



Application of Clay Minerals to Decrease Hazard of Heavy Metals in Some Egyptian Soils

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Abstract: The hazards of potential toxic elements are aggravated by their almost indefinite persistence in the environment. Heavy metals cannot be destroyed but can only be transformed from one oxidation stage or organic complex to another. In this study, the sorption behavior of Pb^{+2} , Zn^{+2} and Ni^{+2} affected soils onto natural Zeolite and bentonite treated soils have been studied in order to evaluate these remediation materials as natural materials applied in different contaminated soil (calcareous and sand) ecosystems. Kinetic approach using electrical Stirred Flow Unit (ESFU) devise method was used to evaluate the minimizing hazards of pollutants released from the remediated soils. The rate constants of Hoerl's and Elovich kinetic models were determined in remediated soil which was drastically influenced by the concentrations of PTEs found in soils, amount of sand minerals and the type of soil used. The obtained results indicated that according to higher coefficient of determinations R^2 and lower standard error SE, the rate of potential toxic elements PTE's in control or treated soils were mach fitted to Elovich and Horel's kinetic models compared to other tested. The numerical values of rate constants indicated that in natural materials, Zeolite has a sorption capacity to studied PTE's more than bentonite used. Also, results showed that sorption of pollutants on treated soils depend on pollutants charge density and hydrated ion diameter. According to the kinetic studies, the selectivity of pollutants to be sorbed on clay minerals take the order $Zn^{+2} > Ni^{2+} > Pb^{2+}$. On the other hand the quantity of adsorbed heavy metals was in the sand soil more than calcareoussoils due to the charges on the surface sand particle and the big surface area. This study suggests that using of available natural materials could be an economic and promising alternative solution in contaminated soils to minimize hazards of such PTE's. Different mechanisms take place in removing of PTEs from the used soils were reported.

Keywords: Zeolite, Bentonite, Lead, Zinc, Nickel, Calcareous

1. Introduction

Heavy metals are harmful for living organisms because of their stability, toxicity and tendency to accumulating in the environment. The industrial wastewaters are considered to be the main source of heavy metal impurities. Their purification prior to discharge into a recipient is, therefore, necessary. Various chemical and physico-chemical methods for heavy metal removal are followed such as chemical precipitation, sorption, solvent extraction, ultra filtration and ion exchange according to Vaca et al 2001 and Peri et al 2004. One of the most serious environmental problems concerning heavy metals is the disposal of metal-finishing- industry liquid effluents that have hazard, but relatively low Cr, Ni, Zn, Cu and Cd

concentrations of tens to hundreds of mg/L. The problem is a serious one, due to both the number of enterprises involved in this sector and their geographical distribution.

A number of conventional technologies such as coagulation, precipitation, ion-exchange, electrochemical methods, membrane processes, extraction, bio-sorption, and adsorption have been considered for the treatment of contaminated wastewater (Wang and Peng 2010;Kwon et al. 2010). Remediation of polluted sites has become increasingly more important in recent years in most developed countries. Sites contaminated by heavy metals, organic compounds and other pollutants could be represents as sources of contamination for groundwater and potentially harmed the inhabitants in the area. In the last few years many researchers have studied new techniques to remove contaminants from

soils (Wahba et al., 2015).

According to Erdem et al (2004), Among various available treatment processes for the removal of heavy metals, such as precipitation, phytoextraction, ultra filtration and reverse osmosis, ion exchange is considered to be a cost effective method provided that low cost ion exchangers, such as zeolites and clays, are used. Clay linings have been used as barriers to prevent contamination of groundwater and subsoil by leach containing metals. So ion exchange and sorption mechanisms of clay and clay minerals are utilized to remove different types of pollutants, for example, Zeolites and bentonite are naturally occurring structured and phyllosilicate minerals respectively, with high cation exchange and ion sorption capacity.

An et al (2001) and Li et al (2002) referred that Lead is attracting wide attention of environmentalists as one of the most toxic heavy metals. The sources of lead release into the environment by waste streams are battery manufacturing, acid metal plating and finishing, ammunition, tetraethyl lead manufacturing, ceramic and glass industries printing, painting, dying, and other industries. Lead has been well recognized for its negative effect on the environment where it accumulates readily in living systems. Lead poisoning in human causes severe damage to the kidney, nervous system, reproductive system, liver and brain. Severe exposure to lead has been associated with sterility, abortion, stillbirths and neo-natal deaths, Geol et al 2005.

