



## Chromatographic separations and recovery of lead ions from a synthetic binary mixtures of some heavy metal using cation exchange resin

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### ABSTRACT

A simple solid phase extraction procedure on cation exchange resin Purolite C100 is presented. The procedure based on a column technique for separation and recovery of lead ions from synthetic binary mixtures. Equilibrium distribution coefficient,  $K_d$  for the different metal ions such as Al(III), Fe(III), Ba(II) and Pb(II) in the presence of nitric acid and ammonium acetate solutions of variable concentrations was determined at 25 °C. The values of separation factor,  $\alpha$  were evaluated. Quantitative separation of lead ions from a synthetic binary mixtures are based on the fact that ammonium acetate is a good elute for lead ions but fails to elute the other cations.

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### 1. Introduction

The rapid industrialization and urbanization has resulted in the deterioration of water, air and land quality. Natural waters are contaminated with several heavy metals arising from mining wastes and industrial discharges. The heavy metals are of special concern because they are non-degradable and therefore persistent. These metals are toxic in both their chemically combined forms as well as the elemental form. Exposure to these contaminants present even in low concentration in the environment can prove to be harmful to the human health. Lead as a pollutant is a major concern as it has been used as one of the raw materials for battery manufacturing, printing, pigments, fuels, photographic materials and explosive manufacturing. The presence of lead in drinking water even at low concentration may cause diseases such as anemia, encephalopathy, hepatitis and nephritic syndrome. It can affect nerves and brain at low concentration [1,2].

The removal, separation and recovery of heavy metal ions from industrial wastewater have been a significant concern in all industrial branches owing to economic and environmental factors. Various separation–preconcentration techniques like solvent extraction [3], electro-deposition [4], coprecipitation [5], cloud point extraction [6], membrane filtration [7] and solid phase extrac-

tion (SPE) [8,9] are used for that purpose. Solid phase extraction is a chromatographic technique which is widely used, e.g. for preconcentration and cleanup of analytical samples, for purification of various chemicals, and for removal of toxic or valuable substances from aqueous solutions. SPE is usually performed using a column or cartridge containing an appropriate resin. Solid phase extraction is preferred by many researchers on account of the fast, simple and higher preconcentration factor, rapid phase separation, time and cost saving [10,11]. Until now, several kinds of sorbents, such as Amberlite XAD resins, activated carbon, ion exchange resins, chelating resins and various polymers have been used as solid phase material [12]. Ion exchange now is a well-established technology, particularly in water purification and the concentration and removal of hazardous substances at very low concentrations in chemical process industries [13]. Many studies on the separation of metal ions by ion exchange resins have been conducted [14–16].

The efficiency of metal recovery and separation depends on choice of eluting agent and elution conditions, as various eluting agent presenting different desorption mechanisms may be used. Lowering pH, e.g. with mineral acids, causes metal desorption resulting from competition between protons and metal ions for binding sites. Ammonium acetate solution is another eluting agent commonly used [17–21]. The purpose of our study is to demonstrate the feasibility of using Purolite C100 resin as a solid phase extracting for separation of lead ions from a synthetic binary mixtures. The recovery % for ion exchange separation of some metal ions in the presence of different eluent was calculated.

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## 2. Experimental

### 2.1. Apparatus

Thermo Jarrell Ash atomic absorption spectrophotometer (AAS) model (POEMS III) USA was used to analyze the concentration of metals in solutions. The pH values of all prepared solution were measured using pH meter OP-021/2 (Germany) with combined electrode.

### 2.2. Material and method

All chemicals were of analytical reagent grade. Distilled water was used throughout the study. Each metal ion stock solution (1000 ppm) was prepared by dissolving a calculated amount of Al(III), Fe(III), Ba(II) and Pb(II) as nitrates, ammonium acetate and nitric acids used for elution, concentrated hydrochloric acid from Merck, Darmstadt. They were used without further purification. The working solutions were prepared by diluting the stock solution to appropriate volumes.

Purolite C100 is a high capacity premium grade bead form conventional gel polystyrene sulphonate cation exchange resin. The exchange capacity was 2.2 mequiv./g and its particle size was 0.42–1.2 mm. Purolite C100 was procured from Purolite International Limited, Hounslow, UK. Prior to use, the resins were washed with HCl (1.0 mol/dm<sup>3</sup>) and were washed with deionized water until all chloride ions removed and were dried in a vacuum oven at 25 °C.

