

Removal of heavy metals Cd (II), Fe (III) and Ni (II), from aqueous solutions by natural (clinoptilolite) zeolites and application to industrial wastewater

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ABSTRACT

The adsorption mechanism of Cd, Fe, and Ni, ions on natural (clinoptilolite) zeolites, a regional low-cost naturally available adsorbent, was studied, in a batch adsorption system. The effect of several parameters such as contact time, zeolite dose, particle size, effect of pH, and initial concentration of metal ions on the adsorption process was estimated. The optimum adsorption was found to occur at pH 6.0, adsorbent dose 1.0 g/L, and initial concentration 2, 20 and 10 mg/L for Cd, Fe, and Ni, respectively. The adsorption efficiency also, increases with decreasing particle size of zeolites and the effect of retention time on adsorption ratio shows that 80% of the Cd, Fe, and Ni, are adsorbed by zeolite during early 120 minutes. Under these optimum conditions, the removal efficiency was 78.8 %, 89.1%, and 65.5% of Cd⁺², Fe⁺³ and Ni⁺², ions, respectively. Sorption data have been interpreted in terms of Langmuir and Freundlich isotherms. The adsorption efficiency of heavy metals in industrial wastewater as application mode was also, investigated using zeolites and these results show that natural zeolites hold great potential to remove cationic heavy metal species from industrial wastewater and confirms the potential use of zeolite for the removal of heavy metals from industrial wastewater via adsorption. It is concluded that zeolites is very promising for the removal of metal ions from aqueous solution and hence may be encourage the utilization of zeolites in environmental applications.

Keywords: Natural (clinoptilolite) zeolites, Adsorption, Heavy metals, Industrial wastewater.

1. INTRODUCTION

Environmental pollution by heavy metals has led to serious problems for humans and other organisms in the environment due to their nonbiodegradability and accumulation in the living organisms [1]. The main sources of these heavy metals into the ecosystem through wastewater streams are electroplating, smelting, paint pigments, batteries, mining operations and agriculture sector [2]. Nowadays, removing the toxic heavy metal contaminants from aqueous waste streams is one of the greatest matters of interest in the literature and studies. The main concern of environmentalists about heavy metals is that these elements are highly toxic and their detrimental impact on human health and surroundings is grave [3]. Heavy metal removal from aqueous solution is one of the most pressing environmental problems throughout the world these days. In the recent years, the removal of heavy metals from industrial wastewater has been inclusively investigated. Conventional methods including, electrodialysis [4], chemical precipitation [5], reverse osmosis [6], ion-exchange [7], ultrafiltration [8], and adsorption are used for removal of heavy metal ions from aqueous solutions. While most of these techniques are expensive and inapplicable on a large scales, ion exchange and adsorption method, among all above-mentioned processes, is the most

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preferable one because it is economically advantageous, highly efficient and applicable [9,10]. Ion exchange and adsorption is one of the few promising alternatives for this purpose, especially using low-cost natural sorbents such as clay materials, zeolite, biomass, perlites and diatomites. In this regard naturally occurring zeolites hold great potential to be used as packing material in subsurface reactive barriers intercepting ground water plumes, and for fixed bed reactors designed to remove heavy metals from industrial wastewater [11]. Zeolites have a framework silicate with a three-dimensional cage structure. Their structure bears negative charges which can be balanced by adsorption of exchangeable cations [12]. Due to high deposit of zeolite in nature, and to its low cost, strong adsorption capacity, it has recently drew attention to be used in the treatment of industrial wastewater. Zeolites are crystalline aluminosilicates enclosing pores occupied by cations and water molecules, permitting reversible ion exchange and reversible dehydration [13]. The cationic makeup of the aluminosilicate consists of aluminum ions (Al^{3+}) in a predominantly Si framework (an aluminosilicate). The charge imbalance resulting from the substitution of aluminum atoms for silicon atoms requires a nearby cation to preserve electrical neutrality, so the cation content is directly related to the Al^{3+} content. In nature, these cations are typically alkaline earth elements such as Na^+ , Ca^{+2} , Mg^{+2} and metal ions. Zeolites can provide adsorption sites with exchangeable cations for heavy metal ions and porosity for free metals, with ion exchange and molecular adsorption being the main mechanisms, respectively [14]. The process of adsorption is now widely accepted, very effective and economically viable to be used to remove heavy metal ions in industrial waste as well as in drinking water. Besides ion exchange and adsorption, the other mechanisms indirectly involved during heavy metal removal from aqueous solutions via zeolites are surface precipitation and destruction of clinoptilolite structure (i.e. dissolution of the clinoptilolite framework cations) [15]. A wide variety of heavy metals can be removed from the liquid phase at significant quantities and kinetics is usually fast. The fact that zeolite exchangeable ions are relatively innocuous (sodium, calcium and potassium ions) makes them particularly suitable for removing undesirable heavy metal ions from industrial effluent waters. The high selectivity for toxic metals such as Pb, Cd, and Zn makes clinoptilolite a promising material for treatment of different type of wastewaters. The safety of using natural Zeolite is attributed to the non-toxicity of its metals that displace unfavorable toxic heavy metals from wastewater in the desalter.