Zinc and cadmium accumulation above threshold values in soil can cause phyto-toxicity, depending on the properties of soil. Soil heavy metals pollution has a pernicious effect on soil microbial properties as mentioned by Vacca et al (2012), also on the taxonomic and functional diversity. Major sources of heavy metals inputs to environment are mining, smelting and metallurgical industries, sludge disposal and agricultural practices (Horak and Friesl, 2007). Burgos et al. (2006) concluded that the application of organic and inorganic amendment increased soil pH and total organic carbon content and decreased As, Cd, Cu, Pb and Zn, solubility.

Furthermore, Sheta et al. (2003) suggested that natural zeolite and bentonite minerals have a high potential for Zn and Fe retention. The availability of the retained Zn was higher than for Fe, and chabazite seems to have the highest ability for Zn sorption and extractability by DTPA. Bentonite has intermediate characteristics for Zn and Fe sorption among the studied zeolite mineral species. In this point Esmaeilpour et al.

(2015) studied the effects of adsorbent minerals (bentonite, zeolite and sepiolite) on transfer of some heavy metals (i.e., Pb, Zn and Cd) from soil to tissues of sunflower.

On the other hand Hasanabadi et al (2015) indicated that zeolite was able to decrease the amount of uptake and transmission of lead and cadmium in plant and with decreasing the harmful effects of these elements cause to increase the growth traits, protein and uptake of nutrient in plant. So, zeolite can be used in order to decrease heavy metals uptake such as lead and cadmium and also improvement of growth of plants in polluted areas. Marzieh (2014) stressed on the bentonite play an important role in the adsorbent of the heavy metals, due to the high density and berry color properties and adsorption played an important role in clarifying water and the addition of natural zeolite will reduce heavy metal pollution significantly.

Finally Mojiri et al (2015) concluded that, for heavy metals removal from landfill leachate and domestic wastewater, employing the powdered zeolite method was more effective than the application of the traditional activated carbon.

The main targets of this research on in situ immobilization of metals were: (1) To evaluate the use of inexpensive, abundant materials naturally found under Egyptian conditions as stabilizing agents in metal-contaminated soils; (2) To determine the influence of stabilizing materials on the mobility and bioavailability of metals in soil using kinetic approach.

2. Materials and Methods

2.1. Soils

The A horizon (0–30 cm) of two cultivated soil types were used in this study. These soils are classified as (*Typic Torrierts*) collected from Kafr El-Shekh governorate sand soil classified and (*Typic Psammments*) collected from Abou-Rawash area. Some physical and chemical properties are presented in table 1.

2.2. Adsorbents Remediation Materials Used

Two types of remediation materials were used namely bentonite (prepared in NRC invention no. 363/2013) and Zeolite. The applied materials were added to soils at four rates i.e. 0, 15, 20 and 25 g/kg. The analytical data of the zeolite and bentonite are recorded in table 2 and 3.

Table 1. Some physical and chemical characteristics of used studied soils.

Soil Type	pH	OM(%)	Particle size distribution %			Text.	Ca CO ₃ %	
			Sand	Silt	Clay		Total	Active
Typic Psam	7.24	1.68	85.2	13.2	1.6	Sand	1.1	0.90
Typic Torrs.	8.00	0.78	2.43	3.82	93.75	Clay	10.50	5.78

Table 2. Selected chemical analyses of zeolite mineral used in the study.

Zeolite used	CEC (cmol g ⁻¹)	Surface area (m ² g ⁻¹)	pH 1:2.5	Cations %		Major elements (oxides) %			
				K ₂ %	Na ₂ O %	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO
	220	89.82	6.8	3.27	0.78	62.220	11.096	4.033	3.583

Table 3. Particle-size distribution and some chemical properties of bentonite.

Bentonite used	Particle size distribution %					pH1:2.5	ECdS/m	CaCO ₃ %	CEC(cmol g ⁻¹)
	C.sand%2000:200u	F.sand%200:20u	Silt%20-2u	Clay%<2u	Text				
	1.1	3.8	5.3	89.8	Clay	8.3	4.10	2.73	53.24

2.3. Experiment Procedure

Three hundred grams of <2 mm air dry soil samples were treated with the remediation materials. The treated soils were in Pb⁺², Ni⁺² and Zn⁺² bated at 60% of their water holding capacity for 16 weeks under laboratory conditions. After incubation periods soil samples were kinetically analyzed for the studied potential toxic elements desorption.

