

# Adsorption of Toxic Ni (II) from an Aqueous Solution by Bentonite

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**Abstract:** In this study, the adsorption potential of bentonite for removal of Ni(II) ions from wastewater has been investigated. The study involves batch type experiments to investigate the effect of initial concentration, adsorbent dose, agitation speed, contact time, temperature and pH of the solution on adsorption process and the optimum conditions were evaluated. The adsorption process fits pseudo-second order kinetic models. Langmuir and Freundlich adsorption isotherm models were applied to analyze adsorption data and both were found to be applicable to the adsorption process. Thermodynamic parameters, e.g.,  $\Delta G^\circ$ ,  $\Delta S^\circ$  and  $\Delta H^\circ$  of the on-going adsorption process have also been calculated and the sorption process was found to be endothermic. Finally, it can be seen that Bentonite was found to be more effective for the removal of Ni(II) at the same experimental conditions.

**Keywords:** Waste Water, Nickel, Bentonite, Adsorption

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## 1. Introduction

Water contamination by heavy metals in industrial effluents is a serious environmental problem. This situation has led to development of research aiming at its reduction or elimination and at the appreciation of residues obtained through physical, chemical, thermal, biological or mixed treatments.

Among heavy metals, nickel is one of the most utilized elements in the manufacturing process of stainless steel, super alloys, metallic alloys, coins, batteries etc. Direct exposition to nickel causes dermatitis. Some nickel compounds, such as carbonyls, are carcinogenic and easily absorbed by skin. The exposure to this compound at an atmospheric concentration of 30 ppm for half an hour is lethal [1].

The existing literature reports many studies on the removal of heavy metals from water and effluents, including chemical precipitation, physical treatment such as ion exchange, solvents extraction and adsorption. However, considering the high costs for the maintenance and the importation of

chemical products or conventional adsorption, some methods have become unsustainable.

Several studies have demonstrated that the selectivity and the efficiency in the removal of pollution agents, such as heavy metals from effluents through an adsorption process, depend greatly on physical properties and chemical composition of the adsorbents.

Recently, the use of clay for sorption or elimination of heavy metals in effluents has been considered as an object of study in a great deal of research due to its several economic advantages [2-4]. The cost of these adsorbents is relatively low when it's compared to other alternative adsorbents, including activated coal, natural and synthetic zeolites, ion-exchange resins and other adsorbent materials.

Clay and minerals as montmorillonite, vermiculite, illite, caulinite and bentonite are some natural materials that are being studied as heavy metals adsorbents [5-6]. Another advantage of using clay as an adsorbent is related to its intrinsic properties such as: great specific surface area,

excellent physical and chemical stability and several other structural and surface properties [7].

The acceptable limit of Ni in drinking water is 0.01 mg<sup>-1</sup> and for the discharge of industrial water is 2.0 mgL<sup>-1</sup>. At higher concentrations, Ni(II) causes cancer of lungs, nose and bone. Dermatitis Ni itches is the most frequent effect of exposure to Ni, such as coins and costume jewels. Ni carbonyl [Ni(CO)<sub>4</sub>] has been estimated as lethal in humans at atmospheric exposures of 30 ppm for 30 min [8]. Acute poisoning of Ni(II) causes headache, dizziness, nausea and vomiting, chest pain, tightness of the chest, dry cough and shortness of breath, rapid respiration, cyanosis and extreme weakness.

Hence, it is essential to remove Ni(II) from industrial waste water before mixing with natural waste sources. In advanced countries, removal of Ni(II) metal ions in waste water is normally achieved by advanced technologies such as precipitation-filtration, ion exchange and membrane separation [9]. However, in developing countries, these treatment can't be applied because of the technical levels and insufficient funds. Therefore, it is desired to simple and economical removal methods which can utilized in developing countries. Although the treatment cost for precipitation- filtration method is comparatively cheap, the treatment procedure is complicated. On the other hand, adsorption method such as ion exchange and membrane separation is simple one for the removal of heavy metals. However, there is a limit in the generality in developing countries because chelating and ion-exchange resins are expensive. In the present study, removal of Ni(II) ions from wastewater was further carried out by adsorption onto bentonite.

The objectives of the present study are: 1) studying the effect of contact time on Ni<sup>+2</sup> ions adsorption onto Bentonite; 2) to investigate the influence of PH on the adsorption of Ni<sup>+2</sup> ions; 3) to study the adsorption of Ni<sup>+2</sup> ions at different temperatures and to calculate the adsorption thermodynamic parameters (i.e.,  $\Delta H^0$ ,  $\Delta S^0$ ,  $\Delta G^0$ ); 4) to find the effect of adsorbent dose and the initial concentration on the adsorption of Ni<sup>+2</sup> ions; 5) to describe the experimental data of adsorption isotherm through Langmuir and freundlich models; 6) to discuss the adsorption mechanism of Ni<sup>+2</sup> ions onto both adsorbents.

## 2. Experimental

### 2.1. Materials and Reagents

All chemicals used in the present work were either of analytical reagent (AR) or laboratory reagents (LR) grade and were used just they have received. Nickel chloride supplied by BDH chemicals Ltd. Distilled water was used in all preparations. Nickel chloride and deionized water were used to prepare synthetic Ni<sup>+2</sup> containing waste water.