Zeolite is structurally stable even at acidic environment that can be easily reproduced with some modification to improve its structure and adsorption capacity. Due to these attracting properties of Zeolite, interest has been increased towards the method of heavy metal adsorption from aqueous solution. Many studies reported the importance of using natural Zeolite for the adsorption of heavy metals under different empirical conditions such as temperature, pH, concentration, granular phase volume, and induction speed [16 - 20].

By comparing our result with the others result, it is in the range of effectiveness, but the advantages of it ,although the global use of this type of zeolite, the Egyptian is rarely used in the Egyptian environment remediation , despite its existence as raw material with very large quantities, it is available at the cheapest prices and because the city of Suez overlooking the Red Sea is concentrated in many types of industries and therefore the use this zeolite has a practical and economic application for the region and the surrounding environment, in particular to reduce pollution to the affected marine environment.

In the present study natural Zeolite was tested as an efficient adsorbent for the removal of ions of Cd^{+2} , Fe^{+3} and Ni^{+2} , from aqueous solutions and wastewater. This article aims to investigate the parameters that affect removal rate i.e. contact time, particle size, pH of initial solution and zeolite dose, determination of maximum adsorption capacity of natural Zeolite

82 which is used to remove the studied metal ions through equilibrium reactions, comparing the
83 empirical data of adsorption balance with Langmuir and Freundlich sorption models in order
84 to evaluate the adsorption performance of natural Zeolite.

85 **2. MATERIAL AND METHODS**

86 **2. 1 Preparation of Materials**

87 Analytical grade chemicals were employed in all experiments. The compounds, Cd
88 $(\text{NO}_3)_2 \cdot 4\text{H}_2\text{O}$, $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$ and $\text{Ni}(\text{NO}_3)_2 \cdot 4\text{H}_2\text{O}$, were purchased from Sigma Aldrich (USA)
89 and used in the experiments. Appropriate amounts of the metal salts were dissolved in
90 mega-pure or de-ionized water (DIW) to yield the stock solutions of concentration 1000
91 mg/L. The stock solutions were further diluted with DIW water to obtain the various
92 concentrations used in the adsorption studies. All glassware were thoroughly washed with
93 soap, followed by 10 % HNO_3 and then rinsed many times with DIW before use. The
94 adjustment of pH was done using either 0.1 M HNO_3 or 0.1M NaOH, and pH was measured
95 with a pocket pH meter model Orion 210. Natural zeolite from Alex Trading & Commercial
96 Agencies Company was used. The grain size fractions were used as received from the
97 company in two Size: <0.5 mm (fraction I), 2.0 – < 6mm (fraction II).

98 **2. 1. 1 Characterization**

99 The main chemical composition of zeolite analyzed by X-ray diffraction(XRD) and X-ray
100 fluorescence(XRF) methods, as well as other Physical properties such as particle size,
101 density, humidity, fire loss, water, porosity, surface area, and hydrogen ion concentration
102 carried at Central Metallurgical Research Institute (CMRDI).

103 **2.1. 2 Industrial wastewater**

104 Industrial wastewater samples were collected, from collected industrial wastewater treatment
105 plant from Adabiya area at Suez bay, Egypt. This wastewater contain different type of waste
106 water include a collection of industries runoff as (Cement, Textile, Vegetable oils and
107 ceramics)located near this area so, it expected to contain high level of pollutant especially,
108 metals in inlet and outlet because a primary treatment process which occurred in the
109 treatment plant. Two main samples form inlet and outlet of this plant were collected, and
110 then stored in acid-washed polyethylene bottles for analysis. All the precautions
111 recommended by [21], to minimize risks of sample contamination were followed during
112 collection and treatment of samples.

113 **2.2 Batch Adsorption Studies**

114 To evaluate the process of single adsorption of Cd^{+2} , Fe^{+3} and Ni^{+2} from aqueous solution,
115 different parameters and factors were studied. The aqueous solutions were agitated at
116 different time intervals in a room temperature and on a mechanical shaker at 200 rpm. After
117 the reactions, the supernatant was collected by a syringe and filtered through a 0.2 μm
118 membrane filter to measure the metal ions concentrations using a flame atomic adsorption
119 spectroscopy (Perkin Elmer A Analyst 100). Samples were diluted before the required
120 analysis to set the calibration linear range.

121 **2.2.1 Effect of pH**

122 In order to investigate the optimum pH of adsorption, 50 ml of aqueous solution containing 2
123 mg/l of single metal ions (Cd^{+2} , Fe^{+3} and Ni^{+2}) and having pH range from 2 to 8 were mixed
124 with 0.5 g of adsorbent in a 250 ml conical flask. After 180 min of contact time, the

suspension were filtered and analyzed for heavy metal ions by atomic-adsorption spectrophotometer.