### 2.3. Batch exchange and elution experiments

In the batch exchange experiments, an aliquot of dry resin (1.0 g) and 40 cm<sup>3</sup> of the aqueous solution containing 26.5 ppm of each metal ion were placed in a 100-cm<sup>3</sup> glass-stopper for 24 h at fixed temperatures (25 °C). After equilibrium, the resin was separated and the concentrations of metals in the aqueous phase were analyzed by an atomic absorption spectrophotometer.

Experiment to study the quantitative elution of lead ions were performed by adding 9.23 g resin in a 100 ml solution containing 26.5 ppm of PbNO<sub>3</sub> solution was passed through the column at a rate of 1 ml/min, resin bed (1.4 cm × 12.9 cm). The resin was washed with 50 ml, of water and then the Pb(II) was eluted with 200 ml of different eluents. The latter include nitric acid (1, 2, 3, 4 and 6 M) and ammonium acetate (1, 3 and 4 M). In each case the elution rate was 1 ml/min and the eluting agent was collected in 10 ml. The elution constant, *E* for each eluting agent is calculated, from the following relation [20]:

$$E = d \frac{A}{V} \quad (1)$$

where *V* is the volume of eluent, which is required to displace Pb(II) under essentially equilibrium conditions through a distance *d* (cm) in a column of cross sectional area *A* (cm<sup>2</sup>), the free column volume in this work is found to be 13 ml.

## 3. Results and discussion

### 3.1. Determination of the equilibrium distribution coefficient, *k<sub>d</sub>*

The distribution coefficient, *k<sub>d</sub>* is defined as the ratio of metal ion concentration on the resin to that in the aqueous solution and can be used as a valuable tool to study metal ion mobility. High values of distribution coefficient, *k<sub>d</sub>* indicate that the metal has been retained by the solid phase, while low values of, *k<sub>d</sub>* indicate that a large fraction of the metal ions remains in solution. The distribution

**Table 1**

Distribution coefficient (*k<sub>d</sub>*) for some metal ions in the presence of HNO<sub>3</sub> using cation exchange resin Purolite C100 (H<sup>+</sup> form) 25 °C ± 0.1 °C.

Metal ions	Concentration of HNO <sub>3</sub>			
	1 M	2 M	3 M	4 M
Pb(II)	47.970	6.360	2.550	1.300
Ba(II)	69.300	11.780	8.640	4.030
Fe(III)	115.600	54.500	14.500	8.950
Al(III)	76.490	30.100	8.210	3.286

coefficient *k<sub>d</sub>* was calculated using the following equation [22]:

$$k_d = \frac{\text{amount of metal ion in adsorbent}}{\text{amount of metal ion in solution}} \times \frac{V}{m} \text{ ml/g} \quad (2)$$

where *V* is the volume of the solution (ml) and *m* is the weight of adsorbent (g).

### 3.2. Effect of nitric acid on distribution coefficient, *k<sub>d</sub>*

The effect of different nitric acid concentrations at 25 °C on *k<sub>d</sub>* values of each metal ions by cation exchange resin Purolite C100 was studied. Table 1 illustrates that the values of *k<sub>d</sub>* for Al(III), Fe(III), Ba(II) and Pb(II) in the presence of 1, 2, 3 and 4 M nitric acid. The result indicates that the *k<sub>d</sub>* values increase with decrease in the concentration of nitric acid due to the anionic complex formation. Since the action of the nitric acid on the exchange equilibrium is a twofold one viz. action of the hydrogen ion as government by the mass reaction equation for a simple exchange and action of the nitrate ion by lowering the effective concentration of the cation in solution through complex formation [23]. The effect of the nitrate anion on the numerical value of *k<sub>d</sub>* was investigated and result indicate that nitrate complexes with stabilities decreasing in the order: Pb(II) < Ba(II); Al(III) < Fe(III). The lower *k<sub>d</sub>* values for Ba(II) compared to Al(III) and Fe(III) in nitric acid are due to relative ion pair of the nitrates of these metal ions. Ion pairing will lower the effective concentration of these cations in the solution by the formation of BaNO<sub>3</sub><sup>+</sup> and thus act in action similar to complex formation. The *k<sub>d</sub>* value of iron has a remarkable increase with decrease in the concentration of nitric acid. Consequently one can assume that iron does not form anionic complexes [24] at low concentration for nitric acid media, behavior similar to iron is shown by aluminum. Pb(II) has lower *k<sub>d</sub>* values, where Fe(III) has higher *k<sub>d</sub>*, hence Pb(II) can be separated from Fe(III) in the presence of nitric acid. Separation of ions depends on the value of separation factors. The separation factor describes the selectivity of extractant between two metals. Separation factors, *α* were calculated from the following equation [25]:

