

Adsorption of Ni(II) on ion exchange resin: Kinetics, equilibrium and thermodynamic studies

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Abstract—This article describes the ion exchange of a heavy metal Ni(II) from aqueous solutions onto a Dowex HCR-S, cationic resin. Batch adsorption studies were conducted to evaluate the effect of various parameters such as pH, resin dose, stirring speed, temperature, contact time and initial Ni(II) concentration on the removal of Ni(II). Adsorption rate increased with the increase in initial nickel concentration, stirring speed and temperature. Equilibrium adsorption isotherms were measured for the single component system, and the experimental data were analyzed by using Langmuir, Freundlich, Elovich, Temkin, Khan, Sips, Toth, Koble-Corrigan and Radke-Prausnitz isotherm equations. The Sips equation appears to fit the equilibrium data. Different models were tested for their applicability. Adsorption kinetic data were modeled using the Lagergren pseudo-first-order, Ho's pseudo-second-order and Elovich models. It was found that Ho's pseudo-second-order model could be used for the prediction of the system's kinetics. Thermodynamic activation parameters such as ΔG° , ΔS° and ΔH° of the adsorption of Ni(II) on Dowex HCR-S cationic resin were also calculated.

Key words: Nickel, Dowex HCR-S, Isotherm, Ion Exchange, Removal

INTRODUCTION

Effluent limits have become stricter in recent years, causing the chemical process industries to upgrade their wastewater. To meet these limits, plants have to employ sophisticated chemical and physical processes because biological treatment alone is not adequate. One of the most water polluting industries is the metal finishing industry. Metal finishing wastewater contains heavy metal ions such as Zn(II), Ni(II), Cu(II), Pb(II), Cd(II), Ag(I) and Cr(VI), besides toxic anions such as CN^- . Nickel ions also exist in waste solutions resulting from the battery industry. Ni has many useful application in our life however, it is harmful if discharged into natural water resources [1]. Ni(II) is present in the effluents of silver refineries, electroplating, zinc base casting and storage battery industries. At higher concentrations, Ni(II) causes cancer of lungs, nose and bone. Dermatitis (Ni itch) is the most frequent effect of exposure to Ni, such as coins and costume jewelry. Ni carbonyl ($\text{Ni}(\text{CO})_4$) has been estimated as lethal in humans at atmospheric exposures of 30 ppm for 30 min. 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 wastewaters before mixing with natural water sources [2,3].

Previous researchers reported reasonable methods, from the economical and technological point of view, to remove heavy metals in general from surface waters, with the aim of the preservation of the entire ecosystem from the damages due to their accumulation [4,5]. Among the various treatment techniques available, the most commonly used ones are [6,7]:

- Reduction and precipitation
- Ion exchange
- Adsorption

These methods suffer from some drawbacks such as high capital and operational costs or the treatment and disposal of the residual metal sludge. The main advantages of ion exchange over chemical precipitation and adsorption are recovery of metal value, selectivity, less sludge volume produced and the meeting of strict discharge specifications. In ion exchange systems, polymeric resins are usually employed [6,8,9].

In the literature are available a number of studies about adsorption and ion exchange of nickel. Some of these studies are listed as follows: mordenite surfaces [10], diatomite [11], carbon nanotubes [12-14], bentonite [15], Na-attapulgite [16], carbon nanotube/iron oxide magnetic composites [17], Na-montmorillonite [18], Na-rec-torite [19,20], bare and ACT-graft attapulgites [21].

The main objective of this work is to investigate equilibrium and kinetic parameters of the Dowex HCR S/H ion-exchange resin as an adsorbent for the removal of nickel from synthetically prepared wastewater. The parameters that influence adsorption such as initial nickel concentration, stirring speed, resin dosage, temperature, pH and contact time were investigated. The experimental information was also fitted to the Langmuir, Freundlich, Temkin, Khan, Sips, Koble-Corrigan and The Radke-Prausnitz isotherm models. The results were analyzed on the basis of first-order Lagergren, second-order and pseudo second-order and intra-particle models.

