

## Ion exchange recovery of nickel(II) on macroporous weak acid resin (D151 resin)

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The recovery and removal of Ni(II) by macroporous weak acid resin (D151 resin) have been investigated, and the optimal ion has been achieved at pH value 6.90 in HAc-NaAc medium. The statically saturated capacity is 152 mg/g resin at 298 K and the thermodynamic parameters are  $\Delta H = 13.2 \text{ kJ/mol}$ ,  $\Delta G = -17.6 \text{ kJ/mol}$ ,  $\Delta S = 103 \text{ J/(mol}\cdot\text{K)}$ , respectively. Both pseudo-first-order and second-order kinetics are applied to search for the best fitted kinetic model to the sorption results. Modelling of the equilibrium data with Freundlich and Langmuir isotherms revealed that the correlation coefficient is more satisfactory with the Freundlich model. EDS analysis confirmed that Ni(II) is adsorbed onto D151 resin. Moreover, the characterization of both before and after adsorption of Ni(II) ion on D151 resin is undertaken using SEM and IR spectroscopic technique. The spent sorbent is eluted with HCl demonstrating the best result ( $\sim 100\%$  desorption).

**Keywords:** Macroporous weak acid resin (D151 resin), Ni(II), Removal, Recovery

Nowadays, the recovery of heavy metals from industrial process solutions has attracted a great attention owing to the gradual rise in the environmental protection and the consequent severity of legislation regarding the disposal of toxic substances; for instance, the effluent limits for Ni(II) ions in Germany, Switzerland and the US are 0.50 ppm (1991), 2.00 ppm (1991) and 3.98 ppm (2001), respectively<sup>1</sup>.

Numerous processes are available for extraction and recycle of metal Ni(II) from industrial influents, such as coagulation, chemical precipitation, slow sand filters, membrane technologies, adsorbing natural products and ion exchange resins. Adsorption and ion exchange are potential alternatives for aqueous solutions<sup>2</sup>. Furthermore, the main objective of the most of the research on ion exchange resins is to prepare functional polymers which can afford more flexible working conditions together with good stability, high capacity for certain metal ions, and even can be reused many times. Therefore, studies have been carried out in regard to the application of ion exchange resins for the recovery of heavy metals from various wastewaters of metal plating, alloy and pigments<sup>1-3</sup>. The capacity of enormous work on removal of metal ions, especially nickel ions, was compared and given in Table 1. It was reported that

metal ions were adsorbed on these different materials such as ion exchange resin, activated carbon and zeolite, and the maximum amounts are not high.

The synthesis, characterization and removal property of many ion-exchange materials have been reported in recent years<sup>17-20</sup>. Macroporous weak acid resin (D151 resin) containing a functional group (-COOH) is a novel polymeric material and it has not only proton that can be exchanged with cation, but also can coordinate directly with metal ions. In this case, D151 resin can be widely used to remove many metal ions.

Here we have investigated the ion exchange process under a set of variables (concentration of metal ion, pH, time and temperature of interaction). The way of ion exchange sufficiently incarnates the idea of green chemistry. As a result it can be used as a new method of the hydrometallurgy and environmental protection, and it is making for good use of resource.

### Experimental Procedure

The macroporous weak acid resin (D151 resin) used in the experiments was provided by Nankai University and the properties were shown in Table 2, activated before their use. Buffer solution with pH value 3.50-6.90 was prepared from appropriate dilution of 0.4 mol/L HAc and 0.4 mol/L

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Table 1– The comparison of uptake capacity of metal ions on different material

Material	Metals	Capacity (mg/g)	Ref.
252H resin	Cu(II)	37.2	[4]
1500H resin		11.8	
Purolite NRW-100 resin	Ni(II)	98.0	[5]
Purolite NRW-100 resin	Ni(II)	101	[6]
Activated carbon	Ni(II)	54.4	[7]
Carbonised coirpith	Ni(II)	62.5	[8]
Dowex HCR S/S resin	Ni(II)	49.6	[9]
	Zn(II)	64.2	
Amberlite IRC 748 resin	Cu(II)	75.1	[10]
	Ni(II)	64.5	
Hazelnut shell activated carbon	Ni(II)	11.6	[11]
Amberlite IRN 77 resin (H <sup>+</sup> type)	Ni(II)	62.0	[12]
Macroporous phosphonic acid resin	Ni(II)	64.3	[13]
Purolite S930 resin	Ni(II)	30.4	[14]
	Co(II)	11.6	
Poly(glycidyl methacrylate-glycine) resin	Ni(II)	63.1	[15]
	Cu(II)	78.1	
	Cd(II)	108	
Zeolite X	Ni(II)	46.3	[16]

