

Synthesis of Chelate Resins Derived from Furfural and Their Adsorption Properties for Metal Ions

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Received 17 March 2005; accepted 24 June 2005

DOI 10.1002/app.22528

Published online in Wiley InterScience (www.interscience.wiley.com).

ABSTRACT: A series of new chelate resins were synthesized by ring-opening polycondensation of the reaction mixture of furfural with diethanolamine, using sulfuric acid as a catalyst, and the resulting chelate resins were employed in the adsorption for metal ions Bi, In, Sn, V, Ga, Y, Ti, and Pb. The composition, structure, and properties of the resulting chelate resin were studied by means of fourier transform infrared (FTIR), electron paramagnetic resonance spectrum (EPR), and elemental analysis methods. Meanwhile, the adsorption properties of the resulting chelate resins for the above metal ions were investigated by inductively-coupled plasma-atomic emission spectrometry (ICP-AES) procedures. The results show that the resulting chelate resins hold

the structure consisting of hydroxyl groups, amine groups, and conjugated π bonds, as well as more crosslinkages, and so they exhibit a good reactivity and chemical stability. The adsorption experiments show that the chelate resins could well adsorb V, Ga, Y, Ti, and Pb in a wider acidity range and exhibit a good adsorption selectivity. Particularly, the chelate resins could adsorb and desorb for Pb, Bi, In, V, Y, and Ti, quantitatively, in the given conditions. © 2005 Wiley Periodicals, Inc. *J Appl Polym Sci* 99: 1620–1626, 2006

Key words: chelate resin; furfural resin; metal ions; adsorption; separation; ICP-AES procedure

INTRODUCTION

With the development of modern industries, the transitional, rare, and heavy metals are often present in wastewater from the mining, metallurgy, surface finishing, as well as chemical industries. The concentrations of these metals vary from a few to a few hundred milligrams per cubic decimeter.¹ The effluents containing the above metals can cause serious environmental problems. Especially, the metal ions are not biodegradable in nature, which means that they will accumulate in the organism body, and further endanger the health of human beings through food chains.² Much attention has been paid to the detection and removal of undesirable metal ions from wastewaters and process streams to protect environment and reclaim resource.^{1–3} The selective concentration of metal ions from aqueous breakdown solutions or their removal from wastewaters play an important role in many industrial applications as well as in environmental chemistry, and the adsorption using chelating

resins is one of the most convenient methods for the selective separation and preconcentration of metal ions (M^{n+}),^{3–5} because the chelating resins hold polymeric ligands consisting of the reactive functional groups based on O, N, S, and P donor atoms, and exhibit excellent chelating adsorptions for metal ions.^{4–9}

For the sustainable development of social economy and scientific technology, the materials or products derived from renewable resources were very important.¹⁰ As one of the compounds derived from renewable resource, furfural and its derivatives have gotten wide applications in polymers and functional polymers because of their reactive properties. For example, the chelating resins were synthesized by the ring-opening polycondensation of furfural derivatives with the given functional group, and the chelate resins were also prepared by the functionalization of the polymers from furfural and its derivatives.^{11–14} Those chelate resins hold many reactive groups, i.e., carboxy groups, hydroxy groups, amine groups, imine groups and etc. Meanwhile, there are structures based on conjugated-unsaturated π bonds in the chelate resins, whereas conjugated-unsaturated π bonds should exhibit coordination with metal ions well.¹⁵ Consequently, the synthesis of the chelating resins based on the furfural and its derivatives, and the adsorption

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Contract grant sponsor: Key Research Project of Gansu Province; contract grant number: GS99-A52–034.

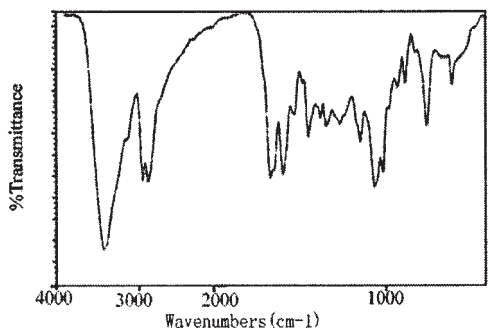


Figure 1 FTIR spectrum of the intermediate form furfural and diethanolamine.

properties of the resulting chelate resins for metal ions presented in wastewater, as well as the selective separation and preconcentration of trace metal ions will be very interesting.