2. 2. 2 Effect of Adsorbent Dose

Furthermore, to evaluate the optimum dosage of the, adsorbent dose studies were carried out with 0.25, 0.5, 0.75, 1, 1.5, 2 and 4.0 g adsorbent and 50 mL of solution containing 2 mg/l of heavy metal ions concentrations at optimum pH obtained from section above during the contact time of 180 min at room temperature.

2. 2. 3 Effect of particle size

In order to investigate the grain size effect of zeolite, the batch experiment was performed in two sizes: < 0.5 mm (fraction I), 2.0 – < 6mm (fraction II). In these experiments, 50 mL of solution containing 2 mg/l of heavy metal ions concentrations at optimum pH and adsorbent dose, the contact time of 180 min at room temperature.

2.2.4 Effect of initial heavy metal ions concentration

The kinetic study for metals was also performed using different concentrations (1.0, 2.0, 5.0, 10.0, 20.0, 50.0, 100.0 mg /l) of each single metal ion. Optimum conditions such as pH and adsorbent dose determined previously in the batch studies were applied for this batch studies.

2.2.5 Effect of contact time

The time-dependent behavior of Cd^{+2} , Fe^{+3} and Ni^{+2} adsorption was also studied by varying the contact time between the adsorbate and the adsorbent at 5, 15, 30, 60, 90, 120, and 180 min at room temperature. The optimum conditions of solution such as pH, adsorbent dose, and metals concentrations determined previously in the batch studies were used to determine the effect of contact time on the adsorption behavior of zeolite.

2.3 Equilibrium

The main objective of the equilibrium studies was to determine the maximum capacity of natural zeolite towards Cd^{+2} , Fe^{+3} and Ni^{+2} removal under the studied conditions and according to make a selectivity comparison for these. Experimental data were fitted to conventional adsorption mathematical models. These were used to predict the adsorption performance of natural zeolite. Adsorption capacity formula is given in the following equation: $q_e \text{ (mg/g)} = \frac{K}{m} = \frac{(C_i - C_e) \times V}{m}$, where q_e is the quantity of dissolved adsorbed material in mg per g of the adsorbent at equilibrium, C_i : initial concentration of contaminant in solution at equilibrium (mg/l), V : volume of water phase (l), M : mass of solid phase (g). Percentage of metal removal can also be displayed by the percentage of metal removal as follows: Metal removal (%) = $100 (C_i - C_e) / C_i$.

2. 3. 1 Langmuir Adsorption Isotherms

Langmuir model suggests that adsorption occurs on monolayer of the surface which contains unlimited number of adsorption sites of equal energy. Linearity of Langmuir equation is expressed as follows: $\frac{C_e}{q_e} = \frac{1}{q_0 b} + \frac{C_e}{q_0}$. Where q_0 is the maximal adsorption capacity at the surface availability of binding sites (mg/g), b is Langmuir constant which is

related to the radical energy of adsorption, b and q₀ can be extrapolated from the slope of linear plot of $\frac{q_e}{C_e}$ with index of C_e [22, 23, 24].

2. 3. 2 Freundlich Adsorption non Isotherms

Freundlich model suggests energetically heterogeneous surface of porous matter so that adsorption capacity is due to adsorption temperature. Linear equation of Freundlich model is as follows: $\ln q_e = \ln K + \frac{1}{n} \ln C_e$, where K is Freundlich constant related to maximal adsorption capacity, n is a constant related to adsorption density or binding strength 1/n is heterogeneity coefficient i.e. values of 1/n < 1 refer to heterogeneous adsorbents while those values close or equal to 1 refer to relatively homogenous adsorbents at binding sites [23, 25], ln K, 1/n can be extrapolated from the slope of linear plot ln q_e with index of ln C_e.

2. 4 Application test on industrial wastewater:

Wastewater samples were preconcentrated with APDC-MIBK extraction procedure according to the standard methods [26]. Total metal concentrations were measured by flame atomic adsorption spectrophotometer (FAAS; Perkin Elmer A Analyst 100). Concentrations of heavy metals are expressed as (mgL⁻¹). Zeolite (clinoptilolite), were applied to the same samples at the optimum conditions (C_i= 2 ppm ,pH = 6, m=0.5g ,V=50ml , t=180 min, particle size < 0.5 mm), then simulated the removal rate of metals in wastewater. The same extracted method was applied to the wastewater after adsorption with zeolite.

3. RESULTS AND DISCUSSION

3. 1 Properties of studied zeolites

Zeolite sample is a non-dusting, hard and resistance to attrition, non-clouding in liquids (due to absence of clays), good permeability, relatively high density and high water retention. The qualitative composition of natural (clinoptilolite) zeolites, has obtained by X-ray spectroscopy analysis, where the physical properties and the results of chemical compositions present in zeolite along with peaks of all compounds as shown in Fig. 1, and presented in Table 1 & 2. The natural (clinoptilolite) zeolites were composed mainly of SiO₂ and Al₂O₃ components whose Si/Al ratio becomes 1.88 that means there are two Si atoms for each single Al atom. While the MnO and K₂O contents were very low. The SNZ contained large amounts of CaO as compared with the other component, thus appears that a high CaO content might enable the formation of hydroxy sodalite. It has higher contents of calcium compound so it's called calcium zeolite.

