

ADSORPTION OF HEAVY METAL ON ACTIVE CARBON DERIVED FROM COCONUT LEAVES AGRO-WASTE

Abhijit Jadhav¹, ✉, Govindaraj Mohanraj¹, Suseeladevi Mayadevi², Ashok Gokarn²

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Abstract. In this paper activated carbon is prepared from coconut leaves by chemical activation during slow pyrolysis at 673 K in an inert atmosphere. Activated carbon is prepared in the stoichiometric ratio of 1:1 (CL₁), 2:1 (CL₂) and 3:1 (CL₃). Optimized 3:1 ratio is preferable for further study. BET surface area of CL₃ activated carbon was found 1060.57 m²/g. It is greater than those of CL₁ and CL₂. The batch sorption study experiments were conducted with respect to solute concentration of 2.5–122.8 mg/l and solution temperature of 313–343 K. The Langmuir, Freundlich and Temkin isotherm studies were conducted. The experimental data fitted very well for the pseudo-first order and pseudo-second-order. The results have established good potentiality for the CL₃ activated carbon to be used as a sorbent for the removal of lead from wastewater.

Keywords: Pb(II), coconut leaves, pseudo-first order, second-order, Langmuir isotherm, Freundlich isotherm, Temkin isotherm.

1. Introduction

The most universal problem in environmental pollution is water pollution. The discharge of heavy metals into water-courses has become the pollution problem and is affecting the quality of water and health mainly due to their non-degradability and toxicity. Numerous metals such as, copper (Cu), lead (Pb), manganese (Mn), mercury (Hg), *etc.* are known to be significantly toxic [1]. Furthermore, heavy metal contamination of drinking water and wastewater is a serious problem [2]. Thus, adsorption process is referred as the most effective technique for heavy metals removal from waste streams [3]. Removal of metal ions from aqueous solutions by adsorption on abundant and low-cost adsorbents is one of the possibilities [4]. Various techno-

logies are available for water treatment including the use of activated carbon [5]. Biomass waste activated carbon is the most widely used adsorbent for this treatment. It is assumed that the activated carbon removes metal ion, which is happening due to a surface complex formation [6]. The ability of activated carbon to remove metal ions from solution depends on the textural properties of the activated carbon, including total surface area and pore size, and its surface chemistry based on heteroatom concentrations. The surface chemistry can be inferred from carbon pH [7]. The activated carbons prepared from lignocellulosic materials are good adsorbents. These materials were prepared from coconut shell [8], coffee residue [9], apple pulp [10], tamarind wood [4, 11], hazelnut husks [12], cones of the European Black pine [13], palm shell [14], and longan seed [15]. To improve the sorption capacity of these biomaterials, the agricultural wastes were converted to activated carbon. In this paper the removal of heavy metals using adsorbents is performed in batch. Coconut leaves derived activated carbon is used for removal of Pb from PbCl₂ solution. The batch adsorption technique using activated carbon has been studied by many authors [2, 4, 8-13, 16]. In this research, the batch adsorption of lead performed by coconut leaves activated carbon was studied to determine the maximum uptake of lead ion. The activated carbon in laboratory scale is manufactured by chemical activation method during slow pyrolysis at 673 K denoted as one-stage process [4]. One-step procedure appears to be preferable because of lower activation temperature used, which reduces production costs in term of energy and time saving. This process results in activated carbon with high adsorption capacity [5].

2. Experimental

2.1. Materials

The adsorbents were prepared from coconut leaves. Adsorbate solutions were prepared from lead chloride (PbCl₂, molecular weight of 278.1 g/mol), purchased from

¹ Department of Chemical Engineering, Birla Institute of Technology, Mesra, Ranchi, India

² Department of Chemical Engineering, National Chemical Laboratory, Pune, India

✉ asj.paper@gmail.com

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M/s. Thomas Baker, India. Metal removed is lead (Pb^{2+}). Chemical activation utilizes chemicals like phosphoric acid (H_3PO_4) were purchased from M/s. Thomas Baker, India.

2.2. Preparation and Analyses of Activated Carbon

Raw coconut leaves based activated carbon (Fig. 1) was used for adsorption in this work. The activated carbon of 300 g batch size with impregnation ratio of 1:1, 2:1 and 3:1 was prepared and dried at the heating rate 3 K/10 min in the presence of N_2 flow (3ml/min). The heating continued up to final temperature of 673 K for 90 min. The carbon was left to be cooled and then was washed with distilled water, dried at 383 K and stored in stopper

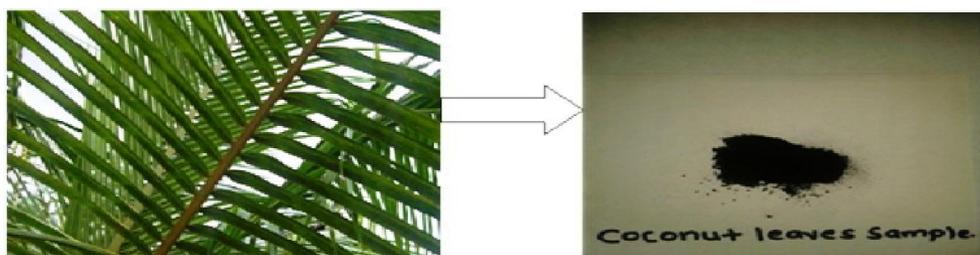


Fig. 1. Coconut leaves derived activated carbon

2.3. Adsorbate

Stock solutions of $PbCl_2$ (1000 ppm) for adsorption study was prepared from solid powders of pure metal salts (Thomas Baker Pvt Ltd, India) [6].