MATERIALS AND METHOD

Synthetic Dowex HCR S/H in hydrogen form was obtained from Fluka Co. The properties of Dowex HCR S/H are given in Table 1. Both acidic and salt forms of the resin are stable up to 100 °C. Stock

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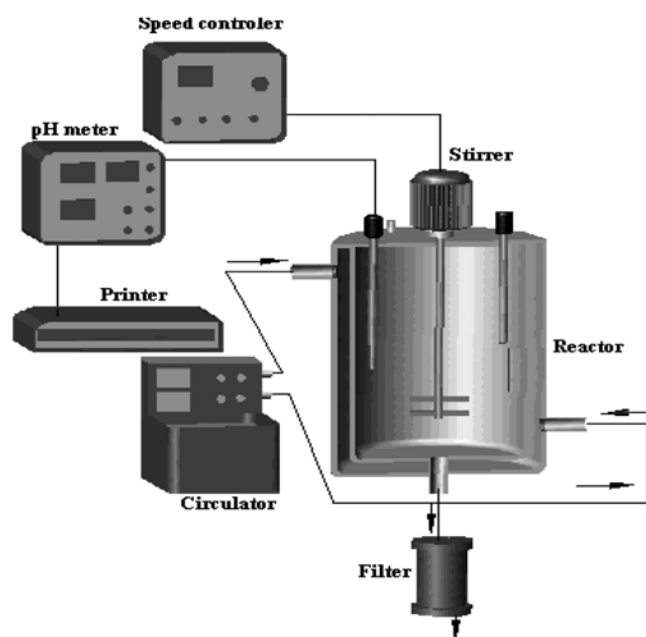
Table 1. Properties of Dowex HCR-S resin (a) and experimental parameters (b)

Parameters	Value
Type	Strong acid cation
Change capacity	1.8 meq/ml
Particulate size	300-1,200 μm
(a) pH	0-14
Max. oper. temperature	100 $^{\circ}\text{C}$
Ionic form	H^+
Ionic density	1.22 g/cm^3
Physical form	Uniform particle size spherical beads
Parameter	Study ratio
(b) Initial nickel concentration mg/L	25, 50, 100, 250, 500 and 1000
Adsorbent dosage ($\text{g}/500 \text{ ml}$)	0.25, 0.50, 1.00, 1.50 and 2.00
pH	3.0, 4.0, 5.0, 6.0 and 7.0
Stirring speed (rpm)	200, 300, 400, 500 and 600
Solution temperature (K)	293, 313, 333 and 353

solutions of Ni(II) chloride (Analytical grade from Sigma Co) were prepared in double-distilled water. The parameters chosen in the experiments were initial pH of the solution, contact time, adsorbent dosage, stirring speed, solution temperature and initial metal ion concentration, whose ranges are given in Table 1. A batch system was used for removing by the exchange reaction of nickel from wastewater. The temperature of the reactor was controlled with a HAAKE D8 thermostat connected to reactor. Experimental setup is seen in Fig. 1.

The amount of metal adsorbed (mg g^{-1}), (q_t), onto Dowex HCR S/H was calculated from the mass balance equation as follows:

$$q_t = \frac{(C_o - C_t) \cdot V}{m} \quad (1)$$

**Fig. 1. Experimental set up.**

where C_o and C_t are the initial and equilibrium liquid phase concentrations of metal solution (mg L^{-1}), respectively; V the volume of metal solution (L), and m the mass of resin amount used (g). Kinetic experiments were done by using 500 ml of nickel solutions of various concentrations. Samples were taken at different time intervals, and remaining metal concentrations were analyzed with a Shimadzu AA-6800 atomic absorption spectrophotometer according to Standard Methods [22]. The rate constants were calculated using conventional rate expressions. The following formula was used to determine adsorbed metal concentration q_t :

$$q_t = \frac{(C_o - C_t) \cdot V}{m} \quad (2)$$

where q_t (mg g^{-1}) is the adsorption capacity at time t , C_o (mg L^{-1}) is the initial metal concentration, C_t (mg L^{-1}) 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.

