a Hitachi model Z-2000 polarized Zeeman atomic absorption

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spectrophotometer. The instrument has a strong magnetic field across the burner and graphite furnace which provides a double-beam optical correction system based on the Zeeman effect. A water cooled, premix, fish-tail type burner, having a slot of $10 \times 0.05\,\mathrm{cm}^2$, was used for the air-acetylene flame. A hollow cathode lamp of lead from Hitachi was used as a radiation source.

Reagents

Stock solution of lead ($1000\,\mathrm{mg\,L^{-1}}$) was prepared by dissolving 0.1 gram of specpure metal (Johnson and Mathey) in a minimum amount of distilled nitric acid. The resultant solution was diluted to $100\,\mathrm{cm}^3$ with water. Standard solutions were prepared by appropriate dilution of this stock solution. Fresh working standards were made immediately before use. Distilled and deionized water was used throughout.

Buffer solutions of pH 1 to 12, having ionic strength of $0.1\,\mathrm{mol\,L^{-1}}$, were prepared by using appropriate volumes of solutions of KCl and HCl (pH 1–3), CH_3COONa and CH_3COOH (pH 4–6), NH_4Cl and NH_4OH (pH 6–7.5) and H_3BO_3, NaCl and NaOH (pH 8–12). All pH measurements were made with a Metrohm 605 digital pH meter equipped with a combined glass/calomel electrode. All the reagents used were of analytical grade and were used as such.

The coconut coir was obtained from a local market and cut into small pieces of 1–1.5 mm length. The sample was then washed thoroughly with deionized water and oven dried at 80°C till it reached constant weight. The dried material was stored in air tight polyethylene bottles and used as such without any further physical or chemical pretreatment.

Sorption Measurements

A known amount of coconut coir was taken in a $35\,\mathrm{cm}^3$ culture tube with a screwed polyethylene cap along with $10\,\mathrm{cm}^3$ of standard acid solution. A fixed amount of stock solution of lead was pipetted into it. The contents were equilibrated on a mechanical wrist-action Vibromatic shaker for a specific time. The phases were separated by centrifugation at 5000 rpm for 3 minutes. The supernatant solution was withdrawn and the amount of lead was determined in the solutions before and after equilibrium by atomic absorption spectrophotometry at 283.3 nm and using the optimized instrumental parameters. A blank solution without metal was also prepared and treated similarly. All experiments were conducted at room temperature ($296 \pm 1\,\mathrm{K}$) unless otherwise specified.

The percentage sorption of lead ions from the solution was calculated using the following relationship:

$$\%\ \mathrm{Adsorption} = \frac{C_i - C_f}{C_i} \times 100 \qquad (1)$$

The distribution coefficient "K_d" ($\mathrm{cm^3\,g^{-1}}$) was calculated from the equation

$$K_d = \frac{C_i - C_f}{C_f} \times \frac{V}{m} \qquad (2)$$

where

C_i = initial concentration of lead ions in the solution ($\mathrm{mg\,L^{-1}}$)

C_f = concentration of lead ions in solution after equilibrium ($\mathrm{mg\,L^{-1}}$)

V = volume of adsorbate solution ($\mathrm{cm^3}$)

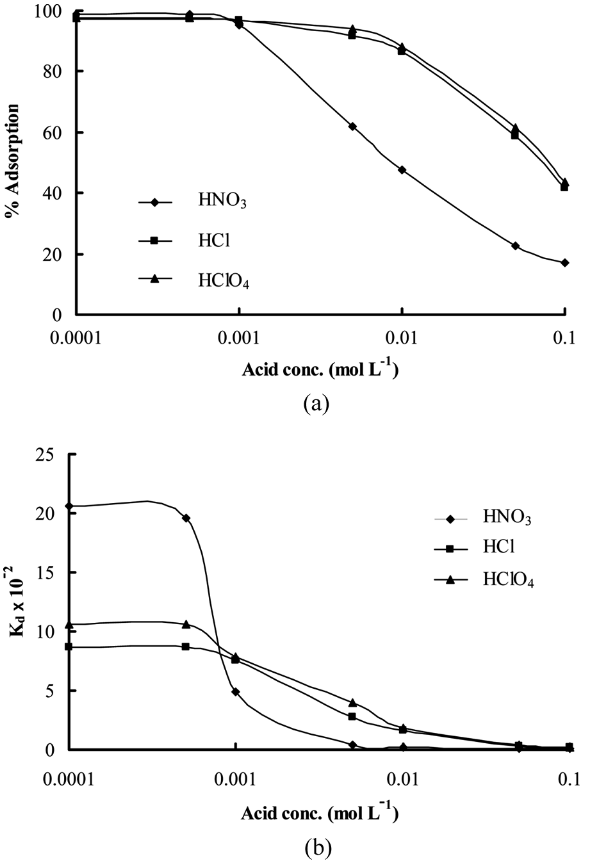
m = amount of adsorbent (g).