Table 2—General description and properties of resin

Items	Properties
Resin	D151 resin
Functional group	-COOH
Structure	macroporous
Granularity (%) (0.315–1.25mm)	≥95
Capacity (m mol/g)	8.0
Ground pellet ratio (%)	≥ 90
Wet superficial density (g/mL)	0.70-0.80
True wet density (g/mL)	1.10-1.15
Surface area (m <sup>2</sup> /g)	3.41
Pore volume (cm <sup>3</sup> /g)	6.39×10 <sup>-3</sup>
Average pore diameter (nm)	3.92

NaAc. Standard solution of Ni(II) was prepared by dissolving nickel vitriol (AR) in deionizer water. Chromogenic reagent of 0.5% xylenol orange solution was obtained by dissolving 0.5000g xylenol orange into 100 mL purified water. Other chemicals were of analytical grade.

Ni(II) concentration was determined with Shimadzu UV-2550 UV-VIS spectrophotometer. Mettler toledo delta 320 pH meter was used for measuring pH. The samples were shaken in the DSHZ-300A and the THZ-C-1 temperature constant shaking machine. The IR spectra were recorded on the Nicolet 380 FTIR. And all the glass apparatus were cleaned in the SK5200LH ultrasonic cleaning instrument.

The experiments were carried out under batch experiments and dynamic column conditions. The resins were previously swollen for 24 h in butter solution with a fixed pH 6.90. Then, a required

amount of standard solution of Ni(II) was added. The flask was shaken in a shaker at constant temperature. The upper layer of clear solution was taken for analysis when exchange equilibrium was reached. The ion exchange capacity ( $Q$ ) and distribution coefficient ( $D$ ) were calculated as follows<sup>21</sup>:

$$Q = \frac{C_o - C_e}{W} V, D = \frac{Q}{C_e} \quad \dots (1)$$

Where  $C_o$  is initial concentration of metal ion in solution (mg/mL),  $C_e$  is equilibrium concentration of metal ion in solution (mg/mL),  $V$  is total volume of solution (mL),  $W$  is resin weight (g).

Ni(II) was determined by a spectrophotometrical method. A solution containing lower than 75  $\mu$ g of Ni<sup>2+</sup> was accurately added into a 25 mL colorimetric tube, and then 1 mL chromogenic reagent of 0.5% xylenol orange solution and 10 mL pH 5.73 HAc-NaAc buffer solution were added. After the addition of purified water to the mark of colorimetric tube, the absorbency was determined in a 1 cm colorimetric vessel at wavelength of 578 nm and compared with the blank test.

The influence of pH on the ion exchange process<sup>22</sup>, has been regarded as master variable in most processes governed by adsorptive separation. The test was carried out according to the above-mentioned method. The pH experiments in the range of 3.50-6.90 buffer solution were carried out by adding 15.0 mg resin to 25 mL of 1.0 mg/mL Ni(II) solution, and then shaking at 100 rpm, 298 K.

The ion exchange kinetics was studied by carrying out a set of experiments at constant temperature and monitoring the amount adsorbed with time. The reaction kinetic parameters were studied on the batch experiment of 20.0 mg resin and 5.0 mg/30 mL Ni(II) at pH 6.90, 100 rpm. 0.1 mL of upper layer clear solution was taken out at intervals for the determination of residual concentration. After the remnant kept constant and volume was corrected, then a series of data were obtained.

The adsorption kinetics of Ni (II) were tested using pseudo-first-order and pseudo-second-order sorption equations. The pseudo-first-order equation is given as:

$$\lg(Q_e - Q_t) = \lg Q_e - k_1 t \quad \dots (2)$$

where  $k_1$  (g/mg·min) is the rate constant of the pseudo-first-order sorption, which can be calculated by plotting  $\lg(Q_e - Q_t)$  versus  $t$ .

