

## Low Cost Natural Adsorbent for Removal of Pb (II) Ions from Waste Solutions

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In this paper, the adsorption behavior of Pb<sup>2+</sup> ions from aqueous solutions onto *castor* stem as a natural adsorbent was investigated under various experimental conditions. Characterization of *castor* sorbent was evaluated by SEM, XRD, FTIR, TGA, BET surface area analysis, and CHNS elemental analyses. Operational parameters such as pH, contact time, initial ion concentrations, sorbent amount, particle size, competing ions, and temperature were also studied. Adsorption data fitted well with the Langmuir and Freundlich models. However, Freundlich isotherm displayed a better fitting model than Langmuir isotherm because of the higher correlation coefficient that the former exhibited, thus, indicating the applicability of multilayer coverage of the Pb (II) on the surface of adsorbent. On the basis of distribution studies, the distribution coefficient ( $K_d$ ) increases with increasing the reaction temperature of the solution. Thermodynamic parameters,  $\Delta H^0$ ,  $\Delta G^0$ , and  $\Delta S^0$  were calculated and indicated an endothermic and spontaneous process.

**Keywords:** *Castor*; Characterization; Lead; Distribution studies; Adsorption isotherms; Thermodynamics

### Introduction

Air Lead (Pb) and its compounds are widely used in industry, hence they are commonly found in air, water, soil, and food[1]. Lead (Pb) may be released into the general environment as a result of automobiles using leaded gasoline as an antiknock agent [2] lead-containing paint [3], water due to lead solder in water pipe systems [3], and atmospheric emissions of lead from industrial sources such as smelters[2].

Some researchers suppose that the use of Pb-Bi or Pb as a coolant in fast reactors could improve NPP reliability due to the elimination of fire hazard [4]. However, when using Pb or Pb-Bi, attention should be paid to  $\alpha$  radioactivity polonium contamination, produced during reactors operation [4]. The main gamma-emitters in the coolant with operating nuclear reactors are radionuclides of lead: <sup>207m</sup>Pb, <sup>204m</sup>Pb, and <sup>203m</sup>Pb generated because of threshold nuclear reactions. Lead-204m is of

practical importance with activity level  $(1-2) \times 10^7$  Bq/cm<sup>3</sup> and <sup>203</sup>Pb with activity  $(2-5) \times 10^6$  Bq/cm<sup>3</sup>[4].

Lead (Pb) is a heavy metal of a great environmental concern and poses threats to plants, animal and human health due to its bio-accumulative tendency and toxicity [5]. Lead has no known beneficial biochemical attribute [6] and it is known to have a toxic effect on the human body causing nausea, encephalopathy, headache, vomiting, learning difficulties, mental retardation, hyperactivity, vertigo, kidney damage, birth defects, muscle weakness, anorexia, cirrhosis of the liver, thyroid dysfunction, insomnia, fatigue, degeneration of motor neurons, and schizophrenic-like behavior are also resulting from lead toxicity [7].

Lead (Pb), being a heavy metal, tends to accumulate in food chain because of its persistent nature, and it is therefore necessary

to remove it from waste water [8]. Various treatment techniques have been employed to treat wastewater, such as chemical precipitation, ion exchange, reverse osmosis, electro dialysis, ultrafiltration, nanofiltration, coagulation, flocculation, and floatation, etc.

However these methods have several disadvantages such as high reagent requirement, unpredictable metal ion removal, and generation of toxic sludge etc. An adsorption process being very simple, economical, effective, and versatile has become the most preferred method for removal of toxic contaminants from wastewater [7].

Many researchers are interested in the removal of lead ions from the aqueous wastes using anaerobically digested sludge [9], bacteria [10], fungi [11], algae [12], and others. Agricultural waste materials have also attracted the attention of researchers as biosorbents for the removal of heavy metals in wastewaters [13-16].

The objective of this work is to use *castor* as a low-cost adsorbent derived from the plant wastes for removing  $Pb^{2+}$  ions from aqueous wastes. The produced adsorbent was characterized using different analytical techniques such as chemical stability, SEM, TGA, XRD analysis, surface area analysis (SSA), and FTIR spectra. The effect of various factors such as contact time, pH, initial metal ion concentration, sorbent amount, particle diameters, competing ions, and temperature on the removal of  $Pb^{2+}$  ions from aqueous wastes was determined. The adsorption isotherm parameters were also calculated and discussed.

## Materials and Method

### Chemicals

Chemicals such as HCl,  $HNO_3$ , and KOH were supplied by Merck as analytical-grade reagents, and de-ionized water was used. Aqueous solutions containing lead ( $Pb^{2+}$ ) at various concentrations were prepared from nitrate lead salt ( $Pb(NO_3)_2$ ). The initial pH of the solutions was adjusted by adding  $HNO_3$ . Measurements of the initial pH of lead ion solutions were carried out using a laboratory pH-meter (model pH 540 GLP) equipped with a combined glass electrode (SENTIX 41). A preliminary calibration is

systematically carried out using suitable buffer solutions.