$$\alpha = \frac{k_d A}{k_d B} \quad (3)$$

Table 2 illustrates that the highest separation factor of Pb(II) from Fe(III)  $\alpha_{Fe}^{Pb} = 8.569$  is obtained in the presence of 2 M nitric acid, thus it was the most effective concentration for the elution and separation of lead from iron.

**Table 2**

Separation factors of some metal ions in the presence of different concentration of HNO<sub>3</sub> using cation exchange resin Purolite C100 (H<sup>+</sup> form) 25 °C ± 0.1 °C.

Cations	Separation factors	Conc. of HNO <sub>3</sub>
Pb(II)–Fe(III)	8.569	2 M
Pb(II)–Fe(III)	5.686	3 M
Pb(II)–Al(III)	4.733	2 M
Pb(II)–Ba(II)	3.388	3 M

**Table 3**

Distribution coefficient ( $k_d$ ) and loading percentage (L%) of some metal ions in the presence of different concentrations of ammonium acetate using cation exchange resin Purolite C100 (H<sup>+</sup> form) 25 °C ± 0.1 °C.

Metal ion	Concentration of ammonium acetate					
	1 M		3 M		4 M	
	$k_d$	L%	$k_d$	L%	$k_d$	L%
Pb(II)	0.38	0.90	0.24	0.62	0.02	0.04
Ba(II)	88.89	68.96	15.87	28.41	2.87	3.75
Al(III)	73.48	73.90	19.21	32.45	2.64	6.42

### 3.3. Effect of ammonium acetate on distribution coefficient

The distribution coefficient  $k_d$  of some metal ions in the presence of different ammonium acetate concentrations are reported in Table 3. In all the cases the sorption of metal ions decreases with increasing the concentrations of ammonium acetate. Generally, the metal ion forms a complex with the acetate ion and the sorption depends upon the nature of complex formed [26]. As the concentration of ammonium acetate is increased, acetate ion replaces the coordinating water molecule resulting in the formation of complex species of a small positive charge, and consequently  $k_d$  is lowered. A further increase in the concentration of ammonium acetate lead to the formation of a neutral species and this also results in decrease of  $k_d$ . When the concentration of ammonium acetate is higher and a neutral metal acetate is likely to be present in solution, the predominant species in the resin phase would be  $M^{2+}$  (OAc)<sup>+</sup> or  $M^{3+}$  (OAc)<sup>2+</sup> as inferred by workers [27].

The  $k_d$  values of Pb(II) ions are very small where as Al(III) and Ba(II) have higher  $k_d$  values. Hence Al(III) and Ba(II) can be separated from Pb(II) in this concentration range of NH<sub>4</sub>OAc. The loading percentages of the metal ions [28] were calculated from the following equation and are shown in Table 3.

$$L\% = \frac{\text{mequiv. of metal ions/g of resin}}{\text{mequiv. of metal ions initially taken}} \times 100 \quad (4)$$

The separation factors in the presence of ammonium acetate are given in Table 4.

### 3.4. Quantitative elution of lead ions

In an aim to recover or separate metal ions from aqueous samples elution of retained metals from the extractant was studied. The behavior of lead ions towards various eluting agent using cation exchange resin Purolite C100 was studied. Quantitative elution of lead ions was possible with 200 ml of nitric acid and ammonium acetate. The elution curves in the presence of nitric acid in the concentration range of 2–4 M and ammonium acetate in the concentration range of 1–4 M were studied. Figs. 1 and 2 illustrate the elution peak is seen to be gradually shifting towards the left with increased eluent concentrations. The elution constant and total lead recovery % was presented in Table 5. The elution of lead was found 95.59% at 2 M nitric acid and increased with increasing nitric acid concentrations. Ammonium acetate was found to be an efficient eluent for the quantitative elution of lead in the concentration range of 1–4 M.

