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Characteristics of Lead Sorption by Zeolite Minerals

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Abstract: Lead adsorption behavior was investigated using four Zeolite minerals (clinoptilolite, analcime, phillipsite and chabazite). The used Pb^{2+} concentrations were 0, 0.1, 0.5, 1.0, 2.0, 3.0 and 5 $\mu\text{mol mL}^{-1}$. Results indicated that Pb^{2+} sorption followed the Langmuir adsorption isotherm, but over limited concentration ranges for clinoptilolite and analcime. The binding energy (K_d) reached, 2.400 and 0.875 g L^{-1} for phillipsite and chabazite, respectively. The maximum adsorption capacity for such minerals reached 208.33 and 204.08 mg g^{-1} with correlation coefficient (R^2) reached, 0.997 and 0.995, respectively. Meanwhile, two stages for Pb^{2+} adsorption were observed with clinoptilolite and analcime in the low and high concentrations of the applied Pb^{2+} . Data also was applicable to the Freundlich adsorption isotherm over the used entire Pb^{2+} concentration ranges. The binding energy (n) reached, 1.014, 1.005, 1.001 and 1.001 g L^{-1} for clinoptilolite, analcime, phillipsite and chabazite, respectively. However, the b values (maximum adsorption capacity) reached 202.582, 201.651, 207.062 and 206.871 mg g^{-1} with correlation coefficient (R^2) nearly one for all studying minerals, respectively. Desorption data indicated that most of the sorbed Pb^{2+} was extracted in the 1st extraction following the adsorption experiment. The ability of the used zeolite minerals to retain Pb^{2+} was high and there were differences between the studied minerals in sorption of Pb^{2+} . In conclusion, data eliminated that, zeolite minerals especially, phillipsite and chabazite, could be successfully used as packing material in subsurface reactive barriers intercepting ground water plumes and for fixed bed reactors designed to remove Pb^{2+} from industrial wastewater.

Key words: Lead, Langmuir and Freundlich models, clinoptilolite, analcime, phillipsite, chabazite

INTRODUCTION

Soils and water resources were approved to be contaminated with heavy metals, as a result of increasing industrialization and mining activities (Al-Farraj and Al-Wabel, 2006). Increasing levels of heavy metals including Pb^{2+} in the environment, represent a serious threat to human health, living resources, soil quality and ecological systems (He, 1998; Kham *et al.*, 2000; Nigam *et al.*, 2001). Thus, a great deal of attention should be paid to overcome and/or avoiding environment against lead and other heavy metals pollution. Firstly, understanding the behavior of heavy metals, especially lead is important for minimizing the risk of soil and water contamination with such metal. In this respect, information regarding the mechanisms of lead adsorption/desorption in soil minerals is important as these reactions control the strength of metal-soil surface interactions. Moreover, the slow desorption of Pb^{2+} in soils has been a major impediment in estimating the environmental hazard and the successful phytoremediation of contaminated sites with such metal (Mench *et al.*, 1994; Salt *et al.*, 1995; Wu *et al.*, 2003). Also, understanding the processes governing the migration and plant availability of trace metals in soils is essential for predicting the environmental impact of

spreading metal-containing wastes on agriculture land. The adverse effects of heavy metals including Pb^{2+} are related to the soils ability to adsorb and release these elements. A fair number of investigations indicated that, clay minerals, due to their low permeability, could play an important role, as physical barriers, for the isolation of metal from metal rich wastes (La Grega *et al.*, 1994). Also, they could be used as a chemical barrier too, as consequence of the ability of some types of clay minerals to adsorb heavy metals and to avoid their environmental dispersion (Vega *et al.*, 1995). In this regard, naturally occurring zeolites hold great potential for use as packing material in subsurface reactive barriers intercepting ground water plumes and for fixed bed reactors designed to remove heavy metals from industrial wastewater (Bowman *et al.*, 1995; Steimle, 1995). Such minerals group is one of the Tectosilicates that characterized by three dimensional framework structure with higher cation exchange capacity and a cage-like structure that offers large internal and external surface areas for ion exchange, (Ming and Mumpton, 1989; Bowman *et al.*, 1995). In another study Gatima *et al.* (2006), pointed out that the adsorption of lead or lead removal from lead contaminated soils was depended upon the cation exchange capacities of the used red mud, bone meal and pulverized fly ash.