### Preparation of the sorbent

The sorbent material was prepared from *castor* stem which was dried at  $110 \pm 5^\circ C$ , then the material was grinded. *Castor* stem is immersed in 1M potassium hydroxide with heating at  $85 \pm 2^\circ C$  for 2 hours, the mixture was left for one day, then washed several times with distilled water until pH became 6.5. The sorbent material was left in air to dry then immersed in 4M hydrochloric acid. The *castor* stem washed by distilled water several times until the pH became 5 then left it in air to dry and finally grinded.

### Characterization of castor sorbent

Particle size was determined using sieves of different particle sizes. Packed and apparent densities were determined by a tamping procedure using a 25 mL graduated glass cylinder. The sorbent was analyzed for their BET-specific surface area using Quantachrome NovaWin - Data Acquisition and Reduction for NOVA instruments ©1994-2013, Quantachrome Instruments version 11.03 (calculated using the BET standard method). The XRD spectra of the powdered sample was carried out using a Shimadzu X-ray diffractometer obtained from Shimadzu Kyoto "Japan", model XD-D1, with a nickel filter and a Cu  $K_\alpha$ -X-ray tube ( $\lambda = 1.5418 \text{ \AA}$ ), in a diffraction angle ( $2\theta$ ) range of  $4^\circ - 90^\circ$ . SEM image of the particles was identified using Jeol scanning electron microscope of JSM-6510A Model, Japan, operating with beams of primary electrons ranging from 5 to 10 keV. The chemical composition of the studied sorbent was performed by Flash EA Analyzer, Italy (Elemental analysis, C, H, and N concentrations). The IR spectrum of the *castor* sorbent was measured by the KBr disc method by mixing of the solid with potassium bromide in ratio 1:4 and ground to a very fine powder. A transparent disc was formed in a moisture free atmosphere. The IR spectrum was recorded using a Shimadzu infrared spectrometer (BOMEM-FTIR) obtained from Shimadzu Kyoto "Japan", in the range  $400 - 4000 \text{ cm}^{-1}$ . Measurements of thermogravimetric analysis (TGA) were carried out using a Shimadzu DTG-60/60H thermal analyzer obtained from Shimadzu Kyoto "Japan". The sample was measured from ambient temperature up to  $1000^\circ C$  in  $N_2$

atmosphere, with a heating rate of 10°C/min and using alumina powder as a reference material.

*Batch adsorption studies*

Some experimental conditions such as effect of solution pH, contact time, sorbent amount, adsorption temperature, initial ion concentrations, and interfering ions, on adsorption of Pb<sup>2+</sup> ions were studied. For each experiment run, 0.05 g of *castor* was contacted with 5 mL of Pb<sup>2+</sup> ions solution at a V/m ratio of 100 mL.g<sup>-1</sup> at a shaking speed of 400 rpm for 4 h was performed. The effect of solution pH on the equilibrium adsorption of the studied metal ions was investigated under similar experimental conditions at range of pH 1 to 5. The pH of the solutions was adjusted using solution of nitric acid and was measured before and after equilibration. The influence of contact time on batch experiments was examined by varying the contact time from 10 to 1440 min. The sorbent amounts used were varied between 0.005-0.2g/5 mL with an initial concentration of 50 mg.L<sup>-1</sup> of the above mentioned metal ions solutions. The effect of initial ion concentrations was examined by varying the initial metal ion concentrations from 50 to 500 mg.L<sup>-1</sup>. The adsorption temperature effect was carried out on the prepared sorbent at 25, 45, and 65±1°C. After equilibrium, the solutions were separated by centrifugation. The adsorption percentage (U%) of metal ions by solid phase was deduced as in equation 1. The concentration of the metal ions was measured using atomic absorption spectrophotometer (AAS). All tests were repeated for three times and the total experimental error was found to be about ± 3%.

$$U(\%) = \frac{A_o - A_f}{A_o} \times 100 \tag{1}$$

$$K_d (mL / g) = \frac{[A_o - A_f]}{A_f} \times \frac{V}{m} \tag{2}$$

where K<sub>d</sub> is the distribution coefficient, A<sub>o</sub> and A<sub>f</sub> are the concentrations of the ions in solution before and after equilibration (mg.L<sup>-1</sup>), respectively, V is the solution volume (mL), and m is the exchanger mass (g).

*Adsorption isotherm experiments*

The adsorption isotherms were done by a gradual increase in the concentration of the sorbate ions in solution and measuring the amount sorbed at each equilibrium concentration. The degree of adsorption should, therefore, be a function of the concentration of sorbet ions only. The adsorption isotherms were investigated for Pb<sup>2+</sup> in the concentration range from 50 to 500 mg.L<sup>-1</sup> at a constant V/m value of 100 mL.g<sup>-1</sup>. After equilibration, the respective mixture was filtered, and then the filtrate was measured using atomic absorption spectrophotometer.

**Results and Discussion**

*Characterization of castor sorbent*

The physico-chemical characterization and chemical composition of the studied sorbent are shown in Table (1).