Powder bentonite produced from natural origin by ADWIC was used as adsorbent as well as American Wyoming used in Alexandria Company for refractories.

Powder Bentonite was supplied from ADWIC and Alexandria Company for refractories, respectively. The surface area and particle size for the adsorbent were checked Table (1).

**Table 1.** The surface area and particle size analysis of bentonite.

Adsorbents analysis	Bentonite	
Surface area (BET) Nova 2000 Quanta chrome	119.8 m <sup>2</sup> /g (dry)	
	Size (micrometer)	Wt. %
	> 63	1
	63 - 32	1
Particle size (XRD) Philips PW 1730	32 - 16	2
	16 - 8	3
	8 - 4	2
	4 - 2	4
	< 2	87

### 2.2. Apparatus and Instrumentation

Magnetic hot plate stirrer was used to stir the solutions of heavy metals ions with adsorbents (bentonite). A definite volume of heavy metal ions solution with a known initial ions concentration was stirred with a definite amount of adsorbents for a certain time at fixed temperature and agitation rate. The pH values of the solution were measured by digital pH meter (Model g pH system-361, India). The metal ions concentrations were measured by using atomic-absorption spectrophotometer, AAS, (Model, AA55; Varian Inc., USA).

### 2.3. Experimental Procedures

Nickel (II) chloride (NiCl<sub>2</sub>.6H<sub>2</sub>O), and redistilled water were used to prepare stock solutions with a concentration of 1000 ppm of the Ni(II) which was diluted for preparation of test solutions. Several solutions with different initial concentrations of nickel chloride (50, 100, 200, 300 and 400 ppm) were prepared. Adjustment of pH was carried out by using 0.1 N NaOH and or 0.1 N HCl. All experiments conditions were optimized to achieve maximum removal efficiency (RE) for all heavy metals ions by adding different amounts of both adsorbent (0.1, 0.3, 0.5, 0.7 and 1.0 g) to different concentrations of 250 mL of heavy metal ions solution. The agitation rate for all experiments was 200 rpm and the residence time was (0, 15, 30, 45, 60, 75, 90 and 120 min) at 25°C.

1 mL of Sample was taken from each reaction solution and diluted to 10 mL by redistilled water, adsorbents were then separated from the solution by using filter paper (Watman No. 40) and the residual Ni(II) ions concentrations in the each solution was then determined by atomic- absorption spectrophotometer (AAS). The effects of several parameters, such as contact time, initial concentration, adsorbent dose, pH value and temperature on the adsorption of Ni(II) ions onto bentonite were studied.

### 2.4. Data Analysis

The uptake of Ni(II) ions were calculated by the mass

balance, which was stated as the amount of solute adsorbed onto the solid. It equals the amount of solute removed from the solution. Mathematically, it can be expressed by Eq. (1):

$$q_e = (C_i - C_e) / S \tag{1}$$

Where

$q_e$  is the heavy metal ions concentration adsorbed by an adsorbent at equilibrium

(mg of metal ions/g of adsorbent)

$C_i$  is the initial concentration of metal ions in the solution (mg/l)

$C_e$  is the equilibrium concentration or final concentration of metal ions in the solution (mg/l)

$S$  is the dosage concentration and it is expressed by Eq. (2):

$$S = m / V \tag{2}$$

Where  $V$  is the initial volume of metal ions solution used (L) and  $m$  is the weight of dried adsorbent (g) used.

The percentage of adsorption (%) is calculated using Eq. (3):

$$\% \text{ adsorption} = [(C_i - C_e) / C_i] * 100 \tag{3}$$

*Adsorption kinetic's*

To investigate the mechanism of nickel (II) ions adsorption onto bentonite, two kinetics models were considered as follows:

Largergren pseudo-first order model can be expressed by Eqs. (4) and (5):

$$dq/dt = k_1(q_e - q) \tag{4}$$

$$\ln(q_e - q) = \ln q_e - k_1 t \tag{5}$$

The pseudo-second order model is given by Eqs. (6) and (7):

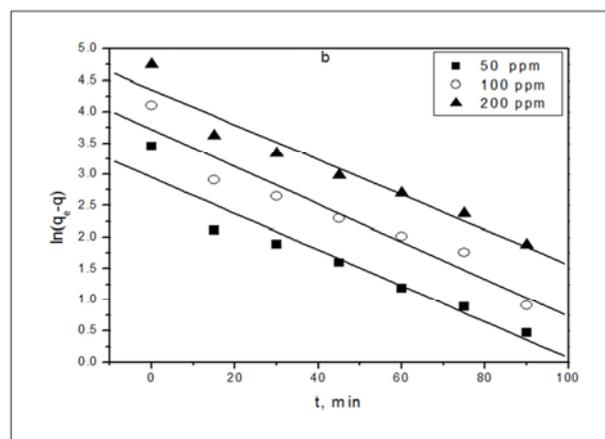
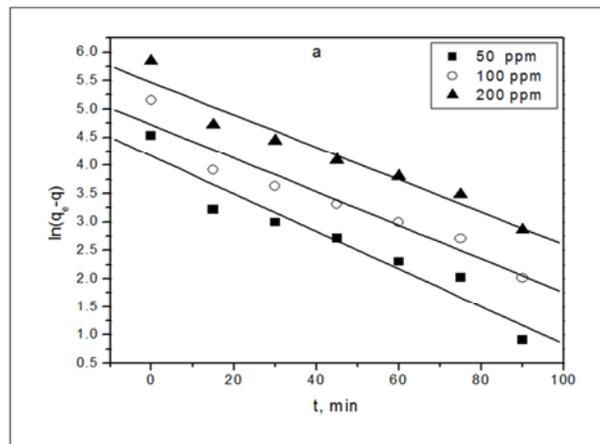
$$dq/dt = k_2(q_e - q)^2 \tag{6}$$

