



Enhancement Adsorption of Lead and Cadmium Ions From Waste Solutions Using Chemically Modified Palmfibers



Walaa M. Thabet^a, Somia B. Ahmed^b, Ola Abdelwahab^{a*}, Naglaa F. Soliman^{c,d}

^a Marine Environmental Division, National Institute of Oceanography and Fisheries, NIOF, Egypt

^b Basic science department, preparatory year deanship, Imam Abdulrahman Bin Faisal, Saudi Arabia

^c Department of Environmental Studies, Institute of Graduate Studies and Research, Alexandria University, Egypt

^d Technology Management Department, Egypt-Japan University of Science and Technology (EJUST), Egypt

Abstract

Efficiently chemically modified adsorbents based upon palm fibers were prepared through chemical treatments of palm fibers by sulfuric acid (PF-AC), oxalic acid as a chelating agent (PF-Chel), HNO₃ as an oxidizing agent (PF-OX) and Na₂SO₃ as a reducing agent (PF-Rd). The four produced adsorbents were applied for the removal of Pb(II) and Cd(II) from synthetic waste solutions. The removal capacity of all chemically modified adsorbents has been investigated through the batch tests to determine the optimum parameters for maximum removal. The kinetics and isotherm studies have been applied to identify the adsorption type. All data in this work has been used as determining factors to predict the adsorption process mechanism. The characterization of the surface of the chemically modified adsorbent [FTIR and SEM] was also studied as another contribution to proving the suggested adsorption mechanism. Experimental data were best fitted by Langmuir model while kinetic results were appropriately expressed by the pseudo-second-order model. The results demonstrated the highest capacity values of 56 and 33 mg/g using PF-Rd for both Pb (II) and Cd (II) ions, respectively. Throughout this study, PF-Rd and PF-OX achieved the maximum capacity with the adsorption of both heavy metals.

Keywords: Palm fibers; chemical treatment; Adsorption; lead and cadmium ions; mechanism

1. Introduction

Pollution by heavy metals represents a dangerous environmental downside that has raised dramatically in the past 50 years [1,2]. Heavy metal pollution mainly originates from anthropogenic sources via various industrial processes and waste furnaces [3]. Aquatic ecosystems expose to pollution with hazardous chemicals especially with heavy metals because of the fast universal population increase and severe domestic activities as well as the discharge of effluents from industry and urban development's and agricultural production [4,5]. The toxicity of heavy metals confirmed its threads on environmental health

and consequently human and animal health [6]. Above all, lead and cadmium ions as risky heavy metal pollutants, cannot be accepted, owing to their non-biodegradability, teratogenicity, and hidden poisoning [7, 8].

There are a variety of techniques have been expended for the removal of heavy metals. However, adsorption using an appropriate material is more applicable than different techniques to remove heavy metals from wastewaters of different sources. Meanwhile, it is eco-friendly, unproblematic design, less requirement of control systems, and cost-

*Corresponding author e-mail: olaabdelwahab53@hotmail.com

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effective approach for heavy metals removal from wastewater [9].

Several studies used low-priced adsorbents for removal of heavy metals, using agricultural wastes, industrial byproducts and wastes and natural substances as adsorbents for the treatment of wastewaters containing heavy metals. Researchers investigated chemically modified plant wastes, industrial by-products such as lignin, diatomite and clino-pyrrhotite for treatment of wastewater heavily polluted with heavy metals [10-14].

Palm fibers (scientifically called; *Phoenix dactylifera*) is a flowering plant species from the palm family *Areaceae*, which counted as a sweet edible fruit [15]. It is a natural fibrous material, it is considered as being eco-friendly and alternative cheap adsorbents which annually accumulated as large amounts of biomass wastes without proper utilization and can be respectable for different industrial applications [16]. Palm fibers contain fibers of cellulose surrounded by lignin medium. To enrich the characteristics of PF, it was treated with different chemicals. Where it enhances its mechanical properties in addition to its strengthened polymer composites [17].

In the present study, chemically modified adsorbents produced by chemical treatment of palm fibers were used for the removal of lead and cadmium ions in synthetic media. Batch adsorption tests were conducted to verify optimum experimental conditions such as contact time, metal ion concentration, amount of adsorbent and pH which could be applied to remove heavy metals from synthetic solutions. The adsorption capacities of Pb^{2+} and Cd^{2+} ions on different chemically modified adsorbents were produced. The physicochemical properties of samples were characterized and different mechanisms of heavy metal removal from water by chemically modified adsorbents were investigated. This study could help to support in the reduction of heavy metal contamination from wastewater economically and efficiently.

2. Experimental Techniques

2.1. Synthesis of adsorbent fibers

The palm fibers, PF, were obtained from local palm trees in Egypt. Fig 1 shows a photo of the flowering

plant palm fibers. After obtaining palm fibers, they were cleaned, dried, cut and sieved to homogenize pieces. They were divided into four portions for the purpose of activation by different chemical treatments. All the chemicals used all through this study were of analytical-grade reagents product of Finar Company.