2.4. Batch Adsorption

Adsorption was performed in batch where 2 g of activated carbon was interacted with 40 cm^3 of dye wastewater and allowed to stand for 30 min. It was filtered using whatman filter paper (No. 42). The process was carried out for 60, 90, 120 and 150 min. The concentration of lead in the wastewater was determined before and after interaction with the activated carbon by a bulk scientific atomic absorption spectrophotometer (MODEL 210VGP). 20 mg of the adsorbent in 25 ml reagent bottles containing 10 ml of lead solution (30 ppm) were mixed and placed in the shaker at constant temperature for different time intervals. The adsorbent was finally removed by filtration and $Pb(II)$ chloride concentration was determined. The contact time required for complete metal adsorption was determined and utilized in the remaining tests.

2.5. Surface Area Analysis

The surface area of the activated carbon was measured by BET (Brunauer-Emmett-Teller nitrogen

bottles. The samples were given the abbreviations CL_1 , CL_2 , and CL_3 according to impregnation ratio. Before the experiments the samples were sieved and particles of 105 micron were used.

The surface area of the activated carbon was measured by BET (Brunauer-Emmett-Teller nitrogen adsorption technique) [3-7]. The physicochemical characteristics were determined for these activated carbons. H_3PO_4 was used as activating agent [9]. Determination of surface area of adsorbent is accomplished by using N_2 adsorption.

The morphology of the prepared activated carbon surface was examined using scanning electron micrographs. These images provide positive reception of the porosity of adsorbents and consequently their ability to adsorb.

adsorption technique) [3, 7]. The physicochemical characteristics were determined for these activated carbons. H_3PO_4 was used as activating agent [9]. Determination of surface area of adsorbent is accomplished by using N_2 adsorption. The surface areas and pore volumes of adsorbents are represented in Table 1. Coconut leaves (CL_3) has the highest surface area and pore volume. The surface areas of different carbons follow the order: $CL_3 > CL_2 > CL_1$. CL_3 exhibits similar nitrogen adsorption capacity at relative pressure up to 0.9. The presence of micropores contributed to the high surface area of CL_3 . Thus CL_3 is adapted for further study.

Table 1

Surface area and pore volume of adsorbents

Adsorbents	Surface area, m^2/g	Pore volume, cm^3/g
Coconut leaves (1:1)	760.54	0.5430
Coconut leaves (2:1)	1003.90	0.4589
Coconut leaves (3:1)	1060.57	0.6697

2.6. SEM Analysis

The morphology of the prepared activated carbon surface was examined using scanning electron micrographs. These images provide positive reception of the porosity of adsorbents and consequently their ability to adsorb. CL_3 has small cavities with micro pores found on

the surface due to phosphoric acid treatment. SEM analysis represents that coconut leaves derived activated carbon has sand, fiber-like structure.

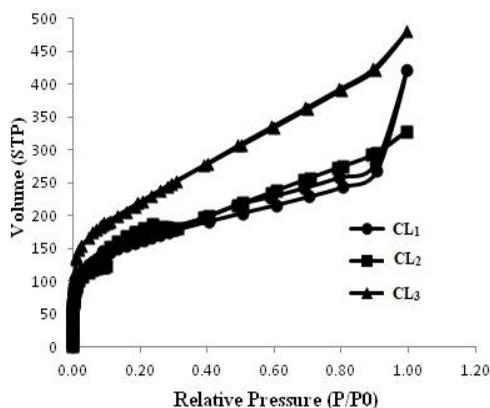


Fig. 2. N₂ adsorption-desorption isotherm

SEM image shows fiber-like sand sheet like structure, which indicates that the adsorption capacity of active carbon in turn will help to describe the adsorption kinetics. The SEM 3D is shown in Fig. 4.

2.7. Kinetic Models

In order to investigate the reaction mechanism, the pseudo-first order kinetic model and the pseudo-second order kinetic model studies were performed. The kinetic model for sorption analysis is the pseudo first order rate expression of Lagergren [10] in the form:

$$\frac{dq}{dt} = k_1(q_e - q_t) \tag{1}$$

Integrating this for the boundary conditions $t = 0$ to $t = t$ and $q_t = 0$ to $q_t = q_t$, Eq. (1) may be rearranged for linearized data plotting as shown by Eq. (2). The first order kinetic equation [11] may be expressed as:

$$\log(q_e - q_t) = \log q_e - \frac{k_1 t}{2.303} \tag{2}$$

where q_e is the amount of adsorbate adsorbed at equilibrium state, mg/g; q_t is amount of solute sorbed on the surface of the sorbent at any time t , mg/g, k_1 is the rate constant for pseudo-first order adsorption, l/min.

The values of $\log(q_e - q_t)$ were linearly correlated with t . The plot of $\log(q_e - q_t)$ vs. t gives a linear relationship from which k_1 and q_e are determined from the slope and intercept of the plot, respectively.