RESULTS AND DISCUSSION

The adsorption of lead ions from aqueous solutions on coconut coir was studied by optimizing various physicochemical parameters such as the effect of acid concentrations, pH, equilibration time, amount of adsorbent, and concentration of adsorbate, using the batch method and employing atomic absorption spectrophotometry. The effect of temperature on the adsorption of lead ions was also checked. The criterion for the optimization was the selection of parameters where maximum adsorption occurred. All the reported results are the average of at least triplicate independent measurements with expected error of within ±3.2% unless otherwise specified.

Effect of Acid Concentration

Interaction of various chemical compounds and electrolytes may alter the surface properties of the adsorbent, therefore, the adsorption behavior of $4.83 \times 10^{-5}\,\mathrm{mol\,L^{-1}}$ lead ions was checked in mineral acid solutions of HNO_3, HCl, and $HClO_4$ having a concentration range from 0.0001 to $0.1\,\mathrm{mol\,L^{-1}}$ using 0.4 g of coconut coir. Sulphuric acid was not included in this study since it forms insoluble lead sulphate. The concentration of lead and an amount of 0.4 g of coconut coir was selected arbitrarily. The results presented in Figs. 1a and 1b show that maximum adsorption of lead ions was observed at $0.0001\,\mathrm{mol\,L^{-1}}$ acid concentration. The percent adsorption remained constant from $0.0001–0.001\,\mathrm{mol\,L^{-1}}$ concentration of all the acids. With further increase in acid concentration the adsorption of lead started decreasing up to $0.1\,\mathrm{mol\,L^{-1}}$. These results are in conformity with the lead ion adsorption on rice husk (26) and saw dust (27). The decrease in adsorption of lead ions at higher acid concentration may be attributed to the competition between the excess of H^+ ions in the medium and positively charged lead ions. It was also observed that maximum adsorption of lead ions occurred from 0.0001 to $0.001\,\mathrm{mol\,L^{-1}}$ HNO_3 as compared to the other acids, therefore, $0.001\,\mathrm{mol\,L^{-1}}$ concentration of HNO_3 was used for all the subsequent experiments regarding the optimization of adsorption conditions for lead ions on coconut coir.



(a)

(b)

FIG. 1. (a) Variation of percent adsorption of lead ions on coconut coir as a function of acid concentration; and (b) Variation of K$_d$ for the adsorption of lead ions on coconut coir as a function of acid concentration.

The adsorption of lead ions on the surface of the coconut coir can probably be explained on the basis of the surface complex formation model due to the presence of poly hydroxyl and other functional groups in lignin and cellulose contents of the coir. The cation exchange reaction between the solid surface (C_xOH) and metal ion in aqueous solution may occur as follows:

$$m[C_xOH] \rightleftharpoons m[C_xO-]^- + mH^+ \tag{3}$$

$$M^{n+} + m[C_xO-]^- \rightleftharpoons M[C_xO-]_m^{+(n-m)} \tag{4}$$

The overall reaction can be represented as:

$$M^{n+} + m[C_xOH] \rightleftharpoons M[C_xO-]_m^{+(n-m)} + mH^+ \tag{5}$$

where

M^{n+} = metal ion with n+charge
C_xOH = solid part of the coir surface
mH^+ = number of protons released.

The reaction (5) is reversible in acid solution. The decrease in the adsorption of lead at higher acid concentration can be explained on the basis that at higher concentrations of H^+ ions present in the aqueous medium will compete with the positively charged M^{2+} ions for the surface adsorbing sites thus leading to a decrease in the removal of the metal ion. At lower concentration of H^+ ions the pH of the medium increases while the concentration of the metal ions remains constant, resulting in increase in metal ion removal.

Variation of pH

The solution pH is an important parameter that affects the surface charge, degree of ionization, and speciation of the metal. The pH dependence study of lead adsorption on coconut coir was, therefore, carried out from aqueous solutions of different pH covering a range of 1 to 12, using 0.4 g of adsorbent and fixed amount of lead (4.83×10^{-5} mol L^{-1}). The results obtained are shown in Fig. 2. The percent adsorption increases with an increase in pH of the solution, and was maximum at pH 5–7. With further increase in pH the adsorption starts decreasing probably due to the formation of hydroxide of lead. A similar trend has been reported for the adsorption of lead on sawdust (27). The low adsorption at lower pH could probably be due to the competition between H^+ ions and positively charged lead ions for a fixed number of surface adsorbing sites. The maximum adsorption at pH 7 could be due to cellulose where site-binding sorption takes place. It can, therefore, be concluded that the overall adsorption of lead ions on the surface of coconut coir used is mainly due to the combined effect of site binding sorption and surface complexation phenomena.

