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Synthesis, characterization and application of triethylenetetramine modified polystyrene resin in removal of mercury, cadmium and lead from aqueous solutions

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ABSTRACT

Polystyrene-triethylenetetramine resin (PS-TETA) was synthesized from chloromethylated polystyrene (PS-Cl) and triethylenetetramine (TETA) and employed as a new adsorbent for heavy metal removal from aqueous solutions. The effects of reaction parameters (reaction solvent, molar ratio of reagents, reaction temperature and reaction time) on the functional group capacity of PS-TETA resin were monitored to specify the best synthesis conditions. The functional group capacity and conversion percentage of functional group of PS-TETA prepared under the optimum condition were 2.13 mmol FG/g and 49.79%, respectively. The structure of PS-TETA was confirmed by elemental analysis and infrared spectra. The optimization of experimental conditions and parameters including pH, contact time, initial metal ion concentration for the removal of heavy metals were investigated. The maximum adsorption capacities of the resin for Hg(II), Cd(II) and Pb(II) evaluated from the Langmuir model were 344.8, 212.8 and 147.1 mg/g, respectively. Desorption studies revealed that Hg(II), Cd(II) and Pb(II) can be easily removed from PS-TETA by altering the pH values of the solution using HCl, which indicate that PS-TETA is a promising adsorbent for heavy metals removal from aqueous medium.

1. Introduction

The contamination of water recourses by heavy metal is a serious worldwide environmental problem [1]. Numerous metals such as mercury, cadmium, chromium, lead, etc. are known to be significantly toxic. These facts have motivated many physicochemical methods for heavy metal removal from aqueous solution, including chemical precipitation, membrane separation, electrochemical reduction, ion exchange, and adsorption [2–6]. Among these methods, adsorption is generally preferred for the removal of heavy metal ions due to its high efficiency, easy handling, availability of different adsorbents and cost effectiveness. As one of the adsorbent materials, chelating resin is reusable, easy to be separated, and often has high adsorption capacities [7]. Thus, much attention has been drawn to the synthesis of chelating resins and the investigation of their adsorption behaviors for the extraction and preconcentration of metal ions from various matrices [8–11].

Chelating resins are typically characterized by functional groups containing O, N, S, and P donor atoms which can coordinate to different metal ions. Many studies have shown the functionalization of a polymeric matrix with different chelating functionalities such as heterocyclic or linear functional groups for metal ions removal or separation [12]. Several functional groups such as iminodiacetic acid [13], iminoacetate [14], benzimidazolylazo [15], 2-mercaptobenzothiazole [16], salicylaldoxime [17], dithiocarbamate [18], diethylene-triaminetetraacetic [19], imidazole [20] have been immobilized on a resin bed. These introduced functional groups will modify the chemical composition of the polymeric matrix surface and hence improve their adsorption behaviors. Among these chelating ligands, linear polyamine often can form stable metal complexes with a variety of metal ions, and triethylenetetramine (TETA) is one of them [21,22].

The aim of this work was to prepare a novel chelating resins by friedel-crafts substituted reaction inducing TETA onto PS-Cl and summarize synthesis and adsorption characteristics of PS-TETA resin for the removal of metal ions. The influence of experimental conditions such as reaction solvent, reaction time, reaction temperature, molar ratio of reagents of synthesis will be discussed. Meanwhile the influence of experimental parameters such as pH, contact time and initial concentration on adsorption will be revealed.

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Table 1
Operating parameters used for recording AAS for different metal ions.

Metal ion	Lamp current (mA)	Slit width (nm)	Wavelength (nm)
Hg(II)	3.0	0.5	253.7
Cd(II)	3.5	0.5	228.8
Pb(II)	5.0	0.5	283.3

2. Materials and methods

2.1. Materials and instrumentations

Macroporous chloromethylated polystyrene beads (PS-Cl) (crosslinked with 8% DVB, chlorine content 18.0%, specific area 43 m^2/g, mean pore size 19 nm) was purchased from Chemical Factory of Nankai University of China. Triethylenetetramine (TETA), $Hg(NO_3)_2$, $Cd(NO_3)_2 \cdot 4H_2O$ and $Pb(NO_3)_2$ of analytical grade were purchased from the Sinopharm Group Chemical Reagent Co. Ltd., China. Standard stock solutions of 2.0 g/l Hg(II), Cd(II) and Pb(II) ions were prepared by dissolving appropriate amounts of above nitrates in distilled water, respectively, and further diluted prior to use. All other reagents, solvents were of analytical reagent grade.