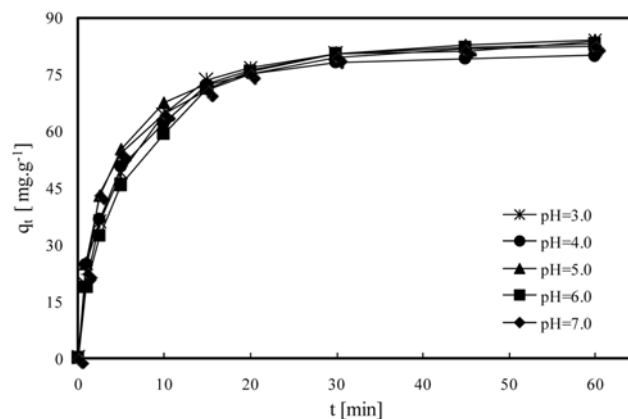
RESULTS AND DISCUSSION

1. Effect of pH on Removal by Ion Exchange

The effect of solution pH was studied for Ni(II) removal by Dowex HCR S/H in a range of 3.0 to 7.0 under the conditions given in Table 1. It was found that the adsorption capacity unchanged with a changed in pH; as it can be seen from Fig. 2. Strongly acidic resin was used in experimental studies. The pH values ranged from 2.5 to 3.5 in experiments that examined change in the pH balance. There was no effect of initial pH value of solution adsorption rate. Similar results were reported in the literature [23]. Therefore, in all the experiments, 250 mg L^{-1} solution of natural pH value of about pH 6 was studied.

2. Effect of Initial Nickel Concentration on Removal by Ion Exchange

The effect of initial metal concentration in the range of 25 to 1,000 mg L^{-1} on Ni(II) removal was investigated and is shown in Fig. 3. The initial metal concentration provides the necessary driving force to overcome the resistance to the mass transfer of Ni(II) between aqueous phase and the solid phase. The increase in initial metal concentration also enhances the interaction between Ni(II) and resin. Therefore, an increase in initial concentration of Ni(II) enhances

**Fig. 2. The effect of initial pH on adsorption capacity (250 mg L^{-1} initial Ni^{2+} concentration, 293 K solution temperature, 400 rpm stirring speed, 1 $\text{g}/500 \text{ ml}$ resin dosage).**

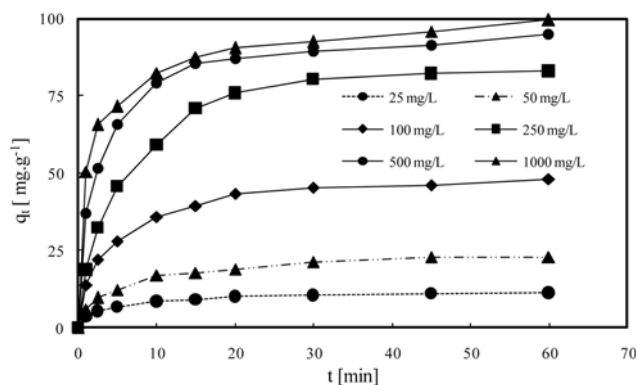


Fig. 3. The effect of initial nickel concentration on adsorption capacity (pH 6.0, 293 K solution temperature, 400 rpm stirring speed, 1 g/500 ml resin dosage).

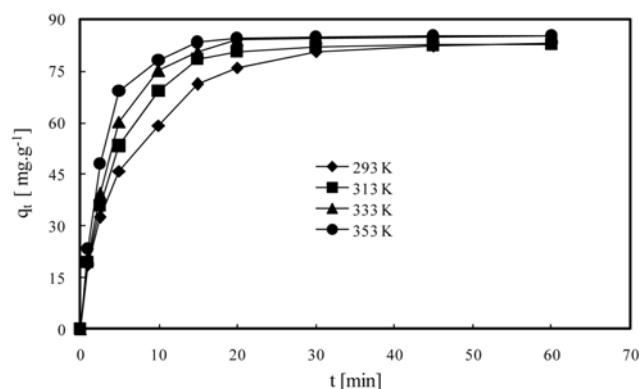


Fig. 5. The effect of solution temperature on adsorption capacity (pH 6.0, 1 g/500 ml resin dosage, 400 rpm stirring speed and 250 mgL⁻¹ initial Ni²⁺ concentrations).

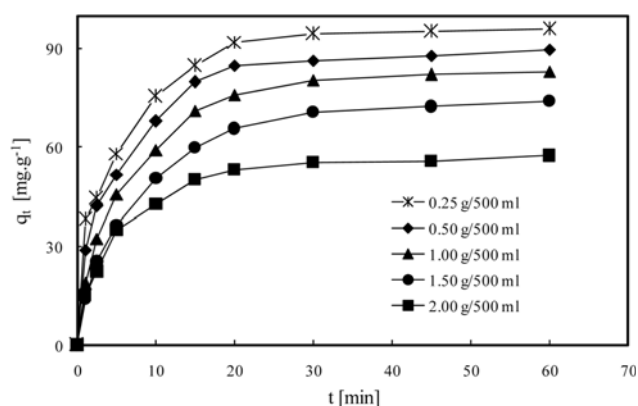


Fig. 4. The effect of resin dosage on adsorption capacity (pH 6.0, 293 K solution temperature, 400 rpm stirring speed and 250 mgL⁻¹ initial Ni²⁺ concentrations).