Influence of Equilibration Time

The time dependence adsorption of lead on coconut coir was studied using 10.0 cm^3 of 4.83×10^{-5} mol L^{-1} of

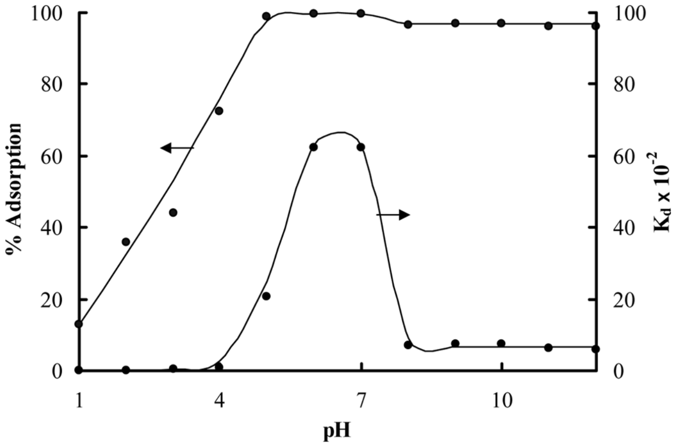


FIG. 2. Effect of pH on the adsorption of lead ions on coconut coir.

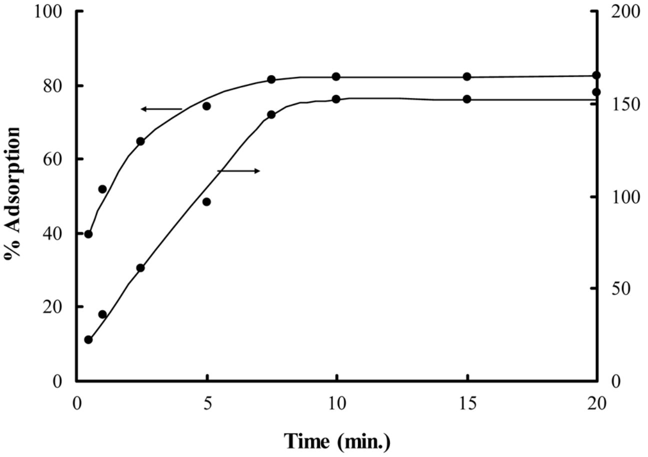


FIG. 3. Adsorption profile of lead ions on coconut coir as a function of equilibration time.

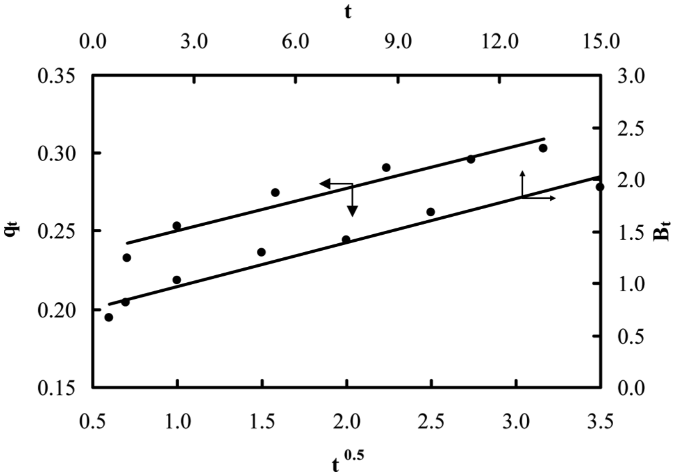


FIG. 4. Morris–Weber and Reichenberg plots of lead adsorption on coconut coir.

lead solution in 0.001 mol L^{-1} of HNO_3 with an arbitrarily chosen weight of 0.3 g of coconut coir. The equilibration time was varied from 0.5–20 minutes and results have been shown in Fig. 3. It is seen that the percentage adsorption increases with the increase in equilibration time. Maximum adsorption was observed at ten minutes time, beyond which there was no further increase in the adsorption. Therefore, ten minutes equilibration time was considered to be sufficient for the adsorption of lead on coconut coir and was employed for all the subsequent experiments.