The specific surface area and the mean pore size of PS-Cl were determined on an Autosorb-1 Automatic Surface Area and Pore Size Analyzer. Batch experiments were carried out in the DSHZ-300A temperature constant shaking machine. A flame atomic absorption spectrophotometer (M6 Thermo) was used for metal ion concentration determination. The operating condition was presented in Table 1. A Nicolet 380 FT-IR and a Vario EL Elemental Analyzer were used for the structure determination of the chelating resin. The water used in the present work was purified using Molresearch analysis-type ultra-pure water machine. Mettler toledo delta 320 pH meter was used for measuring pH.

2.2. Synthesis of PS-TETA resin

30.0 mg PS-Cl beads and 15 ml purified solvent were added into a 100 ml three neck round bottom flask, swelling over night. After swelling, a certain amount of TETA and a small amount of metallic sodium used as catalyst were added into the flask. The system was degassed by bubbling with a high purity nitrogen flow to remove oxygen, and then the reaction mixture was reacted with magnetic stirring under nitrogen atmosphere at a certain temperature. After reaction, the resin was washed thoroughly with solvent, deionized water, acetone and ether successively. The resin was dried at 50 °C under vacuum for analysis.

2.3. Adsorption experiments

2.3.1. Batch studies

Batch adsorption experiments were conducted by placing a desired amount of treated PS-TETA resin in 100 ml conical flasks containing 30 ml of various concentration of metal ions solution. The sample pH was adjusted to the desired value with HAC-NaAC solution. The flasks were agitated at 100 rpm in a DSHZ-300A temperature constant shaking machine at the constant temperature to reach equilibrium. Aliquot samples were taken from the flask at appropriate time intervals as necessary. The residual concentration of the metal ions in the aqueous phases was determined by a flame atomic absorption spectrophotometer. The adsorption capacity (q_e) was calculated with the following formula:

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

where C_0 and C_e are the initial and equilibrium concentrations of metal ions in solution, V the total volume of solution and m is the mass of the fiber.

2.3.2. Desorption studies

Desorption of metal ions was performed by mixing PS-TETA–metal complexes and HCl eluent solutions of different concentrations, and stirred at 100 rpm for 24 h at 298 K. The final metal ion concentrations in the aqueous phase were similarly analyzed as described above. The desorption ratio (E) was calculated as follows:

$$E(\%) = \frac{C_d V_d}{(C_0 - C_e)V} \times 100\% \tag{2}$$

where E is the desorption ratio; C_d is the concentration of the solutes in the desorption solutions; V_d is the volume of the desorption solution; and C_0, C_e and V are the same as defined above.

2.3.3. Column studies

The fixed-bed experiments were carried out at in a water-jacketed glass column with an inner diameter of 6.0 mm and a full length of 200 mm. An aliquot of the fresh PS-TETA resin (100 mg) was putted into the bed. The aqueous solution with known concentrations of metal ions was then fed to the top of the bed at a desired flow rate until the breakthrough curve was completed. The samples in the outlet were taken at the preset time intervals and the concentrations of metal ions were similarly determined as above. In addition, dynamic desorption procedures were also carried out.

3. Results and discussion

3.1. Synthesis of PS-TETA resin

The effects of the reaction conditions including reactive solvent, molar ratio of reagents, reactive temperature and time on the conversion of functional group of PS-TETA resin were investigated.

Firstly, it was found that the solvent had a significant effect on the synthesis process. The nitrogen content varied dramatically with different solvent of various polarities. Maximum nitrogen content (11.03%) was obtained in toluene. However, it was only 6.79% and 7.66% when the solvent were 1,4-dioxane and DMF, respectively. According to the molecular diffusion theory, the modification reaction depended on the permeability of the parent resin in a certain solvent [23].

Effect of moral ratio on the conversion of functional group is given in Fig. 1. The conversion was increased with the moral ratio (TETA/Cl) increased from 3 to 5 due to a higher concentration of the ligand at the reaction sites. However, the conversion kept almost constant when the moral ratio was higher than 5, and that may be resulting from the limited availability of the active sites on the PS-Cl resin. According to the results of this study, the optimal moral ratio for the efficient synthesis of PS-TETA resin was 5.

The reaction temperature also had a great effect on the conversion of functional group of PS-TETA resin. As shown in Fig. 2, the nitrogen content increased rapidly with the increase of temperature in the range from 50 to 80 °C and then kept almost constantly. Higher temperature may make more molecules be able to overcome the activation energy of the reaction, increasing the diffusion of TETA to the reaction sites, and as a result, lead to higher conversion. Therefore, an optimal reaction temperature should be 80 °C.