2.4. Kinetic Study

Release experiments were carried out using Electrical Stirred Flow Unit (ESFU) method for all soil samples and for different incubation times i.e. 2, 8 and 16 weeks. A Diagram of ESFU used in this paper, the modification of the new set up and mechanism of kinetic working were previously mentioned in more details (Zaghloul, 2002). Exactly 20g from each soil samples was put in the kinetic part of the device with 100 ml of 0.1 N DTPA solutions. The system was vigorously shaken and the solution samples were received after different periods ranged between 1 min to 14 days. at 25°C±2°C and analyzed for their concentrations of Pb, Zn and Ni using atomic absorption as described by Cottenie, et al (1982). Heavy metals released data were fitted to kinetic models represented empirical equations namely:

- Hoerlequation in the form:

$$q = a t^b e^{-(b/t)}$$

- The Elovich equation in the form:

$$q_t = 1/b \ln ab + 1/b \ln t$$

Where:

q = the amount of HM desorption in time t

b & b⁻¹ = constant represents desorption rate coefficient (9ppm)⁻¹.

a & a⁻¹ = capacity constant in mg HM kg⁻¹ soil.

t = time (min).

The kinetic parameters of the tested equations were calculated for different treatments applied. Different statistical parameters such as regression analysis applied to test the conformity of used models to describe HM released from different treated soils, evaluation of significant differences in rate coefficients and cumulative quantity of metals desorbed after remediation were done using SAS software (SAS institute, 1999).

3. Results and Discussion

3.1. Rate Process of Pb, Zn and Ni Desorption of Used Soils as Affected by Different Treatments Applied

Data illustrated in figures 1-3 represent rate of Pb, Zn and Ni desorbed from used soils as affected by zeolite (A&B) and bentonite (C&D) treatments applied at the rates 0, 15, 20 and 25 g/kg. As a general output of all treatments, the rate processes starting with high speed rate trend of HM desorption, followed by decreasing order to almost steady state condition, this trend was even observed in control treatment. As shown in these figures, the rate of heavy metals desorption was influenced by soil type, type and rate of sorbate and type of sorbent. However, all remediation materials applied significantly decrease HM desorption from the treated soil samples.

Concerning the effect of soil type, data indicated that decreasing order of rate of heavy metals desorbed was more pronounced in sand soil compared to calcareous one. For example (Figure.1) in Pb treated soil, the maximum concentrations desorbed in control treatment was 181 and 152 ppm in sand and calcareous soils respectively. The same trend was also observed in both clay minerals treated soils and other heavy metals tested. This result also observed in figures of sand soil with almost narrow trend between control and different treatments of clay minerals applied in this soil.

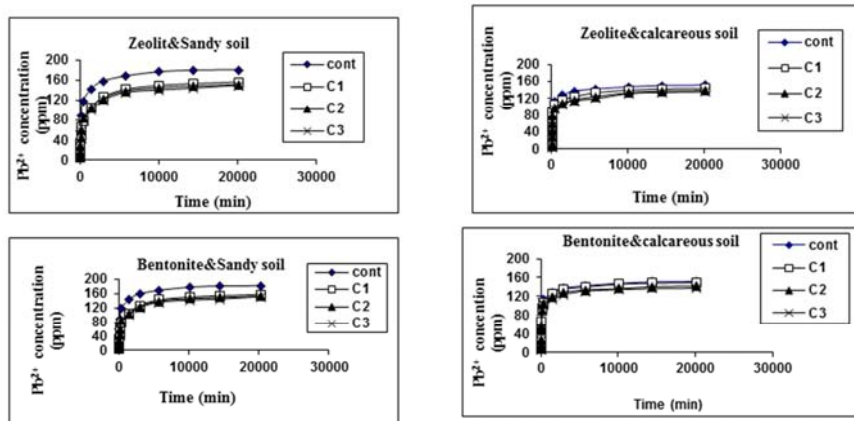


Figure 1. Kinetics of Pb²⁺ release from used soils as affected by different rates of Zeolite and Bentonite application.