$$t/q = t/q_e + 1/k_2 q_e^2 \tag{7}$$

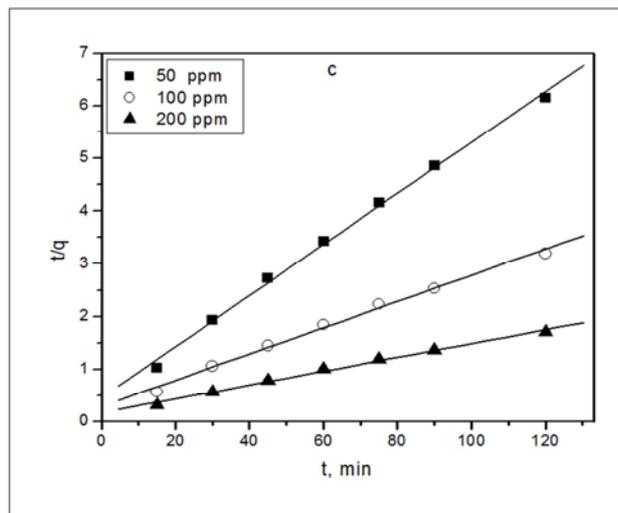
Where  $q$  and  $q_e$  are the amount of  $Ni^{+2}$  metal adsorbed per unit weight of adsorbent (mg/g) at time  $t$  and at equilibrium, respectively, and  $k_1$  and  $k_2$  are the adsorption rate constant. The applicability of the above two models can be examined by each linear plot of  $\ln(q_e - q)$  vs.  $t$ , and  $(t/q)$  vs.  $t$ , respectively and are represented in Figure (1) and (2). The kinetics study for the adsorption of  $Ni^{+2}$  was conducted at optimum pH 5.0 and completed in 2 h for the concentrations (50, 100, and 200 mg/l) of  $Ni^{+2}$  ions onto (0.1, 0.3, 0.5, 0.7, and 1.0 g/250 mL) doses of adsorbents at 25°C. The validity of the kinetics models is tested by the magnitude of the regression coefficient  $R^2$ , given in Table (1). It is important to note that for pseudo-first order, the correlation coefficient is always less than 0.98, which is indicative of less significant correlation. In contrast, the application of pseudo-second order model leads to much better regression coefficient, all greater than 0.99. moreover, from Table (1) and Figure (1) and (2), the  $q_e$ , the values estimated from the pseudo-first

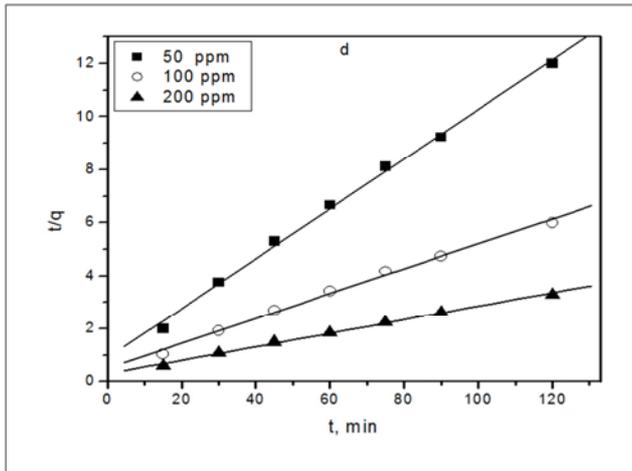
kinetic model gave significantly were also found to be lower. However, in pseudo-second order kinetic model the calculated  $q_e$ , the values are very close to  $q_e$ , exp values at various initial concentrations and various adsorbent doses.

For the pseudo-second order kinetics model, the rate constant decrease with increasing of initial  $Ni(II)$  concentration.



**Figure 1.** Pseudo-first order kinetic plots for the adsorption of different initial concentrations: 50, 100 and 200 ppm  $Ni^{2+}$  ions onto different doses of bentonite: a) 0.1 g/250 mL and b) 0.3 g/250 mL, (pH: 5.0; agitation speed: 200 rpm; temperature: 25°C).