The variation of the conversion of functional group of PS-TETA resin with the reaction time is given in Fig. 3. The conversion increased with the reaction time at the beginning and reached equilibrium within 8 h. The conversion is controlled primarily by the diffusion of ligand. At the early stage of synthesis, the ligand reacts with the active sites on the PS-Cl easily and the substrate surface is gradually covered. The ligand then has to diffuse into the interior of the substrate to react with free $-CH_2Cl$ in the sublayer, and this

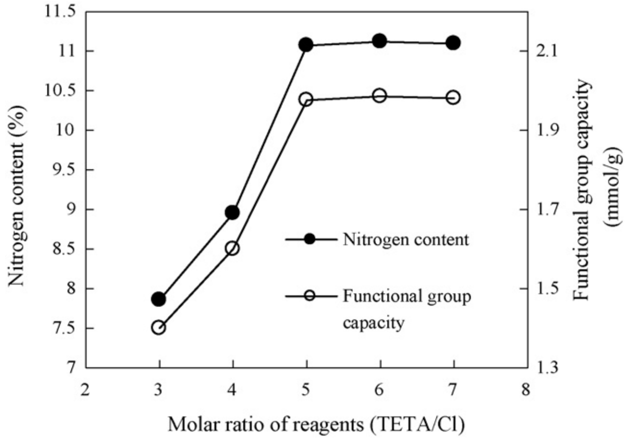

Fig. 1. Effect of moral ratio of reagents on conversion of functional group of PS-TETA resin. Reaction temperature (70 °C), reaction time (6 h).

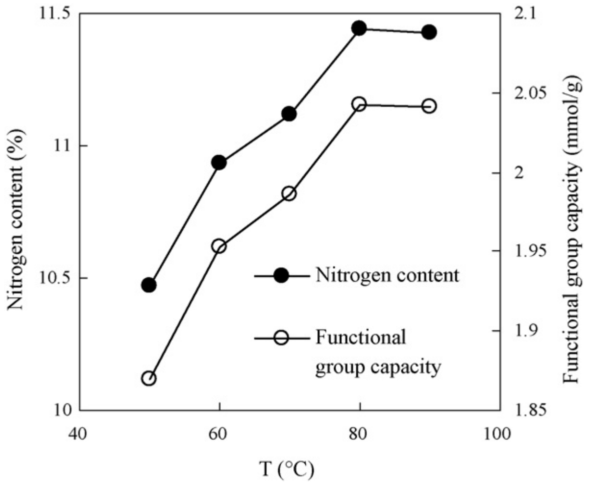

Fig. 2. Effect of reaction temperature on conversion of functional group of PS-TETA resin. Moral ratio (5), reaction time (6 h).

process will gradually slow down due to the active sites sheltered by other earlier formed grafting chains.

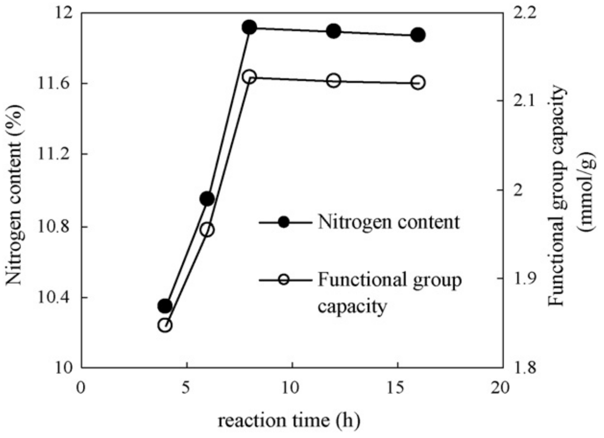

Fig. 3. Effect of reaction time on conversion of functional group of PS-TETA resin. Reaction temperature (80 °C), moral ratio (5).

3.2. The characterization of new polymeric resin

3.2.1. Conversion of functional group of PS-TETA resin

The conversion of the functional group of the resin synthesized under the optimum condition can be calculated from the functional group capacities of PS-Cl and PS-TETA resins as well as the molecular weight of TETA as shown in the following equation:

$$\frac{1 \times F_0 X}{1 + (1 \times F_0 X (M_1 - 2M_2)/1000)} = F_c \tag{3}$$

where X is the conversion percentage of the functional group. F_0 (5.07 mmol Cl/g) is the functional group capacity of PS-Cl beads and F_c (2.13 mmol/g) is the calculated functional group capacity of PS-TETA resin. M_1 and M_2 are the molecular weight of TETA and HCl, respectively.