In this paper, a series of new chelate resins containing coordination groups and conjugated-unsaturated π bonds based on Nitrogen–Oxygen were formed by the further polycondensation of reactants of furfural with diethanolamine, and the resulting chelate resins were employed in the separation and preconcentration of metal ions Bi, V, In, Y, Sn, Pb, and Ga. The composition and structure of the obtained chelate resins, as well as the adsorption properties and chelate mechanism of them for the above metal ions, have been investigated by means of fourier transform infrared (FTIR), electron paramagnetic resonance spectrum (EPR), inductively-coupled plasma–atomic emission spectrometry (ICP-AES), and elemental analysis methods, respectively.

EXPERIMENTAL

Reagents and solvents

Furfural (analytically pure, bp 160–163°C, $D_4 = 1.590$ – 1.610), was newly distilled before use; diethanolamine (analytical reagent) was directly used without further purification; the standard solutions of Bi, V, In, Y, Sn, Pb, and Ga were prepared by dissolving high pure or spectroscopically pure $\text{Bi}(\text{NO}_3)_3$, NH_4VO_3 , In_2O_3 , Y_2O_3 , SnO_2 , PbO_2 , and Ga_2O_3 into diluted HNO_3 , respectively, to give stock standard solutions containing $100 \mu\text{g mL}^{-1}$ of Bi, In, Sn, Pb, and Ga, and $10 \mu\text{g mL}^{-1}$ of Y, Ti, and V in 1M HNO_3 , and were used for

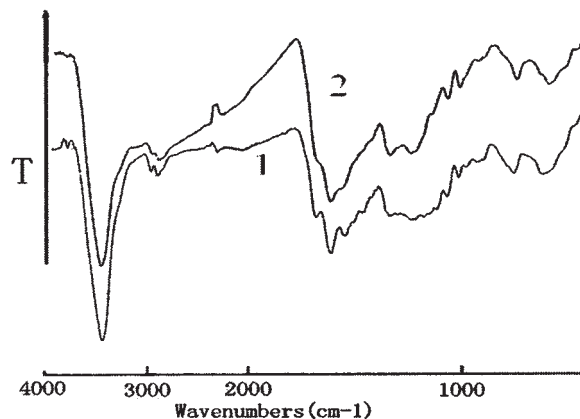


Figure 2 FTIR spectra of the chelate resins based on furfural.

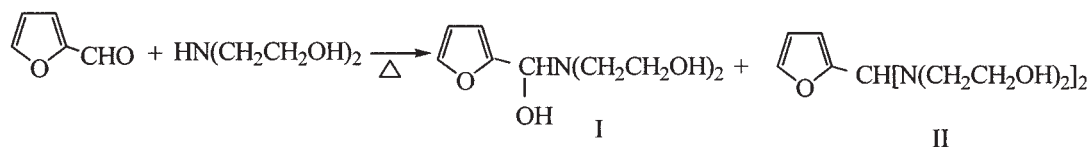
adsorption of the chelate resins; other reagents are of analytical grade.

Instruments and characterization

Perkin–Elmer ICP/6500 inductively couples plasma spectrometer (ICP-AES, RF power supply: 1100 W, plasma gas flow 14.0 L min^{-1} , auxiliary gas flow 0.5 L min^{-1} , nebulizer gas flow 1.0 L min^{-1} , viewing height 8 mm), Nicolet 170-SX Fourier transform infrared spectrometer (FTIR, KBr plate), Bruke ER 200D-SRC electron paramagnetic resonance spectrometer (EPR), and Tiansin pHs-73 digital pH meter (Shanghai Instrument Plant). The micro-type adsorption column made from a glass tube of 10 cm length, 0.4 cm i.d., and 0.15 cm i.d. at the lower tapering end was loaded with 0.1–0.2 g of the resulting chelate resin, using a funnel with 50 mL capacity, which was attached to its top, and its underside joints a plastic tube with a screw clamp.