**Table 4**

Separation factors of some metal in the presence of different concentrations of acetate using cation exchange resin Purolite C100 (H<sup>+</sup> form) 25 °C ± 0.1 °C.

Cations	Separation factors	Concentration of CH <sub>3</sub> COONH <sub>4</sub>
Pb(II)–Ba <sup>2+</sup>	233.92	1 M
Pb(II)–Al <sup>3+</sup>	193.37	1 M
Pb(II)–Al <sup>3+</sup>	80.04	3 M

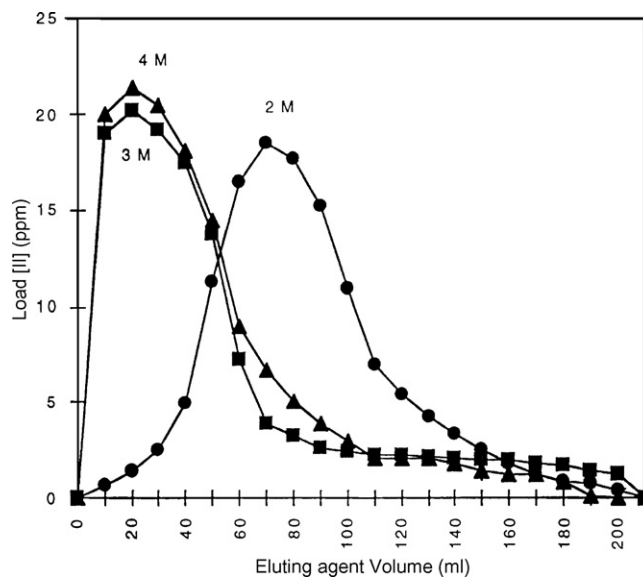


Fig. 1. Elution of lead ions by eluting agent 2, 3 and 4 M HNO<sub>3</sub> using cation exchange resin Purolite C100. Conc. lead(II) = 26.5 ppm. Wt of dried resin = 9.23 g.

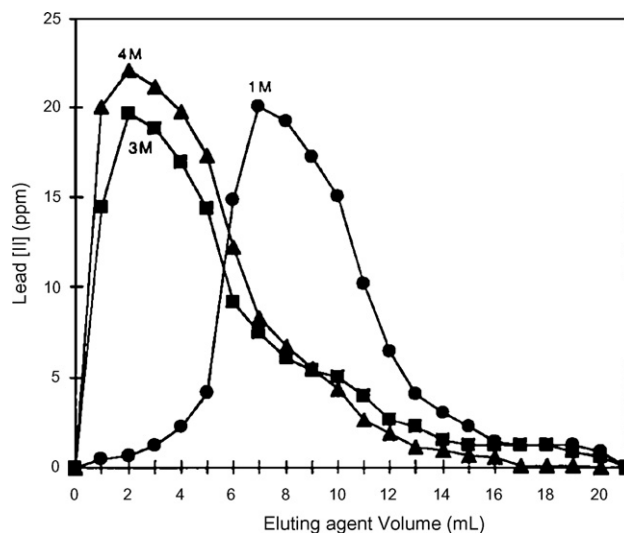


Fig. 2. Elution of lead ions by eluting agent 1, 3 and 4 M CH<sub>3</sub>COONH<sub>4</sub> using cation exchange resin Purolite C100. Conc. lead(II) = 26.5 ppm. Wt of dried resin = 9.23 g.

### 3.5. Quantitative separations of metal ions from binary mixtures

An effective way of separating solute particles and capable of extracting positively charged ions is ion exchange technique. Ion exchange technique is widely used method for the separation and preconcentration of inorganic ions. In ion exchange, ions of positive charge and negative charge ions from an aqueous solution

**Table 5**

Total lead recovery % and elution constant,  $E$  various in the presence of different eluting agents, using cation exchange resin Purolite C100. Conc. lead(II) = 26.5 ppm, wt dried resin = 9.23 g.