The first portion was treated by soaking 4.0 g of PF in H_2SO_4 acid (2% v/v) overnight at room temperature, then washed by distilled water and oven-dried and labeled as (PF-AC) [18]. Oxidized Palm Fibers adsorbent (PF-OX) was prepared by the reaction of 75.0 g of PFs with 1.0 L solution of an oxidizing agent, HNO_3 acid (2:1, v/v ratio) with continuous stirring. After four hours of stirring the reaction mixture, the adsorbent was separated by filtration. Then washed with distilled water and dried. Reduced PF (PF-Rd) adsorbent was made by adding a known weight of PF (75 g) to a liter of 1.0 M Na_2SO_3 solution with stirring the reaction mixture for 4 h. The produced (PF-Rd) adsorbent was separated, washed by distilled water and dried [19]. Chelating Palm Fibers (PF-Chel) was obtained by treating PF with 0.1M oxalic acid solution and soaking overnight then the mixture was filtered and the produced PF-Chel adsorbent was dried [20]. All the produced adsorbents were sieved after drying the particles of average size of 60 mm were separated and kept in a glass bottle for further use.



Fig. 1. A photo of the raw palm fibers

2.2. Characterization

Fourier transform infrared (FTIR) spectroscopy (FTIR, VERTEX-70, Burker ram II.) was used to identify surface functional groups of PF and all produced chemically modified adsorbents after chemical treatment. The FTIR data were recorded in the 200– 4000 cm^{-1} region with a Thermo Nicolet FTIR spectrophotometer using KBr pellets to determine the FTIR spectra of all chemically treated adsorbents. All adsorbents were also imaged by the use of a scanning electron microscope, SEM. An ion sputtering coating device (FE-SEM, JEOL JSM 6710F) was used to coat the SEM specimens with gold to increase their conductivity. The lead and

cadmium ions were measured with atomic absorption spectroscopy AAS (GBC Sens AA model), all instrumental settings were those recommended in the manufacturer's manual book, using the wavelengths of 228.8 and 217 nm for Pb and Cd, respectively. The limits of detection (LODs) for Pb and Cd were 0.012 and 0.0087 mg/L respectively.

2.3. Heavy metal uptake experiments and models

Lead acetate and Cadmium chloride were used to prepare a stock solution of lead and cadmium aqueous solutions, respectively. Batch adsorption experiments were carried out at room temperature by shaking a series of 100 mL measuring flasks containing a certain dose of the adsorbent for 90 min at 120 rpm. Each adsorbent material was added to 50 mL of a single heavy metal ion solution of a known concentration at 25°C. The initial pH of the solution was adjusted to the desired value either by nitric acid or sodium hydroxide solution. After shaking, samples were withdrawn at different intervals. All samples were filtered through a 0.45-µm Millipore filter. The Pb(II) or Cd(II) concentration in the filtrate was analyzed with a flame atomic absorption to determine Pb(II) or Cd(II) in the liquid phase.

Adsorption capacity (*q*), the amount of lead or cadmium adsorbed per gram of adsorbent, can be calculated in mg/g by the following equation:

$$q = \frac{C_i - C_f}{m} \times V \tag{1}$$

Where: *C_i* is the initial and *C_f* is concentration of heavy metal at any time, respectively (mg/ L), *V* (L) volume of the metal solution, *m* (g) weight of adsorbent.

2.4. Kinetics and Isotherm studies

For adsorption kinetic experiments, a sample of 0.1 g of dry adsorbent was added to 50 mL of 100 mg/L heavy metal solution. The mixture was shaken and samples were withdrawn at different intervals of time. The filtrate of each sample was separated and the metal concentrations in the collected liquid samples were determined.

The kinetics of heavy metal adsorption were simulated using pseudo first order kinetic model (Eq. (2)) and pseudo second order kinetic model (Eq. (3)), which were applied to the experimental data, which can be presented as follows [21-24]

$$\ln (q_t - q_e) = -k_1 t \tag{2}$$

$$\frac{t}{q_t} = \frac{1}{k_2 q_e^2} t + \frac{1}{q_e} \tag{3}$$

Where: *q_t* (mg/g) and *q_e* (mg/g) are the adsorption capacity for heavy metals at time *t* and at equilibrium, respectively. *k₁* and *k₂* are the pseudo-first order rate constant (1/min), rate constant of the pseudo second order adsorption (g/(mg.min)), respectively.

Adsorption isotherms were produced with the initial Pb(II) and Cd (II) concentration in the range of 25–150 ppm using 0.1 g of adsorbent at the normal pH of each solution. All flasks were shaken at 120 rpm and 25 °C for 24 h. In order to successfully represent the equilibrium adsorptive behavior, four kinds of several isotherm equations were tested to fit the experimental data. Langmuir (Eq. (4)), Freundlich (Eq. (5)), Tempkin (Eq. (6)) and Dubinin–Radushkevich (D–R) (Eq. (7)) isotherm models were used [25, 26]. All model equations are listed in Table1.