The sorption data was subjected to Morris–Webber (28) equation:

$$q_t = k_p t^{0.5} \tag{6}$$

where q_t is the adsorbed concentration (mg/g) at time "t" and k_p is the intraparticle diffusion rate constant of the Morris–Webber model. By plotting q_t against $t^{0.5}$, a straight line was obtained (Fig. 4). The value of "k_p" was computed from the slope of this straight line and was found to be 0.027 mg/(g $min^{0.5}$).

The nature of the adsorption either via film diffusion or intraparticle diffusion mechanism was verified by using the Reichenberg (29) equation:

$$X = \left(1 - \frac{6}{\pi^2}\right) e^{-B_t} \tag{7}$$

where

$$X = \frac{q_t}{q_c} = \frac{\text{Amount of metal adsorbed at time "t"}}{\text{Amount of metal adsorbed at equilibrium}}$$

The value of B_t is a mathematical function of X and can be calculated for each value of X by using the relationship:

$$B_t = -0.4977 \ln(1 - X) \tag{8}$$

The plot of B_t versus time is a straight line (Fig. 4), which depicts that intraparticle diffusion is the rate controlling step with a small fraction of the sorption that occurs through film diffusion because the plot does not pass through origin.

The kinetic data obtained for the adsorption of lead ions on coconut coir was also evaluated for the first order Lagergren (Eq. 9) and pseudo-second order (Eq. 10) models using the linearized forms as:

$$\log(q_e - q_t) = \log q_e - \frac{k_1}{2.303} t \tag{9}$$

$$\frac{t}{q_t} = \frac{1}{k_2 q_e^2} + \frac{1}{q_e} t \tag{10}$$

where

q_e = amount of lead adsorbed at equilibrium (mg g^{-1})
q_t = amount of lead adsorbed at time "t" (mg g^{-1})
t = time in minutes
k_1 = rate constant of the first order model (min^{-1})
k_2 = rate constant of the pseudo-second order model (g mg^{-1} min^{-1}).

The plots of $\log(q_e - q_t)$ against "t" and t/q_t against "t" are straight lines with correlation coefficients (R^2) of 0.958 and 0.9996 respectively, and are shown in Fig. 5. The calculated kinetic parameters for the first order and pseudo-second order models have been reproduced in Table 1. The higher correlation coefficient and very good correspondence between the calculated (0.3165 mg Pb g^{-1})

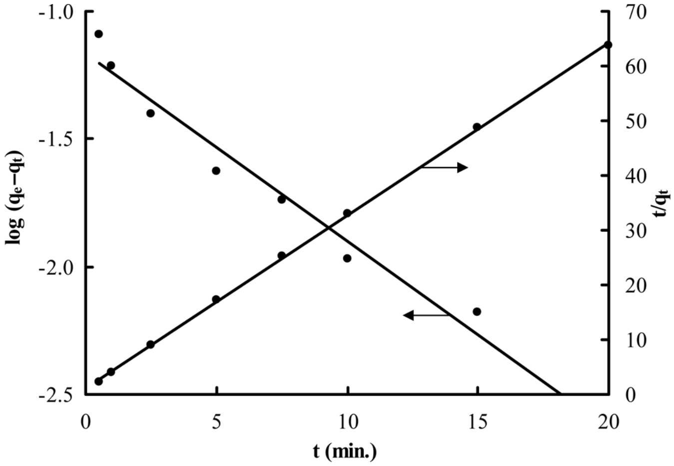


FIG. 5. Lagergren and Pseudo-second order plots of lead adsorption on coconut coir.

and the experimental ($0.314\,\mathrm{mg\,Pb\,g^{-1}}$) values of sorption capacity show that the experimental kinetic data are in agreement with the pseudo-second order rate equation. Similar observations have been reported for the adsorption of lead ions on peat (14) and palm kernel fiber (30).

Influence of Amount of Adsorbent

The influence of the amount of adsorbent on the adsorption efficiency was also studied by shaking $10\,\mathrm{cm^3}$ of $4.83 \times 10^{-5}\,\mathrm{mol\,L^{-1}}$ of lead solution using the optimized parameters. The amount of coconut coir was varied from 0.05 to 1.0 g and the results have been represented in Fig. 6, which depicts that maximum adsorption was observed with 0.4 g of coconut coir which remains constant up to 1.0 g. Therefore, 0.4 g coconut coir was considered sufficient for the quantitative removal of lead from the aqueous solution used.