As, the CEC could be a major parameter in the adsorption capacity of the soil. One of the most abundant natural zeolite minerals is clinoptilolite, has characteristic tabular morphology shows an open reticular structure of easy access, formed by open channels of 8±10 member rings (Mondale *et al.*, 1995). Moreover, such mineral has been shown to selectively remove cesium and strontium ions from radioactive wastewater (Lukae and Foldesova, 1994) and its use for removing other dissolved heavy metal cations is receiving increasing attention in this respect, considerable research has been conducted to characterize the chemical, surface and ion exchange properties of clinoptilolite (Ackley and Yang, 1991; Carland and Aplan, 1995; Mondale *et al.*, 1995; Semmens and Martin, 1988; Zamzow and Murphy, 1992; Trasevich *et al.*, 1997; Alexander and Tsadilas, 2003; Yang *et al.*, 2005; Sprynskyy *et al.*, 2006). However, there is a shortage in the information concerning the characteristics of Lead sorption by the other zeolite minerals. Therefore, the objectives of this study were to investigate the kinetics of Pb²⁺ sorption by variable zeolite minerals. The possibility to use such zeolite minerals in remediation of lead polluted areas was evaluated.

MATERIALS AND METHODS

Zeolite samples: Four zeolite minerals namely, clinoptilolite, analcime, philipsite and chabazite were taken from (South west USA, Barstow California, PineValley Nevada and Christmas, Arizona), respectively. In each sample cation exchange capacity was determined with the method for arid zone soils described by Rhoades (1982). Surface area was measured using Ethylene Glycol Mono Ethyl Ether (EGME) adsorption according to the method described by Carter *et al.* (1965). The chemical compositions of the tested Zeolite samples were determined by the method described by Moore and Reynolds (1997) and Tarasevich *et al.* (1997) (Table 1).

Adsorption of Pb²⁺: An adsorption/desorption experiment was conducted-in March 20, 2006, under the growth chamber of the Department of Soil Science, College of Food Sciences and Agriculture, King Saud University,

Riyadh, Saudi Arabia. Twenty milligram from each of the studying clayminerals were separately weighed into duplicate centrifuge tubes and each mixed with 40 mL solution of 0.0, 0.1, 0.5, 1.0, 2.0, 3.0 and 5 Pb μmol mL⁻¹ as Pb (NO₃)₂ in solution with an ionic strength of 10 μmol L⁻¹ Ca (NO₃)₂. The isotherm data were obtained at pH which were not kept constant, but were verified to remain <6.5 (Straw *et al.*, 1998; Shen *et al.*, 1999; Mario *et al.*, 2002). The tubes were flushed with N₂ gas for 1 min and capped tightly before being shaken at 60 rpm at 23°C for four days. The pH values were measured thereafter, centrifugation (3000 rpm for 15 min, at 25°C). Then the supernatant was taken from each tube for the determination of Pb using the ICP-AES, (Prkin Elemer, Model 4300 DV). Lead sorbed by the clay minerals was calculated as the difference between the initial Pb²⁺ and equilibrium Pb²⁺ concentrations. The amount of native adsorbed Pb²⁺ initially present in the used minerals was estimated by extrapolating the adsorption isotherms derived from higher to zero concentration of soluble Pb²⁺ and from the amount of Pb²⁺ extracted with 10 μmol L⁻¹ Calcium nitrate Ca (NO₃)₂. The native Pb²⁺ so estimated was taken into account to establish the corrected adsorption isotherm. The data of Pb²⁺ sorption were firstly calculated according to Langmuir equation. The linear form of the isotherm used was:

$$(c)/(x/m) = 1/b (c) + 1/kb,$$

Where:

- (c) = Equilibrium concentration (μmol Pb²⁺ mL⁻¹),
 - (x/m) = Adsorbed Pb²⁺(μg Pb²⁺ g⁻¹ soil),
 - b = Dsorption maximum (μg Pb²⁺ g⁻¹ soil) and
 - k = A constant related to bonding energy (mL μg⁻¹).
- The data were also described by the Freundlich equation. The linear form of the isotherm used was:

$$\log (x/m) = 1/n \log (c) + \log k d$$

Where 1/n is the slope of the regression line and k_d and n are empirical constants.