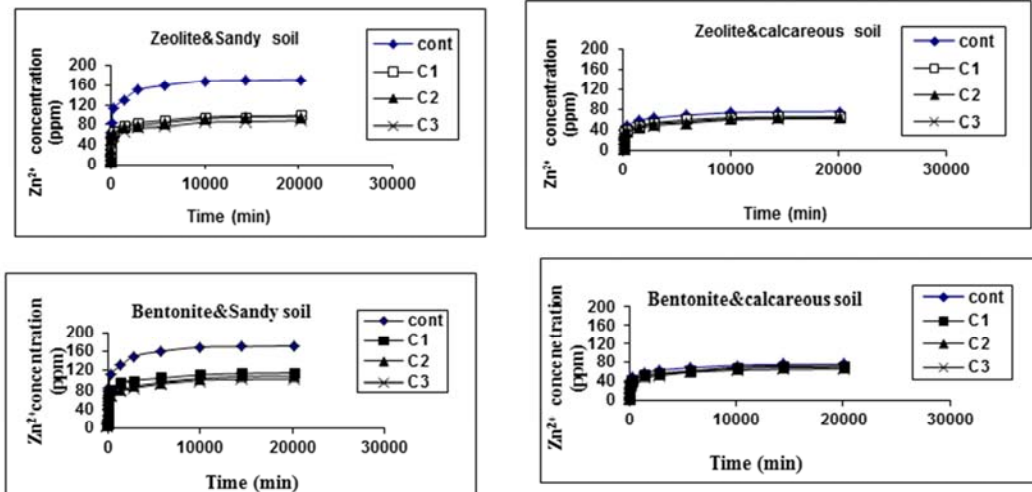


Figure 2. Kinetics of Zn^{2+} release from used soils as affected by different rates of Zeolite and Bentonite application.

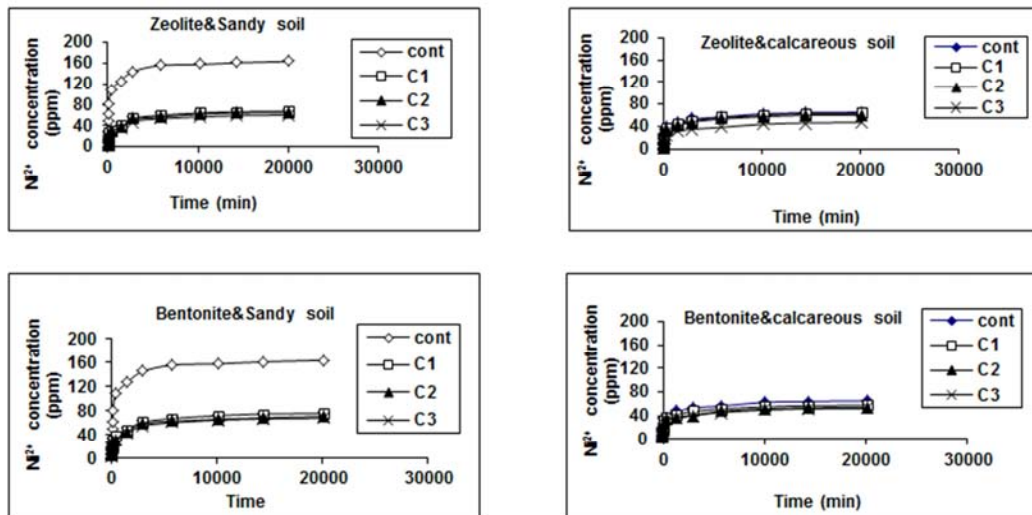


Figure 3. Kinetics of Ni^{2+} release from used soils as affected by different rates of Zeolite and Bentonite application.

The kinetic data represented in these figures (1, 2 and 3) clearly indicated that although the studied heavy metals applied 200 ppm concentration, the variation was observed between different pollutants studied. In this respect (Figure) Zn was retained by soils treated with zeolite more than Ni followed by Pb. For example, in sand soil treated with higher concentration of zeolite 75 mg kg^{-1} , the extracted Zn after 14 days was 47 ppm. At the same concentration applied, data indicated that the respective (Figure 3) values for Pb and Ni were 136 and 62 ppm respectively.