Synthesis of the chelate resins

The given molar ratios between furfural and diethanolamine were 2:1, 1:1, 1:1.5, and 1:2, respectively. The furfural and diethanolamine were mixed to get a mixture in a beaker under room temperature. When the mixture became reddish-brown and its temperature was raised about 10°C , it was transferred to a three-neck flask with thermometer and stirrer, and was refluxed at 60°C for about 2 h with stirring to form a



Scheme 1 Condensation reaction of furfural and diethanolamine.

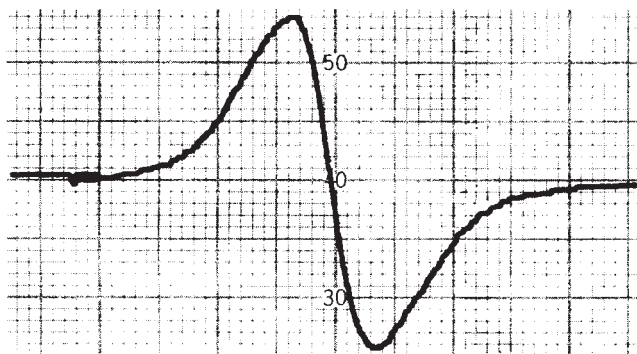


Figure 3 Electron paramagnetic resonance spectrum of the chelate resin.

viscid intermediate. It was cooled and transferred into a beaker, and the mixture solution formed by adding 10% of sulfuric acid on the basis of the content of the mixture was stirred at a high speed at 100°C until a black solid was obtained, and a hard solid product with black luster was obtained after curing for 20 h at 120°C under vacuum. Finally, it was crushed and filtrated to get the above chelate resin.

Pretreatment of the chelate resin

The resulting chelate resins, which held 0.4–1.0 mm of size, were eluted by 5% NaOH solution and 5% HCl alternately until the elution solution became colorless. Finally, they were treated with 5% NaOH for 2 days, washed with distilled water to removal free base, and dried at 60°C under vacuum. The nitrogen content of the resulting chelate resins was measured by means of Kjeldahl's method, and the physical properties of the resins were estimated according to the methods reported by Li et al.¹³

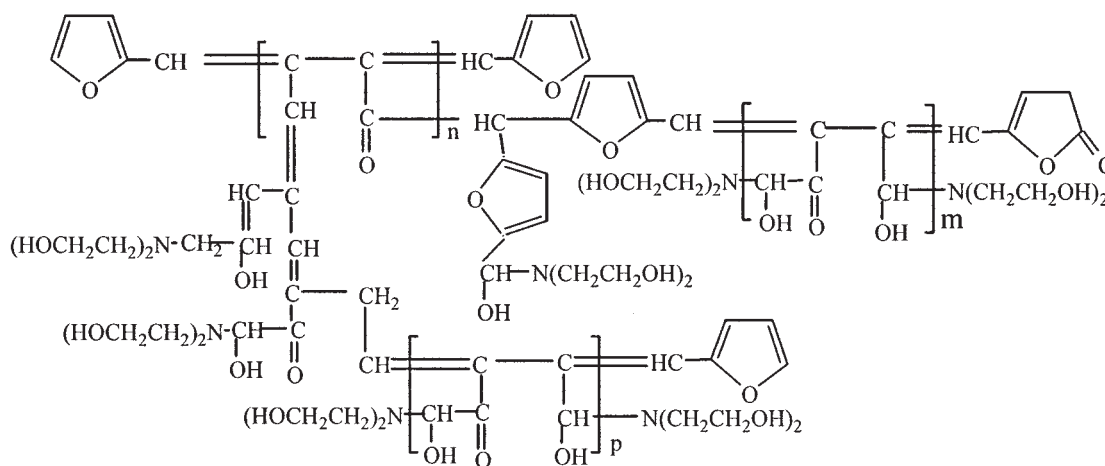
Procedure of adsorption and analysis

One milliliter of the above stock standard solution was accurately pipetted to 50 mL of beaker and diluted to 40 mL using distilled water. The solution was adjusted to the expected pH value, using diluted KOH or HCl aqueous solution to form the adsorption solution, and the cubage of adsorption solution was reached to 50 mL finally. The adsorption solution was passed through the above micro-type adsorption column at a flow rate of 1–2 mL min⁻¹. Then the metal ions adsorbed by the chelate resin in column were eluted using 20 mL of 1 mol L⁻¹ HCl solution. The elution solution collected by 50-mL of beaker was evaporated at lower temperature and transferred into 10 mL of volumetric flask quantitatively and made up to volume with distilled water. The contents of the metal ions were determined by means of ICP-AES procedure, comparing with the standard solution and the blank one, and the value of the enrichment factor for the above metal ions was controlled to 5 here.