Table 1: The chemical and mineralogical properties for the used clay minerals

Compositions	Zeolite minerals			
	Clinoptilolite	Analcime	Philipsite	Chabazite
Impurities	Quartez, feldspar, mica	Quartez	Mica	Mica, quartez
Surface area (m ² g ⁻¹)	407.900	313.000	961.700	1100
CEC (cmol kg ⁻¹)	98.400	39.000	223.000	195.0
CaO (%)	1.519	1.792	5.502	7.290
K ₂ O (%)	2.486	1.588	2.486	1.369
Na ₂ O (%)	1.036	0.829	8.626	7.21
Fe ₂ O ₃ (%)	1.369	1.248	1.806	1.764
MgO (%)	2.094	2.435	11.300	11.546

Desorption of Pb²⁺: Desorption of Pb²⁺ was accomplished by repeated replacement with metal-free Ca (NO₃)₂ solution following adsorption. The tube with the mineral residue separated from the supernatant solution by the centrifugation was weighed to measure the residual Pb²⁺ in the mineral solution. Forty milliliter of 10 mM L⁻¹ Ca (NO₃)₂ were added to each tube containing the Pb-enriched minerals residue. The suspensions were shaken at 200 rpm for 24 h at 25°C. The equilibrated suspensions were then centrifuged at 3000×g relative centrifugal force for 15.0 min. Thereafter, 20 mL of the supernatant were removed and replaced by 20 mL of 10 mM L⁻¹ Ca(NO₃)₂. The procedure was repeated four times, resulting in a total four desorption for each adsorption sample tested. The non-extractable fraction of the adsorbed Pb²⁺ was obtained by the difference between the total recovered Pb²⁺ by four successive extractions with Ca (NO₃)₂ solutions.

Quality control: All the used chemicals were purchased from E. Merck (A.R., 99.9%). The apparatus, tubes and vessels were previously washed with 30% HNO₃, then rinsed three times with deionized water and dried in an oven. All stages of sample preparation, analysis and measuring were carried out in a clean environment.

RESULTS AND DISCUSSION

Properties of the used zeolite minerals: Data presented in Table 1 show the chemical and mineralogical properties of the used zeolite minerals. Apparently, the used minerals are varied in their content of impurities as the major impurities, are (Quartz, feldspar, Mica) (Quartz) (Mica) and (Mica and Quartz) in clinoptonite; analcime; philipsite and chabazite minerals, respectively. Also, the respective surface areas of such minerals are 407.9, 313.0, 961.7 and 1100 m² g⁻¹. it is also obvious that, analcime mineral has the lowest CEC and surface area among the used zeolite minerals followed by clinoptonite mineral. This may reflected on the behavior of Pb²⁺ sorption which will be discussed latter.

Lead adsorption: The kinetics of Pb(II) adsorption were shown by Strawn *et al.* (1998) at the aluminum oxide-water

interface at pH 6.5 to be initially fast, resulting in 76% of the total sorption occurring within 15 min, followed by a slow continuous sorption reaction likely resulting from diffusion through micro pores. Also, Shen *et al.* (1999) indicated that, all the Pb sorption in clay minerals (as smectite groups) took place within 0.1 h, after which the sorption kinetics exhibited a plateau, a time period of four days was considered adequate to reach equilibrium conditions in pH-edge and isotherm studies.