3.2. Effect of Remediation Materials Applied at Different Concentrations on Rate of Heavy Metals Release from the Studied Soil Samples

Before explaining the results of this study, It should be mentioned that two types of sorption mechanisms take place, the first concerning with sorption on the soils used in this study especially the sand one since the calcareous one is almost structureless or inert material, the second on clay minerals used here with different mechanisms according to

type, nature or charge density of these high accumulator materials. Accordingly, in previous work (Wahba et al 2012), indicated that Hoerl model was fitted to explain the data related with HM released to clay minerals or remediated material applied with especial mechanism, while Elovich or any other model showed conformity to describe the kinetic data is suitable to describe the release of pollutants from the soil-remediation material system. Under this experimental condition, Elovich model gave high conformity to describe the kinetic data under different conditions.

Tables 4, 5, 6 represent the coefficient of determination R^2 , Standard error SE, the slope b and the intercept a of Elovich and Hoerl models. These models showed priority to describe the kinetic data by higher R^2 and lower SE compared to other tested models. In these models, the R^2 of Elovich equation ranged between 0.90^{**} - 0.99^{**} for different pollutants desorbed from calcareous or sand soils. The respective values of Hoerl equation were ranged between 0.90^{**} and 0.97^{**} . It should be mentioned here that in sand and calcareous soils, Elovich equation was the best to describe a number of

reaction mechanisms for various inorganic ions react with different soil systems (Hellal and Zaghloul 2008).

Data in table (4) showed that the slope values of constant b which represents the rate of Pb desorbed were significantly influenced by soil type and rate of zeolite applied. Concerning the effect of soil type, in control treatment, the rate values of Pb release was 19.21 in sand soil, decreased to 12.65 in calcareous soil. Addition of zeolite in both soils, led to decrease these values with the same above mentioned trend. For example, addition of 50 g/kg, soil led to decrease the rate constant from 19.20 in control to 15.40, the same trend was observed in different concentrations applied of zeolite. The a constant, represents the capacity factor, of the same equation almost gave the same trend.

The same values of Pb in sand polluted soil were decreased from 15.61 in control to 14.70, 14.50 and 14.36. These values were less than the values of calcareous soil. In other words, although 200 ppm Pb was add to both types of soil, this pollutant was retained in sand soil more than calcareous soil.

The efficiency of bentonite applied on Pb release is presented in table (4). The rate constant of Elovich equation showed that bentonite applied at different rates, led to decrease Pb release from used soils. In this respect, application of 25 g kg⁻¹ decreases a constant from 19.21 in control to 16.94. As shown in the same table, a reverse trend was observed in capacity constant a . Under the same rate of application, the capacity constant of Elovich equation was increased from 13.30 to 14.63. In sand soil enriched with bentonite at the same rate the respective values of a rate constant were 15.61 and 13.66 in control and treated soil. The comparison between calcareous and sand soil, data revealed that a higher capacity to minimize the rate of Pb release was observed in both control and bentonite enriched soils compared to calcareous one, which represents the role of sand in retention heavy metals pollutants to unavailable form. The same trend was documented by Wahba *et al.*, 2015, they found that the presence of sand, led to minimize Pb desorption under varied conditions.

In Hoerl model, unlike Elovich equation, there is a reverse trend represented in tendency of increasing the rate constant of Pb release with increasing rate of remediation material applied in both soils with high rate observed in calcareous soil compared to sand soil. This increasing could be explained by increasing the remediation materials applied to adsorb pollutants. A reverse trend, however, was observed in capacity factor in both soils and with increasing the rate of bentonite applied by increasing the capacity factor by increasing the rate of remediation materials applied. Concerning Zn release from treated soils, data in table (5) showed that zeolite decreased significantly the rate of Zn desorption. In percentage expression, application of 25g kg⁻¹ zeolite, for example, led to decrease a constant of Elovich equation by about 60%. Increasing the application rate to 50 and 75 g kg⁻¹, increased this constant to 62 and 64% compared to control treatment. In sand soil, the effect of zeolite was more pronounced than in calcareous soil. For

example, application of low rate of the added material led to increase a constant by about 97% under control treatment, by increasing the rate of application the percentage value was increased to about 99%. The capacity factor, b constant, data showed that application of zeolite led to increase this constant compared to control.

Table 4. Rate constants of Pb release from soils treated with zeolite and bentonite.