3.1.1 Mineral component, %

The XRD patterns of zeolite and iron dust are shown in Fig.1. The XRD pattern of zeolite proved that the major part of it is Clinoptilolite. According to survey on the zeolite structure, adsorption behavior in zeolite is based on Louise acid theory in pore structure [13]. The zeolite structure causes zeolite to have negatively charged surface. Negatively charged surface of zeolites can be used for adsorption of alkali earth metals. This structure consists of three dimensional frameworks of SiO₄ and AlO₄ that are linked to each other by sharing oxygen atoms. Thus, existing oxygen atom in tetrahedral structure of zeolite (Si-O-Al) lead to negative charge on adsorbent surface that are available sites for metal adsorption. Therefore, Si/Al ratio decline and presence of oxygen atom in zeolite structure is considered as two potential factors in metals adsorption process [27].

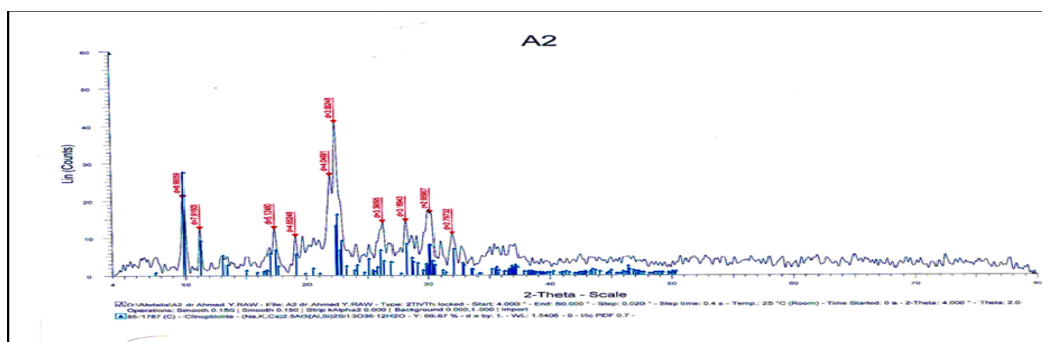


Figure 1. The XRD pattern of the sample confirming its Clinoptilolite mineralogy.

Table 1: Physical properties of natural (clinoptilolite) zeolites:

Bulk (particle) Density, gcm^{-3}	1.83
Overall Surface area, m^2gm^{-1}	89.82
Porosity, %	27.80
Total pore area, m^2gm^{-1}	35.836
Average pore diameter, μm	0.0181
Solubility, %	7.38
Swelling Index	2.52
pH	6.8
Apparent (Skeletal) Density, gcm^{-3}	2.377
Appearance (Color)	Greyish-white
Humidity, %	6.75
Loss on ignition %	13.6
Hardness, Moh' no.	4
Grain Size	< 6 mm

Also, zeolite has cages and tunnels that can loosely hold water molecules in contrast to other tecto-silicates such as feldspar and quartz. These channels and cages are adequate for adsorbing molecules smaller than these channels and/or tunnels, so in this regard, zeolites are known as “molecular sieves” [28].

Table 2: Chemical composition of natural (clinoptilolite) zeolites:

Cations, %		Major elements (oxides), %		Other elements, (trace)	
K ₂ O, %	3.266	SiO ₂	62.22	Cl	0.025
CaO, %	3.583	Al ₂ O ₃	11.096	BaO	0.085
Na ₂ O, %	0.780	Na ₂ O	0.78	P ₂ O ₅	0.033
		MgO	0.599	ZnO	0.025
		CaO	3.583	SrO	0.047
		Fe ₂ O ₃	4.033	PbO	0.002
		K ₂ O	3.266	MnO	0.120
		TiO ₂	0.339	SO ₃	0.035
		ZrO ₂	0.112		

The replacement of tetravalent silicon by trivalent aluminium in the mineral's structure creates a net negative charge that is counterbalanced by the presence of cations (usually Ca^{2+} , Na^{+} and K^{+}) which are situated in cavities [29, 30]. The removal of the heavy metal ions with zeolite is a result of ion exchange and/or adsorption property of zeolite. Both processes

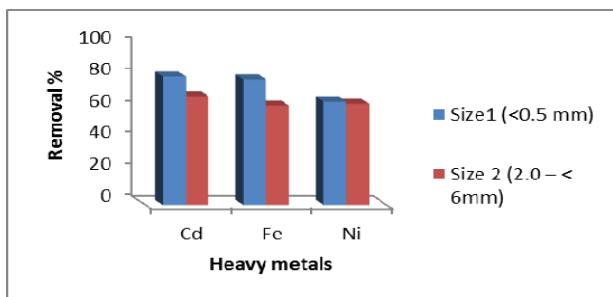
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are parallel but one of them is prevailing depending on the solid to the liquid ratio, [31]. Ion exchange properties of zeolites are due to the weakly bonded extra-framework cations which are mobile and easily exchanged with solution cations [32]. As it has been stated, removal of heavy metals from aqueous solution by means of zeolite mainly is based on adsorption and ion exchange process and a lot of researches have been done over the past decade. However, other mechanisms such as physisorption and chemisorption are also employed by zeolites for the sorption [33].

