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<th>Zhang, Lijun; Hu, Xun; Yu, Chengzhong; Crawford, Russell; Yu, Aimin</th>
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Preparation of Sinapinaldehyde Modified Mesoporous Silica Materials and Their Application in Selective Extraction of Trace Pb(II)

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E-mail: aiminyu@swin.edu.au
Abstract

A new solid phase extractant, sinapinaldehyde (SA) modified SBA-15 mesoporous silica, was developed for selective extraction and preconcentration of trace Pb(II) from aqueous solution. The successful immobilization of SA on SBA-15 and the strong interaction between SA-SBA-15 and Pb(II) were characterized and confirmed using FTIR spectroscopy and scanning electron microscopy. Parameters such as solution pH, shaking time, eluent condition and sample volume were optimized so that the maximum removal of Pb(II) from solution could be achieved. At pH 4.0, the maximum adsorption capacity of the sorbent for Pb(II) was found to be 33.6 mg g$^{-1}$ and the adsorbed Pb(II) could be completely eluted by using a mixed solution of 2 M HCl and 5% CS(NH$_2$)$_2$. Some common metal ions such as K(I), Na(I), Mg(II), Ca(II), Cr(III), Fe(III), Co(II), Ni(II), Cu(II), Zn(II), Cd(II) and Hg(II) did not interfere with the adsorption of trace Pb(II). The detection limit of the present method was found to be 1.3 ng mL$^{-1}$ and the relative standard deviation was less than 2.0% (n=8). These results suggested that this sorbent is very efficient and selective for the determination of trace Pb(II) in water samples.

**Keywords:** Mesoporous silica; sinapinaldehyde; lead(II); surface modification
1. Introduction

The contamination by toxic metals from the aquatic environment continues to be of great concern. Lead pollution has received particular attention over the years because of its extreme toxicity, even at very low concentrations and its stability in contaminated sites [1]. Lead could accumulate in plants and animals, and act progressively over a long period through food chains [2-4]. As a result, lead pollution has posed a significant threat to our ecosystem, especially for human beings. As lead ions usually exist at trace levels in the aquatic environment, it is essential to develop simple, rapid and efficient techniques for extraction and preconcentration of trace lead so that it can be measured by common analytical techniques.

Solid phase extraction (SPE) has been one of the most widely used preconcentration techniques for the separation and enrichment of metal ions, due to its high enrichment factor, rapid phase separation, low consumption of organic solvents and the easy combination of SPE with other on-line or off-line detection techniques [5-7]. However, the main drawback of SPE is its low selectivity, which leads to interference when extracting a target metal ion amongst other co-existing species [8]. One solution is to modify the surface of matrix supports with some organic compounds that possess suitable functional groups to enhance the specific interaction between the support and the targeted metal ion. The factors that influence the selectivity include the structure of the organic compound such as the incorporated donor atoms O, N, P and S, the positioning of the functional groups along the surface of the solid support and the steric requirements of the complex formed after uptake of the desired metal ion [9]. Hence, the choices of the support and the organic compounds for modification are crucial for the performance of SPE.

Among various types of mesoporous materials, SBA-15 is a biocompatible material and possesses large surface area and high hydrothermal stability [10]. Current techniques have enabled the functionalization of silica material with various organic compounds either by incorporating organic groups into the silica framework via a synthesis procedure or by post-grafting organic substances onto the surface via chemical bonding or physical adsorption [11,12]. Recently, the modification of SBA-15 surface with organic chelating agents has been widely used to improve the efficiency and selectivity of solid-phase adsorbent for removing
heavy metals. For example, aminopropyl [13], pyridine [14], N-propylsalicyldimine [15], iminodiacetic acid [16], 1-furoyl thiourea [17], N-(3-triethoxysilylpropyl)-4,5-dihydroimidazole [18] and N’-[2-hydroxy phenyl)methylene] benzohydrazide [19] have been immobilized on SBA-15 and good results were achieved for adsorbing metal ions, such as Ag⁺, Cr⁶⁺, Zn²⁺, Cu²⁺, Cd²⁺, Hg²⁺, Pt²⁺, Pd²⁺ and Dy³⁺.

Most published works on lead removal have been focused on organic compounds with amino- and thiol-groups [1,20-22]. However, the selectivity of these materials for Pb(II) are usually unremarkable. Some other heavy metals such as Cu(II), Ni(II), Hg(II), Cr(III) and Zn(II) are more efficiently adsorbed. In addition, a long equilibrium time (≥120 min) is normally required for completing the adsorption. In this study, we attempt to use sinapinaldehyde (SA) as an organic chelating agent to modify SBA-15 to prepare a new type of solid phase extractant (SA-SBA-15) for the preconcentration of trace Pb(II) from water samples which is then determined by atomic absorption spectroscopy. SA is chosen because it possesses functional groups containing N and O atoms which are good electron donor and tend to interact with positively charged metal ions to form metal complexes [23]. Besides, OH- and CH₃O- groups of SA are considered as hard Lewis bases according to hard and soft acids and bases principle. So the hard Lewis acid-type metal cation such as Pb(II) tend to bind to these functional groups to form metal complexes [24]. For optimal performance, the effects of solution pH, the incubation time, the elution condition, the sample volume and the interfering ions on adsorption characteristics of the prepared material are investigated by batch and column methods. We also explore the application of this method to the extraction of Pb(II) from various water samples.