Pb²⁺ sorption by the studied clay minerals generally, conformed to the Langmuir sorption isotherm but over limited concentration ranges (Table 2 and Fig. 1). However, at high concentrations of the applied Pb²⁺, data deviated from the Langmuir model. Such deviations from the Langmuir model indicated that there were different reactions might occurred at higher Pb²⁺ concentrations especially for analcime and clinoptilolite. The maximum adsorption capacities (i.e., b values) were, 208.33 and 204.08 mg g⁻¹ for philipsite and chabazite, with correlation coefficient (R²) equal to 0.997 and 0.995, respectively. Also the corresponding binding energy (i.e., K_d) were 2.400 and 0.875 mg L⁻¹, respectively. While for clinoptilolite and analcime the b values were differ in the low and high concentrations of applied Pb²⁺. The b1 (in low concentrations) reached 88.5 and 100.0 mg g⁻¹ with correlation coefficient (R²) equal to 0.894 and 0.865 for such minerals, respectively (Table 2 and Fig. 1). The differences in b values may be rendered to the large difference between the studied minerals in their contents of Fe and Al oxides as well as, the differences in their impurities content, C.E.C and/or their surface area, (Table 1). Also, the binding energies (K_d) of Pb²⁺ were high for the studying minerals. This means that the surfaces of zeolite minerals-especially Philipsite and chabazite-strongly adsorbed Pb²⁺. The maximum adsorption capacities of such minerals for Pb²⁺ were in the same sequence. This may be due to the higher initial surface area and C.E.C of chabazite and philipsite in (Table 1). In contrast the binding energy (K_d) of analcime was relatively the lowest one among the studying zeolite minerals. Possibly due to its relatively lower cation exchange capacity and surface area, (39 C mol kg⁻¹ and 313.0 m²gm⁻¹, Table 1). In this respect Gatima *et al.* (2006), pointed out that the adsorption of lead

Table 2: The Maximum Adsorption Capacity (MAC) and Binding Energy (BE) for the adsorbed Pb²⁺ in the studying Zeolite minerals according to Langmuir Equation

Clay minerals	Equation	MAC (b) (mg g ⁻¹)	BE (K _d) (g L ⁻¹)	R ²
Clinoptilolite	C/(x/m) = 0.0113 x+0.2207*	88.50*	*0.051*	0.894*
	C/(x/m) = -0.0007 x+1.3225**	-1428.57**	-0.478**	0.478*
Analcime	C/(x/m) = 0.01 x+0.4019*	100.00*	0.025*	0.865*
	C/(x/m) = -0.015 x+1.5364**	-666.67**	-0.0009**	0.852**
Philipsite	C/(x/m) = 0.0048 x+0.002	208.33	2.400	0.997
Chabazite	C/(x/m) = 0.0049x+0.0056	204.08	0.875	0.995

*Low concentrations and **high concentrations, (R² was calculated based on 14 points obtained from 7 concentrations of applied Pb in two replicates)