The two sides of the equality represent the theoretical and calculated values of the functional group capacity (mmol/g) of PS-TETA resin, respectively. On the left side of the equality, the denominator represents the weight of PS-TETA resin prepared from 1.0 g PS-Cl resin and the numerator represents the number of millimoles of the new functional group produced from 1.0 g PS-Cl resin, while the value on the right side of the equation, is the functional group capacity of PS-TETA resin calculated from the nitrogen content according to the elementary analysis results. As a result, the percentage conversion of the functional group of PS-TETA resin calculated from the equation is 49.79%.

3.2.2. IR spectrum

The structures of PS-Cl, TETA and PS-TETA resins were confirmed using FT-IR method. In the spectra of TETA, the appearance of characteristics bands at around 3355 and 3281 cm^{-1} is due to the stretching vibrations of N–H of amine and secondary amine groups. In the spectra of PS-TETA resin, the appearance of characteristics bands of N–H of secondary amine groups at 3427 cm^{-1}, in addition to a band at 1362 cm^{-1} due to C–N stretching vibration, suggested the presence of amine moiety on the modified polymer. The disappearance of the band at 1264 and 671 cm^{-1} is associated with the –CH$_2$Cl groups in the non-functionalized polymer, confirmed the chemical modification of the PS-Cl polymer and indicates the reaction between a –CH$_2$Cl in the polymeric support and amino ligands. The proposed structure of the new prepare resins is presented in Fig. 4 and the FT-IR spectra of the PS-Cl and PC-TETA resins in Fig. 5.

3.3. Batch studies

3.3.1. Influence of pH on the sorption of Hg(II), Cd(II) and Pb(II)

The removal of metal ions from aqueous solution by adsorption is highly dependent on the pH of the solution which affects the surface charge of the adsorbent and the degree of ionization and speciation of the adsorbate. In this work, to verify the effect of pH on metal adsorption on PS-TETA resin, experiments were carried out in a pH range of 2.00–7.00. The results obtained are shown in Fig. 6. It could be noted that the maximum adsorption amounts of the metal ions were obtained at pH 6.0 for Hg(II) and Pb(II), and 5.0 for Cd(II), respectively. And the maximum adsorption amounts of the resin for the metal ions obey the following order: Hg(II) > Cd(II) > Pb(II), which indicates that the PS-TETA resin has higher sorption ability towards Hg(II) than Cd(II) and Pb(II) from aqueous solutions. The fact that the amount of metal ions removal at lower pH is considerably lower may be accounted for the competition between metal ions and H$^+$ ions for the active sites on the surface of adsorbent, whereas the decrease of the removal amount at higher pH may be accounted for the diminution of free ions due to formation of soluble hydroxyl complexes [24].

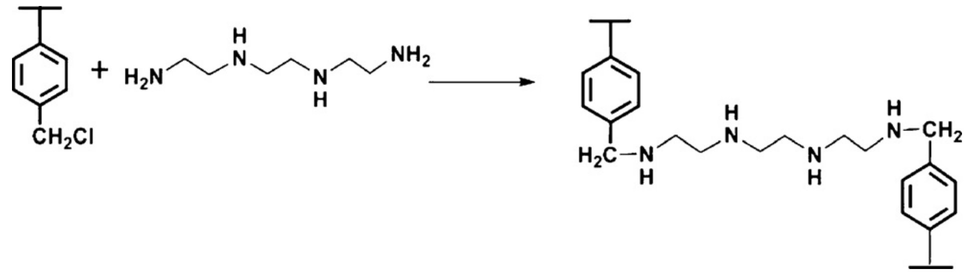

Fig. 4. Proposed synthesis routes for PS-TETA resin.

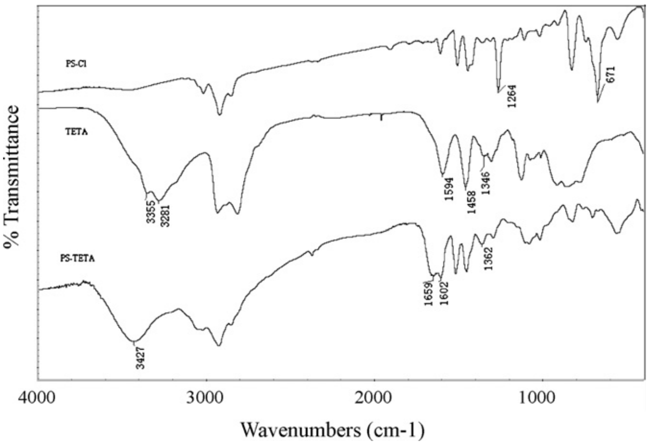

Fig. 5. FT-IR spectra of: TETA, PS-Cl and PS-TETA resin.