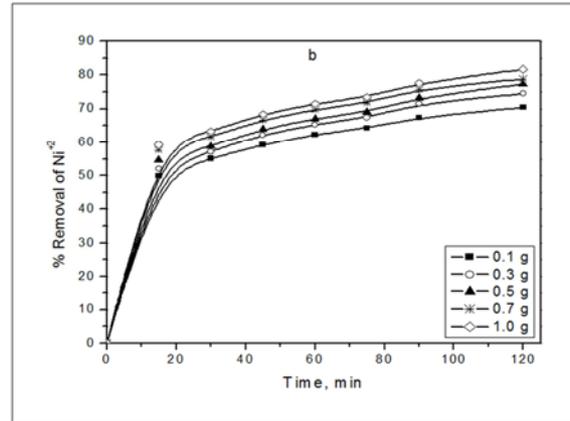
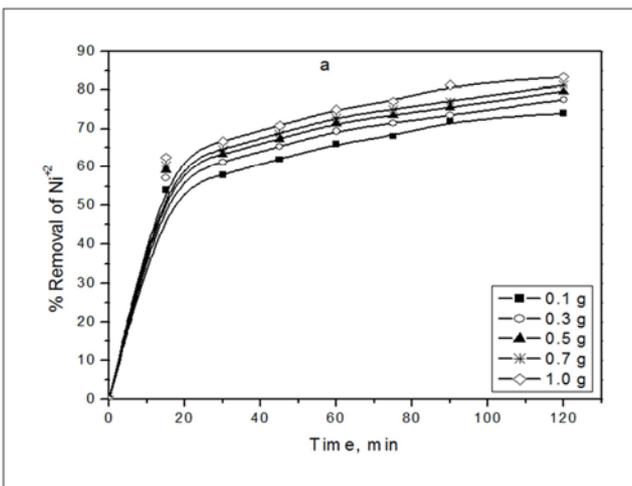
**Figure 2.** Pseudo-second order kinetic plots for the adsorption of different initial concentrations: 50, 100 and 200 ppm Ni<sup>2+</sup> ions onto different adsorbent doses of bentonite: c) 0.5 g/250 mL and d) 1.0 g/250 mL, (pH: 5.0; agitation speed: 200 rpm; temperature: 25°C).

**2.5. Effect of Contact Time**

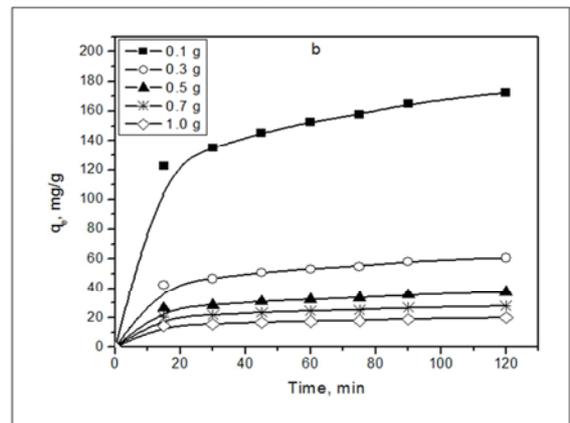
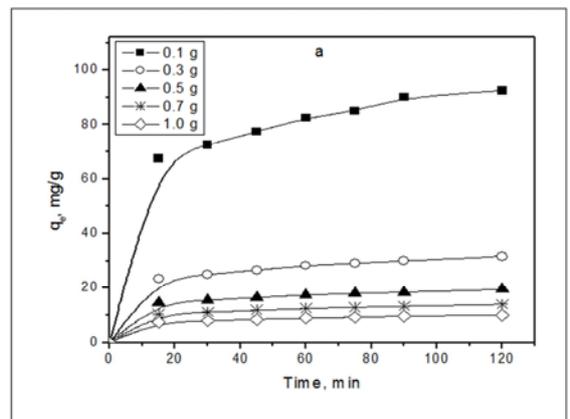
The effect of contact time for five different concentrations of Ni<sup>+2</sup> (50, 100, 200, 300 and 400 mg/l) onto (0.1, 0.3, 0.5, 0.7 and 1.0 g/250 mL) of Bentonite doses, pH 5.0 at 25°C is shown in

Figure (3). Thenickel (II) percentage removalincreased by time until the equilibrium is attained between the amounts of nickel (II) adsorbed onto both adsorbents and the remaining solution. The figure shows that the adsorption of Ni<sup>+2</sup> increase with the time from 0 to 30 min and more and then increased slowly up to the end of experiment. It can be concluded that the rate of the Ni (II) binding with bentonitewasmore at initial stages, which gradually decrease and becomes almost constant after an optimum period of90 min.

Figure (4) shows the relation between the amount of adsorbed ions per gram of adsorbent and contact time in the presence of different amounts of adsorbents at 25°C. At the begining raises rapidly and by time it increases slowly till he maximum adsorption.



**Figure 3.** Effect of contact time (min) on % removal of Ni<sup>2+</sup> ions for: a) 50 ppm and b) 100 ppm, in the presence of different amounts of bentonite (temp. = 25°C, pH = 5.0 and equilibrium time = 2 h).

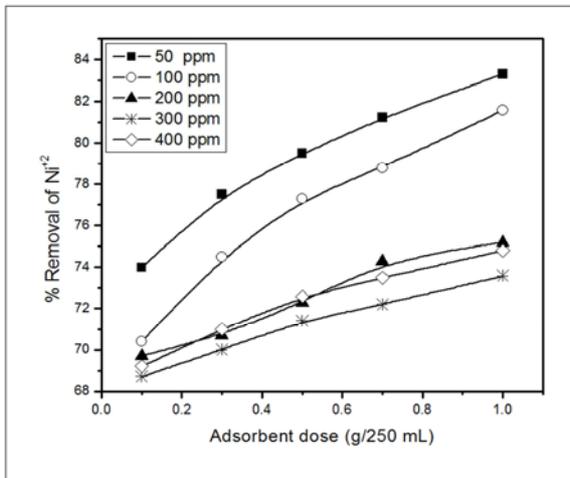


**Figure 4.** Effect of contact time on adsorbed amount of Ni<sup>2+</sup> for different concentrations: a) 50 ppm, b) 100 ppm, in the presence of different amounts of bentonite (temp. = 25°C, pH = 5.0 and equilibrium time = 2 h).