Variation of Adsorbate Concentration

Concentration dependence of lead adsorption on coconut coir was studied under the optimized conditions of acid concentration, equilibration time, and the amount of adsorbent. The initial sorptive concentration of lead was varied from 4.83×10^{-5} to $1.45 \times 10^{-3}\,\mathrm{mol\,L^{-1}}$ and the results are shown in Fig. 7, which indicates that the percentage adsorption decreases with the increase in lead ion concentration. Similar observation has been reported for the adsorption of lead on rice husk (26) and sawdust (27), and mercury on coconut husk (31). The lower adsorption of lead with the increase in lead concentration may be explained on the basis of the limited number of binding sites in a fixed amount of adsorbent as compared to higher concentration of metal ion.

TABLE 1
The calculated kinetic parameters for the first order and pseudo-second order models with correlation coefficient for the adsorption of lead ions on coconut coir

First order			Pseudo-second order		
q_e ($\mathrm{mg\,g^{-1}}$)	K_1 ($\mathrm{min^{-1}}$)	R^2	q_e ($\mathrm{mg\,g^{-1}}$)	k_2 ($\mathrm{g\,mg^{-1}\cdot min^{-1}}$)	R^2
0.0679	0.169	0.9587	0.3165	8.8912	0.9996

Experimentally measured $qe = 0.314\,\mathrm{mg\,g^{-1}}$.

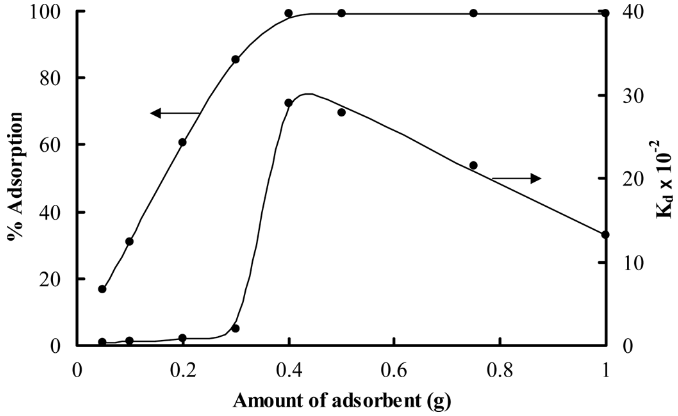


FIG. 6. Effect of amount of adsorbent on the adsorption of lead on coconut coir.

The adsorption data of lead on coconut coir was subjected to the Freundlich isotherm which gives an empirical expression encompassing the surface heterogeneity, exponential distribution of activated sites and infinite surface coverage. The Freundlich adsorption isotherm was capable of describing the data in the concentration range of 2.41×10^{-4} to $1.45 \times 10^{-3}\,\mathrm{mol\,L^{-1}}$. The Freundlich isotherm was tested in the following linearized form:

$$\log C_{ad} = \log K + (1/n) \log C_e \qquad (11)$$

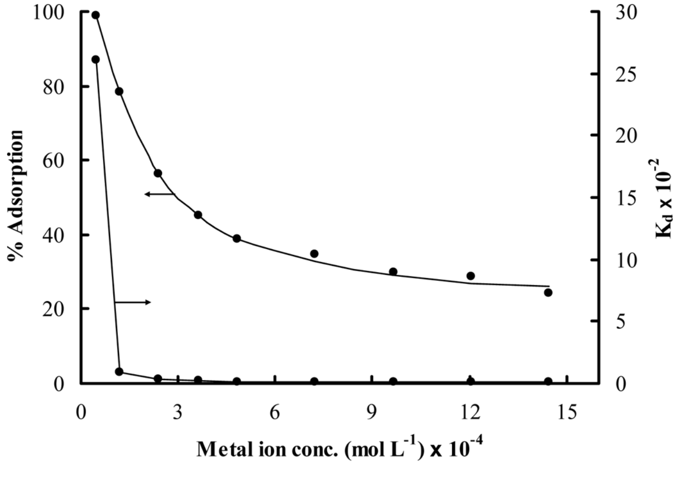


FIG. 7. Adsorption variation of lead ion as a function of its own concentration on coconut coir.

where

C_{ad} = amount of lead adsorbed at equilibrium (mol g^{-1})
C_e = equilibrium concentration of lead in solution (mol L^{-1})
K and 1/n = Freundlich constants.

A plot of $\log C_{ad}$ versus $\log C_e$ yields a straight line (Fig. 8) and supports the applicability of the Freundlich isotherm model in the present study. A similar trend has been reported for the adsorption of mercury on coconut coir (31). The values of Freundlich constants 1/n and K give a measure of the adsorption intensity and capacity of the adsorbent, respectively. These constants were evaluated from the slope and the intercept of the straight line (Fig. 6) using a least square fit program and were found to be 0.44 ± 0.02 and 0.184 ± 0.0096 m mol g^{-1}, respectively. The fractional value of 1/n ($0 < 1/n < 1$) signifies the heterogeneous surface of the coconut coir (32).