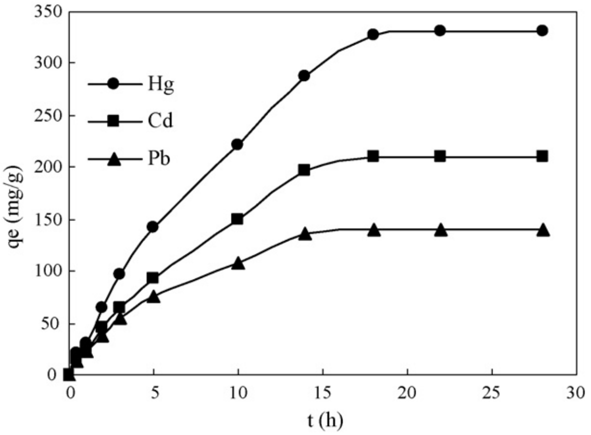

Fig. 7. Effect of contact time on adsorption of Hg(II), Cd(II) and Pb(II) by PS-TETA resin. Initial metal ion concentration (0.333 mg/ml), adsorbent dose (30 mg), batch volume (60 ml), rpm (100).

3.3.2. Influence of contact time on the sorption of Hg(II), Cd(II) and Pb(II)

Fig. 7 shows the time-dependent behaviors of the removal of Hg(II), Cd(II) and Pb(II) from aqueous solution by PS-TETA resin. It is clear that the removal amount of Hg(II), Cd(II) and Pb(II) increased as the contact time elapsed. The removal amount of metal ions increased rapidly during the few hours, and then increased slowly until the equilibrium state was reached. The equilibrium for the removal of Hg(II), Cd(II) and Pb(II) was reached after 14, 18 and 22 h for Pb(II), Cd(II) and Hg(II), respectively. A further increase in contact time had a negligible effect on the removal amount. The initial adsorption rate was very fast may be due to the existence of greater number of resin sites available for metal ions adsorption. As the remaining vacant surface sites decreasing, the adsorption rate slowed down due to formation of repulsive forces between the metals on the solid surface and in the liquid phase. The kinetic curves are single, smooth, and continuous, indicating the possible monolayer coverage of metal ions on the surface of the resin [25].

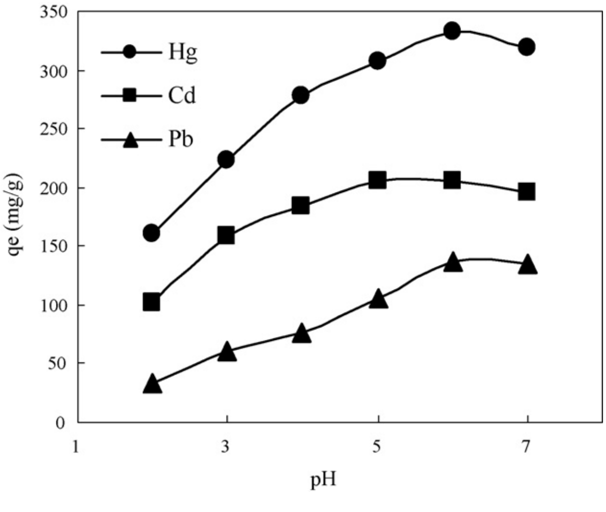

Fig. 6. Effect of pH on the sorption capability of PS-TETA resin for Hg(II), Cd(II) and Pb(II). Initial metal ion concentration (0.333 mg/ml), adsorbent dose (15 mg), batch volume (30 ml), rpm (100), temperature 298 K.

According to the Brykina method [26] the sorption rate constant k can be calculated from:

$$-\ln(1-F) = kt + B, \quad \text{where } F = \frac{q_t}{q_e} \tag{4}$$

where q_t is the sorption capacity at time t and q_e is the sorption capacity at equilibrium. The sorption rate constant can be found from the slope of the straight line (Fig. 8). The calculated sorption rate constants (k) are $k_{\mathrm{Hg(II)}} = 4.17 \times 10^{-5}\,\mathrm{s}^{-1} > k_{\mathrm{Cd(II)}} = 3.40 \times 10^{-5}\,\mathrm{s}^{-1} > k_{\mathrm{Pb(II)}} = 3.05 \times 10^{-5}\,\mathrm{s}^{-1}$ at 25 °C. Zero intercept suggests that the kinetics of the adsorption process is controlled by diffusion through the liquid film surrounding the solid adsorbents [27].