**2.6. The Effect of Adsorbent Dose**

The effect of adsorbent dose on percentage removal of (50, 100, 200, 300 and 400 mg/L) Ni (II) ions concentrations at 25°C are shown in Figure (5). Percentage of nickel (II) ions removal/ increased when the adsorbent dose increased from 0.1 to 1.0 g 1250 mL for bentonite. It can be seen that, the number of adsorption sites or surface area increases with the weight of adsorbent and hence results in a higher percent of

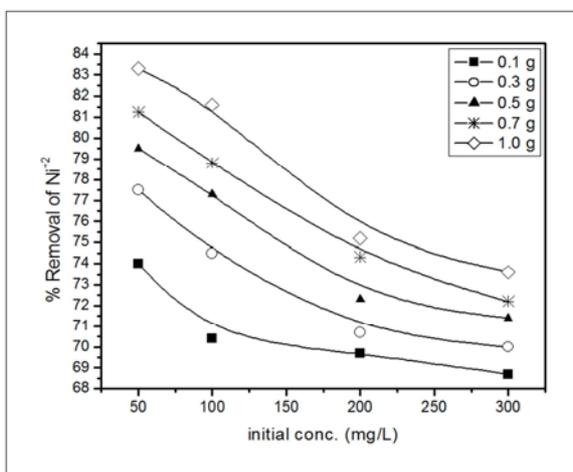
metal ions removal at a high dose. However, the amount of metal ions adsorbed per unit weight of adsorbent ( $q$ ) decreases with the adsorbent dose. This is due to the fact that at higher adsorbent dose the solutions ion concentration drops to a lower value and the system reaches equilibrium at lower values of  $q$  indicating the adsorption sites remain unsaturated.



**Figure 5.** The effect of variant bentonite adsorbent doses (0.1, 0.3, 0.5, 0.7 and 1.0 g/250 ml) on % removal for different  $Ni^{2+}$  ions initial concentrations solutions at 25°C.

### 2.7. Effect of Initial Nickel (II) Ions Concentration

An increase of initial Ni(II) concentration from 50 to 300 mg/L with different amounts of bentonite (0.1, 0.3, 0.5, 0.7 and 1.0 g/250 mL) when other experimental conditions are kept constant, illustrated in Figure (6) It can be seen from the figures that, % removal of Ni(II) increases when the initial concentration decreased. At low ions concentrations the ratio of surface active sites to the total metal ions in the solution is high and hence all metal ions may interact with the adsorbent and be removed from the solution. However, the amount of metal adsorbed per unit weight of adsorbent,  $q$ , is higher at high concentration.



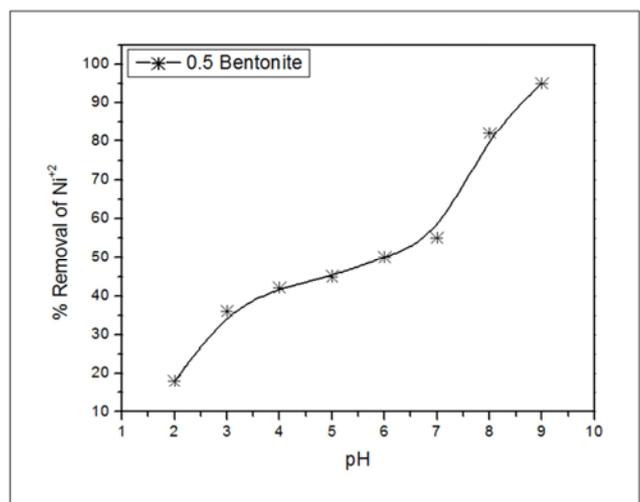
**Figure 6.** The effect of initial concentration (namely 50, 100, 200 and 300 mg/L) on % removal of  $Ni^{2+}$  ions in the presence of different amounts of bentonite (temp. = 25°C, pH = 5.0 and equilibrium time = 2 h).

### 2.8. Effect of pH on the Uptake of $Ni^{+2}$

The pH value of the solution is an important controlling parameter in the adsorption process, and the initial pH value of the solution has more influence than the final pH, which influences both the adsorbent surface metal binding sites and the metal chemistry in water. Hence, the influence of pH on the adsorption of Ni(II) onto Bentonite was examined in the range of 2-9%; the results are shown in Figure (7)

This figure shows that, the sorption of Ni(II) increases with increasing pH at pH 2-7, then decreases with increasing pH at pH >7 and at last maintains a low level at pH >8.5. The abrupt increase of Ni(II) sorption may be attributed to the surface precipitation of  $Ni(OH)_2(S)$  onto bentonite.