Table 1. Types of isotherm models used in present study:

Isotherm model	Mathematical equation	Equation no.
Langmuir	$\frac{C_e}{q_e} = \frac{1}{K_L Q_m} + \frac{C_e}{Q_m}$	(4)
Freundlich	$\ln q_e = \ln K_F + \frac{1}{n} \ln C_e$	(5)
Tempkin	$q_e = B \ln A_T + B \ln C_e$; $B = RT / b_T$	(6)
Dubinin–Radushkevich (D–R)	$\ln q_e = \ln Q_m - K_D \varepsilon^2$; $\varepsilon = RT \ln(1 + \frac{1}{C_e})$	(7)

Where: *C_e* is the equilibrium aqueous concentration (mg/L), *Q_m* is the maximum adsorption capacity of the solute (mg/g) and *K_L* is an adsorption equilibrium constant (L/mg) which is related to the apparent energy of sorption for Langmuir. *K_F* (mg/g) represents Freundlich adsorption coefficient and (*n*) is the Freundlich constant related to the surface site heterogeneity. *A_T* (L/g) is the Tempkin binding constant, *b_T* is Temkin's isotherm constant. *B* (J/mol) is a constant related to heat of adsorption, *R* is the gas constant (8.314 J/mol K), *T* is the absolute temperature (K) and *ε* is the Polanyi potential for Dubinin–Radushkevich. *K_D* (mol²/J²) is a constant in related to the mean free energy of adsorption. The main free energy of adsorbate, *E* (J/mol) per molecule can be computed by the relationship [26]:

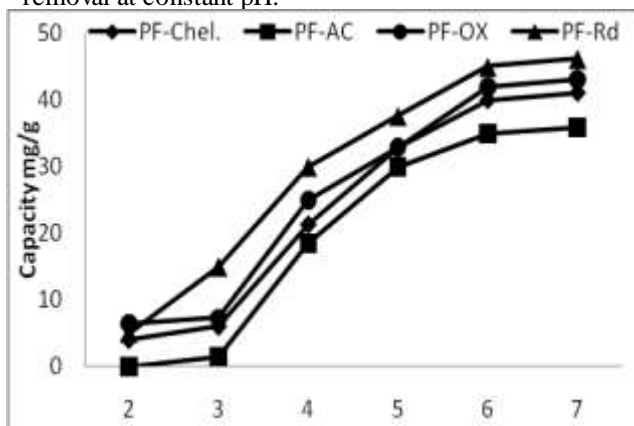
$$E = \frac{1}{\sqrt{2 K_D}} \tag{8}$$

3. Results and Discussion:

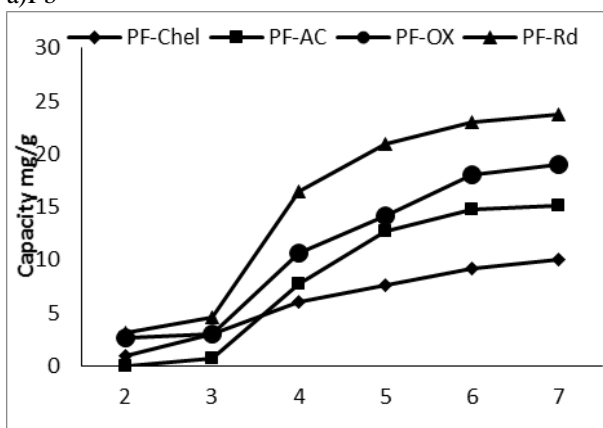
3.1. Effect of process variables on adsorption capacity

3.1.1. Effect of initial pH on adsorption process

The uptake of heavy metals from waste solutions is totally influenced by the pH of solution. Since it establishes the charge on the surface of adsorbent, the degree of ionization and speciation of the adsorbate. In order to study the effect of pH on the adsorption of Pb (II) and Cd (II) ions, the batch equilibrium studies at different pH values were carried out in the range of 2-7 for the two metals respectively in order to avoid precipitation of Pb in the form of metal hydroxides. As shown in (Fig 2). With the increase in pH the capacities of all adsorbents were rapidly increased to reach the highest adsorption capacity at pH 6 and remained steady or slightly increased until pH 7.0, reaching 45 mg/g capacity onto PF-Rd adsorbent for Pb adsorption and 22 mg/g for cadmium. The adsorption capacity increased in the order of PF-Rd > PF-OX > PF-Chel. > PF-AC for Pb (II) and Cd (II) removal at constant pH.



a) Pb



b) Cd

Fig. 2. Effect of initial pH on adsorption capacity of different adsorbents for (a) lead and (b) cadmium removal.

The maximum adsorption capacity for all adsorbents was observed at pH 6-7. Poorer adsorption capacity was observed at lower pH may be attributed to the competition of hydrogen ions with metal ions aimed at adsorption sites. Accordingly, at higher concentration of H^+ ions, the surface of adsorbent becomes vastly charged positively, thus diminishing the attraction between adsorbent and metal ions. In contrast as the pH increases, more negatively charged surface become available, hence, enabling larger metal uptake [27]. Additional experiments were carried out at normal pH of Pb (II) and Cd (II) solutions i.e., pH of ~ 6.0 for both solutions.

3.1.2. Effect of contact time

The effect of contact period on the removal of Pb (II) and Cd (II) via all chemically modified PF adsorbents was investigated at different contact times in the range of 5-90 min using 0.1 g adsorbent and 100 mg/L concentration of Pb (II) and Cd (II) ions at normal pH of each metal ion solution.

The results, represented in (Fig 3), reveal that the adsorption of Pb (II) and Cd (II) ions was rapid in the first 5 minutes, then the adsorption rate slow gradually and finally the equilibrium was established after 60 minutes. After one hour, there was no observed effect of contact period time on Pb (II) and Cd (II) ions adsorption by all chemically modified palm fibers adsorbents. The reason behind such behavior may be owing to the increase of the availability of active binding sites on the adsorbents surfaces, and the adsorption process was diffusion controlled from bulk to surface [28]. Same behavior of Pb (II) adsorption was reported by many authors [29-32]. Among all chemically modified palm fibers adsorbents the PF-Rd and PF-OX showed the maximum and the best uptake capacity for Pb (II) and Cd (II) ions while, other chemically modified palm fibers adsorbents showed lower capacity uptake of the same metal ions.