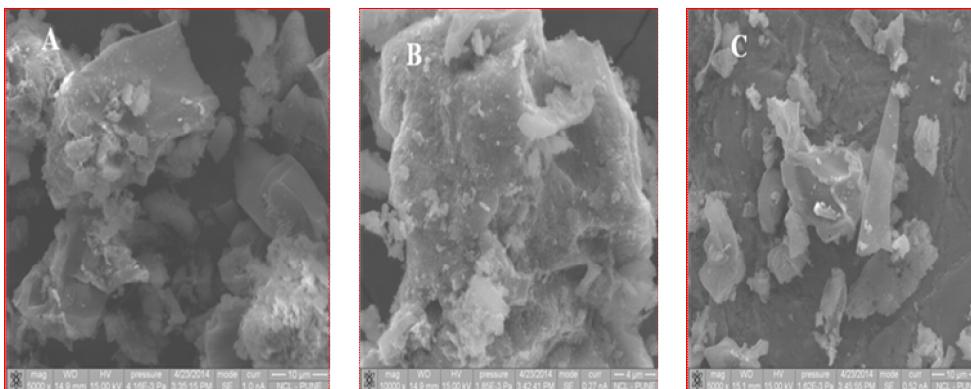


Fig. 3. SEM images of adsorbents with different acid/adsorbent ratio: CL₁ (A); CL₂ (B) and CL₃ (C) (magnification of 5000×)

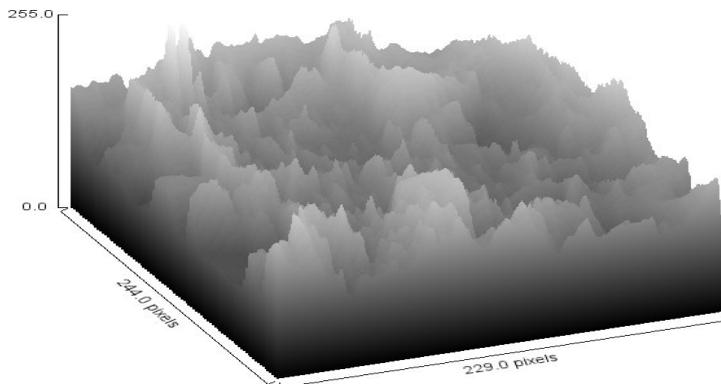


Fig. 4. SEM 3D surface plot of coconut leaves CL₃

To describe lead adsorption, the modified pseudo-second order kinetic equation is expressed as [12]:

$$\frac{dq_t}{dt} = k_2(q_e - q_t)^2 \quad (3)$$

where k_2 is the rate constant for the pseudo-first order adsorption, g/mg·min.

The plot t/q vs. t of the above equation gives a linear relationship with a slope of $\frac{1}{q_e}$ and an intercept of $\frac{1}{k_2q_e^2}$.

$$\frac{1}{(q_e - q_t)} = \frac{1}{q_e} + k_2t \quad (4)$$

Rearranging the terms in the above equation we get:

$$q_t \frac{t}{\frac{1}{k_2q_e^2} + \frac{1}{q_e}} \quad (5)$$

which is the integrated rate law for the pseudo-second order reaction. This has a linear form is given below:

$$\frac{t}{q_t} = \frac{t}{k_2q_e^2} + \frac{1}{q_e}t \quad (6)$$

Applying the limit $(q/t) \rightarrow 0$, the plot t/q vs. t of the above equation gives a linear relationship with a slope of $\frac{1}{q_e}$ and an intercept of $\frac{1}{k_2q_e^2}$.

2.8. Isotherms Modeling

2.8.1. Langmuir isotherm model

The empirical Langmuir equation is given by the following equation:

$$q_e = \frac{q_m K_L C_e}{(1 + K_L C_e)} \quad (7)$$

where q_e is the equilibrium metal concentration on the adsorbent, mg g⁻¹; C_e is the equilibrium metal concentration in solution, mg l⁻¹; q_m is the monolayer capacity of the adsorbent, mg g⁻¹; K_L is the Langmuir constant, related to energy of adsorption, l·mg⁻¹;

The linear form of the equation can be written as:

$$\frac{C_e}{q_e} = \frac{C_e}{q_m} + \frac{1}{K_L q_m} \quad (8)$$

The values of K_L and q_m were determined from the slope and intercept of the representation $1/q_e$ vs. $1/C_e$, respectively. To determine if adsorption process is favorable or unfavorable for Langmuir type adsorption process, Langmuir isotherm is then classified using a dimensionless constant separation factor R_L , which can be defined as:

$$R_L = \frac{1}{1 + K_L C_m} \quad (9)$$

where C_m is the maximum initial metal concentration, mg l⁻¹. The values of this parameter indicated the shape of the isotherm, in which $R_L > 1$ is unfavorable, $R_L = 1$ is linear, $0 < R_L < 1$ is favorable, and $R_L = 0$ is irreversible [16].

2.8.2. Freundlich isotherm

The Freundlich adsorption isotherm is applied to know the non-ideal adsorption on heterogeneous surfaces and multilayer adsorption. It is expressed by the following equation [8]:

$$q_e = K_F C_e^{1/n} \quad (10)$$

where q_e is the amount of metal adsorbed per unit of adsorbent, mg g⁻¹; C_e is the concentration of non-retained dye at equilibrium, mg l⁻¹; K_F (mg^(1-1/n)/g l^{1/n}) and $1/n$ are Freundlich empirical parameters relating to multilayer adsorption capacity and adsorption intensity, respectively.