The selective FTIR bands of *castor* sorbent are shown in Figure (1). The broad peak at 3420 cm<sup>-1</sup> represents stretching vibration mode of hydroxyl groups [17]. The two peaks at 2925 and 2847 cm<sup>-1</sup> related to asymmetric and symmetric C–H stretching vibration mode of methylene group in aliphatic components [18,19]. The peak at 1593 cm<sup>-1</sup> represents C=C stretching of aromatic ring [17]. The peaks at 1421, 1401, and 1376 cm<sup>-1</sup> resulting from deformation vibration of CH<sub>2</sub> and bending of C–H group in aliphatic components [17-20].

**Table (1) Physical characteristics and chemical composition of *castor* sorbent**

Parameter	Value
C%	62.01
H%	4.15
N%	6.13
Moisture content (%)	6.60
Bulk density (g/mL)	0.250
Apparent density (g/mL)	0.156
Ash content (%)	1.32
pH	5.00
Surface area (m <sup>2</sup> /g)	4.35
Particle size (µm)	168-750

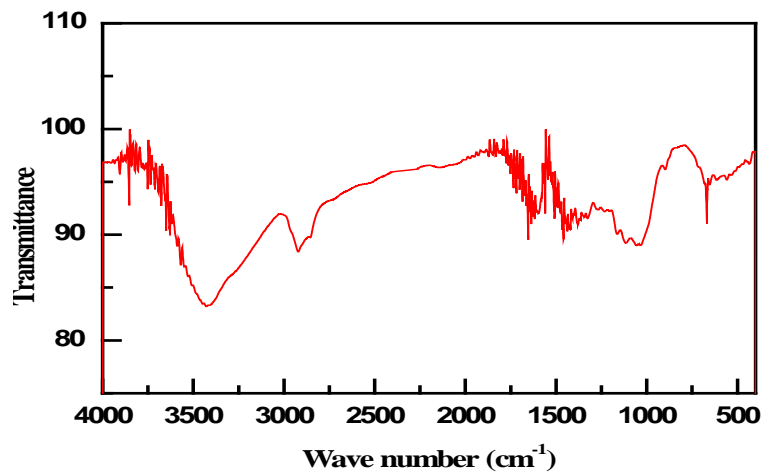


Figure (1) The IR spectrum of *castor* sorbent

The peak at  $1323.50\text{ cm}^{-1}$  represents the symmetric stretching vibration mode of COO- [21]. The peak at  $1233\text{ cm}^{-1}$  represents C–O stretching of ether linkage. The peak at  $1160\text{ cm}^{-1}$  represents the C–O–C asymmetric bridge stretching vibration mode [17]. The peak at  $1106\text{ cm}^{-1}$  represents O–H bending deformation vibration mode of alcoholic, phenolic, and carboxylic groups [22]. The peak at  $1025\text{ cm}^{-1}$  represents the C–OH stretching vibration mode due to several groups at the surface of the biomass [21]. In general, the peaks present from  $1000\text{--}1100$  resulting from the presence of polysaccharides [23]. Bands presented between  $900\text{--}700\text{ cm}^{-1}$  related to C–H out of plane bending deformation in aromatic structure [24]. The peaks present between  $700\text{--}400\text{ cm}^{-1}$  may be resulting from stretching mode of C–C bond [17] or O–H bending deformation in aromatic system [22]. XRD spectrum of the powdered sample is shown in Figure (2), the XRD pattern of *castor* sorbent showed typical spectrum of cellulosic material having the peaks at  $16.5^\circ$  and  $22.4^\circ$ , which indicates the presence of highly organized crystalline cellulose [25], while another peak observed at  $34^\circ$  that could be attributed to presence of less organized polysaccharide structure [26].

Thermogravimetric analysis (TGA) results for *castor* sorbent is presented in Figure (3), there is a loss of initial mass of about 6.60% equivalent to water and volatile material losses from the sample. The second loss of mass of about 67.08 % which corresponding to the burning of organic material Scanning electron microscope (SEM) is presented in Figure 4. From which, it was noticed that the *castor* sorbent material formed of arranged and

(hemicellulose and most of cellulose) begins at approximately  $240^\circ\text{C}$  and extends up to  $376^\circ\text{C}$  [27]. A third weight loss occurred approximately from  $377^\circ\text{C}$  to  $527^\circ\text{C}$  which results from the decomposition of lignin [28].

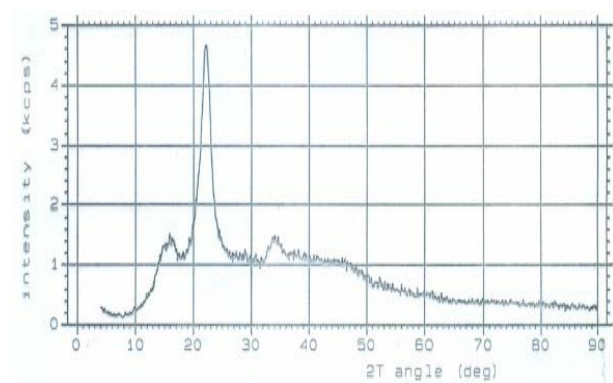


Figure (2) XRD diagrams of *castor* sorbent (as-prepared)