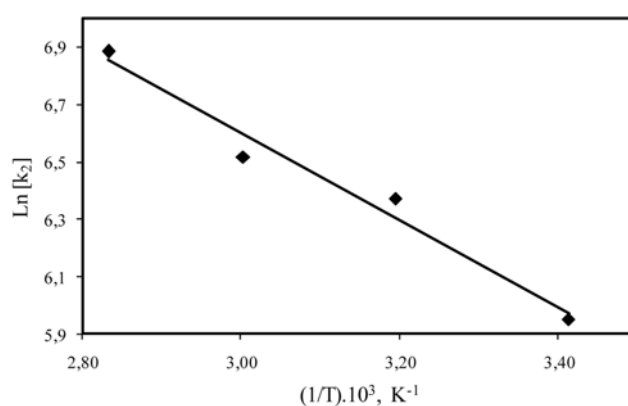


Fig. 6. Arrhenius plots for ion exchange Ni(II) onto Dowex HCR S/H (pH 6.0, 400 rpm stirring speed, 1 g/500 ml resin dosage and 250 mgL⁻¹ initial Ni²⁺ concentration).

the ion exchange of Ni(II). This is due to increase in the driving force of the concentration gradient, as an increase in the initial metal concentration [24].

3. Effect of Resin Dosage on Removal by Ion Exchange

The effect of adsorbent dosage on the adsorption rate of the nickel was studied, while other experimental conditions were kept constant as the adsorbent concentration was varied from 0.25 to 2.0 g/500 ml. Fig. 4 shows the ion exchange of Ni(II) as a function of resin dosages. It is apparent that by increasing the resin dose the amount of adsorbed Ni(II) increases, but exchange density, the amount adsorbed per unit mass, decreases. It is readily understood that the number of available adsorption sites increases by increasing the adsorbent dose and it, therefore, results in the increase of the amount of adsorbed Ni(II). The decrease in exchange density with increase in the adsorbent dose is mainly because of unsaturation of adsorption sites through the exchange process [25]. Similar results were reported in the literature [18].

4. Effect of Solution Temperature on Removal by Ion Exchange

Fig. 5 shows the effect of the temperature on the adsorption of Ni(II) onto Dowex HCR S/H. Metal uptake was studied using different temperatures of Dowex HCR S/H by using 500 ml of solution at pH 6.0, 1.00 g dosage, and initial concentration of 250 mg

L⁻¹. The temperatures were 293, 313, 333 and 353 K, keeping the batch experimental volume the same in each case. The results indicated that the percent ion exchange increased with increase in temperature. The increase in adsorption with temperature may be attributed to either increase in the number of active surface sites available for adsorption on the adsorbent or the decrease in the thickness of the boundary layer surrounding the adsorbent with temperature, so that the mass transfer resistance of adsorbate in the boundary layer decreases. Moreover, increasing temperature results in an increase in the rate of approach to equilibrium [26].

Activation energy is calculated from an Arrhenius plot (Fig. 6). The value of the activation energy indicates the type of sorption (physical, 5-40 kJ mol⁻¹ or chemical, 40-800 kJ mol⁻¹) [27]. The activation energy obtained (12.661 kJ mol⁻¹) for sorption of nickel by Dowex HCR S/H indicates that the sorption faced a potential barrier.

5. Effect of Stirring Speed on Removal by Ion Exchange

The effect of different stirring speeds from 200 to 600 rpm while keeping all other parameters constant on ion exchange capacity was determined (250 mg L⁻¹ initial nickel concentration, 293 K, 1.00 g/500 ml resin amount and solution pH 6.0). Investigated stirring speeds were selected as 200, 300, 400, 500, and 600 rpm (Fig. 7). The quality

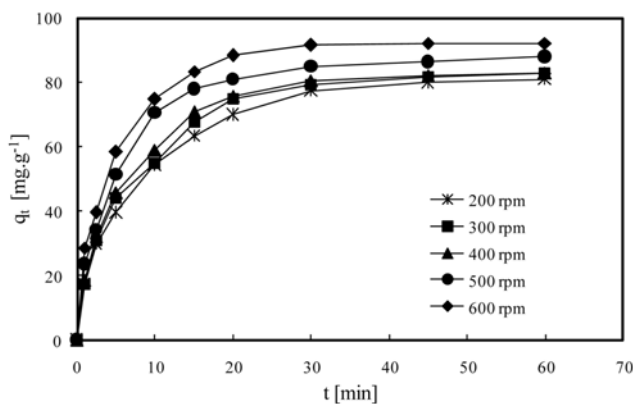


Fig. 7. The effect of stirring speed on adsorption capacity (pH 6.0, 1 g/500 ml resin dosage, 293 K solution temperature and 250 mgL⁻¹ initial Ni²⁺ concentration).