Eluting agents	Elution constant, $E$	Total lead recovery (%)
2 M HNO <sub>3</sub>	0.232	95.59
3 M HNO <sub>3</sub>	0.769	96.01
4 M HNO <sub>3</sub>	0.769	99.90
1 M CH <sub>3</sub> COONH <sub>4</sub>	0.263	99.40
3 M CH <sub>3</sub> COONH <sub>4</sub>	0.769	100.00
4 M CH <sub>3</sub> COONH <sub>4</sub>	0.769	100.00

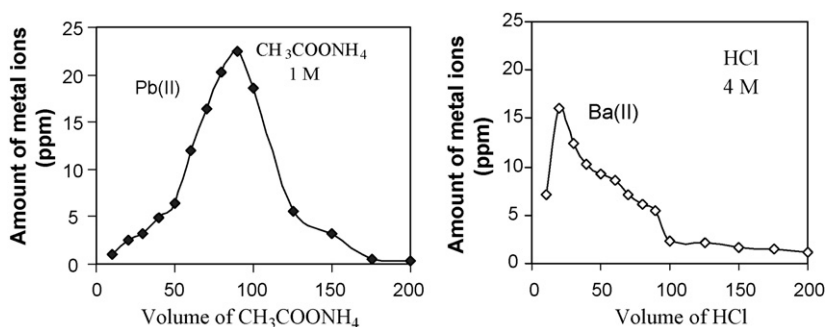


Fig. 3. Elution curves for separation of Pb(II)–Ba(II) binary mixtures using cation exchange resin Purolite C100 (5 g) (H<sup>+</sup> form).

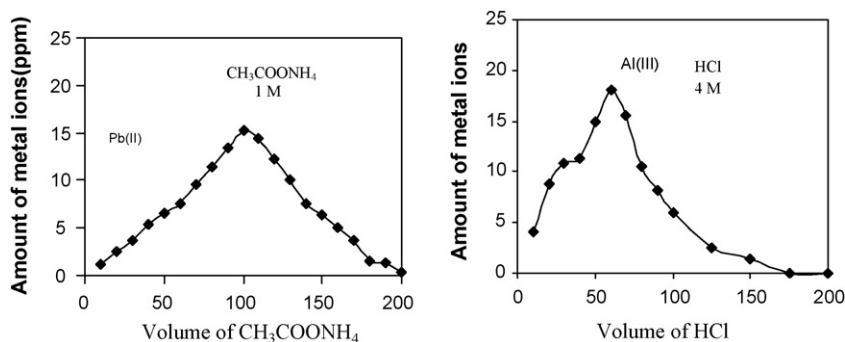


Fig. 4. Elution curves for separation of Pb(II)–Al(III) binary mixtures using cation exchange resin Purolite C100 (5 g) (H<sup>+</sup> form).

replace of the same charge initially in the solid. Cation exchange resins Purolite C100 contain bound sulfonic acid groups. 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 [29].

The over all exchange process can be shown as, the resin in hydrogen form was then equilibrated with metal ions thus displacing the hydrogen ions inside the resin as shown in the following equation:



Quantitative binary separations of metal ions were performed by column chromatography using elution technique. Various interesting separation of metal ions from other ions has been studied. These separations are based on the exploitation of the difference in the exchange potential of different ions with respect to the resin. Certain ions were capable of forming anionic complexes; passed through the column unadsorbed leaving behind the sec-

ond metal ions on the column. This was later eluted with suitable eluent.

The metal ions adsorbed by the resin were then eluted with different eluents depending on the  $k_d$  values. After the metal elutions were complete the resin was regenerated to hydrogen form using mineral acids such as HCl [30]. The results of  $k_d$  values presented in Table 3 indicate that cation exchange resin Purolite C100 shows a selective sorption of Al(III), and Ba(II). The reason for selective sorption and desorption of certain metal ions can be attributed to the larger difference in  $k_d$  values.