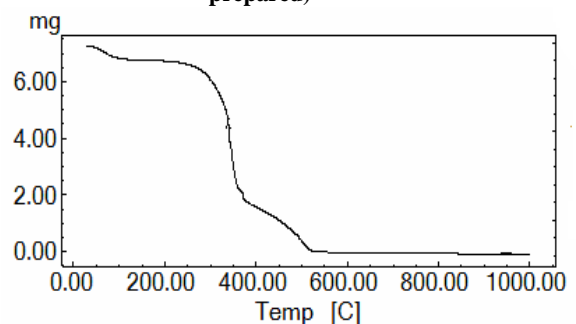


Figure (3) Thermogravimetric analysis (TGA) of *castor* sorbent (as-prepared)

highly condensed fibers forming plates due to the presence of highly organized cellulosic material and appearance of a visible separation between

fibers which caused by treatment of the *castor* material. Dispersed particles are noticed due to lignin materials or another polysaccharide material and also some cavities or gaps appear which result from the modification of *castor* sorbent [17].

**Factors affecting adsorption of  $Pb^{2+}$  ions onto *castor* sorbent**

*Effect of concentration*

The effect of concentration of  $Pb^{2+}$  ions has been tested with constant amount of adsorbent 0.05 g/5mL as shown in Figure (5). The removal of Pb (II) ions decreased from 94 to 63% with increasing the lead ion concentration from 50 to 500  $mg.L^{-1}$ . The results indicated that the adsorption of  $Pb^{2+}$  is

much dependent on its concentration of solution. These observations are in close agreement with those reported in previous studies [22, 29-33]. The decrease in removal efficiency with increasing the initial concentration of  $Pb^{2+}$  ions may be resulting from that increasing the ion concentration of metal ions with a fixed amount of sorbent give a limited available number of active sites thereby adsorbing almost the same amount of adsorbate, this result causes a decrease in the removal percentage of adsorbate corresponding to an increase in the initial ion concentration [34].

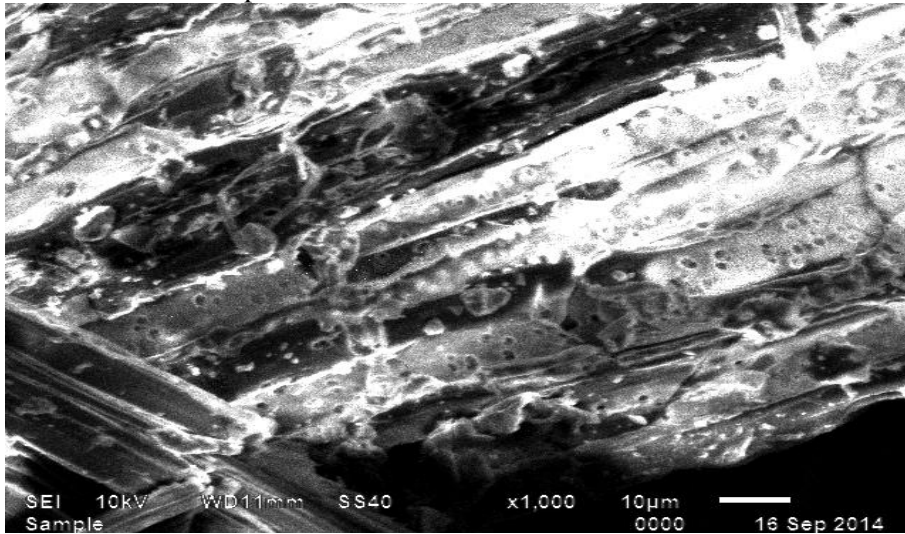


Figure (4) Scanning electron microscope (SEM) of castor sorbent (as-prepared)

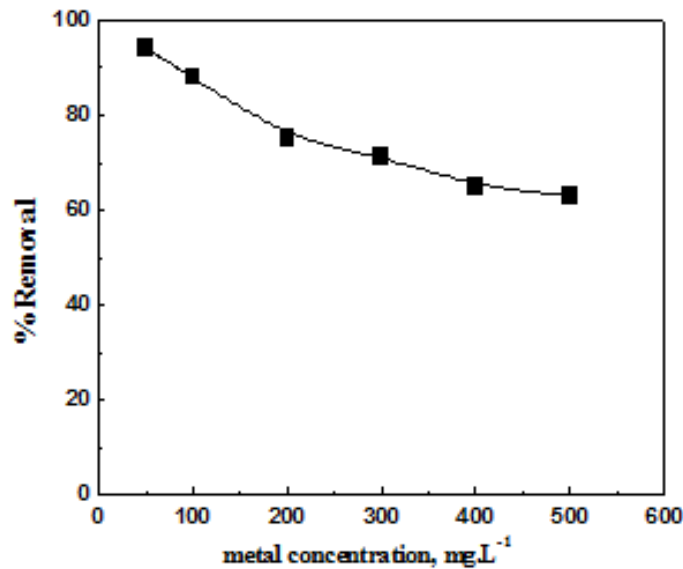


Figure (5) Effect the metal concentration of  $Pb^{2+}$  on the adsorption onto castor sorbent at pH5

### Effect of contact time

Contact time is one of the important parameters for successful employment of the sorbents for practical application. Adsorption experiments were carried out for different contact times with a fixed adsorbent amount of 0.05 g/5 mL at pH 5. The experimental results demonstrate the effect of contact time as shown in Figure (6). The results show that the equilibrium of Pb (II) ions reaches after 4 hours. A higher adsorption rate occurs due to the greater of vacant sites on *castor* surface in the beginning of adsorption process, hence strong attractive forces between  $Pb^{2+}$  ions and *castor* sorbent are observed [35]. Then the number of vacant sites decreases which resulting the decrease in the adsorption rate. Finally the curve became parallel to the X-axis, this point to reaching to the equilibrium of *castor* sorbent with lead ions. So, as the contact time increases the uptake value increases and then, the active site on the sorbent were filled and the rate of adsorption reached constant value.

