

Studies on the Removal of Cobalt (Co²⁺) and Nickel (Ni²⁺) Ions from Aqueous Solution by using Macroporous Cation Exchange Resin.

M.A. Wassel, A.A. Swelam, M.M.B. Awad and A.S. El-Zaref

Chemistry Department, Faculty of Science, Al-Azhar University, Cairo, Egypt.

ABSTRACT

Removal of transition metals from wastewater is occur in order to avoid water pollution. In the present study, performance of AMBERSEP 252H macroporous cation exchange resin was evaluated for removal of cobalt (Co²⁺) and nickel (Ni²⁺) from aqueous solutions. Batch shaking adsorption experiments were performed in order to examine the effects of pH, dosage of resin and contact time on removal process. It was observed that more than 98% removal efficiency was achieved under optimal conditions for cobalt (Co²⁺) and nickel (Ni²⁺). The experimental equilibrium data were tested for the Langmuir, Freundlich and Temkin isotherms. Correlation coefficients indicate the following order to fit adsorption models such as : Langmuir > Freundlich > Temkin for both cobalt (Co²⁺) and nickel (Ni²⁺) ions. Pseudo-first- and -second-order kinetic models were used for describing kinetic data. It was determined that removal of cobalt (Co²⁺) and nickel (Ni²⁺) was well fitted by second-order reaction kinetic. And thermodynamic parameters (ΔH , ΔG and ΔS) can be calculated.

Key words: Kinetics, Adsorption, Resin, Concentration, Freundlich.

Introduction

The release of large quantities of transition metals into the natural environment has resulted in a number of environmental problems. Toxic metals can be distinguished from other pollutants, since they are not biodegradable and can be accumulated in nature. They also cause various diseases and disorders when exceed specific limits (Gode and Pehlivan, 2003) and (Veli and Alyüz, 2007). The nickel (Ni²⁺) ion, compared, with other transition metals, is a more recalcitrant pollutant (Chanet *et al*, 1991).

As it is widely used in many industrial processes, removal of nickel (Ni²⁺) from wastewaters gains importance. Metal treatment industries containing nickel (Ni²⁺) in discharged waters, frequently use nickel in its sulfate form (Dabrowski *et al*, 2004). This affects the decision of treatment method used for removal of nickel (Ni²⁺) from wastewaters. Classical techniques of transition metal removal from solutions include the following processes: precipitation, electrolytic methods, ion exchange, evaporation and adsorption (Forstner and Wittman, 1979).

The main advantages of ion exchange over other techniques are the recovery of the metals value, high selectivity, less sludge volume produced and the ability to meet strict discharge specifications. In addition, the simplicity of ion exchange operation makes it attractive to the chemical purification field. In this regard, ion-exchange resins hold great potential for the removal of metals from water and industrial wastewater (Gode and Pehlivan, 2003), (Rengaraj *et al*, 2001), (Gode and Pehlivan, 2006) and (Rengaraj and Moon, 2002). Among the materials used in ion exchange processes, synthetic resins are commonly preferred as they are effective and inexpensive (Clifford, 1990).

Cation exchange resins generally contain sulfonic acid groups. These groups can also be carboxylic, phosphonic or phosphinic. Certain general rules for cation exchange are: (i) the exchanger prefers ions of high charge (ii) ions of small hydrated volume are preferred and (iii) ions which interacts strongly with the functional groups of the exchangers are preferred (Lin *et al*, 2000) and (Verbych *et al*, 2004)

AMBERSEP 252 H resins are in H-form and due to their high cation exchange capacities they reduce the residual concentration of transition metals below the discharge limits. They are also widely available as they are commercially produced. Furthermore their regeneration properties supply economical benefits. Due to mentioned properties, in this study AMBERSEP 252 H resin has been preferred. Batch technique was used in order to determine the equilibrium data. After defining optimum reaction conditions (pH, resin dosage, contact time), experimental results were applied to Langmuir, Freundlich and Temkin isotherms. First- and second-order reaction kinetics were calculated for determination of adsorption mechanisms. It is thought that results of this study can be useful for treatment processes of sectors containing transition metal in their wastewaters.

Experimental:

I- Materials:

Analytical grade reagents were used in experimental studies. Chloride salts of test metals (CoCl₂ and NiCl₂) were used for preparing certain concentrations of synthetic solutions. Standard 0.001 M EDTA solution,

Muroxide as indicator and buffer solution.

AMBERSEP 252 H is a macroporous cation exchange resin based on sulphonated crosslinked polystyrene from (Rohm and Haas company) . It has a moderate degree of crosslinking resulting in good regeneration efficiency. It is very resistant to osmotic shock and mechanical attrition. Physical and chemical properties of AMBERSEP 252 H are given in (Table 1).

Table 1: Characteristics of tested AMBERSEP 252 H.

Type	Styrene divinyl benzene copolymer.
Physical Form	Light gray beads
Functional group	Sulfonic group (SO ₃ ⁻)
Whole bead count	95% min
Ionic form, as shipped	H ⁺
Total capacity	≥ 1.65 eq/L (H ⁺ form)
Moisture holding capacity	52 : 58 % (H ⁺ form)
Specific gravity	1.18 to 1.22 (H ⁺ form)
Shipping weight	755 g /L
Particle size	
Harmonic mean size	0.90 - 1.10 mm
Uniformity coefficient	≤ 1,4
Fines content	<0.600mm : 1.0 % max
Coarse beads	>1.180 mm: 10.0% max
Maximum reversible swelling	Na → H ⁺ : 7%

II- Equilibrium studies:

The batch ion exchange experiments were performed in a wide variety of conditions including different pH, contact time, and various resin dosages effect. Effects of each factor were determined keeping other variables constant. In the experiments 50 ml of solutions containing of Co(II) and Ni(II) were added into flasks with different amounts of resin varying between 0.25 and 3g. Temperature was kept constant at 25⁰C during batch tests. The solutions were thoroughly shaken. After appropriate intervals, 5, 30, 60, 90, 150, 210 and 270 min., then the metal ion concentration in the liquid phase were determined.

The metal ion solution (1.0 ml) was transferred into 250 ml. Erlenmeyer flask and then diluted to 100 ml with distilled water, 2.0 ml of buffer solution was added, followed by indicator, the solution acquires a yellow colour. Titrate with standard EDTA 0.001 M until there is a sharp change of colour from yellow to pink.

The concentration of Co(II) and Ni(II) before and after equilibrium was calculated by using the Co(II) and Ni(II) factor.