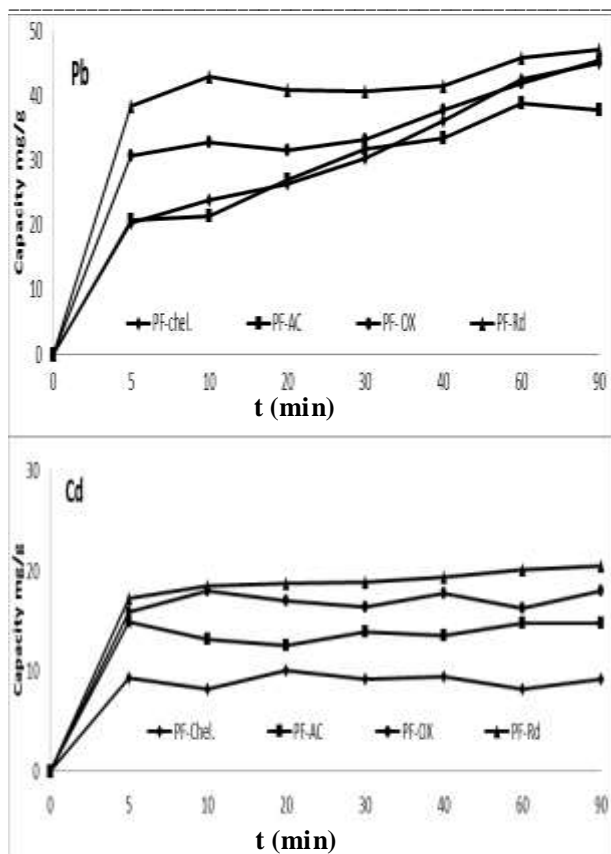


Fig. 3. Adsorption capacity of hybrid PFs at different time intervals for lead and cadmium removal.

3.1.3 Effect of adsorbent dosage

Effect of adsorbent dose on the adsorption capacity of Pb (II) and Cd (II) ions was studied. The used dose was varied from 0.05 to 0.25 g using 100 mg/L concentration of Pb (II) or Cd (II) solutions at room temperature. At constant concentration of metal ion, it was noticed that the adsorption capacities of all chemically modified adsorbents were increased for Pb (II) and Cd (II) ions with the increase of adsorbent dose as shown in (Fig. 4). This is ascribed to the accessibility of great replaceable sites or surface area at higher adsorbent dosage. However, no significant changes in adsorption capacity were observed above 0.15 g and 0.1 g of Pb (II) and Cd (II) ions, respectively. Due to congregation of adsorbent particles, effective surface area of adsorption won't increase [33]. Accordingly, 0.15 and 0.1 g were considered as the optimal dose for adsorbent loading of Pb (II) and Cd (II) solutions, respectively. Likewise here, PF-Rd and PF-OX adsorbents showed the maximum adsorption capacity for Pb (II) and Cd (II) ions, respectively.

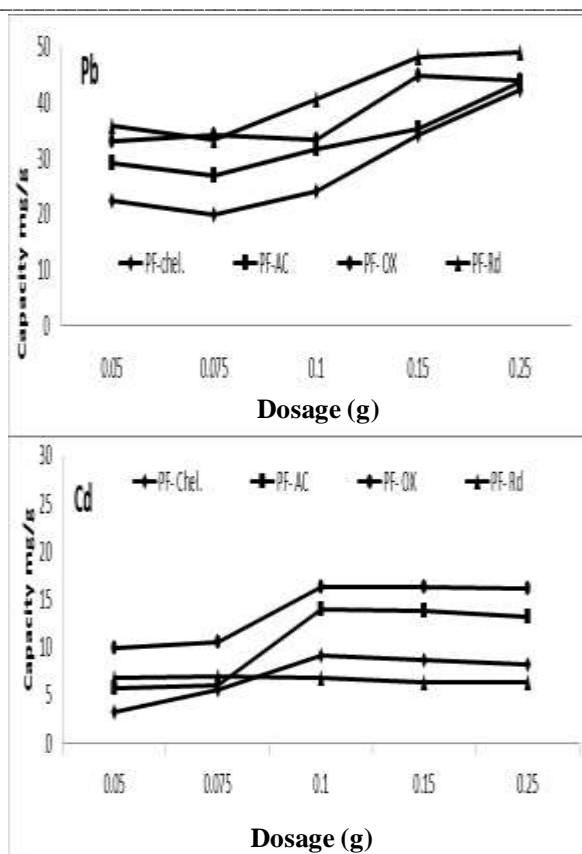


Fig. 4. Adsorption capacity of modified PFs at different weights for lead and cadmium removal.