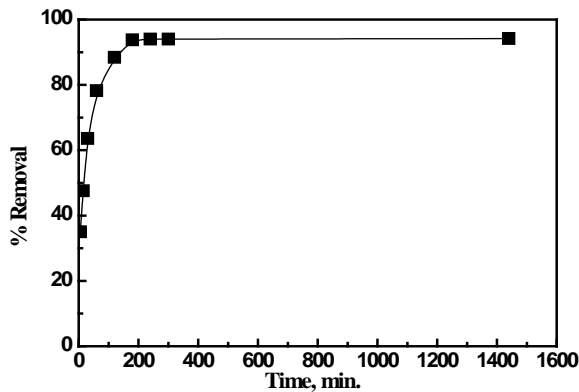


Figure (6) Effect of contact time on the adsorption of  $Pb^{2+}$  ions from aqueous solution at pH 5 using *castor* sorbent

### Effect of sorbent amount

The effect of the amount of selected sorbent was studied by varying the sorbent amount from 0.005 to 0.2 g. From Figure (7), it could be observed that the amount of sorbent was found to have effect on sorbent capability in removing  $Pb^{2+}$  ions from aqueous solution. An increase in the removal percentage of  $Pb^{2+}$  ions was noticed with increasing the amount of sorbent. This happens due to the greater availability of surface area of the sorbent and also increasing the number of active sites on the sorbent surface which leads to increasing the removal of  $Pb^{2+}$  ions [36]. However, further increasing above 0.05 g in the sorbent

amount did not make any significant change in the removal percentage of lead ions. A further increase in the sorbent amount leads to an increase in the number of active sites with a limited number of sorbate of lead ions. The sorbate is removed until it reaches the equilibrium stage and then no more lead ions could be removed [37].

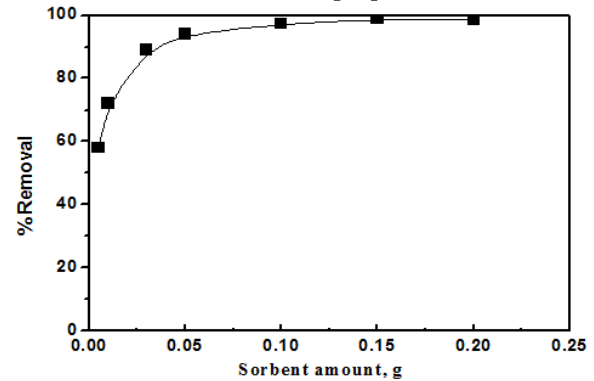


Figure (7) Effect the *castor* sorbent amount on the adsorption of  $Pb^{2+}$  from aqueous solution at pH 5

### Effect of particle size

The sorbent particle size is an important factor in adsorption process. The effect of particle size on the adsorption of  $Pb^{2+}$  ions was studied by conducting a series of experiments with different particle sizes ranging from 231-1000  $\mu m$ . Figure (8) shows that the removal of  $Pb^{2+}$  ions increases with decreasing the particle size of the sorbent. The greater uptake at smaller particle size is due to the fact that the smaller particles move faster in solution than the large particles. Moreover the increasing in surface area due to small particle size also increases the number of sites, and directly increases the removal value [38].

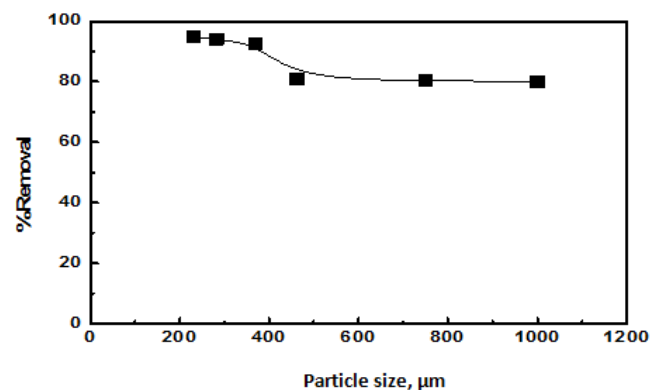


Figure (8) Effect of particle size on the adsorption of  $Pb^{2+}$  from aqueous solution using *castor* sorbent at pH 5

### Effect of interfering ions

The effect of competing cations such as sodium and complexing agent (EDTA) on the adsorption of  $Pb^{2+}$  ions on *castor* sorbent is presented in Figure (9). The influence of various concentrations of  $Na^+$  and EDTA ( $10^{-4}$  - 0.1 M) on the removal of  $Pb^{2+}$  ions on *castor* sorbent was studied. The presence of sodium ions or EDTA complexing agent with  $Pb^{2+}$  ions leads to decreasing the removal percentage of lead ions using *castor* sorbent. Increasing of sodium and EDTA concentrations causes a further decrease in the removal percentage of lead ions. The presence of a low concentration of a chelating agent EDTA which makes a chelation with lead ions to form metal complex which leads to a sudden decrease in the free lead metal ions concentration in the solution so the decreasing of the removal percentage of Pb (II) ions using *castor* occurred [39- 40].