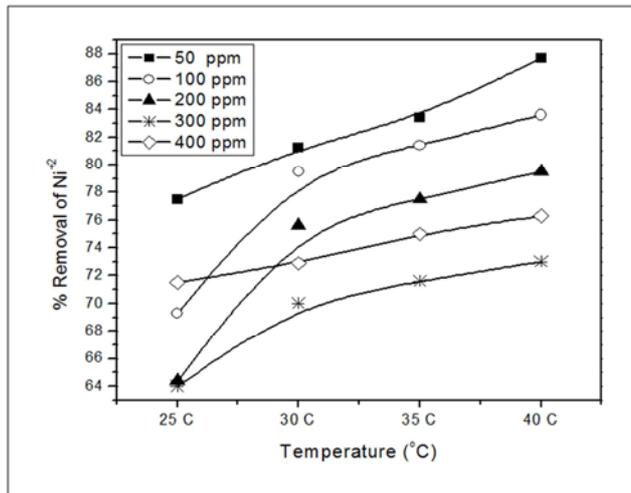
It is well known that Ni(II) can be easily form precipitated because of the low solubility of  $Ni(OH)_2$ . It is clear that Ni(II) ions start to form precipitation at pH~6. However, one can see that more than 90% Ni(II) has been adsorbed to bentonite at pH>5.



**Figure 7.** Effect of pH for the adsorption of  $Ni^{2+}$  ions onto bentonite (conditions;  $Ni^{2+}$  ions initial concentration: 100 mg/L; adsorbent dose: 0.5 g/250 mL; agitation speed: 200 rpm; contact time: 2 h) at 25°C.

### 2.9. Effect of Temperature

The effect of temperature on the efficiency of adsorption of Ni(II) was studied at different temperature in the range of 25-40°C. The adsorption experiments were carried out with (50, 100, 200, 300 and 400 mg/L) initial concentrations of Ni(II) onto 0.5 g/250 mL for bentonite at pH 5.0. The adsorption of  $Ni^{+2}$  onto the adsorbent increase by increasing temperature from 25 to 40°C. Figure (8) indicates that the Ni(II) uptake by adsorption onto bentonite and bentonite favours at higher temperature. This may be due to availability of more active sites of both adsorbent at higher temperature.



**Figure 8.** The effect of temperature between 25 and 40°C for the % removal of different initial Ni<sup>2+</sup> ions concentrations onto bentonite (conditions; pH: 5.0; adsorbents dose: 0.5 g/250 mL; agitation speed: 200 rpm; contact time: 2 h).

### 2.10. Adsorption Isotherm

Adsorption isotherm is an expression that shows the relationship between amounts of adsorbate adsorbed per unit weight of adsorbent ( $q_e$ , mg/g) and the concentration of adsorbate in bulk solution ( $C_e$ , mg/L) at given temperature under equilibrium conditions. Adsorption equilibrium is established when the amount of adsorbate being adsorbed is equal to the amount being desorbed from the adsorbent. At this stage, the equilibrium concentrations in both phases are constant. Adsorption isotherm is very useful in giving information about adsorption mechanisms, surface properties and affinity of an adsorbent towards heavy metals ions [10, 11]. The isotherm data were further analyzed with two most common isotherm models.

The Langmuir and Freundlich models (Langmuir, 1916; Freundlich, 1906), are the most frequently employed to describe equilibrium for the adsorption of (50, 100, and 200 mg/L) Ni<sup>2+</sup> ions concentrations onto (0.1, 0.3, 0.5, 0.7 and 1.0 g/250 mL) of bentonite doses, pH 5.0 at 25°C. The Langmuir isotherm is probably the most widely applied isotherm model in many adsorption studies. The developed model was based on assumptions that adsorption occurs at specific homogeneous sites on the adsorbent and was used successfully in many monolayer, adsorption processes. It also assumes no transmigration of adsorbate in the plane of adsorbent surface.

The Langmuir isotherm for adsorption can be obtained from Eq. (8):

$$C_e/q_e = 1/(q_{\max}b) + (1/q_{\max}) C_e \quad (8)$$

Where  $q_{\max}$  is the maximum metal ions uptake per unit mass of adsorbent (mg/g), which is related to the adsorption capacity and  $b$  is Langmuir constant (L/mol) which is exponentially proportional to the heat of adsorption and related to the adsorption intensity. Therefore, a plot of  $C_e/q_e$  versus  $C_e$  gives a straight line of the slope  $1/q_{\max}$  and intercept  $1/(q_{\max}b)$  as shown in Figure (9)

Freundlich isotherm gives the relationship between equilibrium liquid and solid phase capacity based on the multilayer adsorption (heterogeneous surface). This isotherm is derived from the assumption that the adsorption sites are distributed exponentially with respect to the heat of adsorption. It also assumes that the stronger adsorption sites are occupied first and the binding strength decreases with the increasing degree of site occupation. The Freundlich model is given by (Freundlich, 1906) the classical empirical isotherm, Eq. (9):

$$\ln q_e = \ln K_F + 1/n \ln C_e \quad (9)$$

The Freundlich adsorption isotherm is an indicator of the extent of heterogeneity of the adsorbent surface, where the Freundlich constants  $K_F$  and  $n$ , which respectively indicating the adsorption capacity and the adsorption intensity, were calculated from the intercept and slope of the plot of  $\ln q_e$  versus  $\ln C_e$  as shown in Figure (10)

This Freundlich type behavior is indicative of surface heterogeneity of the adsorbents, i.e. the adsorptive sites (surface of bentonite) are made up of small heterogeneous adsorption patches that are homogeneous in themselves. The activation of adsorption sites takes place, leading to increased adsorption probably through the surface exchange mechanism.