{ 1 cm³ of 0.001 M EDTA = 0.0589332 mg Co(II) }

{ 1 cm³ of 0.001 M EDTA = 0.05871 mg Ni(II) }

III- Isotherm and Kinetic studies:

The adsorption capacity was calculated using the following formula:

$$q_e = \frac{C_0 - C_e}{m} V \quad (1)$$

where q_e (mg/g) is the equilibrium adsorption capacity, C_0 and C_e (mg/L) are the initial and equilibrium concentration of metal ions in solution, V (L) is the volume, and m (g) is the amount of the resin.

By using above formula q_e values for different metal concentrations were calculated.

The rate constants were calculated using conventional rate expressions. Following formula was used to determine adsorbed metal concentration qt , as in the following formula (2):

$$qt = \frac{C_0 - C_t}{m} V \quad (2)$$

where qt (mg/g) is the adsorption capacity at time t , C_0 (mg/L) is the initial metal concentration, C_t (mg/L) is the concentration of metal ions in solution at time t , V (L) is the volume, and m (g) is the amount of the resin.

Results and Discussion

A- Study the effect of contact time and initial concentrations:

As shown in (Fig. 1 and 2) the adsorption of Co^{+2} and Ni^{+2} ions onto the AMBERESEEP 252 H strong acid cation exchange resin at 25°C was rapid for the first 30 min for Co^{+2} and Ni^{+2} and equilibrium was reached within 210 min for Co^{+2} while for Ni^{+2} the equilibrium was reached within 270 min.

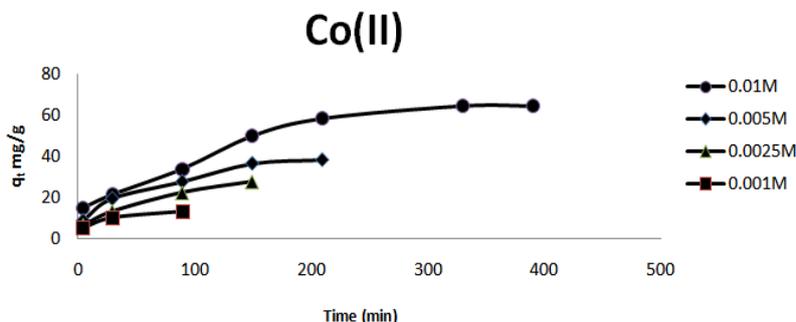


Fig. 1: Effect of Co(II) adsorption on AMBERSEEP 252 H at different concentrations at 25°C .

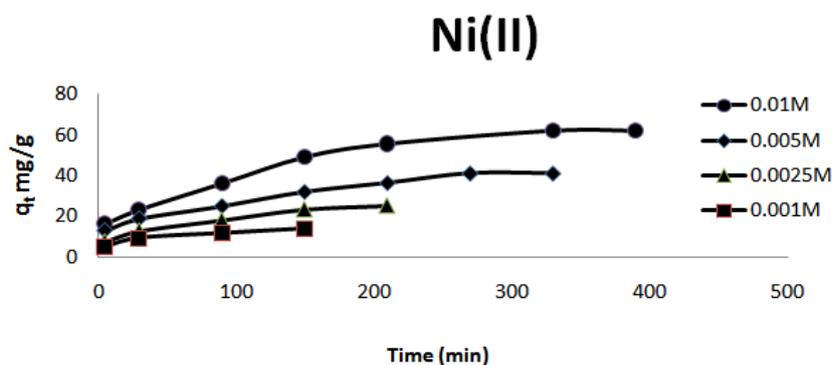


Fig. 2: Effect of Ni(II) adsorption on AMBERSEEP 252 H at different concentrations at 25°C .

The time profile of metal uptake is a single, smooth, continuous curve leading to saturation. Figure (2) shows the adsorption performance, expressed as amount of metal ions removal by AMBERESEEP 252 H strong acid cation exchange resin versus contact time (in minutes) toward two metals present in these studies. The affinity between the adsorbent and the adsorbate is the main interaction force controlling adsorption in Ref. (Crini and Badot, 2010).

Reported that the adsorption mechanisms are complex because a large number of interactions, such as ion exchange, physical adsorption, hydrogen bonding and hydrophobic interactions, are involved. From (Fig. 1 and 2) it can be seen that pollutant removal rapidly increases within the contact time due to fast interactions between metals and the surface of the material, and keeps increasing gradually until equilibrium is reached and then remains constant.

The adsorption isotherms are shown in (Fig. 1 and 2) it is found that the isotherm initially rises sharply, indicating that a large quantity of readily active sites are available in the beginning of adsorption. However, when the AMBERESEEP 252 H strong acid cation exchange resin becomes saturated, a plateau is reached suggesting that no more active sites are available. This increase in adsorption capacity with relation to the two metals ions concentrations can be explained with the high driving force by a higher concentration gradient. In general, the more concentrated the solution is the better adsorption as in ref. (Demirbas et al, 2005).

B- Effect of resin amount:

The resin amount is also one of the important parameters to obtain the quantitative uptake of metal ion. The dependence of metal adsorption on resin input amount was studied by varying the amount of AMBERESEEP 252 H (0.25-3g), while the other parameters such as initial metal concentration, amount of solution, temperature and stirring speed remained constant. It was apparent that the adsorption percentage of metal ions increased with

higher resin dosages and the removal efficiency of 98% was achieved by using 1.5-3g/50mL resin dosage for Cobalt Co(II) and nickel Ni(II) as shown in (Fig. 3 and 4).

This result proved that increasing the amount of adsorbent provides higher removal due to formation of greater adsorption sites according to (Alyüz and Veli, 2009).

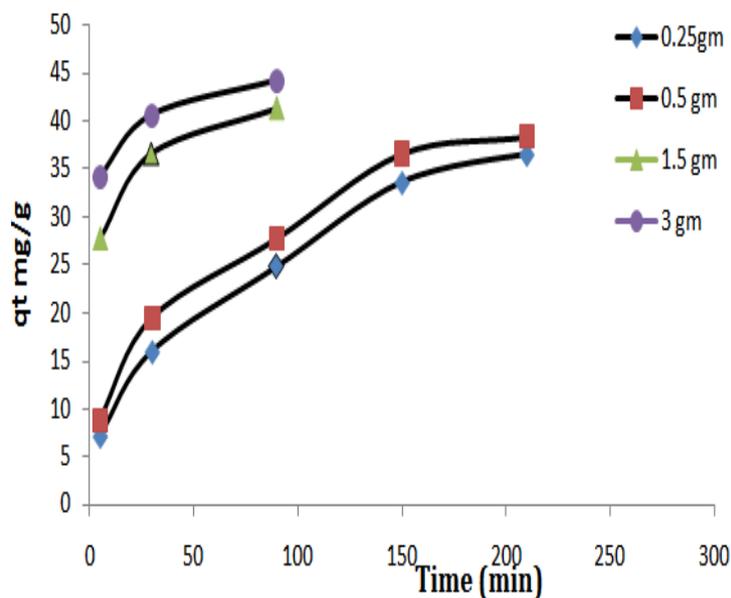


Fig. 3: Effect of different amount of resin in the adsorption of Cobalt Co(II) ion 7.7 mmol/L.