Increasing  $Na^+$  ions in the  $Pb^{2+}$  ions solution leads to a gradual decrease in the removal percentage of Pb (II) ions, because of the competing between lead and sodium ions on the active sites of *castor* sorbent and repulsion force which initiate between lead and sodium ions [13].

### Effect of solution pH

The effect of the solution pH on the adsorption of  $Pb^{2+}$  ions on *castor* sorbent is shown in Figure (10). The pH range was adjusted from 1 to 5. This range was chosen to avoid metal solid hydroxide precipitation. From Figure (10), it was noticed that a very small removal percentage value at low pH, a significant enhancement in  $Pb^{2+}$  ions removal is recorded when the pH of the system increases. At low pH, the sorbent surface has a positive charge, so the smaller adsorption values can be attributed to the repulsion between the same charge of the cation and the sorbent and also due to the competition between the hydrogen and lead ions in highly acidic media. Increasing pH values, a negative charge density on the surface increases due to successive deprotonation of positive charged groups and unprotonated carboxylic groups on the surface of *castor* sorbent and also low  $H^+$  ion concentration. So the electrostatic attraction between the negatively charged sites of the adsorbent and the positively charged cation rise so the removal of lead ions from the solution increased [41- 44].

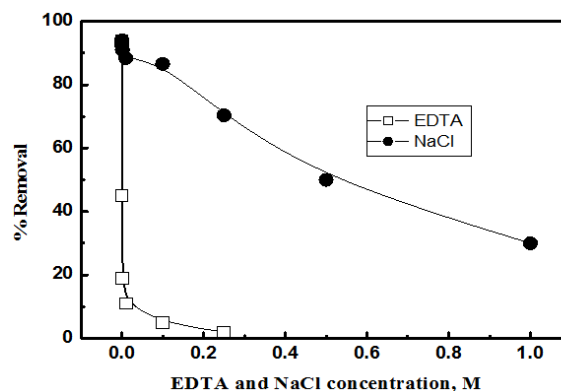


Figure (9) Effect of different concentrations of EDTA and NaCl on the adsorption of  $Pb^{2+}$  ions from aqueous solution at pH 5 using *castor* sorbent

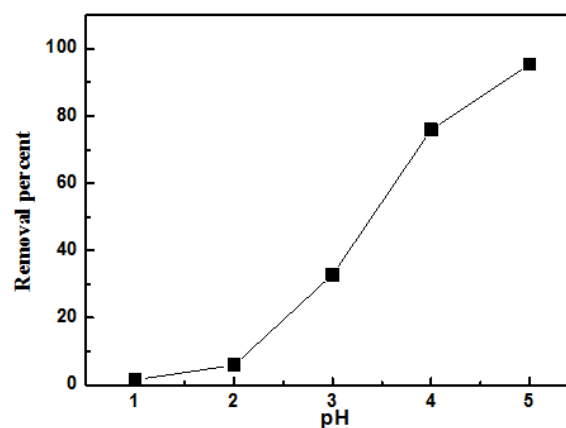


Figure (10) the effect of pH on the removal percent of lead ions using *castor* sorbent.

### Adsorption isotherm

Adsorption isotherm is an invaluable curve describing the phenomenon governing the mobility of the ions from aqueous media to the solid phase at constant temperature and pH. Adsorption models describe the surface properties, adsorption mechanism, and the affinity of the sorbent. Experimental data obtained from the effect of the initial concentration of sorbate on the adsorption capacity of sorbent were evaluated with the two popular adsorption models which are Langmuir and Freundlich models.

### Langmuir isotherm

Langmuir model describes the homogeneous adsorption surface. It assumes monolayer adsorption, adsorption could occur at a fixed number of definite sites. These sites are identical equivalent energetically with no interaction and steric hindrance between the adsorbed molecules, even on adjacent sites. The linear formula of Langmuir equation is given as [45]:

$$\frac{C_e}{q_e} = \frac{1}{bQ} + \frac{C_e}{Q} \quad (3)$$

where  $C_e$  (mg.L<sup>-1</sup>) is the equilibrium concentration of the adsorbate ions,  $q_e$  is the amount of ions sorbed per gram of sorbent (mg.g<sup>-1</sup>) at equilibrium, while  $Q$  and  $b$  are Langmuir constants related to maximum adsorption capacity (monolayer capacity) (mg.g<sup>-1</sup>) and the heat of adsorption (L.mg<sup>-1</sup>), respectively.