For a suitable adsorption system $1/n$ values varies between 0 and 1. Linear form of the Freundlich isotherm model is given by Eq. (6). The values of K_F and $1/n$ are obtained from the linear plot of $\ln q_e$ vs. $\ln C_e$ [11, 16]:

$$\ln q_e = \ln K_F + \frac{1}{n} \ln C_e \quad (11)$$

As implied in the equation, its derivation characterized by a uniform distribution of binding energies (up to some maximum binding energy) is plotted as sorbed quantity q_e against $\ln C_e$ and the constants were determined from the slope and intercept. The model is given by the following equation:

$$q_e = \frac{RT}{b} \ln(A_T C_e) \quad (12)$$

Linearized form can be written as

$$q_e = B \ln A_T + B \ln C_e \quad (13)$$

where $B = \frac{RT}{b}$ is a constant related to heat of sorption, J/mol; A_T is Temkin isotherm equilibrium binding constant, l/g; b is Temkin isotherm constant; R is universal gas constant equal to 8.314 J/mol/K; $T = 298$ K.

2.8.3. Equilibrium studies

Adsorption equilibrium studies were conducted at initial lead solution pH of 4–7. Equilibrium data were obtained by adding 0.5–2 g of CL active carbon into a series of conical flasks each filled with 10 ml of lead solution (5 ppm). The conical flasks covered with aluminum foil were placed in a thermostatic shaker for 4 h at 301 K. The removal efficiency of lead on CL carbon (R_E , %), the sorption capacity (q) and distribution ratio (C_d) were calculated from following equations.

$$R_E = \frac{C_{in} - C_{out}}{C_{in}} \cdot 100\% \quad (14)$$

$$q = \frac{V(C_{in} - C_{out})}{m} \quad (15)$$

$$C_d = \frac{V_s}{V_m} \quad (16)$$

where C_{in} and C_{out} are the initial and final concentrations of lead in aqueous solution, respectively, mg/l; V is the volume of the solution, ml; m is the weight of the adsorbent, mg; V_s is an amount of sorbed adsorbate; V_m is an amount of adsorbate in solution.

3. Results and Discussion

Preliminary experiments show that coconut leaves (CL₃) derived activated carbon gives the highest surface area compared to other carbon adsorbents (CL₁, CL₂). Therefore, CL₃ carbon was selected for detailed experimental investigations. The aim was to find out the effect of various parameters on its affinity towards the uptake of lead chloride (PbCl₂).

3.1. The Effect of Initial pH of Lead Ion Solution

Initial pH and initial lead concentration of lead decides the removal percentage of lead ions. It was also shown that the lead concentration from the solution with initial pH 4 is relatively higher than that at pH 7. The lowest lead concentrations in the PbCl₂ aqueous solution is obtained at pH 7 for all initial lead concentrations. This result is valid for activated carbon used. It assumed that several lead species, such as Pb²⁺, Pb(OH)⁺ and Pb₃(OH)₄²⁺, may be present in aqueous solution. Pb(II) predominantly appears as Pb²⁺ at pH < 6 [18]. As pH is increased or hydrogen ions concentration is decreased, the reaction is shifted from left to right, and results in the formation of higher density of surface complexes and higher level of lead removal [6]. At pH 4, Pb²⁺ is the main lead species present in aqueous solution. The lead ion adsorption at pH 4 can be ascribed to the electrostatic attraction between Pb²⁺ cations and the protonated surfaces of the activated carbons. The acidic groups on surface of activated carbon are present in the protonated forms at pH 4. Therefore, the uptake of Pb(II) is hindered due to electrostatic attraction. However, it was suggested that lead adsorption occurs at pH 4. Lead ion is retained on activated carbon due to the mechanisms differ from ion exchange [7].

3.2. Effect of Contact Time on Concentration and Adsorption Capacity

The adsorption capacity of the lead on coconut leaves derived activated carbon increased with time. This result is in agreement with the work of Imamoglu and

Tekir [12], who demonstrated that there are enough adsorption sites to efficiently adsorb lead at lower initial concentration. However, lead concentration adsorption capacity reaches the equilibrium of 122.8 ppm for 120 min. The adsorption of lead ion on coconut leaves based activated carbon was found good at 323 K and found suitably good at 313, 333 and 343 K. Thus, the results indicate that activated carbon produced from coconut leaves residue with H₃PO₄ activation is an effective adsorbent for the removal of lead from aqueous solutions. The concentration of lead on adsorption of coconut leaves decreases from Pb(II) chloride solution (solute concentration) till 122.8 ppm within 313–343 K. An increased percentage removal of Pb(II) from 75 to 94.75 % is observed with 2 g of the adsorbent during agitation time of 160 min when the initial concentration of the higher uptake of Pb(II) chloride at low concentration may be attributed to the availability of more active centers on the surface of the adsorbent for lesser number of adsorbate species. Pb(II) chloride adsorption curves are single, smooth and continuous (Fig. 5) suggesting the possible monolayer coverage of lead molecules on the surface of the adsorbent.

3.3. Kinetic Models

In order to investigate the mechanism of sorption and potential controlling steps such as mass transport, several kinetic models were tested including the pseudo-first order kinetic model and the pseudo-second order kinetic model for a batch contact time process, where the rate of sorption of lead on to the given adsorbent is proportional to the amount of lead sorbed from the solution phase. The rate constants for the respective equations were found at four different temperatures. The pseudo-first order kinetics plots and the pseudo-second order kinetics plots for lead metal with adsorbates using an adsorbent (CL₃) activated carbon are presented below in Figs. 6 and 7.