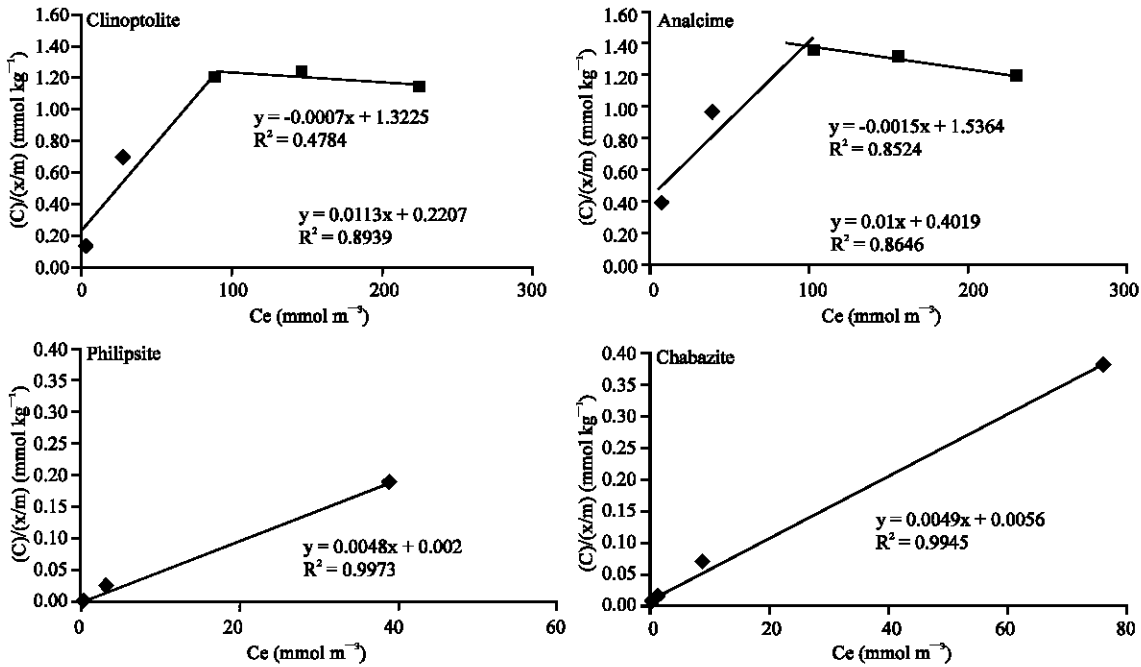


Fig. 1: Langmuir adsorption isotherm of Pb²⁺ in the studying zeolite minerals. (R² was calculated based on 14 points obtained from 7 concentrations of applied Pb in two replicates)

Table 3: The maximum adsorption capacity (MAC) and binding energy (BE) for the adsorbed Pb²⁺ in the studying Zeolite minerals according to Freundlich equation

Clay minerals	Equation	MAC (a) (mg g ⁻¹)	BE (n) (g L ⁻¹)	R ²
Clinoptilolite	Log (x/m) = 0.9866×+0.3066	202.582	1.014	1.0000
Analcime	Log (x/m) = 0.9849×+2.3046	201.651	1.005	0.9998
Philipsite	Log (x/m) = 0.9994×+2.3161	207.062	1.001	1.0000
Chabazite	Log (x/m) = 0.9986×+2.3157	206.871	1.001	1.0000

or lead removal from lead contaminated soils was depended upon the cation exchange capacities of the used red mud, bone meal and pulverized fly ash. As, the CEC could be a major parameter in the adsorption capacity of the soil. The calculating binding energy of Pb²⁺ with the studied zeolite minerals, show that, in low concentrations of the applied Pb²⁺, the k_d of both analcime and clinoptilolite were so much higher than those at higher concentrations in most cases. This means that, the exchangeable sites adsorbed Pb²⁺ with relatively higher adsorption energy in low concentrations, more than the available surfaces for the adsorption in higher concentrations. This may be due to the nature of adsorption sites in low concentration. As the adsorbed Pb²⁺ may be as near as such sites, hence, the adsorption forces could be increased than those under higher concentrations. Generally, the binding energy of the studying zeolite minerals for Pb²⁺ adsorption could be arranged in the following descending order: philipsite>chabazite>clinoptilolite>analcime. On the other hand, at low concentrations of the applied Pb²⁺, the b1 values for clinoptilolite reached 88.5 mg g⁻¹. While for analcime it

was 100.0 mg g⁻¹. The philipsite and chabazite minerals had not any differences in the obtained b values between higher and lower concentrations of the applied Pb²⁺. It is obvious that, analcime showed the lowest Pb²⁺ adsorption capacity. This may be due to its relatively lower CEC and surface area as previously mentioned, (Table 1). The used clay minerals could be arranged due to their maximum adsorption capacity for Pb²⁺ as follows: philipsite>chabazite> clinoptilolite> analcime. The differences between the used clay minerals on their maximum adsorption capacity could be refer to the differences in their impurities content, their CEC and/or their surface area (Table 1). On the other hand, data was applicable to the Freundlich adsorption isotherm over the entire Pb²⁺ concentration ranges of (0 to 5 μmol mL⁻¹). The binding energy (n) reached, 1.014, 1.005, 1.001 and 1.001 g L⁻¹ for clinoptilolite, analcime, philipsite and chabazite, respectively. However, the b values (maximum adsorption capacity) reached 202.582, 201.651, 207.062 and 206.871 mg g⁻¹ with correlation coefficient (R²) nearly one for all studying minerals respectively, (Table 3 and Fig. 2). It is worth to mention that, the maximum adsorption capacities