3.2. Adsorption Isotherms and Kinetics

Adsorption isotherms experiments were conducted to explore the performance of adsorption along with its mechanism. The adsorption isotherms of the under study heavy metals, Pb (II) and Cd (II) ions, onto all chemically modified palm fibers adsorbents (PF-AC, PF-Chel, PF-OX and PF-Rd) are shown in Fig. 5 (a & b) and Table 2. The experimental data were fitted with most widely used models Langmuir, Freundlich, Tempkin and D-R. The parameters of all models were calculated and summarized in Table 2. The Langmuir mono-layer model gives the most fitting in all most cases for all adsorbents with both metals, judging from R^2 . The result also showed less fitting of experimental data when applying both Freundlich and Tempkin models. While applied of D-R model provided the lowest fitting of experimental data among all isotherm models.

Table (2) Isotherm parameters

Sorbent	Langmuir's parameters			Freundlich's parameters			Dubinin-Radushkevich's parameters			Temkin's parameters			
	R^2	q_{\max} (mg/g)	K_L (L/m)	R^2	K_f (mg/g)	n	R^2	q_s (mg/g)	E (J/mol)	R^2	K_T	b_T	
Pb	PF-AC	0.960	32.258	0.283	0.950	10.247	3.533	0.800	30.000	4.70×10^{-2}	0.980	2.193	565.5
	PF-Chel.	0.987	27.777	0.322	0.941	9.845	4.237	0.900	25.000	4.00×10^{-2}	0.900	6.269	320.6
	PF-OX	0.950	41.322	0.249	0.850	12.863	3.806	0.780	43.050	4.76×10^{-2}	0.921	6.800	402.5
	PF-Rd	0.980	56.818	0.141	0.980	8.700	1.930	0.985	53.650	4.20×10^{-2}	0.940	0.958	164.0
Cd	PF-AC	0.940	20.833	0.105	0.918	37.757	3.176	0.784	18.375	1.33×10^{-2}	0.867	0.732	533.5
	PF-Chel.	0.935	16.129	0.010	0.920	32.809	3.802	0.801	14.282	2.67×10^{-2}	0.900	0.863	809.6
	PF-OX	0.936	27.027	0.468	0.850	26.977	4.807	0.819	25.053	1.00×10^{-2}	0.803	14.05	611.9
	PF-Rd	0.993	33.333	0.588	0.900	43.853	4.524	0.910	31.430	1.29×10^{-3}	0.913	17.88	495.0

excluded the assumption of physical adsorption. [34, 35].

The isothermal Langmuir parameters illustrated that the selectivity of all adsorbents to Pb (II) against Cd (II) where, the maximum adsorption capacity of Pb (II) were 41.3 and 56.8 mg/g for both PF-OX and PF-Rd in respective and the maximum adsorption capacity of Cd (II) were in the range at 27 and 33 mg/g for both PF-OX and PF-Rd in respective.

On the other hand, the K_L value which was less than unit for all cases indicate that the adsorption was favorable for all adsorbents specially for PF-Rd adsorbent which showed the lowest K_L in range ~ 0.1 . The n values from Freundlich parameters which was more than one for all cases indicated the homogeneity of fibrous adsorbents surface and excluded the heterogeneity assumption of Freundlich model and support mono-layer homogenous surface of Langmuir model. The apparent energy (E) was calculated here from D-R parameters to give data in the range ~ 0.1 - 1 kJ.

Experimental data attained from batch study were explained using different kinetic models such as pseudo-first-order and pseudo-second-order. Fig 6(a and b) shows the data fitting by pseudo-second-order model only while Table 2 presents resultant kinetic parameters obtained from both kinetic models used. The correlation coefficient (R^2) obtained from plot t/q_e against time indicated that the pseudo-second order kinetic model was the most suitable to fit the experimental data for all chemically modified PF adsorbents. The equilibrium adsorption capacities determined q_e (cal) using the pseudo-second-order plots are approximately the same with the experimental values. That type of results indicated that the adsorption rate of metal ions relies on the ions at the adsorbents surfaces and the behavior over a whole range of adsorption is support chemisorption reaction model. These results were supported by obeying all adsorbents the mono-layer adsorption isotherm (langmuir model) as the most fitted one and

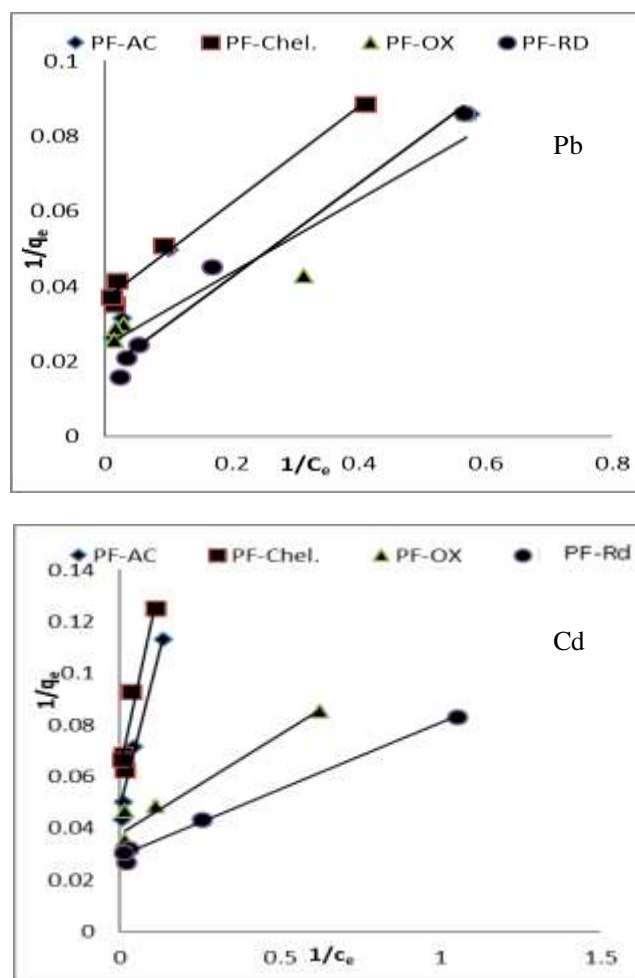


Fig.5. Langmuire Adsorption Isotherm of Pb; and Cd.