The pseudo-second-order equation can be written as:

$$\frac{t}{Q_t} = \frac{1}{k_2 Q_e^2} + \frac{t}{Q_e} \quad \dots (3)$$

where  $k_2$  (g/mg·min) is the rate constant of the pseudo-second-order sorption. The slopes and intercepts of plots  $t/Q_t$  versus  $t$  were used to calculate the pseudo-second-order rate constants  $k_2$  and  $Q_e$ .

In order to perform the further characterization of the removal behavior of Ni(II) on D151 resin, equilibrium isotherms on D151 resin at different temperatures were obtained for Ni(II)<sup>23-24</sup>. The Langmuir and Freundlich equations are used to reveal the linearity fitting and to describe the interaction of solutes with the resins.

Freundlich isotherm were studied by varying the resin dosage in the range of 5.0-25.0 mg at 30 mL  $[\text{Ni}^{2+}]_0 = 0.167$  mg/mL, pH 6.90, 100 rpm.

Langmuir isotherm were studied by varying 30 mL the initial Ni(II) concentration in the range of 0.133 mg/mL - 0.200 mg/mL with 15.0 mg resin at pH 6.90, 100 rpm.

The effect of temperature on the reaction characteristics were investigated by determining the isotherms at 288 K, 298 K, 308 K and 318 K. Thermodynamic parameters have been determined using classical thermodynamic equations at the condition of 15.0 mg resin and 30 mL  $[\text{Ni}^{2+}]_0 = 0.167$  mg/mL at pH 6.90, 100 rpm.

The elution process was conducted as follows: after reaction equilibrium was reached, the resin was first washed by pH 6.90 buffer solution and then eluted with eluant. 0.1 mL of elution solution was taken out at intervals for the determination of the concentration of Ni(II) in aqueous. The flask was shaken (100 rpm) for equilibrium. Then, the percentage of elution in different time was obtained.

The dynamic experiments were carried out in glass columns wet-packed. Sample solution flowed through the glass column at constant flow rate and the Ni(II) contents in the effluent liquid were monitored by ultraviolet-visible spectroscopy analysis.

The dynamic leakage curves<sup>25</sup> on D151 resin were obtained based on the volume of effluent liquid and the Ni(II) concentration herein. With respect to the stripping of Ni(II) from D151 resin, 0.5mol/L HCl was employed.

$\text{Na}^+$  ions can also be exchanged by D151 resin. In order to find out the affinity of resin for Ni(II), we also conducted an investigation into the experiment when  $\text{Na}^+$  was added into the solution.

The samples for IR spectroscopy were prepared according to the following procedure. The resin quantities were saturated with Ni(II) ions (under static). Then, the samples were dried. The resin tablet was carried out with KBr (0.3 mg of resin to 200 mg KBr). The IR spectra were detected on IR spectrometer and identified.

## Results and Discussion

### Influence of pH

The initial pH of medium is one of the most important parameters affecting the ion exchange process. The effect of pH on the D151 resin for Ni(II) was shown that the metal ion uptake was inhibited in this acidic medium and this can be attributed to the presence of  $\text{H}^+$  ions competing with the Ni(II) ions for the sites at lower values. The maximum capacity was attained at pH 6.90, and then almost kept constant when pH was over 6.90. In order to prevent Ni(II) from hydrolyzing, all the following experiments were carried out at pH 6.90.

### Ion exchange kinetics

The influence of contact time on the adsorption of Ni(II) ion onto the D151 resin (Fig. 1) was investigated at the temperatures of 288 K, 298 K and 308 K. The adsorption capacity of Ni(II)

increased from 122 mg/g at 288 K to 171 mg/g at 318 K with the extension of time. In the first 14 h the exchange capacity increased rapidly, after 14 h they increased slowly and reached equilibrium at around 33 h.

Kinetic parameters including the first-order rate constant  $k_1$ , second-order rate constant  $k_2$ , calculated equilibrium adsorption capacity  $Q_{e,cal}$  and experimental equilibrium adsorption capacity  $Q_{e,exp}$  for Ni (II) ions, and regression coefficients ( $R^2$ ), are given in Table 3. The regression coefficients for the pseudo-first-order equation and pseudo-second-order equation are same. Moreover, the experimental  $Q_{e,exp}$  values are in good agreement with the calculated  $Q_{e,cal}$  from first-order model and second-order model. This indicated that the system under study can be estimated by the pseudo-first-order reaction and pseudo-second-order reaction.