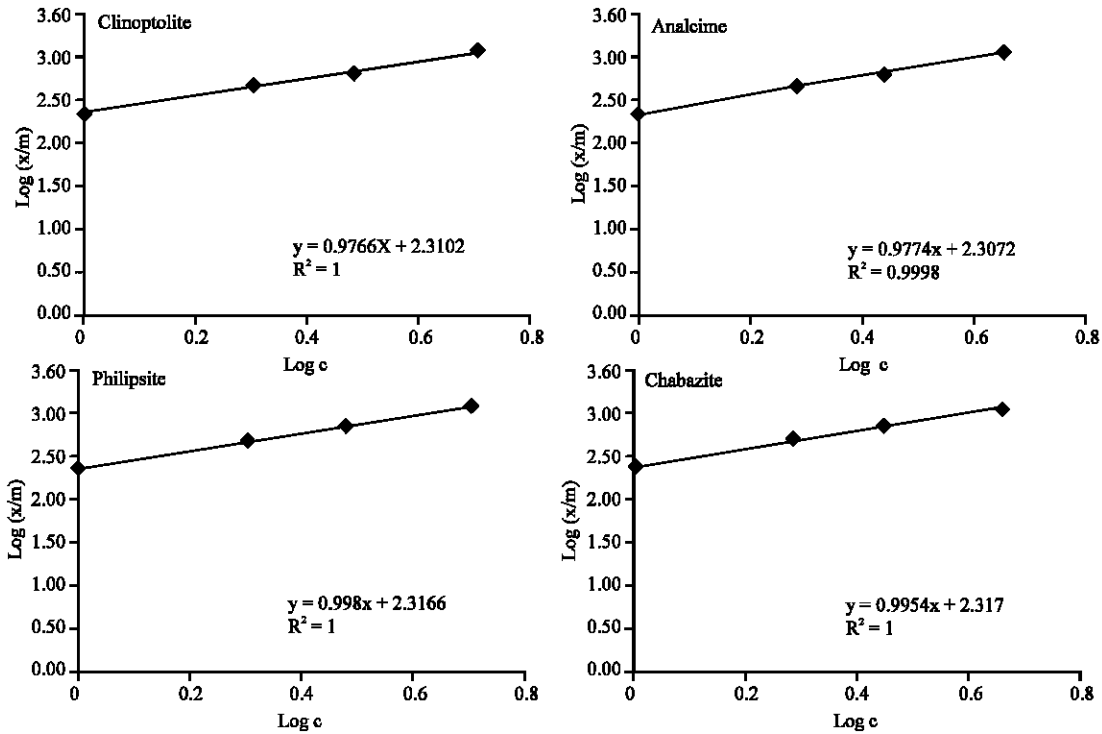


Fig. 2: Freundlich adsorption isotherm of Pb²⁺ in the studying Zeolite minerals. (R² was calculated based on 14 points obtained from 7 concentrations of applied Pb in two replicates)