Plotting of  $C_e/q_e$  vs.  $C_e$ , gives linear relationships with correlation coefficient  $R^2 = 0.966$ , as shown in Figure 11. From the slope and intercept of this linear plot, the value of Langmuir constants  $Q$  and  $b$  are calculated and summarized in Table (2).

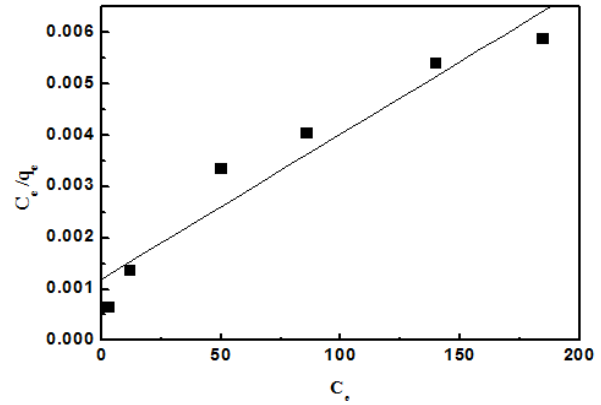


Figure (11) Linearized Langmuir isotherm model for the adsorption of Pb<sup>2+</sup> ions on castor sorbent

Table (2) Parameters of Langmuir and Freundlich isotherms for adsorption of Pb (II) on castor sorbent

Cation	Langmuir constants				Freundlich constants	
	Q (mg.g <sup>-1</sup> )	b (L.mg <sup>-1</sup> )	R <sup>2</sup>	K <sub>f</sub> (mg.g <sup>-1</sup> )	1/n	R <sup>2</sup>
Pb <sup>2+</sup>	35,48	0.023	0.966	2.75	0.450	0.997

*Freundlich isotherm model*

The Freundlich model is applicable for non ideal and reversible adsorption on heterogeneous surface and multilayer adsorption. The linear form of Freundlich model is [46].

$$\log q_e = \log K_f + (1/n)\log C_e \quad (4)$$

where  $K_f$  represents the adsorption capacity when the metal equilibrium concentration equal to 1 and  $1/n$  represents the heterogeneity factor which determines the bond distribution.  $K_f$  and  $n$  are determined from the intercept and slope of plot between  $\log q_e$  and  $\log C_e$ .

The relation between  $\log q_e$  and  $\log C_e$  is presented in Figure (12) giving a straight line relationship with correlation coefficient  $R^2 = 0.997$ , Freundlich constants are summarized in Table (2), and the values of  $1/n$  is 0.450, smaller than one ( $0 < 1/n < 1$ ), which implies heterogeneous surface structure and favorable Freundlich adsorption processes [47].

From the above studies, the results suggest that the adsorption of the studied metal ions on castor is favorable for the Freundlich isotherm more than Langmuir isotherm for the following reasons:

- 1- The correlation coefficient  $R^2$  represented Freundlich isotherm for the studied metal ions is greater than of Langmuir isotherm.
- 2- The numerical values of  $1/n$  for the studied metal ion were found to be ranging between 0 and 1 ( $0 < 1/n < 1$ ) Table (2); this implies a heterogeneous surface structure and favorable Freundlich adsorption processes.

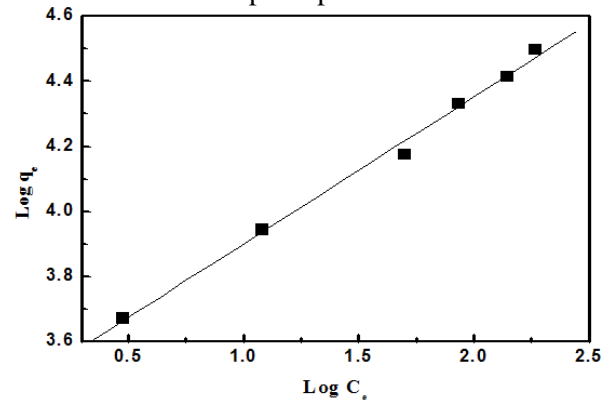


Figure (12) Linearized Freundlich isotherm model for the adsorption of Pb<sup>2+</sup> ions on castor sorbent



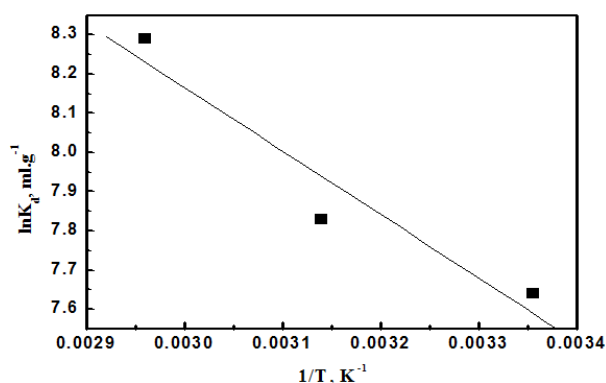


Figure (13) Van,t Hoff plot of the adsorption of Pb<sup>2+</sup> ions by castor sorbent