To classify the physical or chemical adsorption, the data were applied to Dubinin-Radushkevich (D-R) isotherm model. The D-R equation is:

$$C_{ad} = C_m \exp(-\beta \in^2) \tag{12}$$

where C_{ad} is the amount of lead adsorbed on coconut coir, C_m is the maximum amount of lead that can be adsorbed on coconut coir under the optimized experimental conditions, β is a constant with a dimension of energy, and $\in$ (Polanyi potential) = $RT\ln(1 + 1/C_e)$, where R is the gas constant in kJ mol^{-1} K^{-1}, T is the absolute temperature in K, and C_e is the equilibrium concentration of lead in solution. The linearized form of D-R isotherm is:

$$\ln C_{ad} = \ln C_m - \beta \in^2 \tag{13}$$

When $\ln C_{ad}$ is plotted against $\in^2$, a straight line was observed (Fig. 9). The computed values of β from the slope of this straight line was $-4.55 \times 10^{-3} \pm 3.13 \times 10^{-4}$ kJ mol^{-2}.

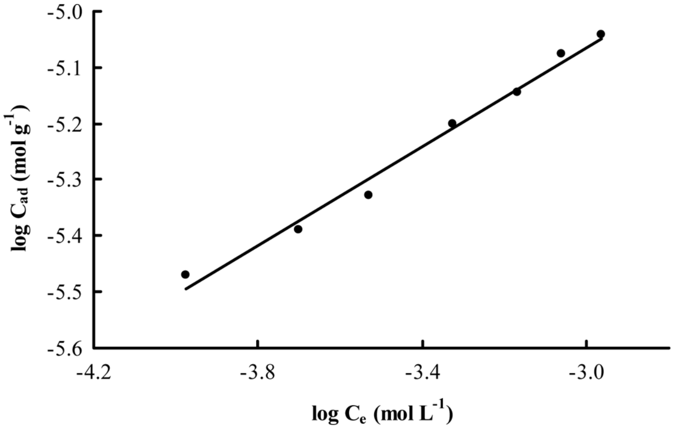


FIG. 8. Freundlich adsorption isotherm of lead on coconut coir.

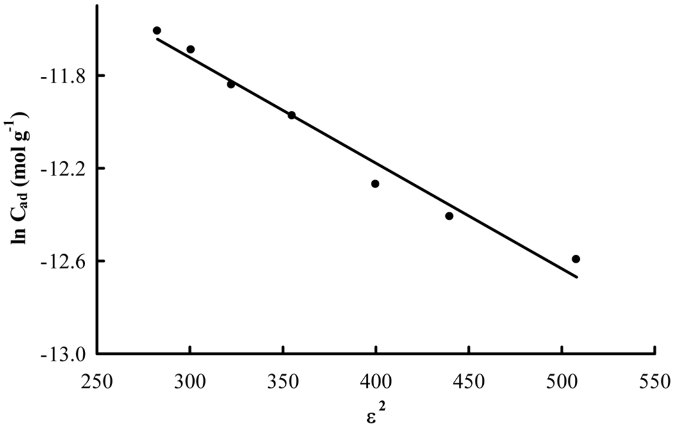


FIG. 9. Dubinin-Radushkevich adsorption isotherm of lead on coconut coir.

From the calculated value of β the mean sorption energy (E_s) was computed as:

$$E_s = \frac{1}{\sqrt{-2\beta}} \tag{14}$$

which is the free energy of transfer of one mole of solute from infinity to the surface of coconut coir. The numerical value of E_s evaluated from Eq. (14) is 10.48 ± 0.72 kJ mol^{-1} which corresponds to chemisorption or the ion exchange process.

Effect of Temperature

The influence of temperature (293 to 333 K) on the adsorption of 9.66×10^{-5} mol L^{-1} of lead ions on coconut coir was also checked using 0.4 g of adsorbent and other optimized conditions and the results have been shown in Table 2. It was observed that the adsorption of lead increases with the rise in temperature. Similar results have also been reported for the adsorption of lead on sawdust (27).