#### The batch isotherms

Application of the Langmuir equation indicates that each site of the adsorbent can adsorb only one particle. Hence, the Langmuir equation describes the ion exchange behavior of monomolecular layer. Freundlich equation is used extensively in the physical and chemical process. It can be used to describe monomolecular layer as well as that of the multimolecular layer.

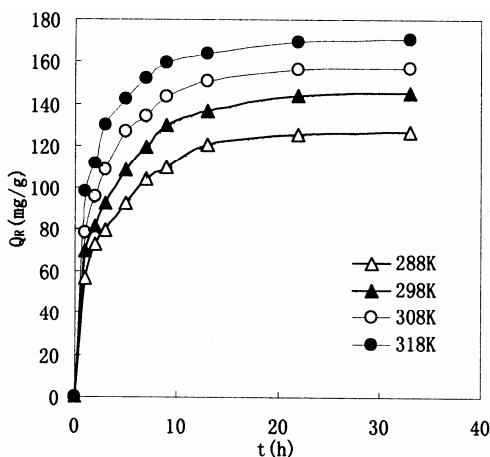


Fig. 1—The kinetics curve of Ni(II)

According to the Freundlich formula:

$$\lg Q = \frac{1}{n} \lg C_e + \lg a \quad \dots (3)$$

where  $a$  presents the Freundlich constant, and  $n$  is an empirical constant related to the magnitude of the reaction driving force.

Then the experimental data were fitted to the Freundlich equation. The  $n$  value can be obtained from the slope in Table 4. It has been stated by that magnitude of the exponent  $1/n$  gives an indication of the favorability and capacity of the adsorbent/adsorbate system. Values  $n > 1$  represent favorable reaction conditions. In most cases, the exponent between  $1 < n < 10$  show beneficial reaction<sup>27</sup>. Hence, the D151 resin is appropriate for separating Ni(II).

According to the Langmuir equation:

$$Q = \frac{Q^0 b C_e}{1 + b C_e} \quad \dots (4)$$

where  $C_e$  is equilibrium concentration of metal ion ( $C_e$ , mg/mL),  $Q$  is the capacity in equilibrium state ( $Q$ , mg/g resin),  $Q^0$  is the monolayer capacity of the adsorbent (mg/g),  $b$  is the Langmuir constant. It is usually line arised by inversion to obtain the following form:

$$\frac{C_e}{Q} = \frac{1}{Q^0 b} + \frac{C_e}{Q^0} \quad \dots (5)$$

The Langmuir equation is converted to the linearized form with  $C_e$  and  $C_e/Q$  as independent variable, the experimental data are statistic analyzed and  $R^2$  are obtained. It is equally used to analyze batch equilibrium data by plotting  $C_e/Q$  versus  $C_e$ , which yields a linear plot if the data conform to the Langmuir isotherm.

Plotting of  $C_e/Q$  versus  $C_e$  gave a straight line over the whole concentration range studies. The results were shown in Table 5. And the correlation coefficient of the straight line obtained by Langmuir

Table 3—Kinetics of D151 resin for Ni(II)

T(K)	$Q_{e,exp}$ (mg/g)	First-order-kinetic model			Second-order-kinetic model		
		$Q_{e,cal}$ (mg/g)	$k_1$ (g/mg·min)	$R^2$	$Q_{e,cal}$ (mg/g)	$k_2$ (g/mg·min)	$R^2$
288	127	122	$4.82 \times 10^{-5}$	0.9946	127	$5.23 \times 10^{-3}$	0.9942
298	146	143	$5.45 \times 10^{-5}$	0.9931	149	$4.23 \times 10^{-3}$	0.9907
308	158	155	$5.86 \times 10^{-5}$	0.9947	161	$4.74 \times 10^{-3}$	0.9974
318	171	171	$6.45 \times 10^{-5}$	0.9939	175	$5.70 \times 10^{-3}$	0.9978

model indicated that Langmuir isotherm model was applicable. As a result, Freundlich isotherm was more suitable than Langmuir isotherm according with the  $R^2$  value.