RESULTS AND DISCUSSION

Synthesis chemistry and structures of the chelate resin

Figure 1 is FTIR spectrum of a soluble intermediate reactant derived from furfural and diethanolamine refluxing at 60°C for about 2 h with stirring. The FTIR spectrum presented in Figure 1 shows that there are typical vibration absorptions from hydroxyl group, carbonyl group, and C—N bond at 3421, 1700, and 1261 cm⁻¹, respectively. This indicates that the intermediate reactant should be a mixture of many reactants. The absorption intensity of O—H stretching, however, was enhanced comparing with that of C=O stretching, that is to say, the condensation reaction of aldehyde groups of furfural with amine groups of diethanolamine has



Scheme 2 Structure model of the resulting chelate resin.

TABLE I
Experimental Data of the Resulting Chelate Resins

Furfural/diethanolamine (molar ratio)	N content (N%)	Apparent wet- density (g mL ⁻¹)	Swelling ratio in water (%)
2:1	2.39	0.64	50
1:1	2.48	0.65	51
1:1.5	2.59	0.65	52
1:2	2.74	0.55	65

formed a lot of hydroxyl groups, and the condensation reaction would firstly form basic product I and II as shown in Scheme 1, and product I, i.e., 2-(2-hydroxy-*N,N*-dihydroxyethyl) methylamine furfural, should be the main resultant due to the steric hindrance.^{11,16} Because furfural and its derivatives will undergo ring-opening polycondensation under heating and base condition to form a series of linear prepolymers,^{13,16} furthermore, the intermediates obtained in this reaction step were viscous solids consisting of all mixing reactants.

The above linear prepolymers, i.e., the intermediates, undergo further ring-opening polycondensation by heating and catalysis of sulfuric acid to form a series of chelate resins derived from furfural. They can also be converted into the related chelate resins with only heating for longer time. The FTIR spectra of the resulting chelate resins (1) the resin prepared by heating only; (2) one obtained by heating and catalysis of sulfuric acid) were illustrated in Figure 2. The FTIR spectra show that there exist characteristic peaks of conjugated C=O stretching, C=C stretching, and C—N stretching from third amine at 1693, 1522, and 1364–1261 cm⁻¹. These indicate that further ring-opening polycondensation of the furfural prepolymers forms a conjugative structure consisting of C=C π bond, C=O and C—N bonds^{12–14,16}; meanwhile, the vibration absorptions of O—H stretching and C—O—C stretching presented at 3412 and 1179–1098 cm⁻¹ show that the resulting chelate resin holds a lot of hydroxyl groups and some furan ring. According to Figure 2, the chelate resin prepared by either heating only or heating and catalysis, using sulfuric acid exhibits basically

TABLE II
Effect of pH on Enrichment Recovery

pH	Recovery (%)							
	Bi	In	Sn	V	Ga	Y	Ti	Pb
2	100.0	80.0	99.5	79.1	77.5	75.1	90.0	73.5
3	97.5	97.8	100.0	81.7	93.0	100.0	100.0	97.0
4	100.0	100.0	100.0	84.8	95.9	93.0	100.0	100.0
5	100.0	99.0	100.0	99.0	99.5	87.4	100.0	100.0
6	100.0	98.0	79.8	99.7	87.3	87.4	100.0	100.0
7	100.0	96.0	75.7	100.0	83.2	87.0	100.0	100.0

TABLE III
Effect of Co-Existing Ions on Enrichment Recovery^a

Co-existing ions	Recovery (%)							
	Pb	Bi	In	Sn	V	Ga	Y	Ti
Al	100.0	100.0	99.3	94.8	93.5	97.1	100.0	100.0
Cu	100.0	96.3	100.0	100.0	94.5	98.8	100.0	100.0
Fe	100.0	100.0	99.5	100.0	98.9	90.0	100.0	100.0
Mn	92.5	100.0	100.0	100.0	98.3	94.7	100.0	100.0
Mg	98.8	100.0	100.0	89.0	96.3	89.2	100.0	100.0
Ni	100.0	98.0	98.8	100.0	99.8	95.3	100.0	100.0
Sb	100.0	100.0	100.0	86.0	97.3	96.8	100.0	100.0
Zn	99.0	100.0	100.0	100.0	98.0	91.5	100.0	100.0
Ca	99.0	100.0	100.0	100.0	98.5	93.2	100.0	100.0