3.3.3. Adsorption Isotherm

The parameters of equilibrium isotherms often provide some insight into the sorption mechanism of the adsorbent. There are many equations for analyzing experimental adsorption equilibrium data. In this work, the experimental results obtained were tested by the Langmuir and Freundlich isotherm models [28,29]. Their linear forms are expressed as follows:

$$\frac{C_e}{q_e} = \frac{C_e}{q_m} + \frac{1}{bq_m} \tag{5}$$

$$\lg q_e = \lg K_f + \frac{1}{n} \lg C_e \tag{6}$$

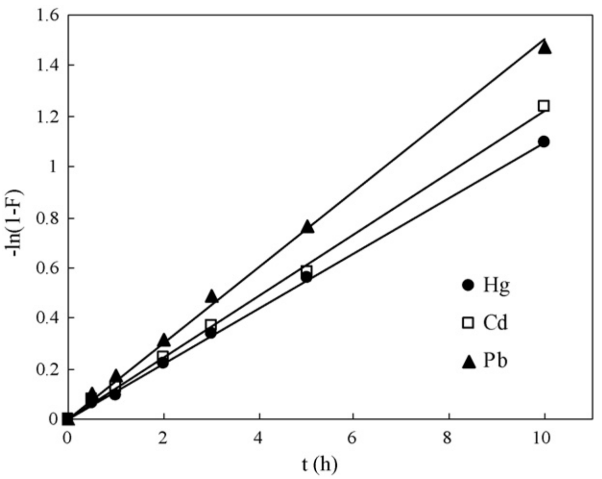

Fig. 8. Linear plots of $-\ln(1-F)$ vs. t by application of Brykina method.

where q_e is the equilibrium sorption amount, C_e is the equilibrium concentration; q_m is the maximum adsorption capacity of Langmuir, b is Langmuir constants; n is a constant indicating the Freundlich isotherm curvature, and K_f is the Freundlich sorption coefficients.

The R^2 values obtained from Langmuir model for Hg(II), Cd(II) and Pb(II) were higher than 0.98 ($R^2_{Hg(II)} = 0.9975$, $R^2_{Cd(II)} = 0.9998$, $R^2_{Pb(II)} = 0.9992$), while that values obtained from the Freundlich model were relatively lower ($R^2_{Hg(II)} = 0.8522$, $R^2_{Cd(II)} = 0.9278$, $R^2_{Pb(II)} = 0.8948$), suggesting the applicability of Langmuir model to this system. This indicates that the adsorption of Hg(II), Cd(II) and Pb(II) ions by PS-TETA resin is monolayer-type, which agrees with the observation that the metal ion adsorption from an aqueous solution usually forms a layer on the adsorbent surface. The q_m values for Hg(II), Cd(II) and Pb(II) were 344.8, 217.4 and 151.5 mg/g, respectively. The Langmuir plots are shown in Fig. 9.

3.4. Desorption and regeneration studies

Whether an adsorbent is an appropriate material in removal of metal ions from aqueous solutions depends not only on its adsorptive capacity, but also on its regeneration ability. For repeated use of an adsorbent, adsorbed metal ions should be easily desorbed under suitable conditions. In this work, desorption of metal ions with various concentrations of eluent solution was carried out. The results (Table 2) show that the elution ratio is different under various eluent concentrations. Maximum recovery of Hg(II), Cd(II) and Pb(II), at 100%, was achieved with 2, 2 and 3 M HCl eluent solutions, respectively. In order to show the reusability of the adsorbent, adsorption–desorption cycle of metal ion was repeated five times by using the same beads. The adsorption capacities for the PS-TETA resin did not noticeably change (only a maximum 3% change was observed) during the repeated adsorption–desorption operations. This can be attributed to decomposition effect of HCl used as stripping agent on adsorbent. These results show that the PS-TETA resin has good regeneration ability.

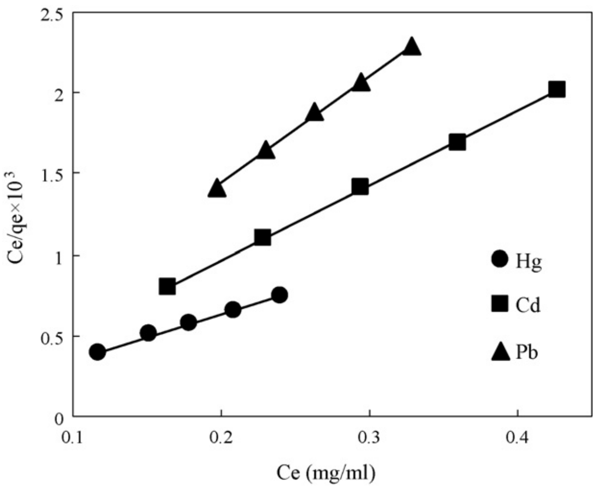

Fig. 9. Langmuir plots for adsorption of Hg(II), Cd(II) and Pb(II) by PS-TETA resin. Adsorbent dose (15 mg), batch volume (30 ml), rpm (100), temperature 298 K.