#### The influence of temperature and the determination of thermodynamic parameters<sup>28</sup>

The distribution coefficient  $D$  is obtained by the ratio of  $Q$  and  $C_e$  at different temperature. The  $Q$  and  $C_e$  is 0.126 mg/mL and 127 mg/g at 288 K, 0.115 mg/mL and 146 mg/g at 298 K, 0.107 mg/mL and 157 mg/g at 308 K, 0.0997 mg/mL and 171 mg/g, respectively. The results obtained and presented in Fig. 2 indicated that an increase of the temperature induced an increase in the capacity of Ni(II). It meant that the ion exchange process was an endothermic process.

The slope of straight line in Fig. 2 was  $K_{\text{slope}} = -0.6883 \times 10^3$ . According to

$$\lg D = -\frac{\Delta H}{2.303RT} + \frac{\Delta S}{2.303R} \quad \dots (6)$$

$$\begin{aligned} \text{where } \Delta H &= -K_{\text{slope}} \times 2.303R \\ &= 0.6883 \times 10^3 \times 2.303 \times 8.314 \\ &= 13.2 \text{ kJ/mol} \end{aligned}$$

and then  $\Delta S = 103 \text{ J/(mol}\cdot\text{K)}$  can be obtained from the intercept of the line. In the light of  $\Delta G = \Delta H - T\Delta S$ ,  $\Delta G_{288K} = -16.6 \text{ kJ/mol}$ ,  $\Delta G_{298K} = -17.6 \text{ kJ/mol}$ ,  $\Delta G_{308K} = -18.7 \text{ kJ/mol}$ ,  $\Delta G_{318K} = -19.7 \text{ kJ/mol}$ . The values reveal that the reaction was a spontaneous reaction under the experimental condition.

Another very important thermodynamic parameter in determining the type is the  $\Delta H$ . If uptake amount decreases with increasing temperature, it may be

Table 4—Linearity relation of  $\lg Q$  and  $\lg C_e$

$T(K)$	Linearity relation of $\lg Q$ and $\lg C_e$	$R^2$	$n$	$Q$ (mg/g)
288	$y=0.5161x+3.8064$	0.9910	1.94	149
298	$y=0.5412x+2.6685$	0.9894	1.85	183
308	$y=0.5863x+2.8275$	0.9913	1.71	208

pH=6.90,  $C_0=5.0 \text{ mg/30 mL}$ ,  $r=100 \text{ rpm}$

Table 5—Linearity relation of  $C_e/Q$  and  $C_e$

$T(K)$	Linearity relation of $C_e/Q$ and $C_e$	$R^2$	$Q^0$ (mg/g)	$b$
288	$y=0.0033x+0.0006$	0.9708	303	5.50
298	$y=0.0029x+0.0005$	0.9622	345	5.80
308	$y=0.0027x+0.0004$	0.9808	370	6.76

$[\text{Ni}^{2+}]_0=4.0 \text{ mg/30.0 mL}$ ,  $4.5 \text{ mg/30.0 mL}$ ,  $5.0 \text{ mg/30.0 mL}$ ,  $5.5 \text{ mg/30.0 mL}$ ,  $6.0 \text{ mg/30.0 mL}$

indicative of physical reaction, and the reverse is generally true for chemical reaction.  $\Delta H$  value was 13.2 kJ/mol, which directly indicated that the ion exchange process was endothermic and chemical process. The positive values of  $\Delta S$  reflected the affinity of adsorbent material towards Ni(II)<sup>29,30</sup>.

#### Elution

The different concentrations of HCl were studied for the elution of Ni(II). It was found when the concentration of HCl was in the range of 0.5 ~ 3.0 mol/L, Ni(II) was eluted quantitatively. The results given in Table 6 show that the percentage of elution was different when the concentration of HCl was changed. Considering the environmental pollution and resource waste, we chose the 0.5 mol/L HCl as the best elution.