3.3.1. Pseudo-first order kinetic model

Fig. 6 shows a plot of the Lagergren equation for the results of Pb(II) ion adsorption on (CL₃) activated carbon in the form of the pseudo-first order equation. In this case, a linear relationship was obtained between $\ln(q_e - q_t)$ and agitation time over whole sorption period with high correlation coefficient (0.9378) as shown in Table 2. It is clear that the pseudo-first order equation describes the kinetics of sorption of Pb(II) on adsorbent (CL₃). However, the pseudo-first order equation does not provide any mechanistic evidence.

3.3.2. Pseudo-second order kinetic model

In Fig. 7 the plots show the pseudo-second order equations for the adsorption of lead metal. There are good

correlation coefficients (0.9508). It is possible to ascertain from this model if the rate determining process is a chemical reaction or not. Thus, with the increase in the initial lead concentration within 313–343 K the amount of Pb(II) sorbed

increases and then decreases. This is obvious for higher initial concentration values. More efficient utilization of the sorptive capacities of the sorbent would be expected due to greater sorption driving force, which is observed at 323 K.

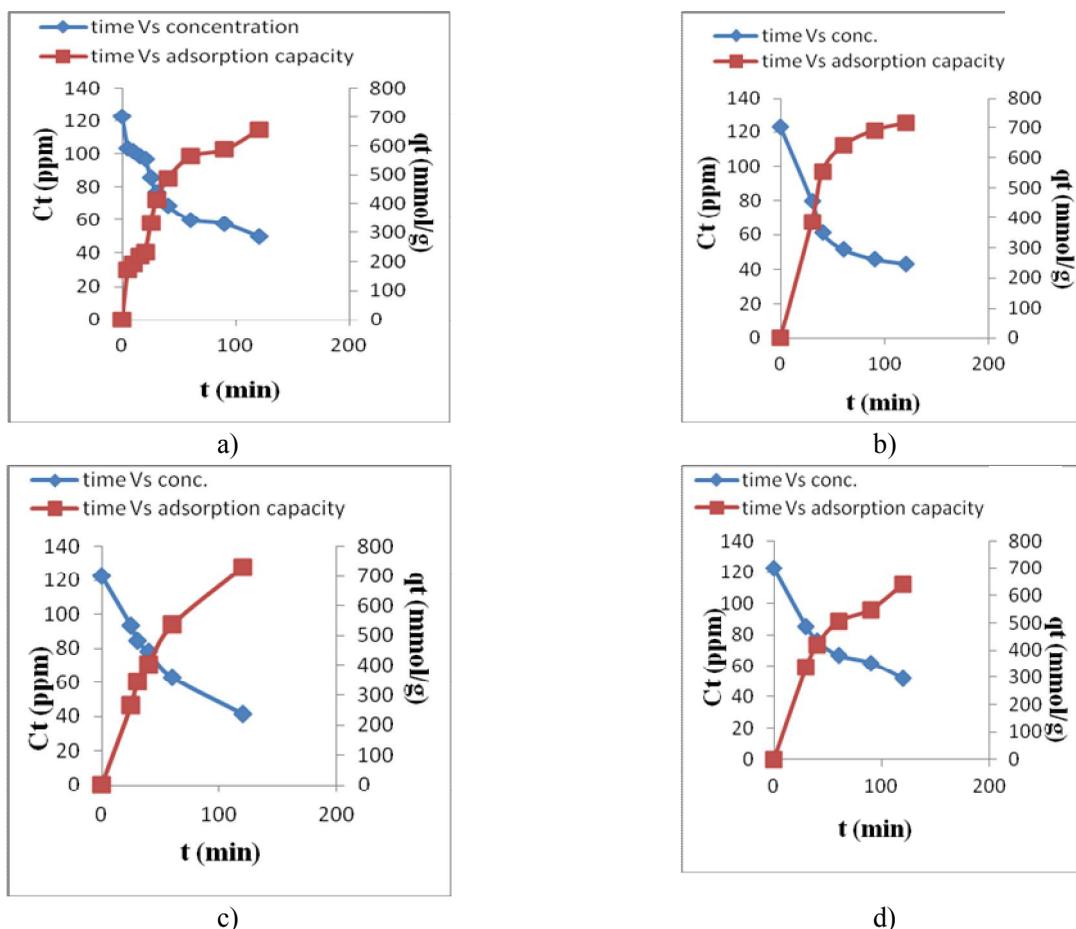


Fig. 5. Variation in concentration of lead metal and adsorption capacity of carbon from coconut leaves with time at different temperatures (K): 313 (a); 323 (b); 333 (c) and 343 (d). Batch conditions: adsorbent weight is 0.02 g, adsorbate volume is 180 cm³, adsorption time is 2 h

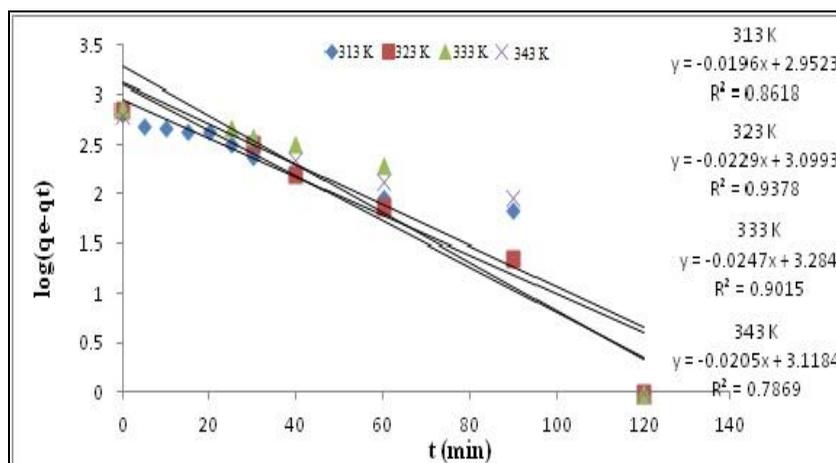


Fig. 6. The pseudo-first order model for the adsorption of lead metal on activated carbon from coconut leaf at different temperatures