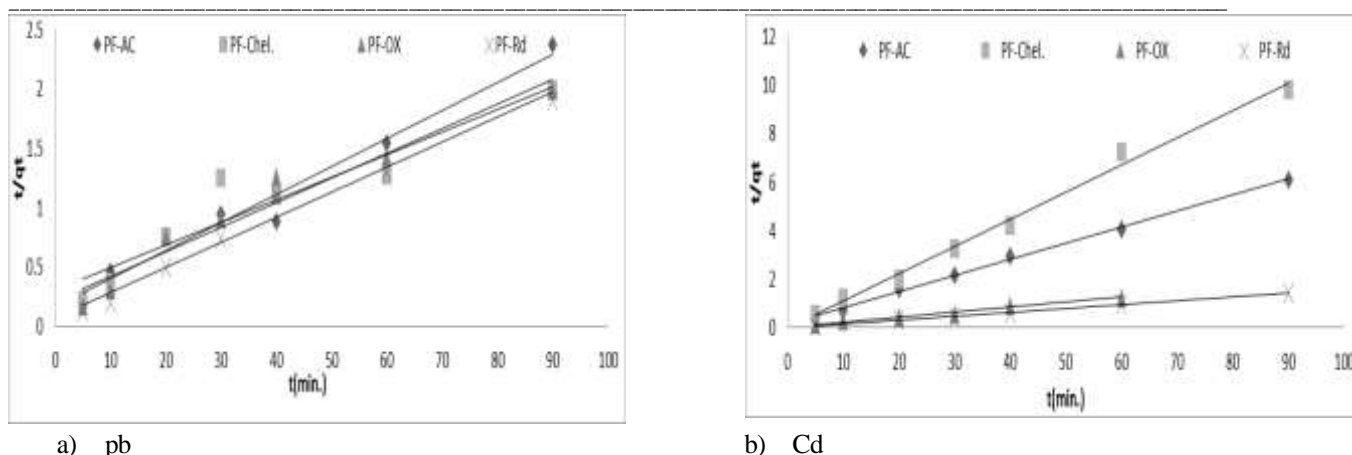


Fig. 6. The Adsorption kinetics model of Pseudo-second order of (a) Pb; and (b) Cd with all adsorbents

Table 3. Kinetics parameters

Metal ion	Adsorbent	Pseudo 2 nd order Parameters			Pseudo 1 st order Parameters	
		R ²	q _e (cal.) (mg/g)	k ₂ (rate constant) (g /mg min.)	R ²	k ₁ (rate constant) (g /mg min.)
Pb	PF-AC	0.973	47.10	0.14	0.900	0.023
	PF-Chel.	0.900	43.47	0.06	0.517	0.013
	PF-OX	0.979	47.62	0.02	0.300	0.023
	PF-Rd	0.980	43.47	0.02	0.320	0.013
Cd	PF-AC	0.994	17.8	1.3	0.114	0.002
	PF-Chel.	0.992	8.92	2.8	0.360	0.002
	PF-OX	0.994	18	1.3	0.440	0.016
	PF-Rd	0.984	16.13	0.62	0.111	0.002

3.3. Surface Characterization

The SEM micrographs of the surface morphology of raw PF and chemically modified PF revealed that the surface morphology was enhanced after chemical treatment generally as shown in Fig 7 (a-e). The untreated PF examination, Fig 6a, showed that the surface of fibers was smooth and having a thin outer layer that can resist strong bonding with the polymer matrix on the other hand after treatment the surface showed highly porous texture. Where the thin outer layer was removed through different treatment processes which can lead to stronger bonding with the matrix.

For the chemically modified PF adsorbents every treatment showed different effect on the fibers, where SEM of PF-AC (Fig 7b) signified a rough surface structure of the micro fibers with the presence of many pores, also it was obvious that SEM of PF-Chel (Fig 7c) showed that the treatment may be caused grooves with rough fiber surface which

became the less favorable treatment for adsorption and this explained why it was the least capacity of the treated fibers.

While PF-Rd showed flower-like shaped surface that might facilitate the penetration inside the pores (Fig 7d). Examinations by scan microscope were proved the efficiency of the chemical treatment. The chemically modified palm fibers adsorbents were characterized before and after chemical treatments by FTIR as shown in Fig 8. FTIR spectra of untreated PF exposed the lignocellulosic structure of the fibers, where the characteristic adsorption peaks at 3421.83 and 2931.30 cm⁻¹ were correspond to O-H and C-H stretching vibration of lignin [36]. The strong absorption peak at 1049.31 is attributed to the stretching vibration of C-O bonds in a cellulosic glucose ring. The absorbance peaks at 1624.12 and 1531.53 cm⁻¹ caused by aromatic nucleus vibration, and the band at 1435.09 cm⁻¹ assigned to the C-H bending vibration in methyl and methylene were all characteristic peaks of lignin [37].