^a 10 multiples co-existing ions.

similar composition and structure, but the chelate resin obtained by the latter would hold excellent stability and mechanical properties due to more crosslinkages, resulting from the catalysis of sulfuric acid. Electron paramagnetic resonance spectrum (EPR) of the chelate resin is shown in Figure 3. The stronger EPR signal and *g* value (2.0033, found taking DPPH as standard) from Figure 3 further confirm the existence of conjugated structures based on big π bonds of C=C and C=O in the resulting chelate resins,^{12,13,16} those that agree with the above results of FTIR analysis. Therefore, the resulting chelate resins probably hold main structures shown as Scheme 2.

According to the analysis results of the above FTIR and EPR spectra, the resulting chelate resins hold carbonyl, hydroxyl, and third amine groups that can exhibit excellent coordination adsorptions for metal ions, and the big conjugated π bonds present in them also display a cooperating coordination for the metal ions. Meanwhile, hydroxyl and third amine groups that provide a hydrophilic microenvironment for the adsorption, as well as the crosslinkages in the resulting chelate resins give them good stability.

Composition and property of the chelate resin

Effect of the molar ratio of furfural and diethanolamine on composition and properties of the chelate

TABLE IV
Effect of Co-Existing Ions on Enrichment Recovery^a

Coexisting ions	Recovery (%)							
	Pb	Bi	In	Sn	V	Ga	Y	Ti
Al	86.5	97.5	83.7	100.0	86.0	85.0	61.0	100.0
Cu	99.0	100.0	100.0	100.0	99.8	93.8	97.5	100.0
Fe	99.5	100.0	100.0	88.3	89.2	86.3	100.0	100.0
Mn	95.8	100.0	99.0	93.2	100.0	94.7	98.7	100.0
Mg	98.5	100.0	100.0	94.0	97.3	94.5	91.3	100.0
Ni	100.0	100.0	100.0	100.0	100.0	94.7	100.0	100.0
Sb	100.0	100.0	95.0	100.0	100.0	98.7	96.5	100.0
Zn	94.3	100.0	100.0	100.0	100.0	96.5	97.5	96.5
Ca	100.0	100.0	100.0	100.0	98.8	81.0	100.0	100.0

^a 50 multiples co-existing ions.

TABLE V
Effect of Flow Rate on Enrichment Recovery

Flow rate (mL min ⁻¹)	Recovery (%)							
	Bi	In	Sn	V	Ga	Y	Ti	Pb
0.5	100.0	100.0	100.0	100.0	95.0	92.0	100.0	100.0
0.8	100.0	98.0	100.0	100.0	97.0	87.0	100.0	100.0
1.0	100.0	98.0	100.0	100.0	93.0	87.0	100.0	100.0
1.4	100.0	96.0	100.0	99.0	86.0	82.0	97.0	97.0
1.7	100.0	96.0	100.0	98.0	86.0	82.0	97.0	97.0
2.0	100.0	95.0	100.0	97.0	78.0	82.0	97.0	97.0

resins obtained by using catalysis of sulfuric acid was shown in Table I. The value of $N\%$ in the chelate resin was increased slightly with the enhancement of the amount of diethanolamine added and this may be the reason for the lower yield of product II (see Scheme 1). Meanwhile, a higher swelling ratio in water of the chelate resins indicates that the hydrophilicity of the resins was improved by introducing lots of hydroxyl groups and amine groups into them, by comparing with previous furfural resins.^{12,13} Nitrogen from diethanolamine and oxygen from furfural and diethanolamine will provide the coordination for metal ions. The crosslinking structures from ring-opening reaction of furfural (see Scheme 2) will make the chelate resin hold an apparent wet-density to be suitable for column operation. In other words, the resulting chelate resins hold basic chemical and physical properties, adsorbing metal ions.