The calculated results of Langmuir and Freundlich isotherm constants are given in Table (2). It can be seen that, the Freundlich model yields a much better fit than the Langmuir model, when the correlation coefficient ( $R^2$ ) values are compared in Table (3) ( $R^2$  values of Freundlich plot >0.99 was closed to unity, indicating isotherm data fitted well to Freundlich model). The Freundlich constant ( $K_F$ ) indicates the sorption capacity of the sorbent. From Table (3), it is noticed that the values of ( $n$ ) are bigger than 1, reflecting the favorable adsorption.

The plots of  $q_e$  versus  $C_e$  are presented in Figure (9) and (10), it is seen that  $q_e$  increased by increasing  $C_e$  with higher slope at the initial stages which indicates that, initially, there are numerous readily accessible sites for adsorption process. Eventually  $q_e$  reaches maximum value at higher  $C_e$ , indicating that the adsorption is saturated at this level.

**Table 2.** The adsorption kinetics model rate constants for adsorption of Ni<sup>2+</sup> ions onto bentonite at various concentrations and constant temperature 25°C.

Adsorbent	C <sub>0</sub> (mg/L)	q <sub>e</sub> exp. (mg/g)	Lagergren first order			Pseudo-second order		
			K <sub>1</sub> (min <sup>-1</sup> )	q <sub>1, theo.</sub> (mg/g)	R <sup>2</sup>	k <sub>2</sub> (gmg <sup>-1</sup> min <sup>-1</sup> )	q <sub>2, theo.</sub> (mg/g)	R <sup>2</sup>
Bentonite (0.1 g)	50	92.5	3.8x10 <sup>-2</sup>	64	0.923	9.5x10 <sup>-4</sup>	92	0.993
	100	172.5	2.9x10 <sup>-2</sup>	112	0.931	5.1x10 <sup>-4</sup>	174	0.996
	200	345	2.8x10 <sup>-2</sup>	237	0.945	2.1x10 <sup>-4</sup>	350	0.997
Bentonite (0.5 g)	50	20	2.8x10 <sup>-2</sup>	12	0.910	5.0x10 <sup>-3</sup>	21	0.998
	100	38	2.7x10 <sup>-2</sup>	24	0.914	2.1x10 <sup>-3</sup>	40	0.994
	200	71	2.6x10 <sup>-2</sup>	47	0.930	9.9x10 <sup>-4</sup>	72	0.990

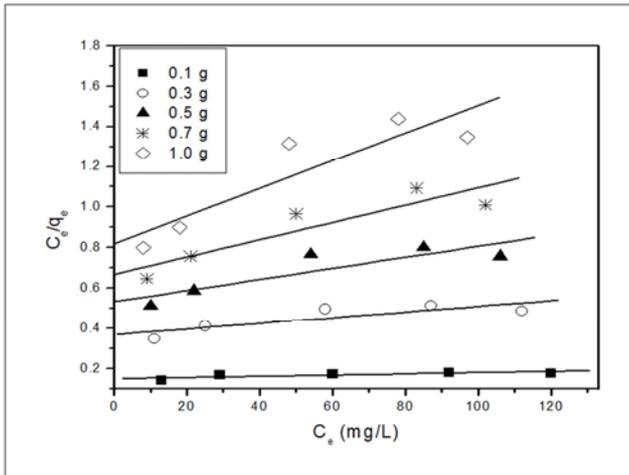


Figure 9. Langmuir adsorption isotherm for Ni<sup>2+</sup> ions adsorption onto different amounts of bentonite at constant temperature 25°C and contact time 2 h.

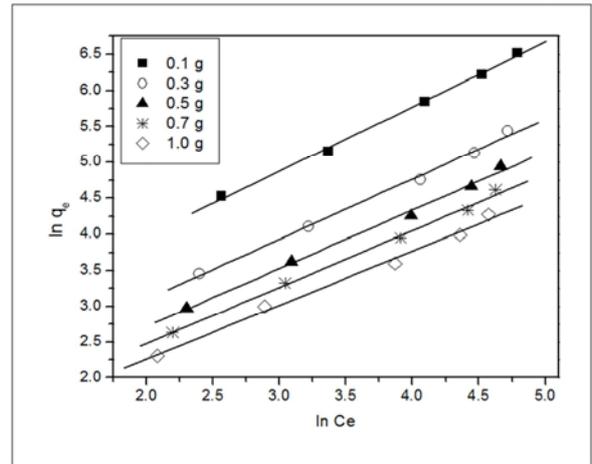


Figure 10. Freundlich adsorption isotherm for Ni<sup>2+</sup> ions adsorption onto different amounts of bentonite at constant temperature 25°C and contact time 2 h.

Table 3. Langmuir and Freundlich isotherm for the adsorption of Ni<sup>2+</sup> ions onto different doses of bentonite at constant temperature (25°C).