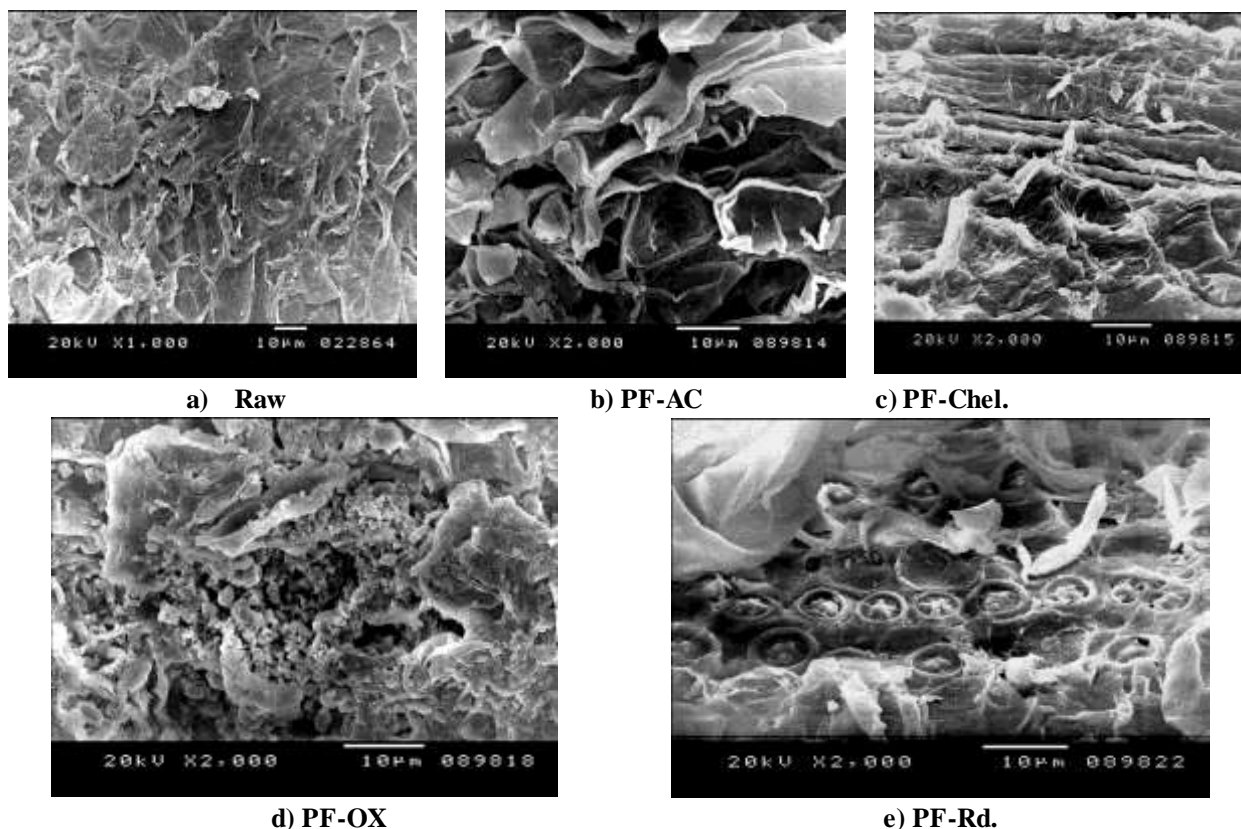


Fig. 7. FE-SEM images of (a) untreated PFs, magnification factor 1000, (b) PF-AC, (c) PF-OX, (d) PF-Rd, and (e) PF-Chel., magnification factor 2000.

However, upon chemical treatments by using acid, oxidizing and redox reactions, few IR peaks were appeared or strengthened. The strong peak related to vibration of O-H functional group (2353 cm^{-1}) was reinforced in PF-AC, the strong peak appearing at 1134 cm^{-1} for PF-Rd is mainly due to (C-O) of methoxy group and the density of peak at 1034 cm^{-1} was increased in PF-OX. Thus, chemical treatment processes of PF were found to improve and intensify the various functional groups of the original PF [38].