Calcareous soil					Sand soil			
Treat.	b	a	R ²	SE	b\	a\	R ²	SE
Zeolite								
Elovich equation								
Cont.	19.21	13.30	0.99**	7.12	15.61	7.69	0.99**	0.70
C1	16.73	13.26	0.97**	8.64	14.7	7.65	0.98**	0.68
C2	16.1	14.53	0.97**	8.54	14.49	8.16	0.98**	0.58
C3	15.4	14.9	0.97**	8.7	14.36	8.19	0.99**	0.57
Hoerl model								
Cont.	4.58	2.74	0.97**	0.002	5.24	2.72	0.93**	0.016
C1	4.71	2.06	0.97**	0.013	5.34	2.57	0.92**	0.018
C2	4.85	1.90	0.96**	0.014	5.64	2.33	0.92**	0.002
C3	5.36	1.71	0.97**	0.015	6.23	2.04	0.93**	0.002
Bentonite								
Elovich equation								
Cont.	19.21	13.30	0.99**	7.12	15.61	7.69	0.99**	0.70
C1	16.94	14.63	0.97**	8.81	13.66	7.79	0.97**	0.78
C2	16.92	14.77	0.98**	8.81	13.06	8.32	0.98**	0.87
C3	16.04	16.13	0.94**	13.91	12.92	8.72	0.93**	1.19
Hoerl model								
Cont.	4.58	2.74	0.96**	0.001	5.24	2.72	0.93**	0.016
C1	3.99	2.26	0.98**	0.002	5.67	2.55	0.93**	0.017
C2	4.93	1.97	0.97**	0.001	5.90	2.41	0.93**	0.002
C3	5.19	1.77	0.97**	0.001	6.48	2.21	0.92**	0.002

According to table (5), application of bentonite led to decrease Zn desorption from both treated soils. Data showed that in Elovich equation, application of 25 gkg⁻¹, led to decrease Zn desorption from 17.85 to 7.61 in calcareous soil and from 6.81 to 6.04 in sand soil. Increasing the application rate of Bentonite also led to decrease this constant to 7.23 and 7.09 in calcareous soil. In Hoerl model data, increasing the application rate of bentonite led to decrease constant values from 5.19 in control to 2.45, 2.84 and 2.98 by application low, medium and high rate of bentonite respectively. Although the same trend was observed in sand soil, the values of capacity factor in sand were higher than that in calcareous soil.

Table 5. Rate constants of Zn release from soils treated with Zeolite and Bentonite.

Calcareous soil				Sand soil				
Treat.	b	a	R ²	SE	b\	a\	R ²	SE
Zeolite								
Elovich equation								
Cont.	17.85	6.43	0.98**	0.78	6.811	0.68	0.99	0.23
C1	7.1	4.86	0.97**	0.46	0.167	17.3	0.91	0.05
C2	6.85	6.67	0.96**	0.42	0.158	15.6	0.93	0.06
C3	6.6	6.61	0.96**	0.44	0.093	11.56	0.94	0.03
Hoerl model								
Cont.	5.19	1.78	0.95**	0.016	3.86	1.74	0.96**	0.012
C1	3.06	1.53	0.98**	0.009	4.49	1.40	0.96**	0.013
C2	3.40	1.26	0.98**	0.001	4.79	1.18	0.96**	0.014
C3	4.24	1.02	0.97**	0.002	4.84	0.87	0.95**	0.018
Bentonite								
Elovich equation								
Cont.	17.85	6.43	0.98**	0.78	6.811	0.68	0.99**	0.23
C1	7.61	0.97	0.98**	0.41	6.04	1.11	0.98**	0.22
C2	7.23	2.25	0.98**	0.39	5.75	2.69	0.98**	0.24
C3	7.09	3.78	0.97**	0.42	5.67	3.48	0.97**	0.25
Hoerl model								
Cont.	5.19	1.78	0.95**	0.016	3.86	1.74	0.96**	0.012
C1	2.45	2.05	0.97**	0.009	4.35	1.52	0.96**	0.013
C2	2.84	1.84	0.97**	0.006	5.08	1.15	0.95**	0.016
C3	2.98	1.68	0.97**	0.001	5.37	0.98	0.95**	0.017

The effect of zeolite applied at different rates on Ni desorption from used soils is presented in Table 6. Data indicated that according to R² values, the conformity of Elovich equation in describing the kinetic data is higher than Hoerl equation. Also, the effect of applied zeolite was more efficient in calcareous soil compared to sand soil.

Table 6. Rate constants of Ni release from soils treated with Zeolite and Bentonite.