Adsorption for metal ions and corresponding influences

The effects of the medium pH on the adsorption percent of the chelate resin for different metal ions were represented by data listed in Table II. According to the data in Table II, the chelate resin exhibits good adsorbability for the given metal ions in the range of pH 2–7, while the optimal pH of enrichment of metal ions should be selected at pH 4–5 as to satisfy the necessary of simultaneous determination of ICP.

TABLE VI
Effect of Dilution Ratio on Enrichment Recovery

Dilution ratio ^a	Recovery (%)							
	Bi	In	Sn	V	Ga	Y	Ti	Pb
2	100.0	46.9	98.4	34.4	63.7	47.1	51.0	39.0
3	100.0	63.8	100.0	52.5	68.6	60.4	60.4	62.0
4	100.0	72.5	93.6	54.1	69.9	59.4	59.9	55.4
5	99.5	84.7	97.6	85.8	77.2	62.5	68.3	58.6
6	100.0	86.8	98.7	62.0	82.5	80.3	70.9	64.5

^a The dilution ratio based on the above adsorption solution.

TABLE VII
Effect of Elution Acidity on Enrichment Recovery

HCl (mol L ⁻¹)	Recovery (%)							
	Pb	Bi	In	Sn	V	Ga	Y	Ti
1.0	72.0	48.0	76.8	15.2	52.5	44.3	85.7	71.8
1.5	76.8	55.0	77.6	18.9	60.2	44.6	89.8	81.2
2.0	81.9	59.8	79.2	25.2	72.2	51.4	94.3	82.5
2.5	86.0	63.7	81.7	35.7	74.2	55.0	94.6	85.0
3.0	89.0	81.7	88.7	38.7	82.8	59.7	100.0	86.0
4.0	97.2	89.7	89.7	38.7	88.3	64.6	100.0	87.0

TABLE VIII
Effect of the Flow Rate of Elution Solution on Enrichment Recovery

Flow rate (mL min ⁻¹)	Recovery (%)							
	Pb	Bi	In	Sn	V	Ga	Y	Ti
0.54	70.6	89.7	87.3	18.3	53.5	44.5	96.7	90.0
0.71	73.5	90.0	89.9	20.2	57.6	47.6	98.9	91.7
1.33	78.7	94.1	91.3	30.1	59.1	55.0	100.0	95.0
5.00	70.6	81.0	85.5	25.2	40.2	42.1	100.0	92.3

The effects of coexisting ions on enrichment recovery of the chelate resin for the given metal ions were shown by data presented in Table III and Table IV. When the medium pH was selected to 4 and the concentration of transition metal ions were 10 and 50 multiples to the given metal ions, respectively, the data in Table III and Table IV indicate that the resulting chelate resin can still adsorb Pb, Bi, In, Sn, V, Ga and Ti well. These are to say that the resulting chelate resins based on furfural have excellent adsorption selectivity for the given metal ions, so that there exist no effects or slight effects of most of coexist ions on the adsorptions of the resins for the above most metal ions besides Y.

The effects of the flow rate of adsorption solution on the chelate resin for the metal ions were shown by data listed in Table V. According to the data presented in Table V, the recovery percent of the chelate resin for

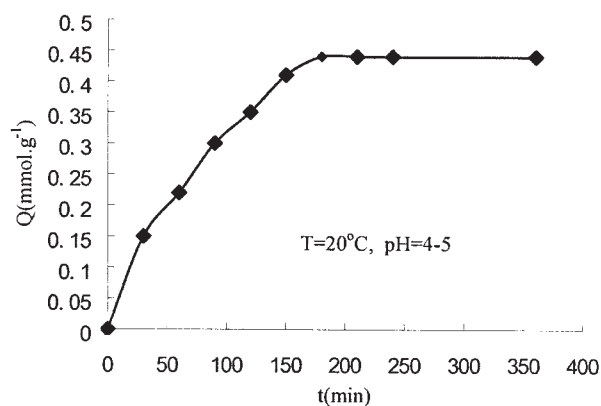


Figure 4 The absorption curve of the resin for Pb(IV).