### 3.6. Column separation

The separation of individual metal ions from their binary mixture was performed by an elution technique. Cation exchange resin Purolite C100 (5 g) was packed into a glass column of 1.4 cm × 12.9 cm with a glass-wool support at the end, and washed 2–3 times with demineralized water. Binary solutions of the metal ions were prepared by mixing solution of each ion. The binary mix-

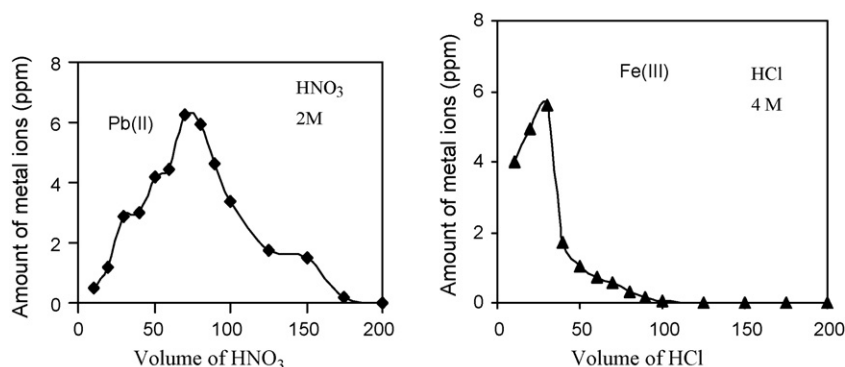


Fig. 5. Elution curves for separation of Pb(II)–Fe(III) binary mixtures by different eluents, by using cation exchange resin Purolite C100 (5 g) (H<sup>+</sup> form).



**Table 6**Recovery % of some cations from a binary mixtures in the presence of different eluent using cation exchange resin Purolite C100 (H<sup>+</sup> form).

No.	Mixture	Taken (ppm)	Eluting, agent	Found (ppm)	Recovery (%)
1	Pb <sup>2+</sup>	26.50	3 M CH <sub>3</sub> COONH <sub>4</sub>	26.28	99.17
	Ba <sup>2+</sup>	26.50	4 M HCl	20.47	77.25
2	Pb <sup>2+</sup>	26.50	3 M CH <sub>3</sub> COONH <sub>4</sub>	26.20	98.87
	Al <sup>3+</sup>	26.50	4 M HCl	23.34	88.08
3	Pb <sup>2+</sup>	10.60	2 M HNO <sub>3</sub>	9.98	94.15
	Fe <sup>3+</sup>	10.60	4 M HCl	3.83	36.13

ture 200 ml was then poured on to the top of the column and the solution was left to flow slowly 1.0 ml/min through the column until a small amount remained above the surface of the resin. The column was then rinsed with demineralized water. The effluent collected was recycled through the column to ensure complete absorption of metal ions. The metal ions were then eluted with an appropriate mobile phase and the effluent was collected in 10-ml fractions. The metal ion content of each 10 ml fraction was determined by atomic absorption spectrophotometer.

The quantitative separation of lead ions from Fe(III), Al(III) and Ba(II) has been achieved. The effluent fractions were collected in 10 ml portion and analyses for the metal ions inside it using atomic absorption spectrophotometer. Lead ions were taken up weakly by the resin in comparison with other ions and hence it was eluted first, while strongly adsorbed ions were eluted later with suitable eluent. The separation of Pb(II) from Ba(II) or Al(III) are based on the fact that ammonium acetate is a good eluent for lead but fails to elute the other cations. Table 4 shows that the most effective separation of Pb(II)–Al(III) mixture is obtained with 1 M ammonium acetate, with the very large separation factor  $\alpha_{Al}^{Pb} = 193.37$  followed by the elution of other ions with 4 M HCl (lead was eluted with 200 ml of 1 M ammonium acetate and aluminum was then eluted with 200 ml of 4 M HCl). In Pb(II)–Ba(II) binary mixture, these metal ions have nearly similar distribution coefficients and low separation factors  $\alpha_{Ba}^{Pb} = 3.388$  in the presence of nitric acid, for this reason no separation is possible. Excellent separation with a separation factor of about 233.92 can be carried out by eluting lead ions with 200 ml 1 M ammonium acetate. Barium ions can then be eluted with 4 M HCl. Fairly a good separation is obtained for the separation of Pb(II) from Fe(III) using 2 M HNO<sub>3</sub> as eluting agent. The separation factor is not very large  $\alpha_{Fe}^{Pb} = 8.569$ , but exchange kinetics are good, lead eluted with 2 M HNO<sub>3</sub>, the finally iron was eluted with 200 ml of 4 M HCl. Results of the possible separation achieved on the column from synthetic solutions are given in Figs. 3–5. The recovery % was calculated from the following equation:

$$\text{recovery\%} = \frac{[M^{n+}]_{\text{eluted}}}{[M^{n+}]_{\text{fixed}}} 100 \quad (6)$$