3. 2. Batch Adsorption Studies

3. 2. 1. Effect of adsorbent particle size

It's noticed from figure 2 that increasing the external surface area by reducing the adsorbent particle size, results in an increase in the number of available sites for metal uptake [34, 23]. Moreover, smaller particle sizes result in the shortening of the diffusion distance that heavy metals have to travel in order to get to an adsorption site, hence a faster rate of reaction. It's also noticed that Cd^{+2} and Fe^{+3} revealed the greatest affinity 80.9 and 79% while Ni^{+2} revealed the lowest affinity (65.2 %). And the more metals were sorbed, however, by fine-grained zeolite than by coarse-grained zeolite [35].

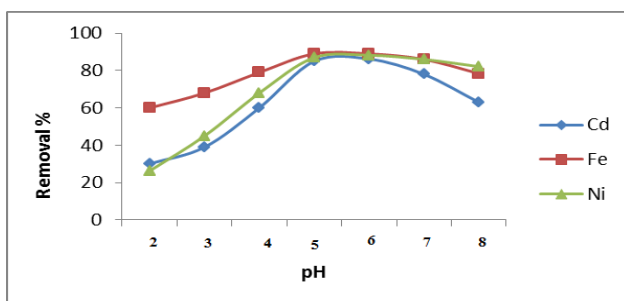


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239 **Figure 2.** Adsorbent particle size affecting on the removal of Cd^{+2} , Fe^{+3} and Ni^{+2} , from
240 the solution ($C_i = 2$ ppm · pH = 6 · m=0.5g · V=50ml · t=180 min)

241 3. 2. 2. Effect of pH on adsorption

242 The solution pH is one of the crucial parameters in the sorption of heavy metals by zeolites,
243 because of its effect on the charge state of metals and also adsorbent surface [36]. The
244 effect of pH on studied metals uptake by zeolite was evaluated and shown in figure 3.



245

246 **Figure 3.** pH affecting on the removal of Cd^{+2} , Fe^{+3} and Ni^{+2} , from the solution ($C_i = 2$
247 ppm · size < 0.5 mm · m=0.5g · V=50ml · t=180 min)

As is known, the cationic metals' adsorption efficiency is lower at acidic pH. It was observed that Cd, Fe, and Ni uptake increased with increase in pH up to pH of 6 and then it decreased with any further increase in pH. It is clear that at pH below 6, hydrogen ions compete with positive charge ions for adsorption sites. Therefore, this condition limits the access of metal ions to the adsorption sites and decreases metal removal [37]. Furthermore, at alkaline pH values, the adsorption of metals decrease because soluble hydroxylated complexes of the metal ions is formed and compete with metal for adsorption sites. Apart from affecting the characteristics of heavy metal ions and their sorption, pH can also affect the structure of zeolites. Aluminosilicate structure is vulnerable to strong basic and acidic environments. Strong bases can lead to desilication, whereas strong acids can break Al atoms. Zeolite structure can be destroyed at extreme pH values, which in turn can reduce sorption [38, 33]. Since zeolite is capable of changing the pH of the solution, there is a possibility for these processes to occur during the treatment of polluted water.

3. 2. 3. Effect of the initial heavy metal ion concentration

In the adsorption process, the initial concentration of ions in solution has a key role as a driving force to overcome the mass transfer resistance between the liquid phase and solid phase. Thus, it is expected that with an increase in metal ions the metal uptake will increase. [33]. The adsorption of Cd, Fe, and Ni as a function of their concentrations was studied at room temperature by varying the heavy metal ion concentration from 1 to 100 mg/L. The results are shown in Figure 4.

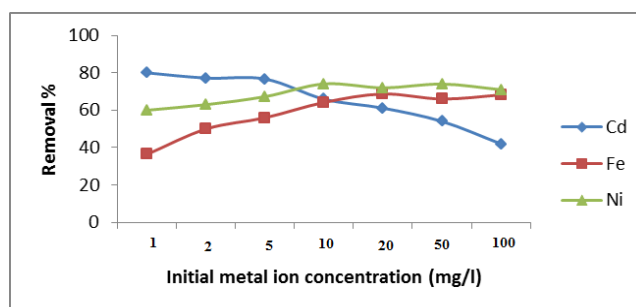


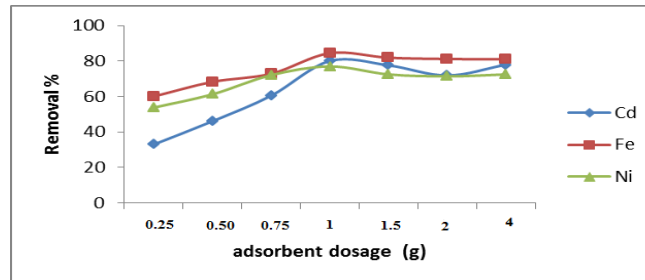
Figure 4. Initial heavy metal ion concentration (mg/l) affecting on the removal of Cd⁺², Fe⁺³ and Ni⁺², from the solution (C_i = 2 ppm, size < 0.5 mm, m=0.5g, V=50ml pH = 6, t=180 min)