#### Dynamic removal and recovery

For the dynamic removal curve, the effluents from the column were analyzed quantitatively with the above-mentioned method. At the bottom of the column, a stainless sieve was attached followed by a layer of cotton wool. 300 mg of D151 resin were dropped in from the top of the column. A solution having a known concentration of 0.405 mg/mL of Ni(II) was continuously fed into the column at a constant flow rate. When the concentration of Ni(II) emerging from the bottom of the column was equal to that entering the top of the resin bed, the experiment was terminated, then

Table 6—The elution test of Ni(II)

Concentration of HCl (mol/L)	0.5	1.0	2.0	3.0
Elution (%)	100	93	89	85

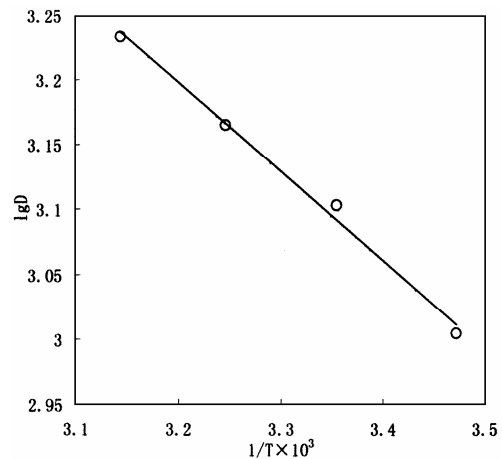


Fig. 2—Influence of temperature on distribution ratio

a plot of  $C_e/C_0$  versus the volume of effluent gave a typical breakthrough curve in Fig. 3. The dynamic saturated capacity is 131.6 mg/g by calculating. It approximated to the statically saturated capacity because the contact time of the ion concentration with resins was transitory in the dynamic reaction process.

Elution curve (Fig. 4) was plotted the effluent concentration ( $C_e$ ) versus elution volume from the column at a flow rate of 0.30 mL/min, less than the flow rate so that volume of elution is less which helps in easy handling and high in concentration so that economical metal recovery is possible.

It was observed that the total volume of eluent was 40 mL and the elution process took 2 h, after which further elution was negligible. Therefore, 0.5 mol/L HCl could help in easy handling and recovering of Ni(II).

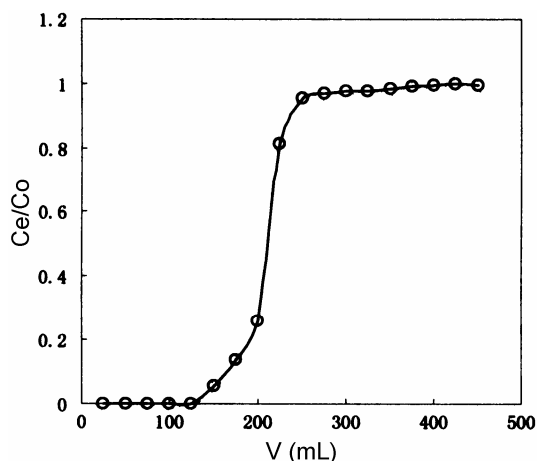


Fig. 3—Dynamic removal curve

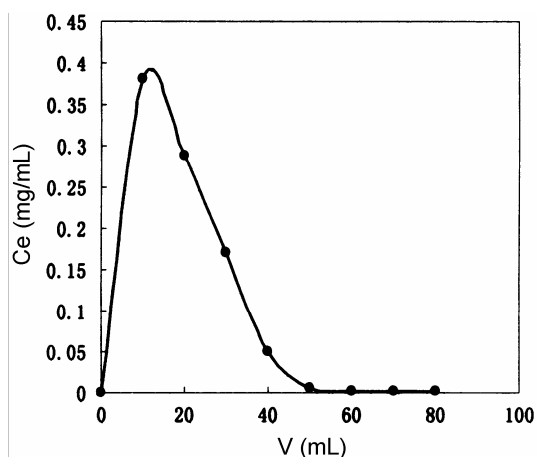


Fig. 4—Elution curve of Ni(II)

#### Effect of $\text{Na}^+$ , $\text{Ca}^{2+}$ and $\text{Mg}^{2+}$ on D151 resin

The conditions were shown in Table 7. The cation test did not show any significant effect on the removal of Ni(II) ions with the increase of  $\text{Na}^+$ ,  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  in the solution. Therefore, it might be concluded that D151 resin has a good choice to Ni(II) and coordinates with it strongly in  $\text{Na}^+$ ,  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  solution.