The values of ΔH and ΔS were calculated from the slope and intercept of the linear van't Hoff plot, respectively, using the relation:

$$\ln K_c = \frac{\Delta S}{R} - \frac{\Delta H}{RT} \tag{15}$$

where

K_c = equilibrium constant
ΔS = entropy change for the process
ΔH = enthalpy change for the process
R = gas constant
T = absolute temperature

The equilibrium constant "K_c" was calculated by using the equation:

$$K_c = C_{eq \cdot S}/C_{eq \cdot L} \tag{16}$$

TABLE 2
Adsorption studies of lead ions on coconut coir as a function of temperature

Coconut coir	400 mg
Shaking time	10 min.
Volume equilibriated	10 cm^3
Concentration of HNO_3	0.001 $mol\,L^{-1}$
Concentration of lead	9.66×10^{-5} $mol\,L^{-1}$

Temp. (K)	1/T (K^{-1})	Concentration adsorbed ($mol\,L^{-1}$)	Concentration in bulk ($mol\,L^{-1}$)	K_c	ln K_c
293	3.413×10^{-3}	6.771×10^{-5}	2.881×10^{-5}	2.35	0.854
303	3.300×10^{-3}	7.003×10^{-5}	2.650×10^{-5}	2.64	0.972
313	3.195×10^{-3}	7.292×10^{-5}	2.360×10^{-5}	3.09	1.128
323	3.096×10^{-3}	7.495×10^{-5}	2.157×10^{-5}	3.47	1.245
333	3.003×10^{-3}	7.818×10^{-5}	1.834×10^{-5}	4.26	1.450

where $C_{eq\cdot S}$ = equilibrium concentration of metal adsorbed on the adsorbent ($mg\,L^{-1}$)

$C_{eq\cdot L}$ = equilibrium concentration of metal in solution ($mg\,L^{-1}$).

The changes in standard free energy (ΔG) and entropy (ΔS) for the specific adsorption have also been calculated using the equations:

$$\Delta G = -RT \ln K_c \tag{17}$$

$$\Delta S = \frac{\Delta H - \Delta G}{T} \tag{18}$$

where the symbols have their usual significance.

The van't Hoff plot of ln K_c vs 1/T was a straight line (Fig. 10). The slope and intercept of this line were equal to ($-\Delta H/R$) and ($\Delta S/R$) respectively, thus allowing us to calculate ΔH and ΔS. The determined values of ΔG, ΔH and ΔS have been reported in Table 3. The negative values of ΔG indicate that the adsorption of lead on coconut coir occurs via a spontaneous process. The increase in the numerical value of −ΔG with the rise in temperature indicates that the sorption process of lead ions on coconut coir is more favorable at higher temperatures. The positive value of enthalpy change (ΔH) confirms the endothermic nature of the sorption process. Since diffusion is an endothermic process, it would be expected that increased solution temperature would result in increased uptake of lead from the aqueous solution. The positive value of ΔS suggests the increased randomness at the solid-solution interface during the adsorption of lead on coconut coir.

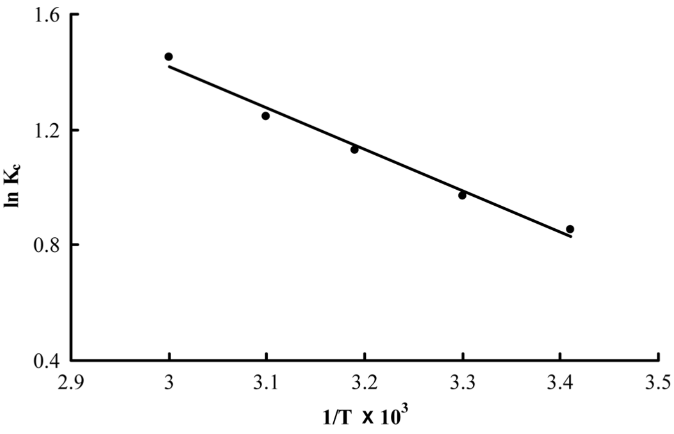


FIG. 10. Van't Hoff plot for the adsorption of lead on coconut coir.

Effect of Diverse Ions

The presence of other cations and anions in the adsorptive medium may change the environment and solution chemistry of the metal of interest, which affects the adsorption efficiency of an adsorbent. Therefore, using the optimized parameters the adsorption of 4.83×10^{-5} $mol\,L^{-1}$ of lead ions on coconut coir was also studied in the presence of high concentrations of various cations and anions. All the anions were used as their sodium salts, whereas for cations the nitrate salts were used. The results are shown in Table 4. The perusal of the data show that adsorption of