The maximum amount of Fe, and Ni removal percentage for natural (clinoptilolite) zeolites at concentrations of 20 and 10 mg/l were obtained 68.7 % and 74.1 %, respectively. Instead, the removal percentage decreased from 80% to 42% for Cd for concentration 2 to 100 mg/l. The results also, showed that Fe, and Ni uptake rate were relatively high at the beginning of the process due to abundance available adsorption sites. However, the number of active sites for the adsorption gradually decreases with an increase in process time and the adsorption rate slightly decreased, leading to the formation of the adsorption equilibrium. At low metal concentrations, adsorption sites are available and could easily be occupied since the ratio between the number of metal moles in solution and available surface area is low. Therefore, adsorption is independent of the initial concentration. Nevertheless, at high concentrations of metal the removal efficiency is dependent on the initial concentration because the number of available sites is less than the number of metal moles. [39], stated when the initial concentration increases, the removal rate decreases. At higher concentration, the number of ions competing for the available binding sites on the biomass surface increases and thus reduces the number of binding sites. Meanwhile, at higher concentration, the average distance between the adsorbed species will be reduced, which

288 affects the distribution of surface charge. Thus, the ability of adsorbate to migrate to the
289 adsorbent surface changes and, as a result, the fixation reduces [40].

290 3. 2. 4. Effect of adsorbent dose

291 Adsorbent dose is one of the important parameters in adsorption processes because it
292 determines the capacity of an adsorbent for a given initial concentration of the adsorbate
293 under a given set of operating conditions [41]. To achieve this aim, a series of batch
294 experiments were conducted with the adsorbent dose of 0.25, 0.5, 0.75, 1.0, 1.5, 2 and 4 g
295 per 50 ml of test solution.



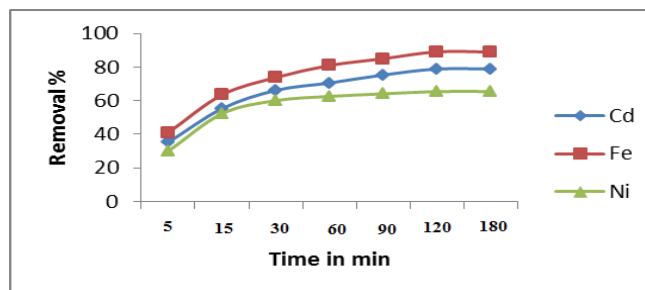
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297 **Figure 5. Adsorbent dose affecting on the removal of Cd⁺², Fe⁺³ and Ni⁺², from the**
298 **solution (C_i= 2 ppm · size < 0.5 mm· pH= 6 ·V=50ml · t=180 min)**

299 Figure 5 shows the effect of adsorbent dose on the adsorption of Cd, Fe, and Ni ions. When
300 the addition of the adsorbent dose increased, the percentage removal of metal ions also
301 increased. A maximum removal of 80.1 %, 84.5 % and 77% of Cd, Fe, and Ni ions
302 respectively was obtained at 1.0 g of the adsorbent. It can be seen from Figure 3 that an
303 adsorbent dose of 1.0 g is sufficient for optimal removal of metal ions in aqueous solutions.
304 A further increase in the quantity of adsorbent dose will not have any significant effect on the
305 removal of metal ions from the solution. The initial increment in adsorption capacity with
306 increase in adsorbent dose was expected because as the adsorbent dose increases the
307 number of adsorbent particles increases, thus more surface areas were available for metals
308 attachment [42].

309 3. 2. 5. Effect of contact time

310 The effect of contact time on adsorption efficiency is depicted in Figure 6. It is clear from the
311 Figure, that the contact time needed to reach the maximum removal of metal by zeolite was
312 dependent on the type of heavy metal [43].



313

314 **Figure 6. Contact time affecting on the removal of Cd⁺², Fe⁺³ and Ni⁺², from the**
315 **solution (C_i= 2 ppm · size < 0.5 mm· pH= 6 ·V=50ml · m=0.5g · t=180 min)**

The result of the effect of contact time on removal efficiency for Cd, Fe, and Ni, using 0.5 g zeolite at room temperature ($25 \pm 0.1^\circ\text{C}$) is represented in Figure 6. The adsorption rate was observed as rapid in the first 30 min, followed by a gradual increase with time until equilibrium adsorption was noticed at 90 min. The fast adsorption at the initial stage was probably due to the initial concentration gradient between the adsorbate in solution and the number of vacant sites available on the adsorbent surface. The attainment of equilibrium adsorption might have been due to reduction in the available active adsorption sites on the adsorbent with time resulting to limited mass transfer of the adsorbate molecules from the bulk liquid to the external surface of adsorbent [41].