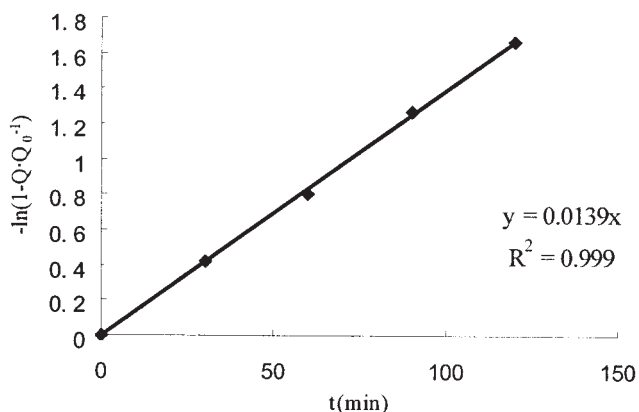


Figure 5 Evaluation of Boyd equation for adsorption of Pb(IV).

Bi, In, Sn, V, Ti, and Pb are all more than 95% within flow rate from 0.5 to 2.0 mL min⁻¹. This is to say that the resulting chelate resin based on furfural holds a good adsorption velocity for the above metal ions. While the recovery percent of the chelate resin for Ga and Y will decrease with increase of the flow rate but being over 80%, this may relate to the coordination model between the chelate resin with Ga and Y ions.¹⁷

The effect of dilution ratio of adsorption solution on the recovery is shown in Table VI. The data exhibit that the dilution ratio doesn't affect the adsorption of the chelate resin for Bi and Sn, but it affects clearly the adsorption of that for other metal ions. The adsorption of the chelate resin for In, V, Ga, Y, Ti, and Pb is enhanced with increase of the dilution ratio. This should be attributed to the decrease of the interaction among metal ions in the case of thin concentration of the metal ions, which is suitable for the enrichment of the chelate resin for trace metal ions.¹⁸

Elution of the metal ions adsorbed and related influences

Table VII represents the elution rates of the metal ions adsorbed by chelating resin at different elution acidity. The data listed in Table VII indicate that the elution rates of the metal ions adsorbed increase with the enhancement of elution acidity. When the elution acidity was selected to 4 mol L⁻¹ of HCl solution, Pb, Bi, In, V, Y, and Ti could be eluted from the chelate resin quantitatively, whereas Sn and Ga display lower elution rates. Therefore, the metal ions adsorbed could both be recovered and be partially separated by adjusting the elution acidity.

When 20 mL of 1 mol L⁻¹ of HCl solution was passed, the adsorption column loading the resin adsorbed the above metal ions at a flow rate of 0.54–5.0 mL min⁻¹ in air. The elution rates of eight metal ions adsorbed are listed in Table VIII. The data presented in Table VIII indicate that appropriate enhancement of flow rate would be suitable to increase the elution rate of them, and 1.33–1.50 mL min⁻¹ of flow rate should be selected to the optimal flow rate of the chelate resin for all ions, using 1 mol L⁻¹ of HCl solution as elution solution in air.

The adsorption capacity and coordination model of Pb(IV)

Plumbum is a heavy metal, which can be not biodegraded naturally, which will endanger the health of human by the food chains because it will be accumulated in the body by enrichment of organisms¹; therefore, the removal of Pb in wastewater is very important for environmental protection. 0.1 g of the chelate resin was placed in a conical flask, and 100 mL of stock solution of Pb(IV) was added into the flask. The acidity of solution in the flask was adjusted to pH 4–5. The static adsorption of the chelate resin for Pb(IV) was carried out by shaking the flask, using a mechanical vibrator under room temperature. The concentrations of Pb(IV) was