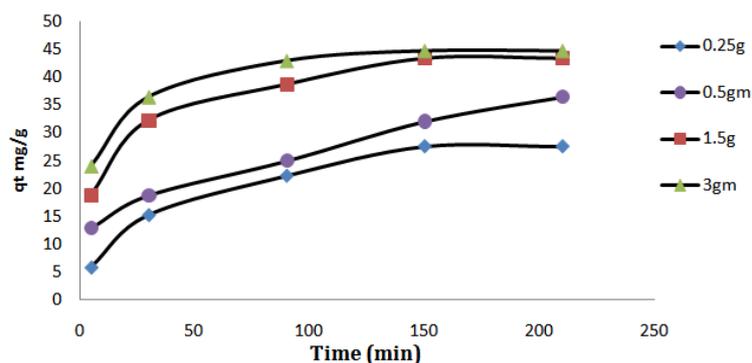


Fig. 4: Effect of different amount of resin in the adsorption of Nickel Ni(II) ion 7.7 mmol/L.

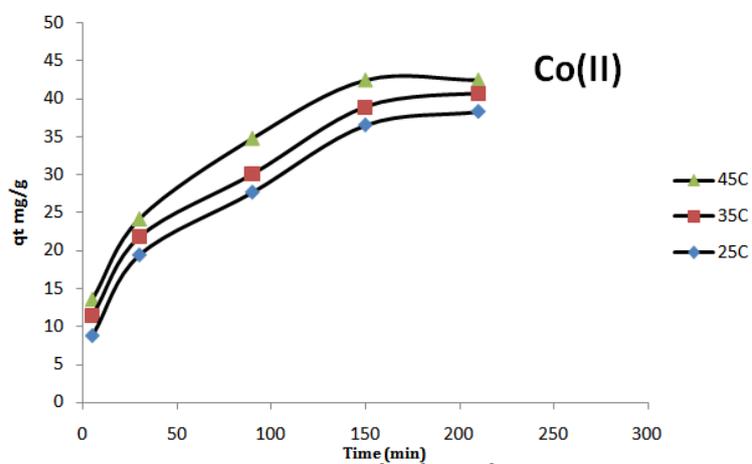


Fig. 5: Effect of different temperatures (25°C, 35°C and 45°C) on the adsorption of Co (II) ions (7.7mmol/l) by AMBERSEP 252 H.

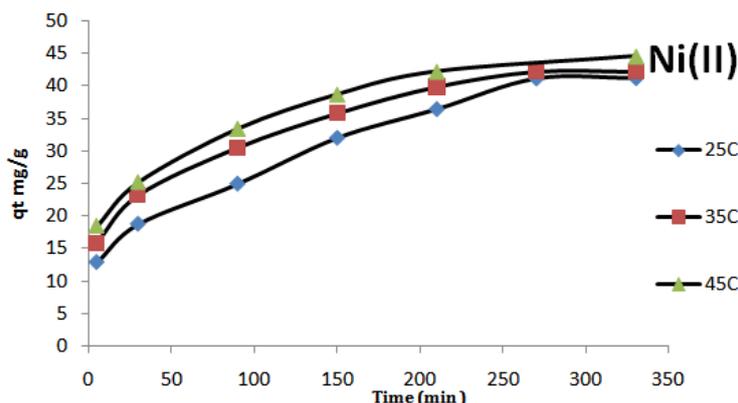


Fig. 6: Effect of different temperatures (25^oC, 35^oC and 45^oC) on the adsorption of Ni (II) ions (7.7mmol/l) by AMBERSEP 252 H.

C- Study the effect of temperatures (25^oC, 35^oC and 45^oC):

The adsorption of metal ions has been found to increase with an increase in temperature from 25 to 45^oC as shown in (Fig. 5 and 6). The increase in adsorption capacity of the adsorbent with temperature indicates an endothermic process as in (Table 2).

The increase in adsorption with temperature may be attributed to either change in pore size of the adsorbent causing inter-particle diffusion within the pores or to enhancement in the chemical affinity of the metal cations to the surface of adsorbent leading to some kind of chemical interaction to take during adsorption process which results into increase in adsorption capacity. At higher temperatures, the possibility of diffusion of solute within the pores of the adsorbent may not be ruled out as reported by earlier workers (Corupcioglu and Huang, 1987) and (Krishnan and Anirudhan, 2002).

Since diffusion is an endothermic process, greater adsorption will be observed at higher temperature. Thus the diffusion rate of metal ions in the external mass transport process increases with temperature.

The effect of temperature on adsorption is further confirmed by the Van't Hoff plots (Fig. 7 and 8) and illustrated in the following equations (3, 4, 5 and 6) and as in Ref. (Xionga et al, 2011), (Jeon et al, 2011) and (Liu et al, 2011);

$$K_D = q_e / C_e \quad (3)$$

$$\Delta G = -RT \ln K_D \quad (4)$$

$$\Delta G = \Delta H - T\Delta S \quad (5)$$

$$\ln K_D = \frac{\Delta S}{R} - \frac{\Delta H}{RT} \quad (6)$$

Where T is absolute temperature in Kelvin (K), R is the gas constant (8.314 J/mol K) and K_D is the distribution coefficient (ml/g). The thermodynamic parameters namely enthalpy change (ΔH) and the entropy change (ΔS) can be calculated from the slope and intercept of the straight line plotted by $\ln K_D$ versus $1/T$, as in (Fig. 7, 8) respectively. The Gibbs free energy change (ΔG) was determined at 298, 308 and 318 K. The obtained thermodynamic parameters were listed in (Table 2). By adsorption of abundant Co^{+2} and Ni^{+2} ions onto the surface of AMBERSEP 252 H strong cation exchange resin, the number of H^+ ions attached to activate sites of the adsorbent decreased. Therefore the positive value of ΔS suggested some structure changes in the adsorbent and adsorbate. In fact, the positive value of enthalpy ΔH further confirmed the endothermic nature of the processes, so increasing temperature supplied with a more favorable adsorption of Co^{+2} and Ni^{+2} ions onto the adsorbent (AMBERSEP 252 H). The positive Gibbs free energy value for Co^{+2} and Ni^{+2} adsorption process on the adsorbent at 298 K indicates the presence of an energy barrier in this process illustrated in Ref. (Sharma and Neetu, 2011), while the increase of temperature results in the decreasing values of these thermodynamic parameters indicating the feasibility of the process.