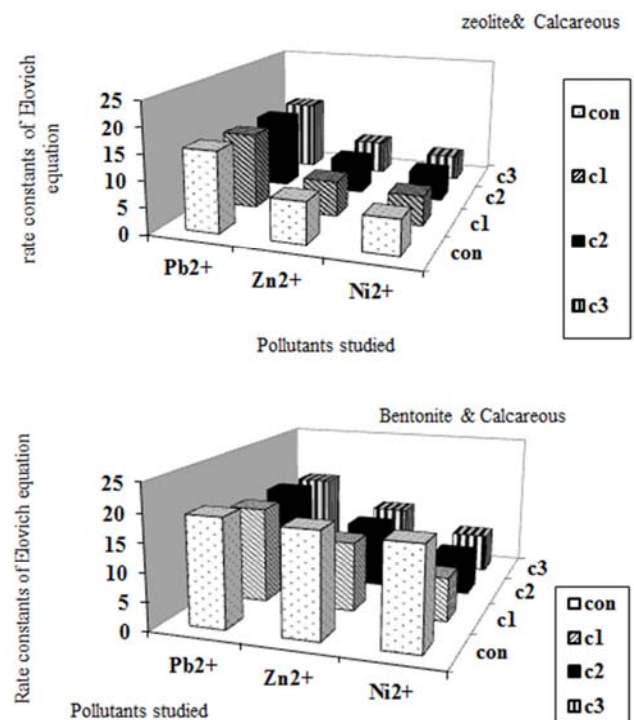
Calcareous soil				Sand soil				
Treat.	a	b	R ²	SE	a [\]	b [\]	R ²	SE
Zeolite								
Elovich equation								
Cont.	18.5	4.31	0.99**	0.57	8.02	1.166	0.99**	0.28
C1	9.99	3.7	0.97**	0.56	6.88	0.65	0.99**	0.23
C2	9.81	2.26	0.97**	0.54	6.76	2.04	0.98**	0.24
C3	9.13	0.66	0.96**	0.59	6.63	3.27	0.99**	0.23
Hoerl model								
Cont.	4.98	2.53	0.96**	0.013	2.53	1.97	0.97	0.82
C1	5.35	2.16	0.92**	0.018	4.35	1.70	0.95**	0.014
C2	5.61	2.01	0.91**	0.011	4.45	1.53	0.96**	0.015
C3	6.09	1.76	0.91**	0.022	4.98	1.29	0.95**	0.016
Bentonite								
Elovich equation								
Cont.	18.5	4.31	0.99**	0.57	8.02	1.166	0.99**	0.28
C1	12.31	0.06	0.98**	0.83	5.81	1.41	0.99**	0.28
C2	11.42	1.56	0.99**	0.58	5.57	1.6	0.99**	0.24
C3	11.02	2.22	0.98**	0.59	4.95	1.7	0.98**	0.23
Hoerl model								
Cont.	4.98	2.53	0.96**	0.013	2.53	1.97	0.97**	0.82
C1	6.36	1.99	0.91**	0.022	3.93	1.79	0.96**	0.39
C2	5.53	1.97	0.93**	0.019	4.54	1.65	0.95**	0.48
C3	6.27	1.77	0.92**	0.021	4.76	1.47	0.96**	0.48

The rate constant of Ni desorption decreased by about 50%

compared to control at low concentration of applied zeolite, however, increasing the rate of zeolite did not influence the rate of Ni release. In sand soil, although the zeolite decreased the rate constant of Ni release compared to control treatment, the decreasing order was not the same like calcareous soil treated with the same amended material used. The application of bentonite almost gave the same results of zeolite in relation to the effect of soil type. As presented in table (6), again the decreasing order of Ni desorption was more pronounced in calcareous soil compared to sand soil. At low concentration applied from bentonite, Ni desorption was decreased by about 35% compared to control treatment.

Comparison between rate constants of Elovich equation for different pollutants as affected by zeolite and bentonite applied to soils.