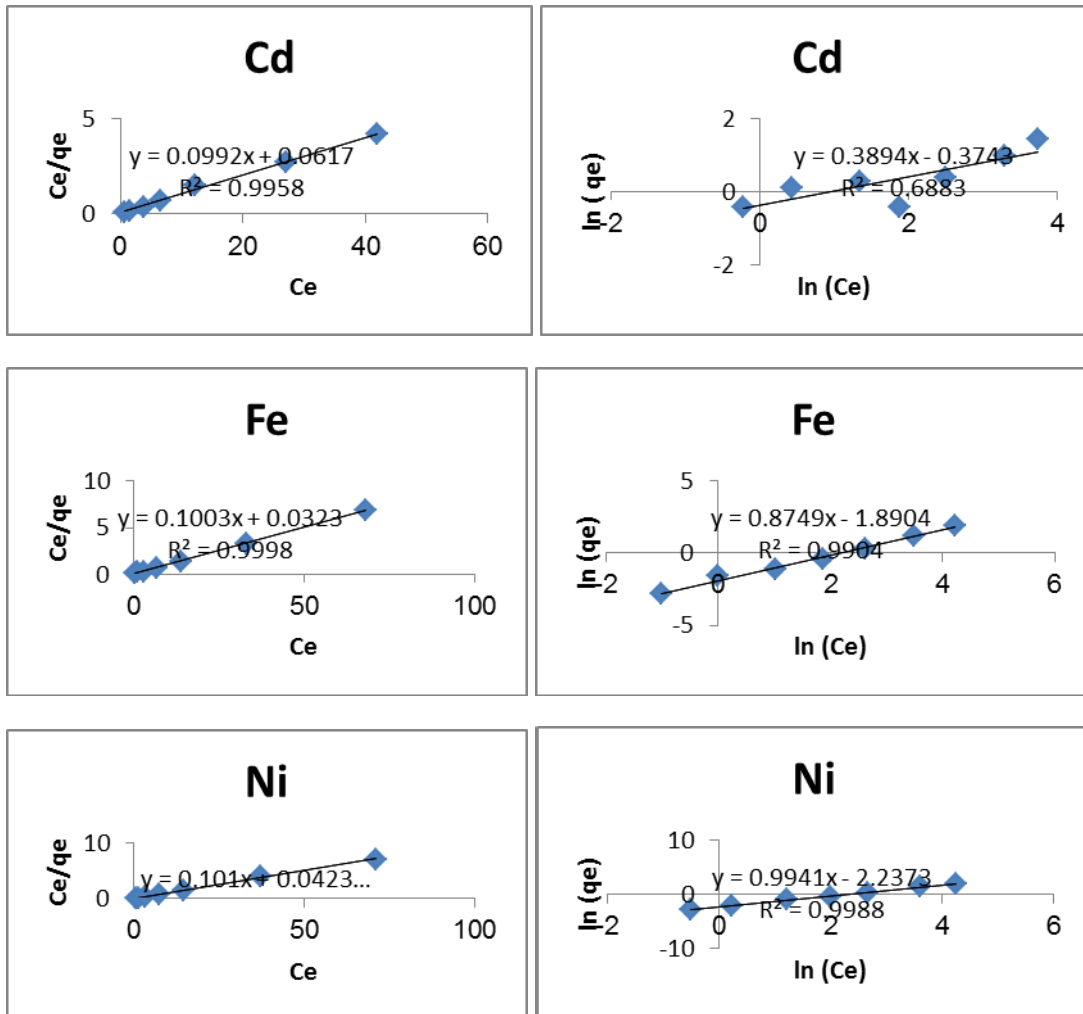
3.3 Adsorption isotherms

Adsorption isotherms are an important factor in system design and describe the interaction between the adsorbent and adsorbate. Freundlich and Langmuir isotherm curves for the adsorption of Cd^{+2} , Fe^{+3} and Ni^{+2} ions from solution as shown in Table 3 and Figure 7, reveal the reliability of experimental findings where the values of correlation coefficient R^2 range from 0.994 - 0.999, the maximal capacities of the given heavy metals adsorption q_0 according to Langmuir model are 10.08, 9.971, and 9.901 mg/g for Cd^{+2} , Fe^{+3} and Ni^{+2} respectively.

Table 3. Calculated equilibrium adsorption isotherm constants for the uptake of Cd^{+2} , Fe^{+3} and Ni^{+2} from solution by natural zeolite.