#### Scanning electron microscope (SEM) analysis

The SEM micrographs of dried unloaded resin, Ni(II)-loaded resin are shown in Fig. 5. The results showed that there were abundant physical holes distributed on the surface of resin. This increased the surface area for metal adsorption. From Fig. 5b, one can see that there are many metal particles on the surface of Ni(II)-loaded resin.

#### EDAX analysis

The EDAX analysis of Ni(II)-loaded D151 resin was examined to determine the adsorption mechanism of D151 resin and shown in Fig. 6. EDAX analysis did not show the characteristic signal of Ni (II) ions in the D151 resin, whereas clear signals were observed at about 0.9 and 7.45 keV in the D151 resin absorbed Ni(II) ions (Fig. 6b). The results revealed that Ni were loaded on the surface of D151 resin, which were consistent with the results of SEM.

Table 7—Effect of different ion on adsorption capacity of D151 resin

No	Mixture	Concentration of ion ( $\times 10^{-3}$ mol/L)	Adsorption capacity (mg/g)
		0	151.0
1	Na(I) Ni(II)	2	150.0
		4	150.4
		6	151.0
		8	151.0
		10	151.3
2	Ca(II) Ni(II)	0	151.0
		2	149.5
		4	149.7
		6	149.8
		8	150.0
3	Mg(II) Ni(II)	10	149.0
		0	151.0
		2	149.0
		4	149.2
		6	149.3
		8	149.0
		10	148.6

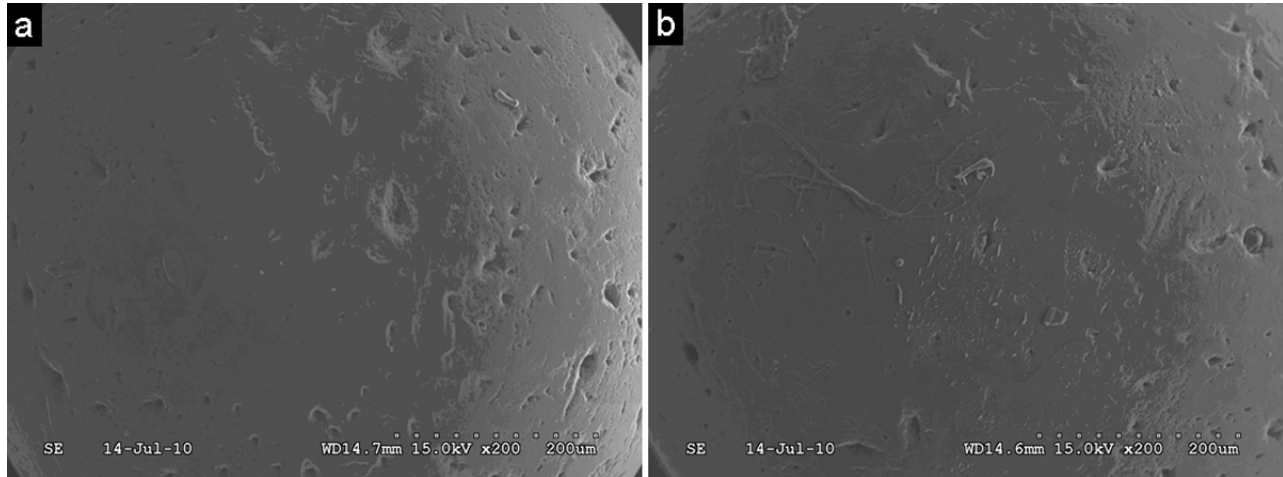


Fig. 5—Scanning electron microscope (SEM) micrograph (a) dried unloaded D151 resin and (b) Ni(II) loaded D151 resin