3.5. Column studies

3.5.1. Dynamic adsorption curve

Batch experimental data are often difficult to apply directly to the fixed-bed sorption because isotherms are unable to give accurate data for a dynamically operated column. The fixed-bed column operation allows more efficient utilization of the adsorptive capacity than the batch process. One of the main tools used in the investigation of the efficiency in adsorption columns is the breakthrough analysis. Total sorption capacity of metal (q_1) in the column for a given feed concentration and flow rate is calculated from [30]:

$$q_1 = \int_0^{V_e} \frac{C_0 - C_e}{m} dV_e \tag{7}$$

where C_0 and C_e are metal ion concentrations in the influent and effluent, respectively, m is the total weight of the sorbent loaded in the column and V_e is the volume of metal solution passed through the column. q_1 is the experimental maximum sorption capacity value obtained by graphical integration. The experimental breakthrough curves of Hg(II), Cd(II) and Pb(II) adsorption by PS-TETA resin are shown in Fig. 10.

The Thomas model was selected for describing the breakthrough for the fixed-bed sorption column in this study since it could be written in a simple form allowing a quick and easy interpretation of the results. The Thomas model can be expressed as [30]:

$$\frac{C_e}{C_0} = \frac{1}{1 + \exp[K_T(q_2 m - C_0 V_e)/\theta]} \tag{8}$$

where K_T is the Thomas rate constant, θ *is* the volumetric flow rate and q_2 is the theoretical maximum sorption capacity value. The linear form of the Thomas model is as follows:

$$\ln\left(\frac{C_0}{C_e} - 1\right) = \frac{K_T q_2 m}{\theta} - \frac{K_T C_0}{\theta} V_e \tag{9}$$

The kinetic coefficient K_T and the theoretical maximum sorption capacity of the bed q_2 can be determined from a plot of $\ln[(C_0/C_e) - 1]$ against t at a given flow rate (Fig. 11). The parameters for the column study obtained from the Thomas model are summarized in Table 3.

The results revealed that Hg(II) required the longest time period to reach the breakthrough concentration than the other metals at the same condition. This emphasized again that PS-TETA resin

Table 2
The elution percentage of metal ions.

Elution percentage (%)	Concentration of HCl (mol/l)			
	0.5	1.0	2.0	3.0
Hg(II)	55.8	81.6	100.0	94.3
Cd(II)	68.87	79.98	100.0	84.6
Pb(II)	63.21	85.7	87.8	100.0

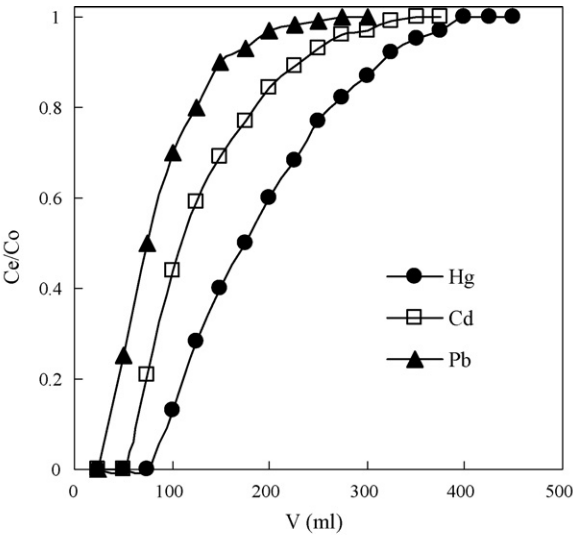

Fig. 10. Breakthrough curves of Hg(II), Cd(II) and Pb(II) adsorption by PS-TETA resin. Initial metal ion concentration (0.2 mg/ml), adsorbent dose (100 mg), flow rate (0.25 ml/min).