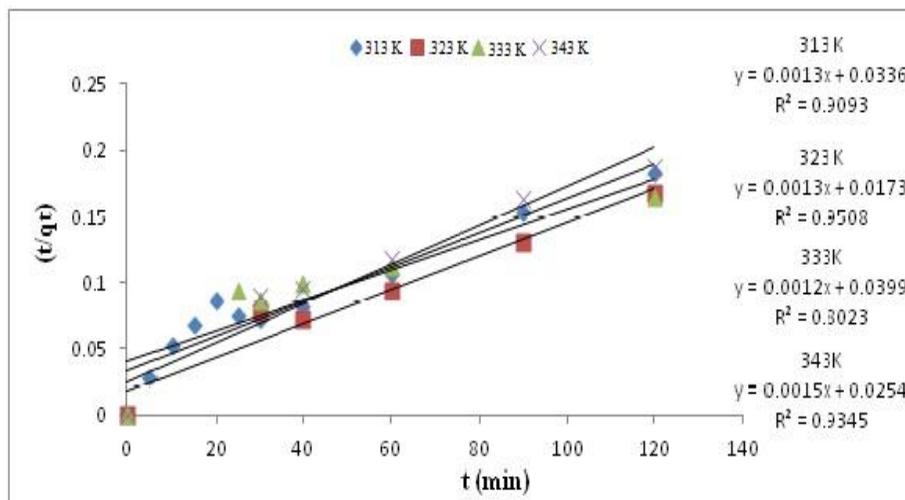


Fig. 7. The pseudo second-order model for the adsorption of lead metal on activated carbon from coconut leaf at different temperatures

Table 2

The pseudo-first order and the pseudo-second order kinetic constants for adsorption of lead metal with using adsorbent (CL₃) at different temperatures

T, K	Adsorbate PbCl ₂				
	The pseudo-first order $\log(q_e - q_t) = \log(q_e - k_2 t)$		The pseudo-second order $t/q_t = (1/k_3 q_e + t/q_e)$		
	k_2	R^2	q_e	k_3	R^2
313					
323	0.0196	0.8618	769.23	0.000143	0.9888
333	0.0229	0.9378	909.09	0.0000478	0.9307
343	0.0247	0.9015	833.33	0.0000637	0.9544
	0.0205	0.7869	769.23	0.000126	0.9841

It is observed from Table 2 that for both kinetic models the correlation coefficients R^2 is close to one. For the pseudo-first-order model, it was attributed to the fast initial uptake of Pb(II). The pseudo-second-order equation fitted the experimental data well. Correlation coefficient R^2 increases to 0.9841 as compared with that of the pseudo-first order kinetics model. This was confirmed by plotting graphs and comparing the linearized form of rate equation with the equation $y = mx + c$. Thus, by plotting t/q_t vs. t for the pseudo-second order rate equation the rate constant for the respective equations were found at four different temperatures. Hence, the pseudo-second order was found to be more suitable than the pseudo-first order.

3.4. Isotherm Modeling

3.4.1. Langmuir isotherm

The Langmuir isotherm model suggests that adsorption takes place as monolayer coverage on homogeneous surface containing a finite number of vacant sites energetically equivalent to each other in respect of adsorption phenomenon and with negligible interaction

between adsorbed molecules. The Langmuir adsorption isotherm obtained after 120 min of agitation time is shown in Fig. 8. The value of $R_L < 1$, obtained in this study indicates the applicability of Langmuir adsorption isotherm. Hence, the values are $0 < R_L < 1$ and adsorption is favorable.

3.4.2. Freundlich isotherm

Freundlich isotherm shows reasonably good fit (Fig. 9). The Freundlich constant “ n ” is known as adsorption intensity. The values of “ n ” are greater than 1, indicating that adsorption of the metals is feasible on all the adsorbents synthesized, the values of adsorption intensity $n \ll 1$ reveals the applicability of this adsorption isotherm. The values of K_F are given in Table 3. The constant K_f is an indicator of adsorption capacity. Temperature effects on the Freundlich parameters reveal decreasing trend in the adsorption capacity with the increase in temperature. However, it is observed that the variation in the adsorption intensity is negligible, while $1/n$ denotes the strength of adsorption process. $n = 1$ indicates that the partition between two phases does not

depend on the concentration. Hence, $n > 1$ and the value of $1/n$ below 1 indicate a normal adsorption. Thus, from these indications, Freundlich isotherm shows normal adsorption as $1/n$ values are below 1. As the temperature increases, the change of constants K_F and n predict that the quantity adsorbed rises more slowly and higher pressures are required to saturate the surface. However, K_F and n are parameters characteristic of the sorbent-sorbate system, which are determined by data fitting, whereas

linear regression is generally used to determine the parameters of kinetic and isotherm models. The linear least-squares method and the linearly transformed equations were widely used to correlate sorption data. $1/n$ is known as a heterogeneity parameter; the smaller $1/n$, the greater the heterogeneity. This expression reduces to a linear adsorption isotherm when $1/n = 1$. In this case $1/n < 1$, which indicates Freundlich adsorption does not fit a favorable sorption process [17].