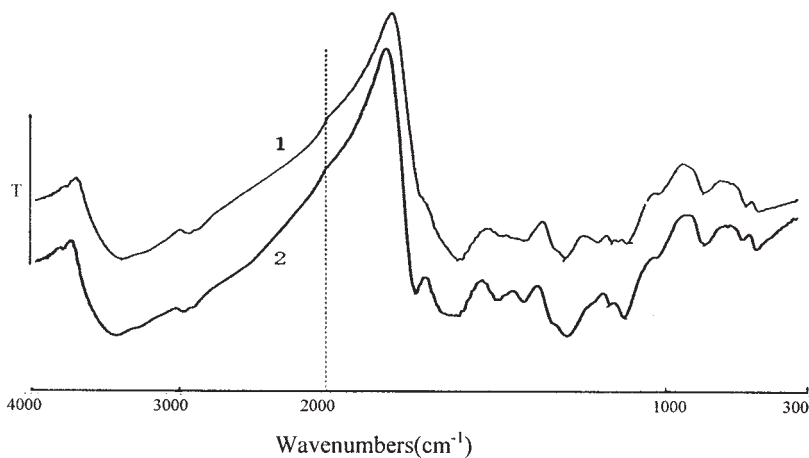
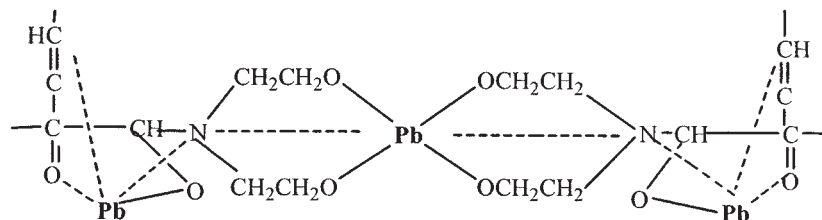


Figure 6 FTIR spectra of chelate resin and one adsorbed Pb(IV).



Scheme 3 The coordination model of the chelate resin with Pb(IV).

measured at regular intervals of 30 min by ICP-AES until adsorption had reached equilibrium. The static adsorption curve of the chelate resin for Pb(IV) is shown in Figure 4.

According to Figure 4, the static adsorption capacity saturated of the chelate resin for Pb(IV) will reach to 91 mg g^{-1} within 5 h, and the chelate resin has adsorbed 74.3 mg g^{-1} of Pb(IV) within 2 h. In other words, the adsorption percentage of the chelate resin for Pb(IV) has been 81.6% of the adsorption capacity saturated within 2 h. This exhibits that the chelate resin holds a good adsorption speed for Pb(IV). Qu and coworkers^{19,20} have observed a similar trend with this. According to diffuse equation from G. E. Boyd:

$$-\ln(1 - QQ_0^{-1}) = k_{\text{ad}}t \quad (1)$$

where, Q is adsorption capacity of Pb(IV) at the given time t , Q_0 is adsorption capacity saturated of Pb(IV), k_{ad} is a constant. Utilizing the data from Figure 4 as basic, the illustration on Boyd equation was gotten (Fig. 5).

The adsorption coefficient k_{ad} of the chelate resin for Pb(IV) was computed from Figure 5. Meanwhile, the linear equation of the absorption of the chelate resin for Pb(IV) can be written, as shown in eq. (2)

$$y = 0.0139t, R^2 = 0.999 \quad (2)$$

According to Figure 5 and eq.(2) the adsorption coefficient found of Pb(IV) on the resin is 0.0139 min^{-1} . It indicates that the time of adsorption saturated of the chelate resin for Pb(IV) is attained quickly. Therefore, the chelate resin could be employed in the treatment process of wastewater containing heavy metal ions.

FTIR spectra of the chelate resin itself and the one that adsorbed Pb(IV) are presented in Figure 6. Comparing with the IR spectrum (1) of the chelate resin itself, the IR spectrum (2) of the resin-adsorbed Pb(IV) exhibits a similar IR absorption. However, the absorption peak of C—N stretching and that of C—O stretching shifted to 1217 and 1054 cm^{-1} , respectively. These are resulted from the vibrations of nitrogen and oxygen atom joined in the coordination with Pb(IV). Considering the lattice pattern of Pb,^{21,22} the coordination model of the chelating resin with Pb(IV) is probably shown in Scheme 3.

CONCLUSIONS

The chelate resins that hold coordination ability based on cooperation of nitrogen with oxygen have been synthesized by ring-opening polycondensation of furfural and its derivatives, using sulfuric acid as catalyst. The resulting chelate resins hold structure characteristic consisting of conjugated π bonds based on C=C and C=O bonds, more crosslinkages, as well as hydroxyl and third amine groups, and they exhibit good absorbability and appropriate selectivity for metal ions, e.g., Bi, V, In, Y, Sn, Pb, and Ga. The resulting chelate resins are suitable for preconcentrating and separating these metal ions; therefore, they could be employed in the enrichment of trace metal ions and removal of heavy metal ions in wastewater.

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