Adsorbent (Bentonite)	Langmuir Isotherm constants			Freundlich Isotherm constants		
	q <sub>max</sub> (mg/g)	b (L/mol)	R <sup>2</sup>	K <sub>F</sub> (mg/g)	n	R <sup>2</sup>
(0.1 g/250 mL)	90	3.7x10 <sup>-2</sup>	0.905	8.96	1.118	0.999
(0.3 g/250 mL)	96	4.2x10 <sup>-3</sup>	0.785	4.15	1.192	0.998
(0.5 g/250 mL)	121	5.1x10 <sup>-3</sup>	0.882	3.11	1.236	0.997
(0.7 g/250 mL)	234	6.4x10 <sup>-3</sup>	0.822	2.46	1.267	0.995
(1 g/250 mL)	245	8.38x10 <sup>-3</sup>	0.815	2.34	1.325	0.995

Thermodynamic parameters

The determination of thermodynamic parameters has a great importance to evaluate spontaneous and heat change for the adsorption reaction. The apparent equilibrium constant (K<sub>c</sub>) of the adsorption is defined as:

$$K_c = C_{Ac} / C_e \tag{10}$$

The standard Gibb's energy was evaluated by:

$$\Delta G^\circ = - RT \ln K_c \tag{11}$$

Where R is the ideal gas constant (8.3 14 J mol<sup>-1</sup>K<sup>-1</sup>) and T is the temperature (K).

Where C<sub>Ac</sub> and C<sub>e</sub> (both in mg/L) are the equilibrium concentrations for Ni (II) ions onto the sorbent and in the solution, respectively. In this case, the activity should be used instead of concentration in order to obtain the standard thermodynamic equilibrium constant (K<sub>c</sub>) of the adsorption system.

$$\ln K_c = \Delta H^\circ / RT + \Delta S^\circ / R \tag{12}$$

The plot of lnK<sub>c</sub> as a function of 1/T yields a straight line is shown on Figure (11) from which ΔH° and ΔS° can be calculated from the slope and intercept, respectively.

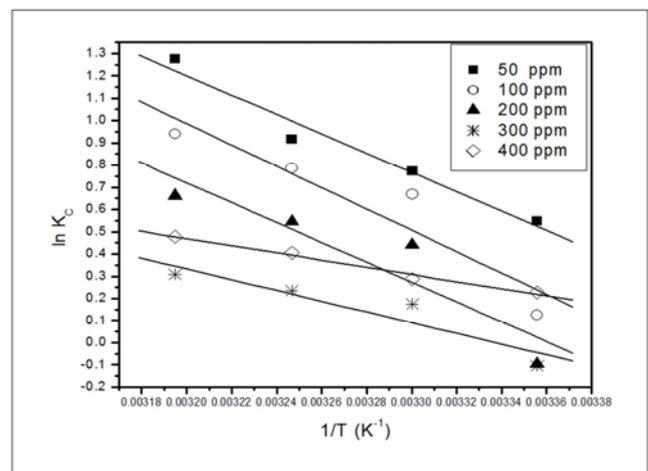


Figure 11. A plot of lnK<sub>c</sub> versus 1/T for Ni<sup>2+</sup> ions adsorption onto bentonite for different initial Ni<sup>2+</sup> concentrations at constant adsorbent dose: 0.5 g/250 mL.

The negative values of ΔG° at all temperatures (25, 30, 35 and 40°C) indicate the spontaneous nature of the adsorption of (50, 100, 200, 300 and 400 mg/L) of Ni(II) onto 0.5 g/250 mL of Bentonite. The change of the standard free energy decreases with increasing temperatures regardless of the nature of adsorbent. This indicates that a better adsorption is actually obtained at higher temperature. It has been reported that, ΔG° values up to -20 kJ/mol are consistent with

electrostatic interaction between sorption sites and the metal ion (physical adsorption), while  $\Delta G^\circ$  values more negative than  $-40$  kJ/mol involve charge sharing or transfer from the surface to the metal ion to form a coordinate bond (chemical adsorption). The  $\Delta G^\circ$  values obtained in this study for Ni(II) ions are  $< -10$  kJ/mol, which indicates that physical adsorption was the predominant mechanism in the sorption

process (Horsfall *et al.*, 2004). The positive value of  $N^\circ$  suggests the endothermic nature of adsorption. The positive value of  $\Delta S^\circ$  shows the increased randomness at the solid/solution interface during the adsorption process. Table (4) summarizes the values of these thermodynamic properties.

**Table 4.** Thermodynamic parameters for different concentrations of  $Ni^{2+}$  ions onto bentonite.

Adsorbent	$C_o$ (mg/L)	$\Delta H^\circ$ (kJ mol <sup>-1</sup> )	$\Delta S^\circ$ (J mol <sup>-1</sup> K <sup>-1</sup> )	$\Delta G^\circ$ (kJ mol <sup>-1</sup> )			
				25°C	30°C	35°C	40°C
Bentonite	50	36	125	-1.3	-1.9	-2.5	-3.2
	100	40	136	-0.6	-1.2	-1.9	-2.6
	200	37	124	-0.2	-0.4	-1.1	-1.6
	300	25	92	-0.1	-0.2	-0.5	-1.0
	400	14	46	-0.3	-0.4	-0.7	-1.0

### 3. Conclusion

This paper demonstrated the efficiency in the removal of pollution agents such as Ni from effluents through an adsorption process. The cost of this method is relatively low when it is compared to other alternative adsorbents.

Some Nickel compounds such as Carbonyls are Carcinogenic and easily absorbed by skin.

Ni (II) ions from wastewater were carried out by absorption onto bentonites. Studying the effect of contact time and pH & T absorbent dose on the adsorption of Ni<sup>2+</sup> ions was carried out in this study. Removal % of Ni (II) increase when the initial concentration of bentonite. Bentonite is found to be more effective for the removal of Ni (II) at certain experimental conditions.

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