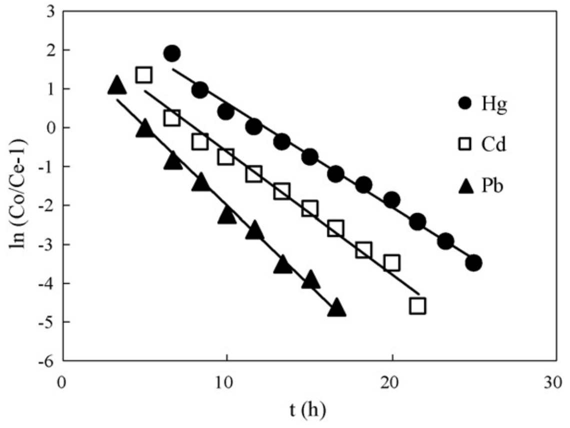

Fig. 11. Linear plots of $\ln(C_0/C_e - 1)$ vs. t by application of Thomas model.

had the greatest sorption capacity for Hg(II). The sorption capacity calculated from the breakthrough curve could be prioritized from high to low as: Hg(II) (355.5 mg/g) > Cd(II) (236.0 mg/g) > Pb(II) (149.1 mg/g). From Thomas model, the sorption capacities for the various metals could also be prioritized with the same order: Hg(II) (364.6 mg/g) > Cd(II) (237.4 mg/g) > Pb(II) (154.7 mg/g). This agreed with the order of maximum sorption capacities obtained from Langmuir studies in batch experiment.

The Thomas model was found in a relatively good fitness with breakthrough curves for sorption of metal on PS-TETA resin with the R^2 value higher than 0.98. Therefore, it can be concluded that the experimental data fitted well to the Thomas model, which indicates that this model was successfully used for the prediction of the breakthrough curves and to determine the characteristics parameters of the column useful for process design.

Table 3
Parameters of Thomas model for the continuous adsorption of metals on PS-TETA resin.

Metal ion	Flow rate (ml/min)	q_e (exp) (mg/g)	q_o (theo) (mg/g)	K_T (ml/(mg min))	R^2
Hg(II)	0.25	355.5	364.6	0.022	0.9893
Cd(II)	0.25	236.0	237.4	0.025	0.9836
Pb(II)	0.25	149.1	154.7	0.034	0.9897

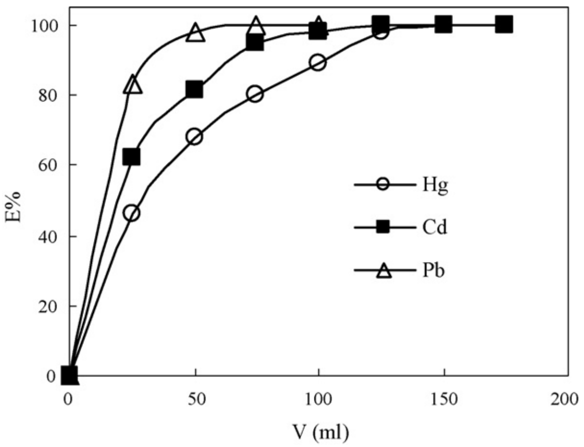

Fig. 12. Desorption curves of PS-TETA resin for Hg(II), Cd(II) and Pb(II). Flow rate (0.15 ml/min).

3.5.2. *Dynamic desorption curve*

Once the column reached exhaustion, efficient elution of adsorbed solute from PS-TETA resin in column is essential to ensure the recovery of metal ions as well as the reuse of resin for repeated adsorption/desorption cycles. In this work, HCl solutions with various concentrations have been used to elute metal. Desorption curve (Fig. 12) was obtained by plotting the effluent concentration (C_e) vs. elution volume from the column at a flow rate of 0.15 ml/min, less than the sorption 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. The results exhibit a sharp increase of Hg(II), Cd(II) and Pb(II) concentration at the beginning of acid elution, and the maximum recovery of Hg(II), Cd(II) and Pb(II), at 100%, was achieved with the optimum HCl eluent solutions selected in batch desorption studies, with the total volumes of 75, 125 and 150 ml, respectively. These results show that efficient elution of Hg(II), Cd(II) and Pb(II) from PS-TETA resin in column is practical, which indicates that the resin has a potential to be employed repeatedly in Hg(II), Cd(II) and Pb(II) extraction and preconcentration from aqueous solutions.

4. Conclusion

In this paper, a new composite chelating resin containing N donor atoms has been synthesized. FT-IR and elemental results indicate that the immobilization of TETA onto PS-Cl was accomplished. The material offers the versatility to complex different metal ions due to the presence of the $-NH(CH_2CH_2NH)_2CH_2CH_2NH-$ ligand. The resin was successfully employed as a new adsorbent material for the removal of metal ions from aqueous solutions. Batch studies clearly suggest the high adsorption capacity of PS-TETA resin for Hg(II), Cd(II) and Pb(II). The adsorption isotherms followed the Langmuir model. Thomas model was applied to experimental data obtained from dynamic studies performed on fixed column to predict the breakthrough curves and to determine the column kinetic parameters. The results of the present investigation showed that PS-TETA resin is a potentially useful adsorbent for the adsorption of Hg(II), Cd(II) and Pb(II), especially for Hg(II).

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