Figure (4) represents the comparison between Elovich rate constants of Pb, Ni and Zn desorbed from calcareous and sand soil as affected by zeolite and bentonite applied at three rates. Generally, according to the standard deviation (SD) it should be mentioned that clay minerals applied in both soils significantly minimize the rate of HM release. However, no significant difference was observed between different rates of applied materials. Also, data referred that both clay minerals used significantly reduced HM concentration in the order Pb < Ni < Zn. Finally, the effect of zeolite in decreasing the rate of heavy metals studied was more pronounced than bentonite. The selectivity of zeolite species, such as clinoptilolite and chabazite, for heavy metals based on the ionic radius and dissociation constant was as in the following order: Pb²⁺ > Ni²⁺ > Cu²⁺ > Cd²⁺ > Zn²⁺ > Cr³⁺ > Co²⁺ (Choi et al. 2001; Ok et al. 2007). Ion exchange of a specific cation is strongly influenced by the presence of competitive cations and complexing reagents such as anions (Inglezakis et al. 2003a,b; Inglezakis et al. 2005).



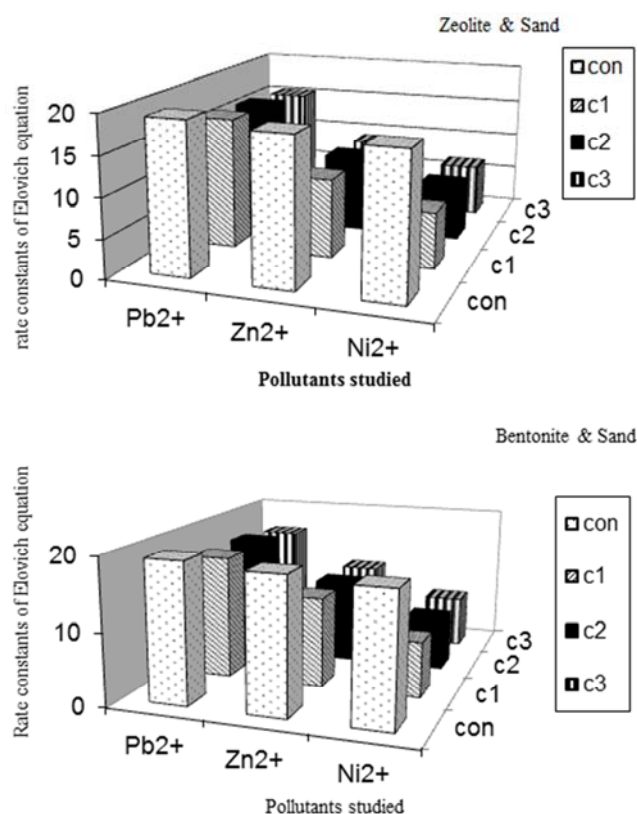


Figure 4. Rate constant of Elovich equation represents heavy metals release from calcareous and sand soils as affected by remediation materials applied at different rates.

Although the same trend was observed in sand soils, the percent of decrease in rate of pollutants release in this soil was significantly less than the calcareous soil. Compared to control treatment data represented in figure 4 showed that at low rate of application, zeolite decreased the rate of Pb desorbed from sand soil by about 6% under control, increasing the application rate of zeolite to 50 and 75 g/kg only decreased the rate of desorption by about 7 and 9% respectively, almost the same trend was observed in bentonite treatment. The effect of the same clay minerals was varied with Ni compared to Pb. At low concentration of zeolite, the decreasing order of the rate was 14.2% under control at low concentration applied of zeolite, increasing the application rate of the mineral, led to decrease the rate of Ni desorption by about 16 and 18% at medium and high concentration respectively. In the case of Bentonite, the corresponding values of decreasing order were about 5, 9 and 11% compared to control treatment. The decreasing of the rate of Zn was drastically affected by soil type and clay minerals used and were more pronounced compared to Pb and Ni. Numerically, data indicated that rate constants of Zn were decreased by about 60-63% in zeolite and 58-60% according to the concentration of remediation material applied in calcareous soil. The corresponding values of sand soil were 14-28 % and 12-19% in zeolite and bentonite respectively. It should be mentioned that the decreasing order of pollutants applied is agreed with the charge density and hydrated ion diameter of the studied pollutants.

4. Conclusion

As a conclusion, attention has focused on the development of in situ immobilization methods that are generally economic and promising tool in minimizing hazards of heavy metals in soils. The obtained results showed the advantage and suitability of using such technique in the polluted soils especially the calcareous one. The application of 50 g kg⁻¹ of zeolite or bentonite in the soil is an economic concentration. Also, these remediation materials could be suitable under specific condition of contamination with Copper or Nickel because of significant minimizing of these pollutants.

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