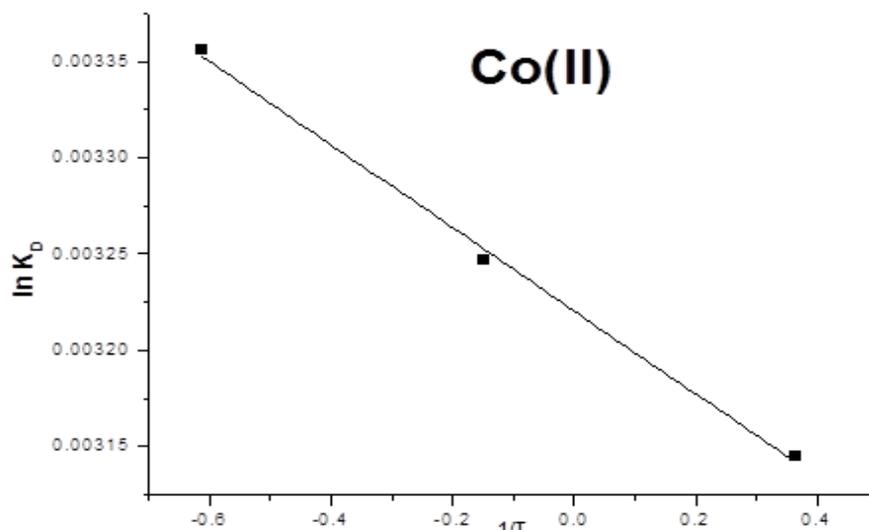


Fig.(7) Van't Hoff plot for the adsorption of Co(II) ion (7.7mmol/l) on the AMBERSEP 252 H at 25°C, 35°C and 45°C

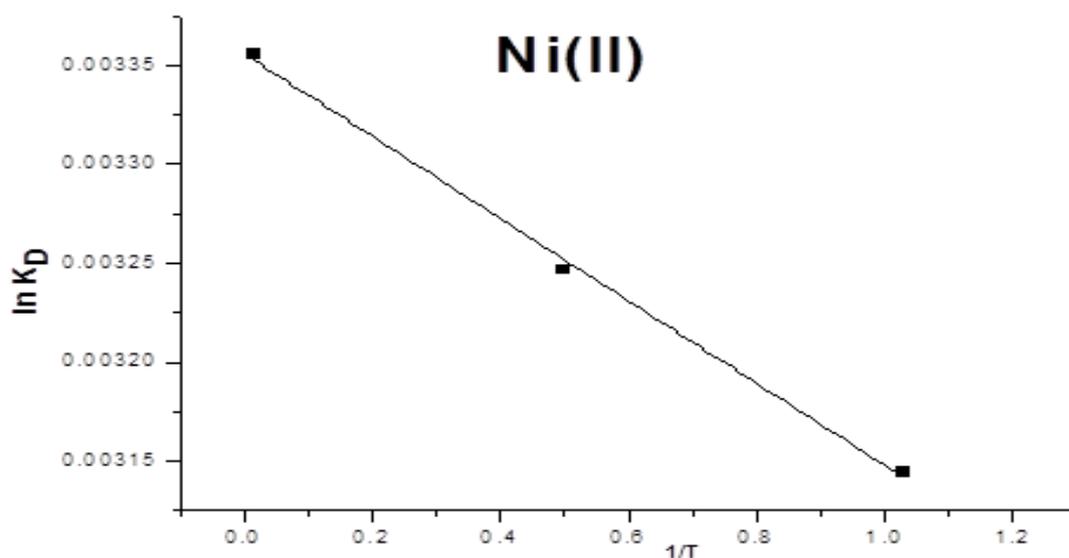


Fig.(8) Van't Hoff plot for the adsorption of Ni(II) ion (7.7mmol/l) on the AMBER SEP 252 H at 25°C, 35°C and 45°C

Table 2: Thermodynamic parameters for Co^{+2} and Ni^{+2} uptake ($C_0=7.7\text{mmol/L}$) at different temperatures (298,308 and 318 K).

Metals	ΔH (J/mol)	ΔS (J/molK)	$-\Delta G$ (J/mol)	
			Temp.,K	Value
Co^{+2}	1.79227×10^{-3}	2.677×10^{-2}	298	378
			308	964
			318	1519
Ni^{+2}	1.72856×10^{-3}	2.794×10^{-2}	298	35.649
			308	933
			318	2718

D- Adsorption isotherms:

The results obtained for the adsorption of Co(II) and Ni(II) ions were analyzed with well-known adsorption models such as Langmuir, Freundlich and Temkin.

1- Freundlich adsorption model:

The Freundlich adsorption model is known as earliest empirical equation and is shown to be consistent with exponential distribution of active centers, characteristic of heterogeneous surfaces (Ho, 2005), (Veliev *et al*, 2006).

The Freundlich adsorption equation as in (7):

$$\ln q_e = \ln k_f + \frac{1}{n} \ln C_e \quad (7)$$

where K_f and n represent the adsorption capacity and intensity, respectively.

K_f is an important constant used as relative measure for adsorption efficiency. The magnitude of the n shows an indication of the favorability of adsorption. Values of n larger than 1 show the favorable nature of adsorption as in Ref. (Daneshvar *et al*, 2002). The plot of $\ln q_e$ against $\ln C_e$, shows data for adsorption of Co(II) and Ni(II) onto AMBERSEP 252 H cation exchange resin fitting well to the Freundlich adsorption isotherm as in (Fig. 9 and 10).

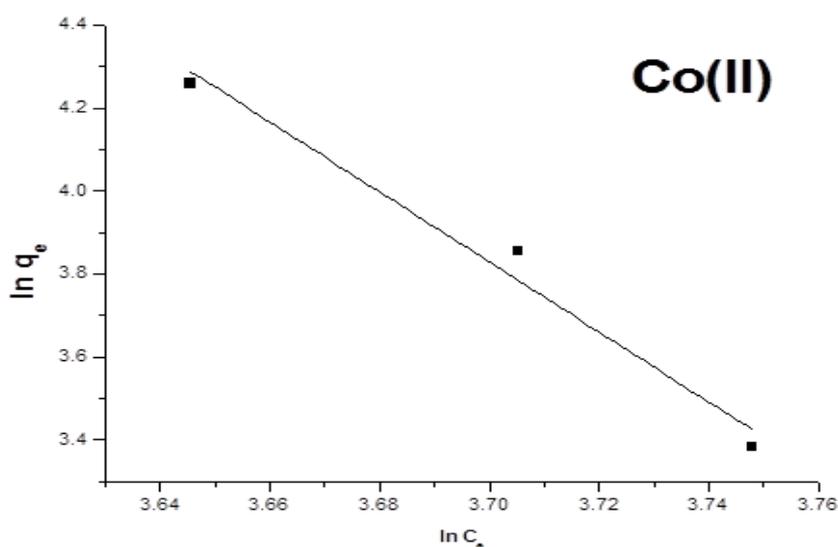


Fig.(9) Freundlich plot for Co(II) ions adsorption (7.7 mmol/l) by AMBER SEP 252 H.