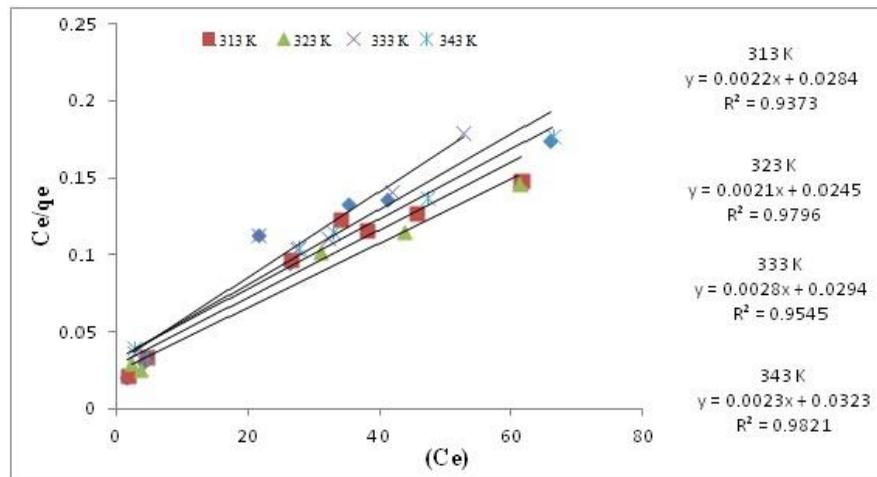


Fig. 8. Plots of C_e/q_e vs. C_e for the adsorption of lead on activated carbon from coconut leaves [CL₃] at different temperatures

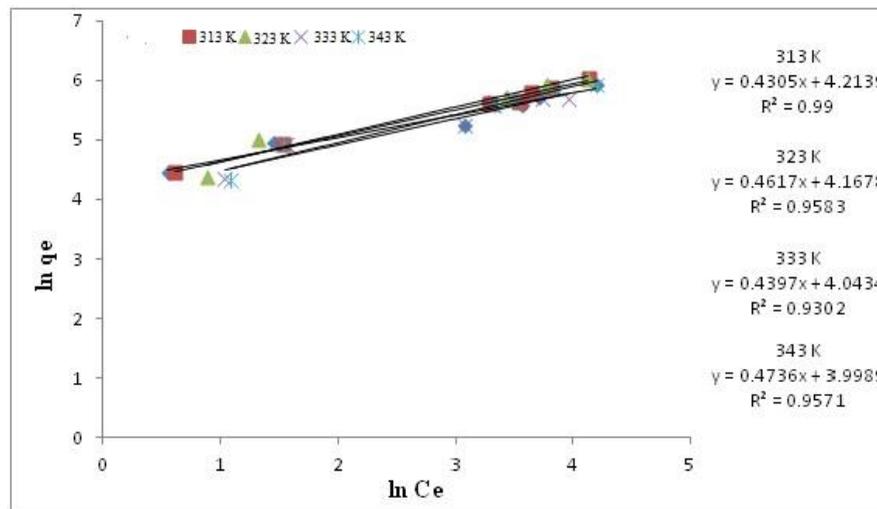


Fig. 9. Plots of $\ln q_e$ vs. $\ln C_e$ for the adsorption of lead on activated carbon from coconut leaves [CL₃] at different temperatures

3.4.3. Temkin isotherm

Temkin isotherm also shows good results for R^2 value. On the other hand, while going through generalized isotherm it does not show good results for these experiments, as shown in Fig. 10. By ignoring the

extremely low and large value of concentrations, the model assumes that heat of adsorption (function of temperature) of all molecules in the layer would decrease linearly rather than logarithmically with coverage.

Table 3 shows that the correlation coefficients R^2 of Langmuir isotherm for activated carbon obtained from

coconut leaves is close to 1, hence Langmuir isotherm gives best fit for the adsorption data. It simply means that the adsorption is restricted to monolayer capacity and metals are physically adsorbed. Values of “*b*” exhibit the amount of binding energy and adsorption capacity of adsorbent. The fit of Langmuir isotherm indicates the homogenous nature of adsorbent surfaces.

3.5. Thermodynamic Parameters

ΔH and ΔS were obtained from the slope and intercept of Vant Hoff plot ($1/T$ vs. $\ln K_c$). Batch adsorption studies were carried out at 313, 323, 333 and

343 K with of Pb solution pH equal to 6. The initial concentration of Pb(II) chloride solution used was 20 ppm with 0.5 g of the adsorbent. Table 4 gives the value of ΔG , ΔS and ΔH for the adsorption of Pb(II). The negative values of free energy change (ΔG) indicate the feasibility and spontaneous nature of the adsorption of lead from Pb(II) chloride solution species [18]. The negative ΔH values of the process suggest the exothermic nature of adsorption of lead on activated carbon derived from coconut leaves. The negative value of ΔS is due to the lower degree of disorderness of adsorbed molecules [19].