Table 6 represents in the recovery % of some metal ions in the presence of different eluent using cation exchange resin Purolite C100. The recovery increased when the affinity of the resin towards metal ion decreased. The separation of lead ions were 94.15, 98.87 and 99.17% recovery for Pb(II)–Fe(III), Pb(II)–Al(III) and Pb(II)–Ba(II) binary mixtures respectively using suitable eluents.

#### 4. Conclusions

The present investigation shows that cation exchange resin Purolite C100 can be employed for the separation and recover metal ion from their mixtures. Batch and column methods were done for the separation of lead ions from the binary mixture. The described methods provide a simple, fast and economic means for separating lead quantitatively from aluminum, trivalent iron and barium.

#### References

- [1] S. Mohan, G. Sreelakshmi, Fixed bed column study for heavy metal removal using phosphate treated rice husk, *J. Hazard. Mater.* 153 (2008) 75–82.
- [2] Y. Zhang, 100 years of Pb deposition and transport in soils in champaign, Illinois, USA, *Water Air Soil Pollut.* 146 (2003) 197–210.
- [3] L.H.J. Lajunen, A. Kubin, Determination of trace amounts of molybdenum in plant tissue by solvent extraction–atomic-absorption and direct-current plasma emission spectrometry, *Talanta* 33 (1998) 265–270.
- [4] Z.C. Ansky, P. Rychlovsky, Z. Petrova, J.P. Matousek, A technique coupling the anolyte electrodeposition followed by in-situ stripping with electrothermal atomic absorption spectrometry for analysis of samples with high NaCl contents, *Spectrochim. Acta* 62B (2007) 250–257.
- [5] S. Saracoglu, M. Soylak, L. Elci, Enrichment and separation of traces of cadmium, chromium, lead and manganese ions in urine by using magnesium hydroxide coprecipitation method, *Trace Elem. Electrolytes* 18 (2001) 129–133.
- [6] Y. Ebihara, T. Shimizu, K. Jinno, N. Uehara, Speciation of chromium(III) and chromium(VI) in river water by graphite furnace atomic absorption spectrometry after cloud point extraction with ammonium pyrrolidine dithiocarbamate, *Bunseki Kagaku* 56 (2007) 737–743.
- [7] A.U. Karatepe, M. Soylak, L. Elci, Separation/preconcentration of Cu(II), Fe(III), Pb(II), Co(II) and Cr(III) in aqueous samples on cellulose nitrate membrane filter and their determination by atomic absorption spectrometry, *Anal. Lett.* 35 (2002) 1561–1574.
- [8] C.E. Dogan, G. Akcin, Solid phase extraction and determination of lead in water samples using silica gel homogeneously modified by thiosalicylic acid, *Anal. Lett.* 40 (2007) 2524–2543.
- [9] M. Soylak, L. Elci, M. Dogan, Flame atomic absorption spectrometric determination of cadmium, cobalt, copper, lead and nickel in chemical grade potassium salts after an enrichment and separation procedure, *J. Trace Microprobe Tech.* 17 (1999) 149–156.
- [10] P. Liang, Y. Qin, B. Hu, T. Peng, Z. Jiang, Nanometer-size titanium dioxide micro-column on-line preconcentration of trace metals and their determination by inductively coupled plasma atomic emission spectrometry in water, *Anal. Chim. Acta* 440 (2001) 207–213.
- [11] G. Absalan, A. Aghaei Goudi, Optimizing the immobilized dithizone on surfactant-coated alumina as a newsorbent for determination of silver, *Sep. Purif. Technol.* 38 (2004) 209–214.
- [12] A. Cigdem, S. Bekts, Preconcentration and determination of lead, cadmium and nickel from water samples using a polyethylene glycol dye immobilized on poly(hydroxyethylmethacrylate) microspheres, *Anal. Sci.* 22 (2006) 1025–1029.
- [13] E. Pehlivan, T. Altun, The study of various parameters affecting the ion exchange of Cu<sup>2+</sup>, Zn<sup>2+</sup>, Ni<sup>2+</sup>, Cd<sup>2+</sup>, and Pb<sup>2+</sup> from aqueous solution on Dowex 50W synthetic resin, *J. Hazard. Mater.* B134 (2006) 149–156.
- [14] M. Ghaedi, A. Shokrollahi, K. Niknam, E. Niknam, H.R. Rajabi, M. Soylak, Flame atomic absorption spectrometric determination of trace amounts of heavy metal ions after solid phase extraction using modified sodium dodecyl sulfate coated on alumina, *J. Hazard. Mater.* 155 (2008) 121–127.
- [15] S. Saracoglu, M. Soylak, L. Elci, Preconcentration of Cu(II), Fe(III), Ni(II), Co(II) and Pb(II) ions in some manganese salt with solid phase extraction method chromosorb-102 resin, *Acta Chim. Slov.* 50 (2003) 807–814.
- [16] P.A. Kavakli, Z. Yilmaz, S. Murat, Investigation of heavy metal ion adsorption characteristics of poly(N,N-dimethylamino ethylmethacrylate) hydrogels, *Sep. Sci. Technol.* 42 (2007) 1245–1254.
- [17] A.I. Ferraz, T. Tavares, J.A. Teixeira, Cr(III) removal and recovery from *Saccharomyces cerevisiae*, *Chem. Eng. J.* 105 (2004) 11–20.
- [18] I. Aldor, E. Fourest, B. Volesky, Desorption of cadmium from algal biosorbent, *Can. J. Chem. Eng.* 73 (1995) 516–522.
- [19] F. Bux, P. Naidoo, H.C. Kasan, Laboratory-scale biosorption and desorption of metal ions using waste sludge and selected acids, *S. Afr. J. Sci.* 92 (1996) 527–529.
- [20] S.M. Khopkar, A.K. De, Cation exchange studies of lead on dowex 50W-X8, *Talanta* 7 (1960) 7–11.
- [21] P. Sharma, S.R. Dubey, Braz, lead toxicity in plants, *J. Plant Physiol.* 17 (2005) 35–52.
- [22] W.L. Argersinger, A.M. Davidson, O.D. Bonner, Thermodynamics and ion exchange phenomena, *Trans. Kansas Acad. Sci.* 53 (1950) 404–410.
- [23] F.W.E. Strelow, An ion exchange selectivity scale of cations based on equilibrium distribution coefficients, *Anal. Chem.* 32 (9) (1960) 1185–1188.
- [24] J. Korkisch, F. Felk, S.S. Ahluwalia, Cation exchange behavior of several elements in nitric acid-organic solvent media, *Talanta* 14 (1967) 1069–1081.
- [25] F.W.E. Strelow, Quantitative separation of calcium from magnesium, aluminum, iron(III) and many other elements by cation-exchange chromatography in