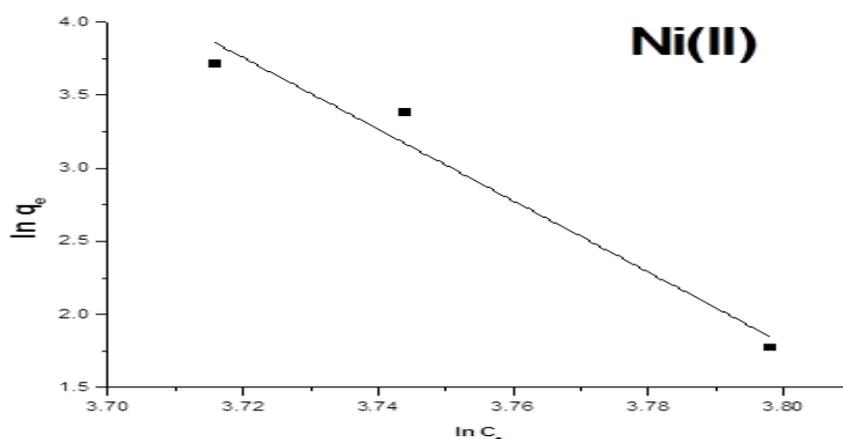


Fig.(10) Freundlich plot for Ni(II) ions adsorption (7.7 mmol/l) by AMBERSE P 252 H.

2- Langmuir adsorption model:

The Langmuir adsorption isotherm is a commonly applied model for adsorption on a completely homogenous surface with negligible interaction between adsorbed molecules as in Ref. (Gode and Pehlivan, 2005). The model assumes uniform adsorption energies onto the surface and maximum adsorption depends on

saturation level of monolayer. Langmuir adsorption model can be represented with the following linear equation(8):

$$C_e q_e = (1/k V_m) + (C_e/V_m) \quad (8)$$

where q_e represents the mass of adsorbed transition metal per unit resin (mg/g), V_m is the monolayer capacity, k is the equilibrium constant and C_e is the equilibrium concentration of the solution (mg/L). k and V_m were determined from the slope, intercept of the Langmuir plot as shown in (Fig.11 and 12).

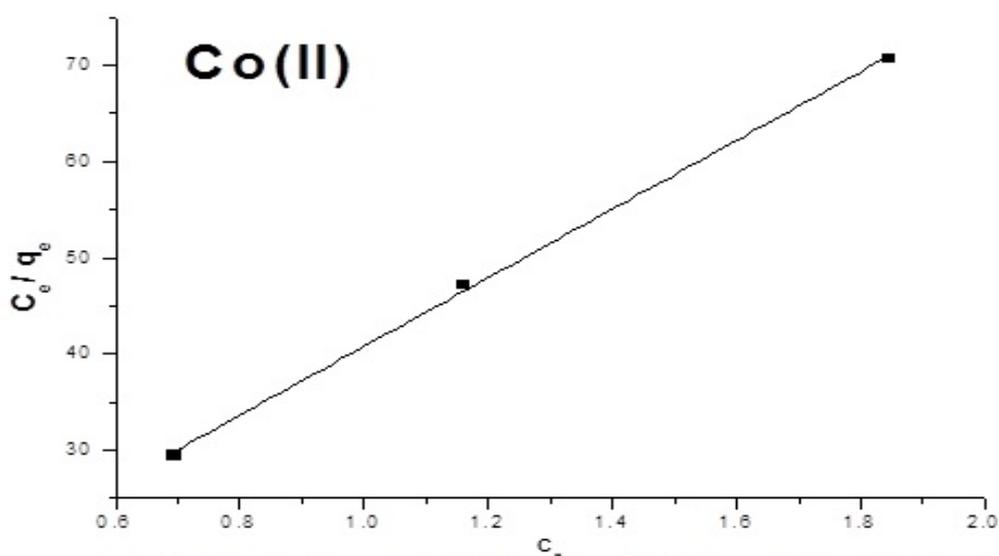


Fig.(11) Langmuir plot for Co(II) ion adsorption 7.7 mmol/l by AMBERSEP 252 H.

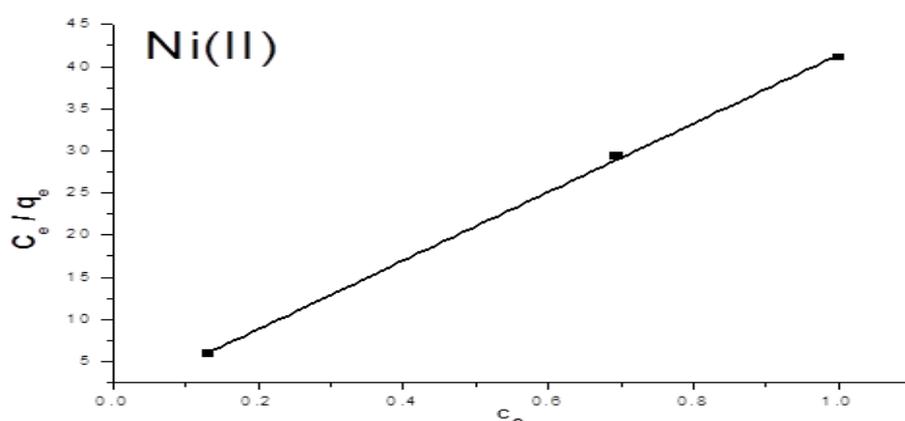


Fig.(12) Langmuir plot for Ni(II) ion adsorption (7.7 mmol/l) by AMBERSEP 252 H.

3- Temkin adsorption model:

Temkin adsorption isotherm is expressed as in equation:

$$q_e = (RT/b) \ln(AC_e) \quad (9)$$

(Eq. 9) can be expressed in its linear form as (Eq. 10):

$$q_e = (RT/b_T) \ln A_T + (RT/b_T) \ln C_e \quad (10)$$

where: (Eq. 11)

$$B_T = RT/b_T \quad (11)$$

where A_T (L/g) and b_T (J/mol) is Temkin constant representing adsorbate-adsorbent interactions and R is the gas constant (8.314 J/mol K) T is the absolute temperature. b_T constant related with adsorption heat as in Ref. (Tanet al, 2007).