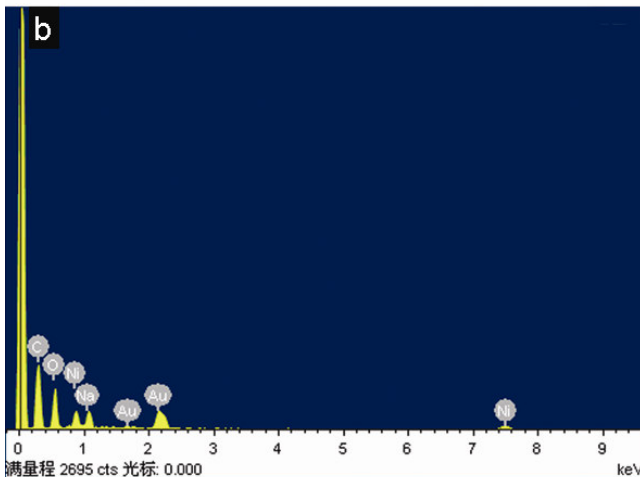
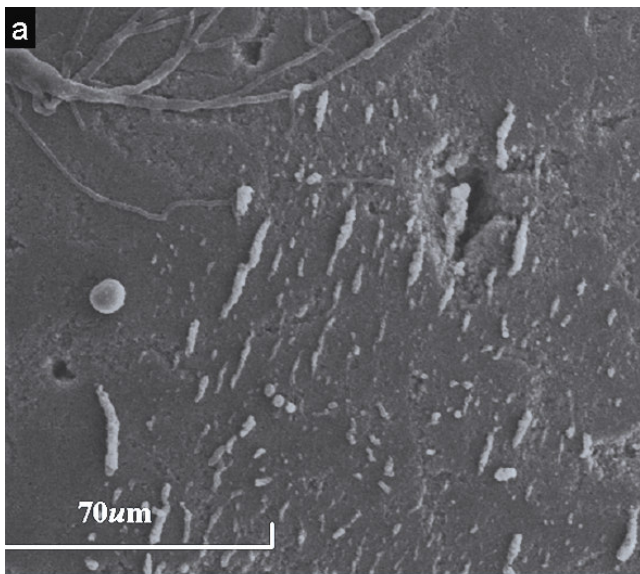


Fig. 6—EDAX analysis of Ni(II) loaded D151 resin (a) surface of D151 resin and (b) EDAX spectrum

#### Analysis of infrared spectra of resin

From the results, it can be deduced that the removal of Ni(II) by D151 belonged to a chemical process. Therefore, the functional groups of D151, C=O of the -COOH and Ni(II) were supposed to form chemical bonds. In order to confirm this, the spectra of resin, before and after Ni(II) was adsorbed, were compared. It was noticed that the band at  $3436.93$  and  $3449.61\text{ cm}^{-1}$  is stretching vibrations of the surface hydroxyl groups,  $2926.39$  and  $2926.24\text{ cm}^{-1}$  is assigned to asymmetric vibration of  $\text{CH}_2$ . It was found that the characteristic peak of the bond C=O ( $1712.51\text{ cm}^{-1}$ ) weakened after removal Ni(II), and the new peak  $1640.10\text{ cm}^{-1}$  and  $1553.27\text{ cm}^{-1}$  formed. These results revealed that the C=O groups participated in the coordination process.

#### Conclusions

The following conclusions can be drawn from this study:

- (i) It could be inferred from pH experiments that change process was dependent on the pH of the solution and uptake capacity could be reached at about pH 6.90. In other words, Ni(II) could be optimally adsorbed on macroporous weak acid resin (D151 resin) in the HAc-NaAc medium at pH=6.90. The Ni(II) adsorbed on macroporous weak acid resin (D151 resin) could be eluted reaching 100% by 0.5 mol/L HCl used as eluant. The resin could be regenerated and reused without decrease of ion exchange capacity.
- (ii) The negative value of  $\Delta G_{298} = -17.6\text{ kJ/mol}$  indicated spontaneity, the positive values of  $\Delta H = 13.2\text{ kJ/mol}$  indicated that the exchange

process was an endothermic process and the positive values of  $\Delta S = 103 \text{ J}/(\text{mol} \cdot \text{K})$  reflected the affinity of adsorbent material towards Ni(II).

- (iii) The SEM, EDAX analysis and IR spectra of Ni(II)-loaded D151 resin were examined to determine the adsorption mechanism of D151 resin. The results confirmed that Ni(II) was adsorbed onto D151 resin.

In summary, D151 resin has many advantages to re-concentrate, concentrate, separate and recover Ni(II) in the HAc-NaAc system. The ion exchange capacity of D151 resin for Ni(II) was high, the operation was simple and convenient. It was possible that the resin could be put to commercial use.

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