TABLE 3
Thermodynamic parameters for adsorption of lead ions on coconut coir

Temperature (K)	ΔG ($kJ \cdot mol^{-1}$)	ΔH ($kJ \cdot mol^{-1}$)	ΔS ($JK^{-1} mol^{-1}$)
293	−2.082	11.839	47.510
303	−2.448		47.151
313	−2.936		47.204
323	−3.344		47.006
333	−4.014		47.606

TABLE 4
Effect of cations and anions on the adsorption of 4.83×10^{-5} mol L^{-1} of lead ions on coconut coir

Cations			Anions		
Ions	Concentration (mol L^{-1})	% Adsorption	Ions	Concentration (mol L^{-1})	% Adsorption
None	–	99.25	None	–	99.25
Li^{+}	14.407×10^{-3}	84.75	Cl^{-}	2.821×10^{-3}	95.45
Na^{+}	4.350×10^{-3}	98.00	Br^{-}	1.252×10^{-3}	95.80
K^{+}	2.558×10^{-3}	97.80	I^{-}	7.880×10^{-4}	91.90
Mg^{2+}	4.114×10^{-3}	72.80	NO_3^-	1.613×10^{-3}	87.90
Ca^{2+}	2.495×10^{-3}	80.10	ClO_4^-	1.005×10^{-3}	95.90
Ba^{2+}	7.282×10^{-4}	91.30	SO_4^{2-}	1.041×10^{-3}	78.90
Mn^{2+}	1.820×10^{-3}	71.20	PO_4^{3-}	1.053×10^{-3}	97.50
Ni^{2+}	1.704×10^{-3}	63.40	CH_3COO^-	1.694×10^{-3}	84.75
Cu^{2+}	1.574×10^{-3}	84.50	Citrate	5.288×10^{-4}	80.50
Zn^{2+}	1.529×10^{-3}	75.10	EDTA	3.470×10^{-4}	10.20
Cd^{2+}	8.896×10^{-4}	54.40	–	–	–
Cr^{3+}	1.923×10^{-3}	9.10	–	–	–
Fe^{3+}	1.791×10^{-3}	98.56	–	–	–

lead on coconut coir was almost quantitative in the presence of all the ions studied except SO_4^{-2}, CH_3COO^- and citrate ions which decreased the adsorption up to 21%, whereas EDTA masked the adsorption completely. Similarly the adsorption of lead on coconut coir was significantly decreased (20–45.6%) in the presence of high concentration of Zn, Mg, Mn, Ni, and Cd ions used in the present study. This decrease in the adsorption of lead could probably be due to the formation of stable compounds/complexes with anions or the competitor action of the cations for the active sites on the surface of coconut coir.

TABLE 5
Determined composition of battery water samples

	Concentration (mg L^{-1})	
Cations/anions	S$_1$	S$_2$
Na^{+}	60.25	89.40
K^{+}	10.70	14.36
Ca^{2+}	40.22	26.20
Mg^{2+}	27.30	24.82
Mn^{2+}	0.03	0.02
Fe^{3+}	0.31	0.22
Cu^{2+}	0.01	0.01
Zn^{2+}	0.15	0.24
Cd$^{2+\$}$	8.20	12.45
CO_3^{-2}	5.50	13.80
HCO_3^{-2}	123.00	93.40
Cl^{-}	14.60	12.60
SO_4^{-2}	18.00	23.84
Pb	5.78	8.32
Pb*	15.78	18.32
Pb**	0.44	0.62

$^{\$}$µg L^{-1}.

*Concentration after spiking.

**Concentration after decontamination.

Application of the Procedure

Applicability of the developed procedure was checked by removing the lead ions from two real samples of battery wastewater (S$_1$ and S$_2$) obtained from local auto workshops, using coconut coir as an adsorbent and employing the optimized sorption parameters. The results have been reported in Table 5 along with the determined composition of the samples. The data shows that an average of 96.91% of lead ions have been removed from the spiked battery wastewater samples under the existing concentrations of the determined cations and anions. It is, therefore, concluded that easily available and cheaper coconut coir has great potential as an effective decontaminant for lead ions from aqueous media.

CONCLUSIONS

Coconut coir has great potential for the removal of lead ions from aqueous solutions as an adsorbent. The quantitative adsorption can be achieved within a short contact time of ten minutes without any prior chemical treatment or time consuming adjustments. The adsorption of lead on coconut coir obeys the pseudo-second order rate equation and follows the Freundlich and Dubinin-Radushkevich isotherms. The thermodynamic parameters

ΔG and ΔH indicate spontaneous process and endothermic adsorption of lead on coconut coir. The process can be successfully applied for the removal of lead ions from battery wastewater samples indicating that the inexpensive coconut coir could be used for the decontamination of lead from aqueous solutions.

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