Temkin isotherm takes into account the adsorbing species adsorbent interactions. Isotherm constants A and B can be determined from plot of q_e versus $\ln C_e$ as shown in (Fig. 13 and 14). From (Table 3) it is seen that value of A_T is larger for Co(II) than Ni(II). This means in cation exchange processes by using AMBERSEP 252 H, adsorbate/ adsorbate interactions are more effective for cobalt(Co^{2+}) comparing with nickel(Ni^{2+}). All constants determined from Langmuir, Freundlich and Temkin isotherms are given in (Table3).

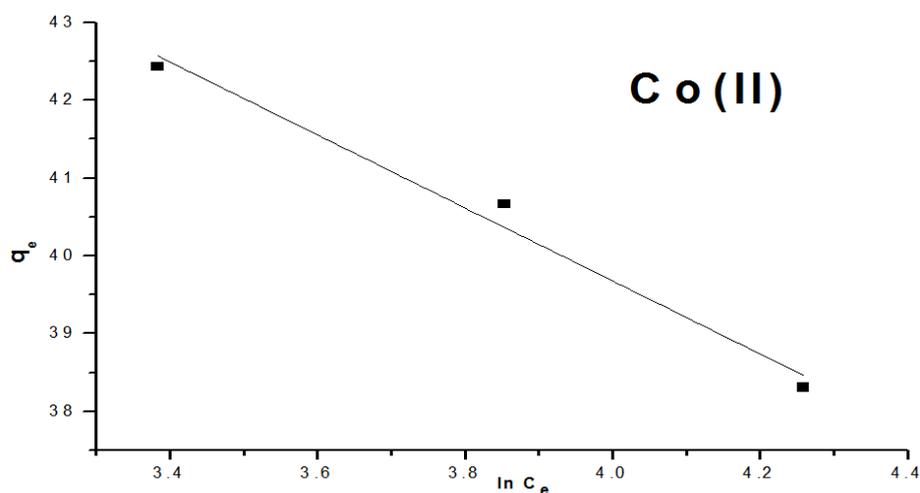


Fig. 13: Temkin plot for adsorption Co (II) ions (7.7 mmol/l) on AMBERSEP 252 H.

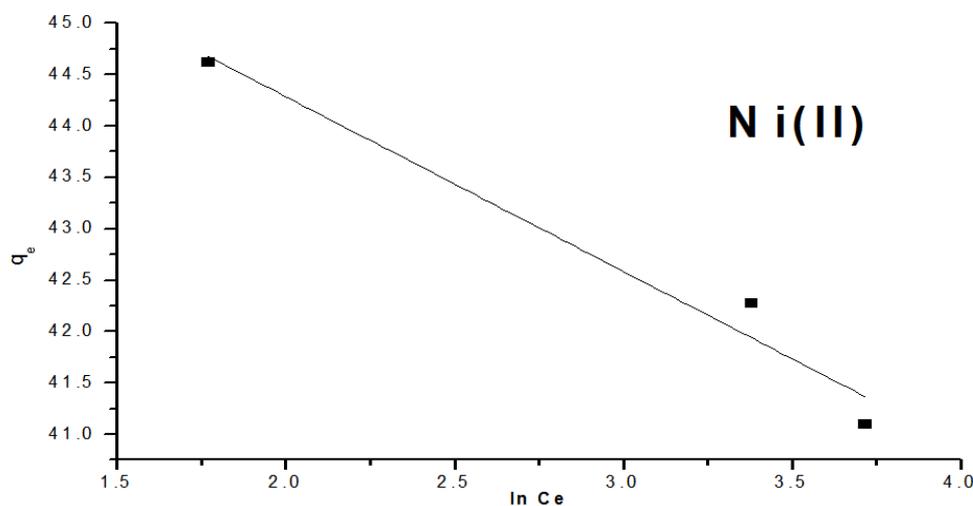


Fig. 14: Temkin plot for adsorption Ni (II) ions (7.7 mmol/l) on AMBERSEP 252 H.

Table 3: Isotherm Parameters of Freundlich, Langmuir and Temkin for removal of Co^{+2} and Ni^{+2} from aqueous solutions (7.7mmol/l).

Metal	Freundlich adsorption isotherm constants			Langmuir adsorption isotherm constants			Temkin adsorption isotherm constants		
	n	K_f	R^2	V_m	K	R^2	A	B_T	R^2
Co(II)	3.184119	1.70954×10^{15}	0.961	0.028006	7.038484	0.998	259249	4.6871	0.969
Ni(II)	1.040853	1.50259×10^{41}	0.935	0.024566	61.35997	0.999	1.53×10^{12}	1.6994	0.94209

E- Kinetics of adsorption:

Adsorption kinetics provide valuable information about the mechanism of adsorption (Veli and Oztürk, 2005). Rate of adsorbate uptake, which is required for selecting optimum operating conditions for the fullscale batch process, can be described with adsorption kinetics (Gupta and Sharma, 2003).

Chemical adsorption mechanism for cobalt (Co^{+2}) and nickel (Ni^{+2}) can be expressed with the following reactions, as in equation (12 and 13):



Rate constants (k_1 and k_2) of pseudo-first-order and pseudo-second-order kinetics were calculated from experimental data obtained from related reactions.

I- Pseudo-first-order reaction kinetic:

Simple linear equation for pseudo-first-order reaction kinetic is given below as in equation (14) and Ref. (Sharma and Bhattacharyya, 2004):

$$\ln(q_e - qt) = \ln q_{e1} - k_1 t \quad (14)$$

Where k_1 is the rate constant of the first-order adsorption, qt is the amount of transition metal adsorbed at time 't' (mg/g) and q_{e1} is the amount of transition metal adsorbed at saturation (mg/g). Plot of $\ln(q_e - qt)$ versus t allows to calculate the rate constant k_1 and q_{e1} and linear regression correlation coefficients (R^2) for pseudo-first-order reaction kinetics are summarized in (Table 4) For both cobalt (Co^{+2}) and nickel (Ni^{+2}) ions removal as illustrated in (Fig. 15 and 16).