Table 4: Adsorption and desorption of Pb²⁺ on the used zeolite minerals

Applied Pb ²⁺ (mmol L ⁻¹)	C _e (mg L ⁻¹)	x/m (mg g ⁻¹)	Desorbed Pb ²⁺ (mg g ⁻¹)				Desorbed/Adsorbed (%)			
			D ₁	D ₂	D ₃	D ₄	D ₁	D ₂	D ₃	D ₄
Clinoptilolite										
0.0	0.000	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.1	0.000	4.14	3.84	0.00	0.00	0.00	91.47	0.00	0.00	0.00
0.5	0.584	20.60	13.84	0.06	0.04	0.02	66.91	0.29	0.18	0.11
1.0	5.804	40.28	18.07	0.53	0.32	0.19	44.74	1.32	0.80	0.48
2.0	19.630	78.95	19.08	2.40	1.25	0.65	24.10	3.03	1.58	0.83
3.0	30.775	118.16	19.56	5.54	2.30	1.11	16.51	4.69	1.95	0.94
5.0	46.600	197.87	21.52	9.78	5.05	1.89	10.85	4.94	2.55	0.96
Analcime										
0.0	0.000	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.1	0.000	4.14	3.30	0.00	0.00	0.00	78.31	0.00	0.00	0.00
0.5	1.498	20.42	11.77	0.13	0.09	0.07	57.37	0.66	0.43	0.35
1.0	7.909	39.86	15.35	0.76	0.41	0.27	38.39	1.91	1.02	0.69
2.0	21.860	78.50	16.14	2.85	1.42	0.79	20.50	3.63	1.81	1.01
3.0	32.550	117.80	16.65	6.99	2.47	1.24	14.09	5.93	2.10	1.05
5.0	47.950	197.60	17.39	10.15	5.25	1.97	8.78	5.14	2.66	1.00
Philipsite										
0.0	0.000	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.1	0.000	4.14	1.66	0.00	0.00	0.00	39.14	0.00	0.00	0.00
0.5	0.000	20.72	3.29	0.00	0.00	0.00	15.67	0.00	0.00	0.00
1.0	0.000	41.44	7.16	0.00	0.00	0.00	17.18	0.00	0.00	0.00
2.0	0.082	82.86	13.53	0.02	0.02	0.01	16.27	0.02	0.02	0.01
3.0	0.633	124.19	16.84	0.07	0.05	0.05	13.53	0.06	0.04	0.04
5.0	7.979	205.59	22.35	0.74	0.53	0.42	10.85	0.36	0.26	0.21
Chabazite										
0.0	0.000	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.1	0.000	4.14	3.49	0.00	0.00	0.00	82.93	0.00	0.00	0.00
0.5	0.000	20.72	11.74	0.00	0.00	0.00	56.42	0.00	0.00	0.00
1.0	0.014	41.44	17.02	0.01	0.00	0.00	40.94	0.01	0.00	0.00
2.0	0.217	82.83	25.83	0.03	0.02	0.04	31.12	0.04	0.03	0.05
3.0	1.783	123.96	27.51	0.19	0.13	0.51	22.15	0.15	0.10	0.41
5.0	15.550	204.08	30.14	1.69	0.98	0.75	14.74	0.83	0.48	0.37

Where: (C_e) is the equilibrium concentrations in (mg L⁻¹); while (x/m) is the adsorbed amount of Pb²⁺ in (mg g⁻¹); and (D₁, D₂, D₃ and D₄) are the four successive desorption

obtained either with Langmuir or Freundlich models were more or less the same for chabazite and phillipsite. Such results stood in a good agreement with the sorption of lead by clay minerals and goethite, founded by Mario *et al.* (2002). Generally, the studying Zeolite minerals differ in their ability to adsorb Pb^{2+} in the following order: philipsite > chabazite > clinoptilolite > analcime. This indicates the profitability of using Zeolite minerals especially, philipsite and chabazite in the field of remediation for the polluted areas as ion exchangers for environmental protection with Pb^{2+} . Also, they could be used for other applications as packing material in subsurface reactive barriers intercepting ground water plumes and for fixed bed reactors designed to remove heavy metals from industrial wastewater. This means that such minerals could play an important role, not only as physical barriers (for the isolation of Pb^{2+} from metal rich wastes) but also as a chemical barrier, as consequence of the ability of such clay minerals to adsorb lead and to avoid their environmental dispersion of such metal.

Amounts of desorbed Pb^{2+} : Data in Table 4 show the amounts of the extracted Pb^{2+} in four successive extractions following the Pb^{2+} adsorption experiment, as well as, percentages of the extracted Pb^{2+} relative to the amount of adsorbed Pb^{2+} (x/m). Apparently, higher and significantly amounts of extracted Pb^{2+} were obtained in

the first extraction from all studied minerals and then gradually and sharply decreased in the other three extractions. Also, the amounts of desorbed Pb^{2+} were differed from one mineral to the others. The clinoptilolite and analcime minerals gave the higher amounts of extracted Pb^{2+} . This behavior may be due to the nature of adsorbing sites in such minerals, which may differ than those of chabazite and philipsite. On the other hand, by calculating the desorbed Pb^{2+} as a percent from the adsorbed Pb^{2+} , one can concluded that, the studied Zeolite minerals were greatly differ than each other. Furthermore, the higher percentages of desorbed lead were obtained in the 1st extraction and then sharply decreased in the following extractions. The differences in such percentages in the 1st extraction were as follows: (10.85-91.47)(8.78-78.31)10.85-39.14)and(14.74-82.93) for clinoptilolite, analcime, philipsite and chabazite, respectively.