Adsorption thermodynamics

Thermodynamic parameters such as (ΔH°) and (ΔS°) were obtained from the following Van't Hoff equation:

$$\ln K_d = \frac{\Delta S^\circ}{R} - \frac{\Delta H^\circ}{RT} \tag{5}$$

Where ΔS<sub>0</sub>(J/mol.oK) is the standard entropy change, ΔH°(kJ/mol) is the standard enthalpy change, and R(8.314 J/mol.°K) is the gas constant, and T(°K) is the absolute temperature. From Figure 13, the ΔH° and the ΔS° values could be calculated from the slope (-ΔH°/R) and intercept (ΔS°/R) of the linear plot of ln K<sub>d</sub> versus 1/T. The thermodynamic parameter, (ΔG°) was calculated using the relation:

$$\Delta G^\circ = -RT \ln K_d \tag{6}$$

Where ΔG°(kJ/mol) is the standard free energy change. Values of these parameters are listed in Table (3). The positive value of ΔH° showed that the adsorption was endothermic in nature, while the positive values of ΔS° indicates that there is an increase in the randomness at solid /solution interface during the adsorption of Pb<sup>2+</sup> ions on castor sorbent [48- 50]. Values of ΔG° are negative, confirming that the adsorption of Pb (II) ions onto castor sorbent is spontaneous and thermodynamically favorable [48- 50]. The more

negative values of ΔG° imply a greater driving force to the adsorption process [22].

A comparison of sorption capacity of Pb(II) ions onto castor with other sorbents

The adsorption capacities of different adsorbents derived from agriculture residues are given in Table (4) for the comparison of capacity of lead ions onto castor with other sorbent. Some of sorbents have sorption capacity more than castor as shown in Table (4). The cost of sorbent is also an important issue that must be considered when selecting a sorbent. Caster can be considered as low-cost material for removal of Pb(II) ions from waste solution.

Application

The application to a real sample is one of the most important factors should be considered for any solid phase used as adsorbent in the removal of any pollutant(s). Castor contains different functional groupings which are capable of sorbing pb(II) from aqueous wastes. This real sample was collected from battery factories in 10th of Ramadan, Egypt. The sample was bottled in a plastic container and was immediately taken to the laboratory for analysis. The pH of the sample was about 3. AAS was used for analyzing the sample, the heavy metals present in this real sample were Cu<sup>2+</sup>, Cd<sup>2+</sup>, Ni<sup>2+</sup>, and Pb<sup>2+</sup> their concentrations was shown in Table (5). The sample was spiked with castor (spiking with 0.01 g/mL). As shown in Table (5), the removal efficiencies of castor are about 12%, 9%, 3%, and 90 for Cu<sup>2+</sup>, Cd<sup>2+</sup>, Ni<sup>2+</sup>, and Pb<sup>2+</sup>, respectively. The results indicated that castor is a good adsorbent for the removal of Pb(II) from heavy metals wastewater and confirmed the validity of the proposed method for real samples. The attractive features of castor are that it is commercially available, effective, and of low-cost.

Table (3) Thermodynamic parameters for adsorption of Pb<sup>2+</sup> ions by castor sorbent at different reaction temperatures

Temperatures, (°C)	Thermodynamic parameters		
	ΔH°, (kJ.mo I <sup>-1</sup> )	ΔG°, (kJ.mol <sup>-1</sup> )	ΔS°, (J.mol <sup>-1</sup> .K <sup>-1</sup> )
298	13.47	-18.93	108.33
318		-20.70	
338		-23.32	

**Table (4) Adsorption capacities (mg/g) of Pb(II) with different adsorbents**

Adsorbent	Pb(II), Capacity ( mg g <sup>-1</sup> )	References
<i>Coffee residue activated carbon</i>	63.00	[51]
<i>Sawdust</i>	3.19	[1]
<i>Algal biomass (Oedogonium sp. and Nostoc sp.)</i>	145.00	[52]
<i>Coconut shell activated carbon</i>	26.50	[53]
<i>Crushed concrete fines</i>	37.00	[54]
<i>Peels of banana</i>	2.18	[55]
<i>Amanita rubescens biomass</i>	38.4	[56]
<i>Fruit shell (Mangostana)</i>	3.56	[57]
<i>Saccharomyces cerevisiae biomass</i>	83.33	[58]
<i>Leucaena activated carbon</i>	15.09	[59]
<i>Castor</i>	35.48	[Current work]

**Table (5) Initial concentration of metal ions in wastewater**

Heavy metals	Initial concentration (mg/L)	Removal (%)
Cu <sup>2+</sup>	14	12
Cd <sup>2+</sup>	8	9
Ni <sup>2+</sup>	25	3
Pb <sup>2+</sup>	3	90

## Conclusion

In this work, *castor* was used as one of the natural sorbent derived from agriculture waste. The produced sorbent is a crystalline material. The removal of lead ions using *castor* sorbent increased with increasing the pH, contact time, *castor* sorbent amount, and reaction temperature, but the removal percentage decreased with increasing the lead ions concentration, particle size, and interfering ions (EDTA–Na<sup>+</sup>). Adsorption data was more fitted to Freundlich model than Langmuir model. The thermodynamic results indicate an endothermic and spontaneous process. *Castor* is a good adsorbent for the removal of Pb(II) from heavy metals wastewater and confirmed the validity of the proposed method for real samples.

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