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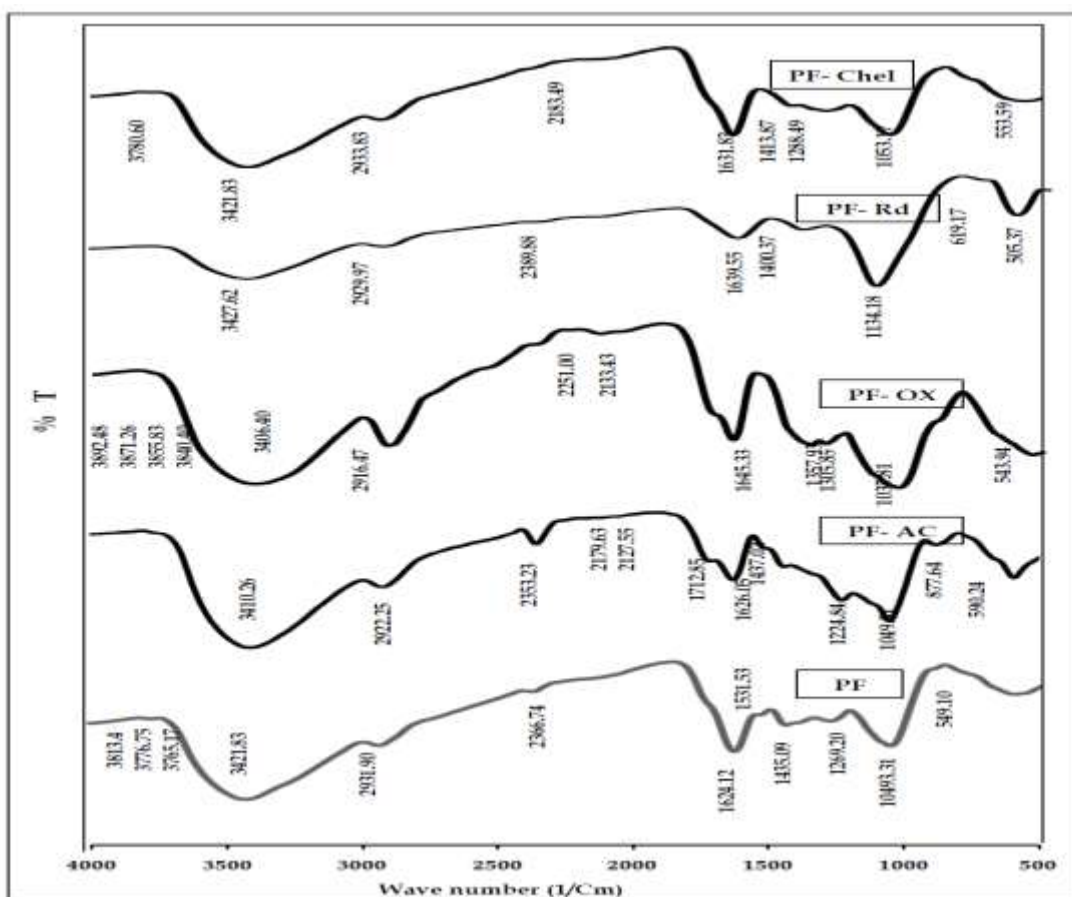
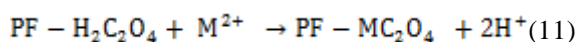
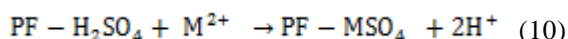
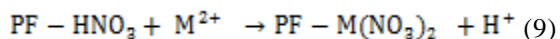
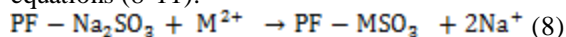


Fig. 8. FTIR Spectra of chemically modified PF adsorbents.

3.4. Mechanism of Adsorption

The adsorption process usually supports the mixed mechanisms of physisorption and chemisorption mechanism. The physisorption mechanism is always considered the adsorption process done through electrostatic transactions between positive charges of metal ions and negative surface of adsorbents which usually full of donating electrons groups such as hydroxyl group, amine group carbonyl group.... etc. [39]. On the other hand, the chemisorption mechanism is explained as ion exchange or chelation interaction one. In this work, the data obtained from kinetic section clarify that all palm fibers chemically modified adsorbents obeyed pseudo second order model which improved the chemisorption pathway [40]. That data agrees with results of isotherm studies which indicated complete following of all palm fibers chemically modified adsorbents to the mono-layer Langmuir model against all other models, the arrangement of adsorbate (Pb (II) and Cd (II)) as only one layer completely support the chemisorption interaction suggestion [17]. Suggested interaction

equations for different adsorbents are demonstrated in equations (8-11).



By the same way, the appearance of new functional groups, at FTIR chart, were formed from the chemical treatment for PF push in the way of chelating interaction between metal ions and PF chemically modified adsorbent or ion exchange one. Therefore, based on all previous results, adsorption process is suggested to take place by means of ion exchange where the metal ion replaces the hydrogen ion from the adsorption site and be located to the adsorbent forming an adsorbent metal complex.

For practical insinuations chemical treatment of palm fibers has been suggested as an economical and efficient technique to improve the capacity of adsorption of Pb (II) and Cd (II) ions from wastewater. From this study, treatment of PF with

Na₂SO₃ (PF-Rd) or with HNO₃ (PF-OX) achieved the maximum capacity with the adsorption of toxic heavy metals.

4. Conclusions

In this study, batch adsorption tests were conducted to investigate the adsorption traits of Pb (II) and Cd (II) ions on chemically- modified PF. Pb (II) and Cd (II) adsorption data could be adequately - explained by the Langmuir isotherm model and followed the pseudo-second-order kinetic model. PF-Rd and PF-OX adsorbents revealed the maximum adsorption capacity for Pb (II) and Cd (II) removal from synthetic waste solutions. The maximum adsorption capacities of Pb (II) were 41.3 and 56.8 mg/g for both PF-OX and PF-Rd in respective while the maximum adsorption capacities of Cd (II) were in the same range at 27 and 33 mg/g for both PF-OX and PF-Rd in respective. Ultimately, the results of the study authenticate the efficiency of the chemically modified palm fibers as adsorbents could possibly have practical application on large scale for the removal Pb (II) and Cd (II) ions from wastewaters, with adequate amounts of adsorbent and acknowledged cost.

5. References

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