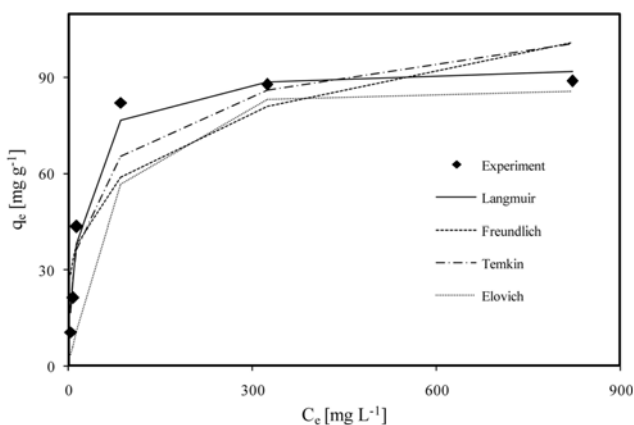


Fig. 8. The comparison between experimental data and isotherm data for two parameter models (pH 6.0, 293 K solution temperature, 400 rpm stirring speed, 1 g/500 ml resin dosage).

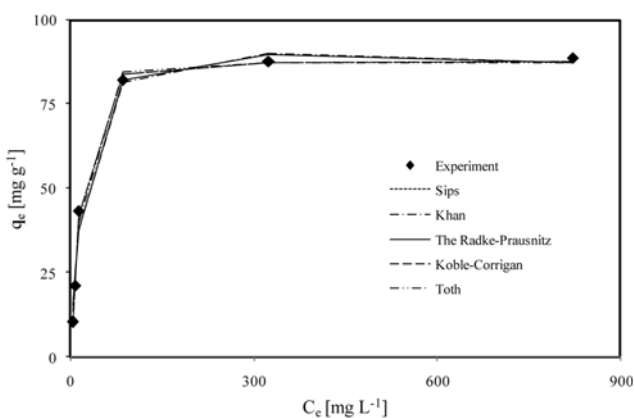


Fig. 9. The comparison between experimental data and isotherm data for three parameter models (pH 6.0, 293 K solution temperature, 400 rpm stirring speed, 1 g/500 ml resin dosage).

of the dispersion of the solid in adsorption on a batch reactor is a significant factor as in all processes of mass transfer. Stirring influences the distribution of the aqueous solution and can also act on

Table 2. Isotherm models equations (a) and kinetic models equations (b)

Isotherm	Mathematical equations	References
Langmuir	$q_e = (q_m K_L C_e) / (1 + K_L C_e)$	[29]
Freundlich	$q_e = K_F C_e^{1/n}$	[30]
Elovich	$q_e/q_m = K_E C_e \exp(-q_e/q_m)$	[31]
(a) Temkin	$q_e = (RT/b) \ln(K_T C_e)$	[32]
Sips	$q_e = (q_m a_s C_e^{1/n}) / (1 + a_s C_e^{1/n})$	[33]
Khan	$q_e = (q_m b_K C_e) / (1 + b_K C_e)^{a_K}$	[34]
Radke-Prausnitz	$q_e = (A R C_e^p) / (A + R C_e^{p-1})$	[35]
Koble-Corrigan	$q_e = (A C_e^n) / (1 + B C_e^n)$	[36]
Toth	$q_e = (q_m C_e) / (K_{To} + C_e^{1/n})$	[37]
Kinetic model	Mathematical equations	References
Pseudo-first order rate model	$\ln(q_e - q_t) = \ln q_e - k_1 t$	[39]
(b) Pseudo-second-order rate model	$t/q_t = [1/k_2 q_e^2] + (1/q_e)t$	[40]
Elovich model	$q_t = \beta \ln(\alpha \beta) + \beta \ln t$	[41]
Intra Particle model	$q_t = k_{diff} t^{1/2} + C$	[42]
Pseudo-first order rate model	$\ln(q_e - q_t) = \ln q_e - k_1 t$	[43]

Table 3. The data for two parameter isotherms (a) and three parameter isotherms (b)