Heavy metals ions	Langmuir			Freundlich		
	q_0 (mg/g)	b	R^2	k	1/n	R^2
Cd	10.08	1.607	0.994	1.454	0.39	0.688
Fe	9.971	3.105	0.999	6.622	0.87	0.990
Ni	9.901	2.387	0.998	9.365	0.99	0.998

The maximal value is for Cd indicating to the higher selectivity of zeolite to Cd in comparison with other metals. Heterogeneity coefficient $1/n$ extrapolated from Freundlich isotherm curve is less than 1 and thus the evaluations are 0.39, 0.87, and 0.99 for Cd, Fe, and Ni respectively. The values indicate a material with relatively homogenous binding sites of natural porous Zeolite. It's been noticed from Fig. 7, the higher concentration of heavy metal ions the higher content of adsorbed metal per gram of natural Zeolite q_e this is attributed to the fact that at high concentration of heavy metal there is a higher solute concentration gradient; and this provides the necessary driving force for metal ions to displace exchangeable cations on the surface and from the internal micro-pores of natural zeolite [43, 44]. The increase continues until the saturation point is achieved.



(a) Langmuir isotherms

(b) Freundlich isotherms

Figure 7. Adsorption isotherms of Cd⁺², Fe⁺³ and Ni⁺² based on the Langmuir and Freundlich models

The removal efficiency (R%) of the metal ions on this adsorbent show good affinity of zeolite for a number of ions such as Cd⁺², Fe⁺³ and Ni⁺² ions in water. The Langmuir and Freundlich models were investigated for adsorption isotherms that the Langmuir isotherm fitted with equilibrium data better than the Freundlich isotherm.

Application test on industrial wastewater:

The results presented in table 4, indicated a relatively high concentrations of measured heavy metals from both inlet and outlet of wastewater treatment plant, since this sample is taken from mixed industrial wastewater and is characterized by high concentrations of these elements[48].

Table 4. The concentration of different heavy metals at industrial wastewater before and after application of zeolite.

Heavy metals mgL ⁻¹	Inlet to wastewater treatment plant			Outlet from wastewater treatment plant			Standard Limit Egypt
	Before	After	% removal	Before	After	% removal	
Cd	0.588	0.189	68.00	0.462	0.111	76.00	0.05
Fe	91.32	17.35	81.01	83.88	14.25	83.00	1.50
Mn	3.102	0.713	77.00	1.890	0.378	80.00	1.00
Ni	3.641	1.456	60.01	1.860	0.651	65.00	0.10
Pb	3.840	1.512	60.60	2.286	0.873	61.77	0.50
Zn	19.08	8.853	53.60	12.52	5.245	58.10	5.00

Industrial wastewater contains various metal ions with influence on potentiality of adsorbent to treat wastewater in competition for exchange sites and within adsorbent [23].

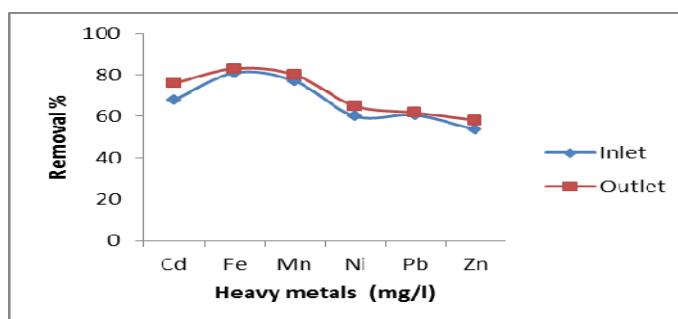


Figure 8. Removal % of different heavy metals in both inlet and outlet samples from industrial wastewater after applying of zeolite.

From figure 8, it was observed that, the metal in industrial wastewater follow the order: Fe > Zn > Pb > Ni > Mn > Cd. These variations depend on the amount and the type of the effluent drained in the study area [46, 47]. These concentration values for metals in both inlet and outlet samples, exceed the maximum levels of the Standard limitations for discharge of industrial effluents in Egypt (Law 4/1994 for the disposal of the marine environment in Egypt). By applying zeolite the order became Fe > Mn > Cd > Ni > Pb > Zn. Each metal has a unique electronegativities, ionic size and bond strength which influence the adsorption capacity of the zeolite [48]. In treatment with zeolite, the removal of heavy metals from industrial wastewater sample is high whereby the percentage of removal is more than 50 percent of the initial concentration. The removal of heavy metals from industrial wastewater in individual industry is effective using zeolite but when using with mixed industrial wastewater, it can diminish the pollution problem to a certain and a considerable extent.

4. CONCLUSION

The removal of heavy metals from aqueous solution was carried out in batch adsorption mode using natural (clinoptilolite) zeolites adsorbent. The natural (clinoptilolite) zeolites exhibited effectiveness in the removal of Cd (II), Fe (III) and Ni (II) ions from aqueous solutions. There are many factors that affect the general reaction rate of adsorption process using natural zeolite. I.e. contact time, zeolite dose, particle size, effect of pH, and initial concentration of metal ions. It was found that the adsorption process is pH-dependent for studied metals, and the maximum uptake was obtained in the pH of 6. The optimal removal rate occurs after 2 hours of contact time, when using adsorbent particles of small size. The best isotherm fit for Cd, Fe, and Ni was obtained with Langmuir model. By applying to

industrial wastewater, the result of the experiments determined that the natural (clinoptilolite) zeolites could be used as an effective and low-cost method in removing metals from industrial wastewater. It is recommended to conduct a research on other toxic pollutant.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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