- methanolic hydrochloric acid on a macroporous resin, *Anal. Chim. Acta* 127 (1981) 63.
- [26] C.T. Eusebius, A. Mahan, A.K. Ghose, A.K. Dey, Cation exchange sorption of some metal ions from aqueous ammonium acetate medium: separation of Ce(IV) from (III), La(III) & other metal ions, *Indian J. Chem.* 15A (1977) 438–442.
- [27] E. Brucher, P. Szarras, Studies on the ammonium-lactate elution of trace lanthanides, *J. Inorg. Nucl. Chem.* 28 (1966) 2361–2369.
- [28] K.B. Ghosh, A.K. Ashok Mahan, K.D. Ghose, Arun, Adsorption behavior of some metal ions on cation exchange resin dowex 50 W-X4 from ammonium acetate-dimethylformamide media, *J. Ind. Chem. Soc.* LVII (1980) 591–595.
- [29] A. Dabrowski, Z. Hubicki, P. Podkoscielny, E. Robens, Selective removal of heavy metal ions from waters and industrial wastewaters by ion-exchange method, *Chemosphere* 56 (2004) 91–106.
- [30] A. Agrawal, K.K. Sahu, Separation Amberlite IRC 718 chelating resin, *J. Hazard. Mater.* B133 (2006) 299–303.