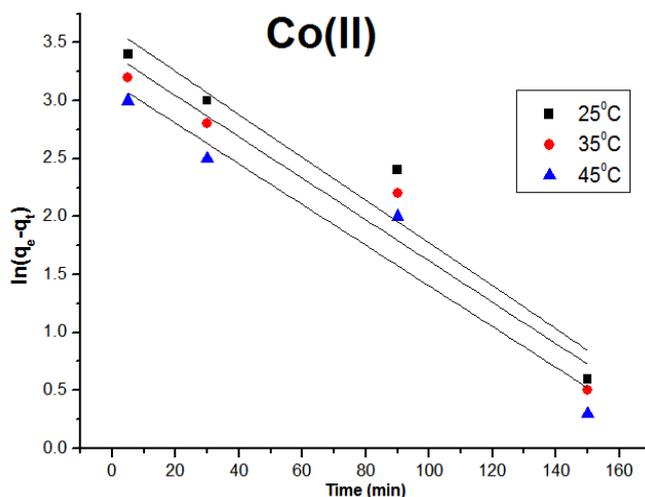


Fig. 15: Pseudo-first-order plot for Co(II) ion adsorption (7.7 mmol/l) on AMBERSEP 252 H at (25°C, 35°C and 45°C).

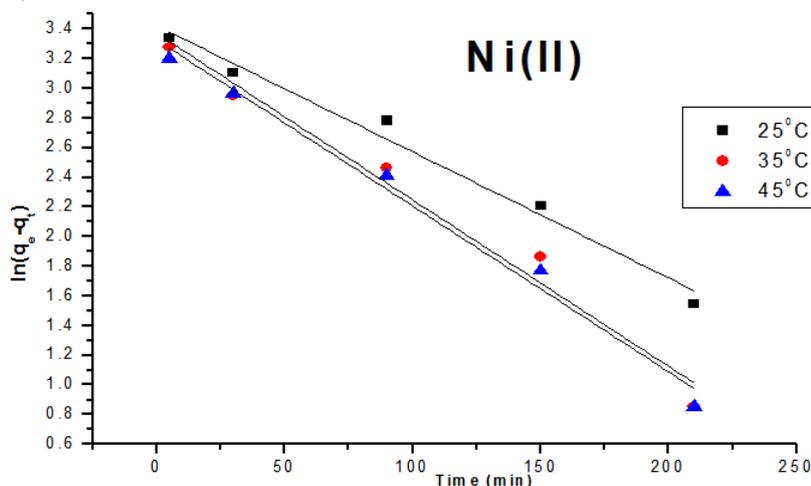


Fig. 16: Pseudo-first-order plot for Ni(II) ion adsorption (7.7 mmol/l) on AMBERSEP 252 H at (25°C, 35°C and 45°C).

Table 4: Parameters of pseudo first -order kinetic models for Co^{+2} and Ni^{+2} at different temperatures (25 $^{\circ}\text{C}$, 35 $^{\circ}\text{C}$ and 45 $^{\circ}\text{C}$).

Metals	Temp.(K)	K_1	q_{e1}	R^2
Co^{+2}	298	0.01848	37.37	0.90898
	308	0.01784	30.01	0.91837
	318	0.01753	23.46	0.90894
Ni^{+2}	298	0.0085	30.58	0.97907
	308	0.01122	29.06	0.97214
	318	0.01118	27.79	0.9837

II- Pseudo-second-order reaction kinetic:

Pseudo-second-order reaction kinetic can be expressed as in equation (15) and Ref.(Ho and McKay, 1998):

$$t/q_t = 1/k_2q_e^2 + t/q_e \quad (15)$$

where k_2 (g/mg h) is the pseudo-second-order rate constant, q_e the amount adsorbed at equilibrium and qt is the amount of metal adsorbed at time ' t '. Similar to the pseudo-first-order reaction kinetic, q_e and k_2 can be determined from the slope and intercepts of plot t/q_t versus t like in (Fig.17 and 18). Calculated rate constant (k_2), adsorbed amounts of transition metals per unit resin mass (q_{e2}) and linear regression correlation coefficients (R^2) for pseudo-second-order reaction kinetics are summarized in (Table5).

In pseudo-second-order reaction kinetic, calculated values of q_{e2} are closer to experimental values for both cobalt (Co^{+2})and nickel (Ni^{+2}). Furthermore as seen from (Table 5), correlation coefficients are higher for second order kinetic studies.

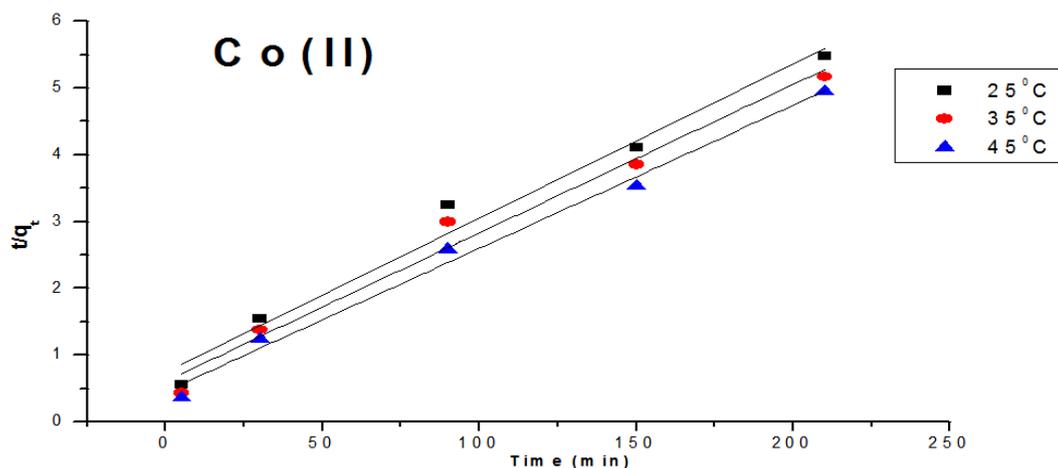


Fig. 17: Pseudo-second-order plot for Co(II) ion adsorption (7.7 mmol/l) on AMBERSEP 252 H at (25 $^{\circ}\text{C}$, 35 $^{\circ}\text{C}$ and 45 $^{\circ}\text{C}$).