Langmuir isotherm	Freundlich isotherm		
K_L	0.051472	K_F	20.22241
q_m	94.10062	1/n	0.239819
R^2	0.98920	R^2	0.89456
(a) Temkin isotherm	Elovich isotherm		
K_T	0.760696	q_m	374.0929
b	155.7899	K_E	0.002222
R^2	0.95244	R^2	0.73920
Sips isotherm	Koble-Corrigan isotherm		
q_m	87.81075	A	0.995674
a_s	0.011240	B	0.011339
n	0.587414	n	1.699156
R^2	0.99926	R^2	0.99922
Khan isotherm	Toth isotherm		
q_m	123.6406	q_m	87.46935
b_K	0.034748	K_{To}	1298.506
a_K	1.09219	n	2.181877
R^2	0.99336	R^2	0.99685
The Radke-Prausnitz isotherm			
A	4.098332		
R	151.4547		
p	-0.078148		
R^2	0.99389		

the formation of an external film of separation. The results show that increases in stirring speed from 200 to 600 rpm significantly modify the coefficient of diffusion of metal ions on the resin. It can be

concluded that liquid film thickness decreases with increasing stirring speed. Therefore, ion exchange capacity increases with increasing stirring speed. Similar results are available in the literature [28].

6. Adsorption Isotherms

Accordingly, we evaluated the fitness of the equilibrium data obtained from the experiments at different conditions (Table 1) with the Langmuir, Freundlich, Temkin, Elovich, Sips, Koble-Corrigan, The Radke-Prausnitz, Khan and Toth (Table 2) models [29-37].

The best fitted model was selected based on the determination coefficient (R^2). The data from the isotherm evaluation are summarized in Table 3 (for two parameters and three parameters). Based on the information in Table 3, the R^2 of the Sips isotherm model for all tested temperatures was higher than the other fitted models, showing that the equilibrium experimental data was better explained by the Sips equation [38].

7. Kinetic Study

To analyze adsorption kinetic behavior of Ni(II) onto resin, adsorption reaction models were given in Table 2 [39-42]. The kinetic mod-

els of pseudo-first order, pseudo-second order and Elovich assume that adsorption is a pseudo reaction, and the adsorption rate can be determined, respectively, for equations of pseudo-first order, pseudo-second order and Elovich equations. Calculated rate constants, adsorbed amounts of heavy metals per unit resin mass (q_e) and linear regression correlation coefficients (R^2) for pseudo-first-order, pseudo-second-order and Elovich reaction kinetics are summarized in Table 4. In pseudo-second-order reaction kinetic, calculated values of q_e are closer to experimental values of nickel. Furthermore, as seen from Table 4, correlation coefficients are higher for second order kinetic studies. The obtained results are shown for initial metal concentrations in Fig. 10.

Besides adsorption on the outer surface of adsorbent, there is also a possibility of transport of adsorbate Ni(II) ions from the solution to the pores of the adsorbent resin due to vigorous stirring during the adsorption process. It is probably reasonable to assume that the rate is not limited by mass transfer of Ni(II) from the bulk liquid to the resin particle external surface. One might then postulate that