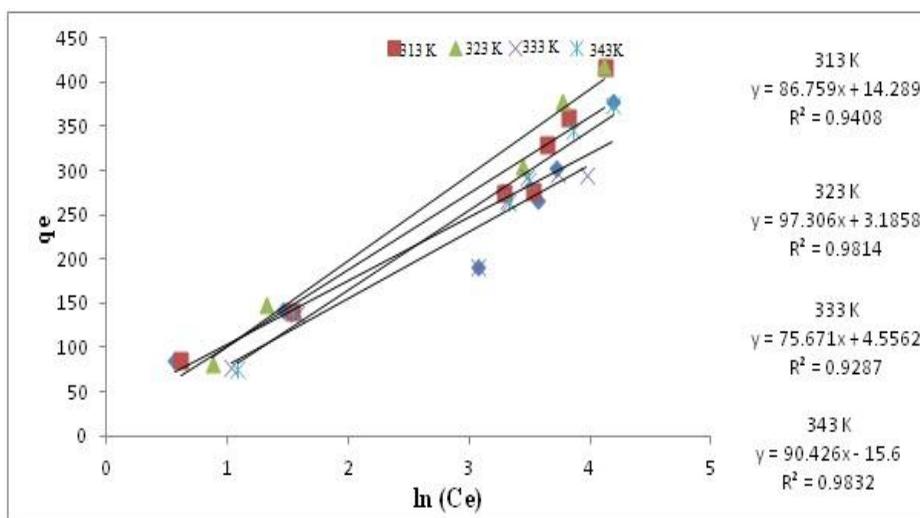


Fig. 10. Plots of q_e vs. $\ln C_e$ for the adsorption of lead on activated carbon from coconut leaves [CL₃] at different temperatures

Table 3

Constants of Langmuir, Freundlich and Temkin adsorption isotherm models for the adsorption of lead on activated carbon derived from coconut leaves (CL-03) at different temperatures

T, K	Adsorbate PbCl ₂								
	Langmuir $1/q_e = 1/(bV_m)1/C_e + C_e/V_m$			Freundlich $q_e = K_f C_e^{1/n}$			Temkin $q_e = B \ln A + B \ln C_e$		
	<i>b</i>	<i>V_m</i>	<i>R</i> ²	<i>n</i>	<i>K_F</i>	<i>R</i> ²	<i>A</i>	<i>B</i>	<i>R</i> ²
313	0.0774	454.545	0.9821	2.322	67.619	0.990	1.179	86.759	0.940
323	0.0857	476.19	0.9796	2.165	64.573	0.9583	1.033	97.306	0.9814
333	0.0952	357.142	0.9545	2.274	57.019	0.9302	1.062	75.671	0.9287
343	0.0712	434.782	0.9373	2.111	54.538	0.9571	0.841	90.426	0.9832

Table 4

Thermodynamic parameters for the adsorption of Pb(II) on activated carbon (CL₃) derived from coconut leaves

T, K	ΔG , kJ	ΔS , J K ⁻¹	ΔH , kJ
313	-3000.0	-1.2062	-2.6231
323	-1600.2		–
333	-830.7		–
343	-750.8		–

4. Conclusions

Coconut leaves activated carbon was prepared by synthesis with phosphoric acid. The adsorbents were investigated using scanning electron microscopy. The changes in their physical and chemical properties with increasing temperature were determined. Adsorption isotherms of lead metal on activated carbon from coconut leaves were generated and the kinetics of adsorption was studied. From the surface area analysis, adsorbent CL₃ activated carbon exhibited higher surface area as compared to CL₁ and CL₂ adsorbents. Equilibrium of Pb(II) adsorption is reached after 120 min. Langmuir isotherm model fitted better to the experimental data as compared to Freundlich and Temkin isotherms. This shows the adsorption is mono-layered and the adsorption sites are homogenous. Also, the Freundlich constant “*n*” is greater than “one” for the synthesized adsorbents and thus was found to be reasonably suitable. The pseudo-second order was considered the most appropriate due to high correlation coefficient. This indicates that the reaction rate depends on concentration of lead and number of active sites in the adsorbents. The adsorption of Pb(II) onto CL₃ activated carbon is an exothermic reaction based on enthalpy change values.

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АДСОРБЦІЯ ВАЖКОГО МЕТАЛУ НА АКТИВОВАНОМУ ВУГЛІЛІ, ОТРИМАНОМУ З АГРОВІДХОДІВ КОКОСОВОГО ЛИСТЯ

Анотація. Повільним піролізом за 673 К в інертній атмосфері одержано активоване вугілля з кокосового листя. Стехіометричне співвідношення приготовлених зразків становило 1:1 (CL1), 2:1 (CL2) і 3:1 (CL3). Коефіцієнт 3:1 визначено найкращим для подальших досліджень. За методом BET встановлено, що площа поверхні активованого вугілля CL3 1060,57 м²/г є більшою у порівнянні з вугіллям CL1 і CL2. Адсорбційні дослідження проводились за концентрації речовин (2,5–122,8 мг/л) і температури розчину 313–343 К. Проведено дослідження ізотерм Ленгмюра, Фрейдліха і Темкіна. Експериментальні дані дуже добре узгоджуються з рівняннями псевдо-першого та псевдо-другого порядку. Показано, що активоване вугілля CL3 можливо використовувати як сорбент для видалення свинцю з стічних вод.

Ключові слова: Рв(II), листя кокосу, псевдо-перший порядок, псевдо-другий порядок, ізотерма Ленгмюра, ізотерма Фрейдліха, ізотерма Темкіна.