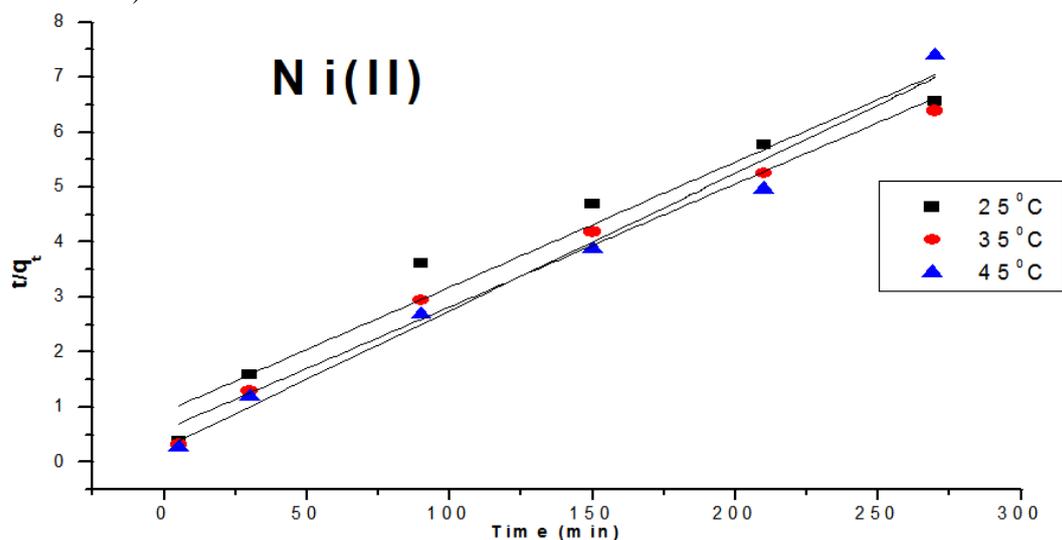


Fig. 18: Pseudo-second-order plot for Ni(II) ion adsorption (7.7 mmol/l) on AMBERSEP 252 H at (25 $^{\circ}\text{C}$, 35 $^{\circ}\text{C}$ and 45 $^{\circ}\text{C}$).

Table 5: Parameters of pseudo second -order kinetic models for Co⁺² and Ni⁺² at different temperatures (25°C, 35°C and 45°C).

Metals	Temp.(K)	K ₂	q _{e2}	R ²
Co ⁺²	298	7.07x10 ⁻⁴	43.37	0.974
	308	8.08 x10 ⁻⁴	45.02	0.975
	318	9.91 x10 ⁻⁴	46.75	0.988
Ni ⁺²	298	5.96x10 ⁻⁴	43.98	0.948
	308	8.56x10 ⁻⁴	44.70	0.982
	318	18.63x10 ⁻⁴	45.58	0.980

Conclusions:

The aim of this work was to investigate removal of cobalt (Co⁺²) and nickel (Ni⁺²) from aqueous solutions by using AMBERSEP 252 H cation exchange resin. Optimal removal conditions for both metals were determined with batch experiments. Adsorption of cobalt (Co⁺²) ions reached equilibrium faster (within 210 min) comparing with nickel (Ni⁺²) ions (within 270 min). Experimental results were evaluated with Langmuir, Freundlich and Temkin adsorption isotherms. In addition to higher values of correlation coefficients, monolayer capacities (V_m) determined from Langmuir isotherm and adsorption intensities (n) determined from Freundlich isotherm indicate appropriateness of Langmuir and Freundlich adsorption isotherms for both metals.

In Temkin adsorption isotherm, it was stated that adsorbate/adsorbate interactions are weaker for nickel (Ni⁺²) removal due to smaller values of Temkin constants. Pseudo-second-order reaction kinetic has provided a realistic description for removal of (Co⁺²) and (Ni⁺²) with closer experimental and calculated values of q_e . Also correlation coefficients are higher in pseudo-second-order kinetics. Experimental and theoretical results of this study demonstrate that AMBERSEP 252 H cation exchange resin is suitable for adsorption of cobalt (Co⁺²) and nickel (Ni⁺²) from aqueous solutions.

References

- Alyüz, B., S. Veli, 2009. Journal of Hazardous Materials, 167: 482-488.
- Chan, S.S., H. Chow, M.H. Wong, 1991. Biomed; Environ. Sci., 4: 250-260.
- Clifford, D.A., 1990. A Handbook of Community Water Supplies, fourth ed., American Water Works Association, McGraw Hill, New York.
- Corupcioglu, M.O., C.P. Huang, 1987. Water Res., 21: 1031.
- Crini, G., P.M. Badot, 2010. Int. J. Environ. Technol. Manage., 12: 129-150.
- Dabrowski, A., Z. Hubicki, P. Podkoscielny, E. Robens, 2004. Chemosphere, 56: 91-106.
- Daneshvar, N., D. Salari, S. Aber, 2002. J. Hazard. Mater, 94: 49-61.
- Demirbas, A., E. Pehlivan, F. Gode, T. Altun, G. Arslan, 2005. J. Colloid and Interface Sci., 282: 20-25.
- Forstner, U., G.T.W. Wittman, 1979. Springer- Verlag, Berlin.
- Gode, F., E. Pehlivan, 2003. J. Hazard. Mater, B100: 231-243.
- Gode, F., E. Pehlivan, 2005. Fuel Process. Technol., 86: 875-884.
- Gode, F., E. Pehlivan, 2006. J. Hazard. Mater, B136: 330-337.
- Gupta, V.K., S. Sharma, 2003. Ind. Eng. Chem. Res., 42: 6619-6624.
- Ho, Y.S., 2005. Bioresour. Technol., 96: 1292-1296.
- Ho, Y.S., G. McKay, 1998. J. Chem. Eng., 70: 115-124.
- Jeong, E., M.B. Ansari, Y. Mo, S. Park, 2011. J. Hazard. Mater, 185: 1550-1557.
- Krishanan, K.A., T.S. Anirudhan, 2002. J. Hazard. Mater, 92: 161.
- Lin, S.H., S.L. Lai, H.G. Leu, 2000. J. Hazard. Mater, 76: 139-153.
- Liua, Y., Z. Liub, J. Gaoa, J. Daia, J. Hana, Y. Wanga, J. Xiea, Y. Yana, 2011. J. Hazard Mater, 186: 197-205.
- Rengaraj, S., S.H. Moon, 2002. Water Res., 36(7): 1783.
- Rengaraj, S., Y. Kyeong-Ho, M. Seung-Hyeon, 2001. J. Hazard. Mater, B87: 273-287.
- Sharma, A., K.G. Bhattacharyya, 2004. Adsorption, 10: 327-338.
- Sharma, P., 2011. Neetu; Desalination, 267: 277-285.
- Tan, I.A.W., B.H. Hameed, A.L. Ahmad, 2007. J. Chem. Eng., 127: 111-119.
- Veli, S., B. Alyüz, 2007. J. Hazard. Mater, 149: 226-233.
- Veli, S., T. Oztürk, 2005. Fresenius Environ. Bull., 14: 347-353.
- Veliev, E.V., T. Oztürk, S. Veli, A.G. Fatullayev, 2006. Pol. J. Environ. Stu., 15: 347-353.
- Verbych, S., N. Hilal, G. Sorokin, M. Leaper, 2004. Sep. Sci. Technol., 39: 2031.
- Xionga, L., C. Chena, Q. Chen, J. Nia, 2011. J. Hazard. Mater, 189: 741-748.