Table 4. Kinetics data calculated for ion exchange of Ni(II) on Dowex HCR-S/H

Resin dosage (g/500 ml)	Temperature (K)	Initial metal concentration (mg L ⁻¹)	pH	Stirring speed (rpm)	Kinetic models												
					The elovich equation			Pseudo - first - order		Pseudo - second - order			Intra-particle model				
					$\alpha (\times 10^{-5})$ mg g ⁻¹ min ⁻¹	β g mg ⁻¹	R^2	k_1 min ⁻¹	R^2	$h=k_2xq_e^2$ mg g ⁻¹ min ⁻¹	$k_2 \times 10^3$ g mol ⁻¹ min ⁻¹	R^2	k_1 mg g ⁻¹ min ^{-1/2}	R_1^2	k_2 mg g ⁻¹ min ^{-1/2}	R_2^2	
1.00	293	250	6.0	400	53.205	0.058	0.973	0.1043	0.991	26.385	0.003	0.996	17.830	0.991	2.892	0.848	
1.00	303	250	6.0	400	73.130	0.060	0.925	0.1601	0.992	38.911	0.005	0.997	20.493	0.978	0.567	0.794	
1.00	313	250	6.0	400	92.927	0.061	0.903	0.1329	0.919	47.170	0.006	0.998	20.954	0.944	0.343	0.981	
1.00	323	250	6.0	400	163.346	0.068	0.852	0.1330	0.889	66.667	0.009	0.999	25.109	0.910	0.467	0.817	
1.00	293	25	6.0	400	11.751	0.503	0.988	0.0853	0.981	4.098	0.031	0.997	1.961	0.971	0.501	0.899	
1.00	293	50	6.0	400	16.351	0.227	0.992	0.0964	0.970	6.614	0.011	0.994	4.230	0.968	1.380	0.924	
1.00	293	100	6.0	400	46.057	0.114	0.982	0.0709	0.916	17.513	0.007	0.997	8.846	0.976	1.916	0.870	
1.00	293	250	6.0	400	53.205	0.058	0.973	0.1043	0.991	26.385	0.003	0.996	17.830	0.991	2.892	0.848	
1.00	293	500	6.0	400	247.554	0.070	0.959	0.0686	0.856	54.348	0.006	0.999	16.769	0.966	2.389	0.990	
1.00	293	1000	6.0	400	1097.067	0.085	0.983	0.0630	0.860	64.935	0.006	0.998	12.282	0.949	2.909	0.987	
0.25	293	250	6.0	400	144.946	0.061	0.951	0.1118	0.954	46.083	0.005	0.997	17.073	0.993	2.354	0.681	
0.50	293	250	6.0	400	99.878	0.062	0.960	0.0872	0.916	19.084	0.002	0.997	17.370	0.997	2.168	0.849	
1.00	293	250	6.0	400	53.205	0.058	0.973	0.1043	0.991	26.385	0.003	0.996	17.830	0.991	2.892	0.848	
1.50	293	250	6.0	400	36.768	0.062	0.979	0.0869	0.976	18.868	0.003	0.993	15.883	0.996	3.363	0.856	
2.00	293	250	6.0	400	45.732	0.089	0.962	0.0815	0.903	21.097	0.006	0.997	12.229	0.980	1.667	0.862	
1.00	293	250	6.0	200	43.606	0.059	0.985	0.0959	0.997	20.833	0.003	0.993	15.829	0.994	4.340	0.853	
1.00	293	250	6.0	300	46.743	0.058	0.980	0.0933	0.989	22.936	0.003	0.994	16.884	0.987	3.595	0.842	
1.00	293	250	6.0	400	53.205	0.058	0.973	0.1043	0.991	26.385	0.003	0.996	17.830	0.991	2.892	0.848	
1.00	293	250	6.0	500	71.346	0.058	0.953	0.0916	0.950	33.670	0.004	0.997	19.787	0.985	2.484	0.918	
1.00	293	250	6.0	600	98.721	0.058	0.947	0.1501	0.996	43.290	0.005	0.998	19.679	0.983	1.983	0.716	
1.00	293	250	3.0	400	66.040	0.061	0.964	0.0801	0.907	31.153	0.004	0.997	18.417	0.982	2.401	0.912	
1.00	293	250	4.0	400	89.345	0.068	0.961	0.1020	0.963	36.101	0.005	0.998	16.301	0.986	1.915	0.874	
1.00	293	250	5.0	400	110.057	0.068	0.970	0.0862	0.964	37.879	0.005	0.998	16.074	0.940	2.955	0.921	
1.00	293	250	6.0	400	53.205	0.058	0.973	0.1043	0.991	26.385	0.003	0.996	17.830	0.991	2.892	0.848	
1.00	293	250	7.0	400	100.873	0.068	0.969	0.0973	0.984	36.101	0.005	0.998	15.689	0.921	2.922	0.881	

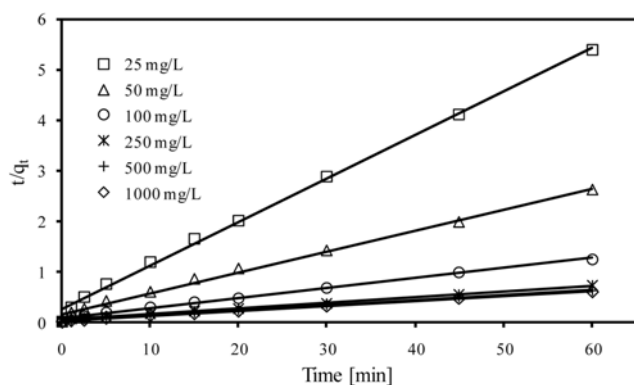


Fig. 10. Second-order kinetic equation for ion exchange Ni(II) onto Dowex HCR S/H at different initial metal concentrations (pH 6.0, 293 K solution temperature, 400 rpm stirring speed, 1 g/500 ml resin dosage).