CONCLUSION

The adsorption of lead onto Zeolite minerals has an ion exchange nature. The data are applied well to the Freundlich model, as the correlation coefficient was almost 1.0 for all studied minerals. The amount of adsorbed Pb^{2+} increase as the rate of applied Pb^{2+} increased from 0 to 5 $mM L^{-1}$ (Fig. 3) for the tested Zeolite minerals.

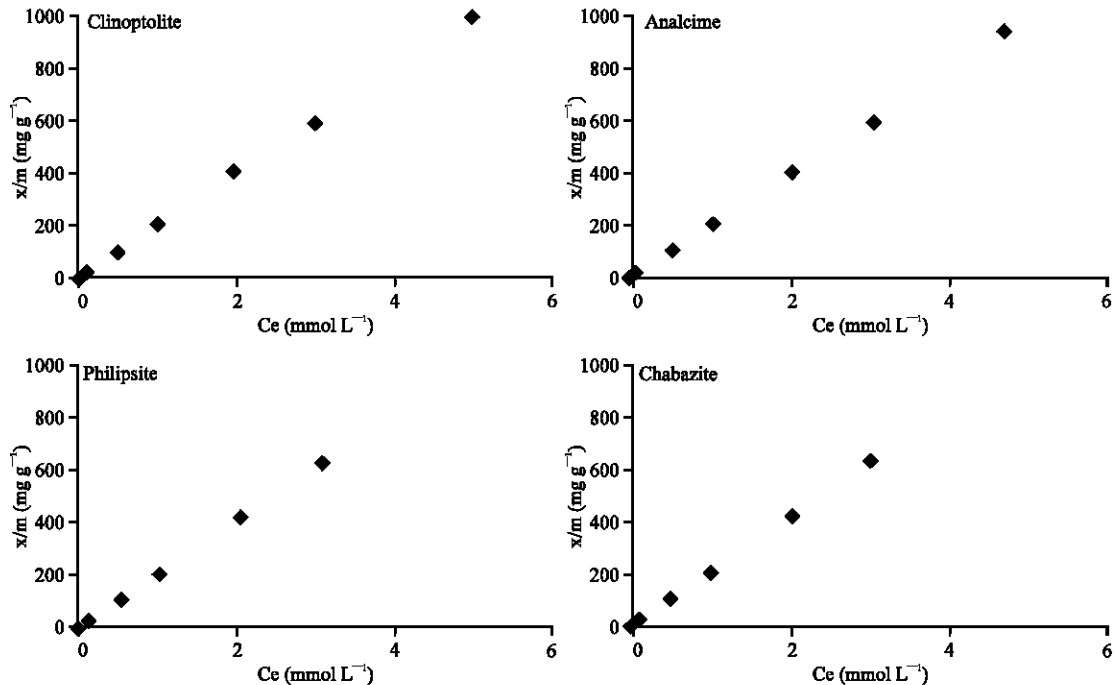


Fig. 3: Relationship between the amount of adsorbed Pb^{2+} by zeolite minerals and the equilibrium concentration of the solution

The order of K_d values for the used clay minerals were philipsite > chabazite > clinoptilolite > analcime. On the other hand, data agreed very well with langmuir equation, (especially at low concentrations of applied Pb^{2+}) for clinoptilolite and analcime. Two different stages are observed in the sorption of Pb^{2+} either by clinoptilolite or analcime, referring to Langmuire model. The process was being with fast adsorption on such Zeolite minerals microcrystal surfaces at low concentrations. Then the Pb^{2+} sorption was gradually decreased in high concentrations. Such data indicated the efficiency of zeolite materials on Pb^{2+} sorption. Most of the sorbed Pb^{2+} was extracted in the 1st extraction following the adsorption experiment. The ability of the used zeolite minerals to retain Pb^{2+} was high and there were differences between the studied minerals in sorption of Pb^{2+} . This indicates the profitability of using such minerals especially, philipsite and chabazite in the field of remediation for the Pb^{2+} polluted areas. In conclusion, data indicated that zeolite minerals could be successfully used as a good tool for other applications as packing material in subsurface reactive barriers intercepting ground water plumes and for fixed bed reactors designed to remove Pb^{2+} from industrial wastewater, however, further researches will be needed to evaluate the efficiency of such zeolite minerals under the other lead compounds such as lead carbonate, lead sulphate etc.

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