Table 5. Thermodynamic parameters for ion exchange of Ni(II) on Dowex HCR-S/H

	293 K	303 K	313 K	323 K
ΔG^* (kJ mol ⁻¹)	57.165	60.385	63.605	66.825
ΔH^* (kJ mol ⁻¹)		9.994		
ΔS^* (kJ mol ⁻¹ K ⁻¹)		-0.16099		

the rate-limiting step may be film or intra-particle diffusion. The most commonly used technique for identifying the mechanism involved in the ion exchange process is by using the intra-particle diffusion model [43] given by Table 4. Correlation coefficients and constants are given in Table 4.

8. Activation Parameters

The second-order rate constants listed (Table 5) have been used to estimate the activation energy of nickel ion exchange on Dowex HCR S/H using the Arrhenius equation [44]:

$$\ln k_2 = \ln k_0 - \frac{E_a}{R_g T} \quad (3)$$

where E_a is activation energy (kJ/mol); k_2 is the rate constant of sorption (g/mol k₀ is Arrhenius factor, which is the temperature independent factor (g/mol R_g is the gas constant (J/K and T is the solution temperature (K)). The slope of plot of $\ln k_2$ versus $1/T$ is used to evaluate E_a , which was found to be 12.661 for Nickel exchange, respectively (Fig. 6).

Free energy (ΔG^*), enthalpy (ΔH^*) and entropy (ΔS^*) of activation can be calculated by Eyring equation [45]:

$$\ln\left(\frac{k_2}{T}\right) = \left[\ln\left(\frac{k_b}{h}\right) + \frac{\Delta S^*}{R_g}\right] - \frac{\Delta H^*}{R_g T} \quad (4)$$

where k_b and h are Boltzmann's and Planck's constants, respectively. According to Eq. (4), a plot of $\ln(k_2/T)$ versus $1/T$ should be a straight line with a slope $-\Delta H^*/R_g$ and intercept $(\ln(k_b/h) + \Delta S^*/R_g)$. ΔH^* and ΔS^* were calculated from slope and intercept of line, respectively. Gibbs energy of activation may be written in terms of entropy and enthalpy of activation:

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

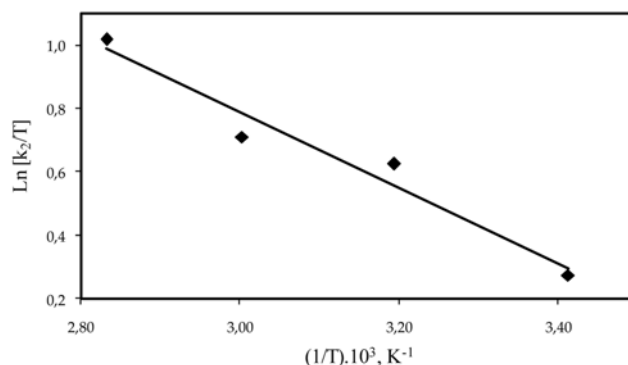


Fig. 11. Plots of $\ln(k_2/T)$ versus $1/T$ for ion exchange Ni(II) onto Dowex HCR S/H (pH 6.0, 400 rpm stirring speed, 1 g/500 ml resin dosage and 250 mg L⁻¹ initial Ni⁺² concentration).

was calculated at 313 K from Eq. (5). It is found that the values of the free energy (ΔG^*), enthalpy (ΔH^*) and entropy (ΔS^*) of activation for nickel are 60.385 kJ/mol, 9.994 kJ/mol and -0.1610 kJ/mol respectively (Fig. 11). The results are shown in Table 5.

CONCLUSION

This study concludes that the adsorbent Dowex HCR S/H resin showed effective Ni(II) adsorption from aqueous solution. The ion exchange rate of Ni(II) on Dowex HCR S/H resin increased with increase in initial metal concentration, stirring speed and temperature. Adsorption isotherms were studied for Ni(II) removal from the aqueous solution. Nickel removal followed the Sips adsorption isotherm and gave a better fit than the other adsorption isotherms, as the regression constant for the Sips model was higher than the others. The better correlation with experimental data suggests that the pseudo-second-order equation can extensively describe the metal adsorption on resin well over the whole study range, and show a better prediction of the equilibrium sorption capacity. Increased ion exchange amount with increasing temperature indicates the endothermic nature of the process and confirms that the rate-controlling mechanism is chemisorption.

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