2. Experimental

2.1 Apparatus

Infrared spectra were recorded using a Perkin Elmer Spectrum One FTIR spectrophotometer in the region 4000–450 cm⁻¹ using spectroscopic quality KBr powder. AAS measurements were performed using an AA-50 Varian atomic absorption spectrophotometer equipped with Varian multi-element hollow cathode lamps and air–acetylene burner. The wavelength used for Pb is 283.3 nm. A Martini Mi 151 pH meter was used for the pH measurements. A Julabo
SW 20C shaker was used for the shaking process at the rate of 150 rpm with the temperature controlled at 25 °C. Macrostructural characterizations were carried out using a XL 30 FEG (Philips) scanning electron microscope (SEM) operated at an acceleration voltage of 10 kV. Thin gold film was coated before measurements. A Gilson Minipuls 3 peristaltic pump was used in the preconcentration process. A self-made PTFE (polytetrafluoroethylene) column (60 mm×4.0 mm i.d.) packed with the new sorbent was used for separation/preconcentration of lead ions.

2.2 Chemicals and reagents
Tetraethylorthosilicate (TEOS, 98%), poly(ethylene glycol)-block-poly(propylene glycol)-block-poly(ethylene glycol), 3-aminopropyltriethoxysilane (APS, 98%), sinapinaldehyde (SA, 98%) and thiourea (CS(NH$_2$)$_2$, ≥99%) were purchased from Sigma-Aldrich (NSW, Australia) and used as supplied. Organic solvents (toluene, diethyl ether and ethanol) were purchased from Ajax Chemicals (NSW, Australia). Hydrochloric acid (32%) and nitric acid (70%) were obtained from Merck (Victoria, Australia). Working standard stock solutions of Cr(III), Fe(III), Co(II), Ni(II), Cu(II), Zn(II), Cd(II), Hg(II) and Pb(II) were prepared by diluting a AA standard solution of 1000 mg L$^{-1}$ of the given elements supplied by Scharlau Chemie S. A. (European Union). The water used in all experiments was prepared in a Millipore Milli-Q purification system and had a resistivity higher than 18 MΩ cm.

2.3 Preparation of SA functionalized SBA-15 silica
The SBA-15 silica was prepared using an adapted sol–gel procedure as described in literatures [10,25]. Briefly, 4.0 g of poly(ethylene glycol)-block-poly(propylene glycol)-block-poly(ethylene glycol) was dissolved in 80 g of 2 M HCl and 30 g of water. After adding 4 mL of TEOS, the mixture was stirred for 20 hours at room temperature. The solid product was recovered, washed, and air-dried at room temperature. The sample was then calcinated in air at 500 °C for 6 h.

Before surface modification, SBA-15 was firstly activated by refluxing at 110 °C in 0.1 mol L$^{-1}$ hydrochloric acid for 12 h to increase the hydroxyl group content on the surface. 2.0 g activated SBA-15 was then dispersed in 70 mL toluene. After gradually adding 2 mL
3-aminopropyltriethoxysilane, the resulting mixture was refluxed at 112 °C under stirring for 8 h. The material was then filtered, washed and dried under vacuum which is denoted as NH₂-functionalized SBA-15 (NH₂-SBA-15).

The SA-SBA-15 sorbent was prepared by adding 2 g NH₂-SBA-15 to a 70 mL ethanol solution containing 1.2 g SA. After refluxing at 85 °C for 12 h, the sorbent was washed thoroughly with ethanol, diethyl ether and dried at 80 °C overnight. The synthesis route of SA-SBA-15 is illustrated in Fig. 1.

2.4 Procedures for preconcentration and determination of Pb(II) ions

2.4.1 Batch method

Standard or sample solution of Pb(II) was transferred into a beaker. After adjusting the pH to the desired value using aqueous ammonia or diluted HCl, the volume of solution was adjusted to 10 mL. 25 mg sorbent was added into the solution to allow the adsorption of Pb(II) ions under shaking at 150 rpm. The sorbent was filtered, washed with Milli-Q water. The adsorbed Pb(II) ions on the sorbent were then eluted using a mixed solution of 2 M HCl and 5% CS(NH₂)₂ and the amount was measured by atomic absorption spectroscopy (AAS) after dilution, if required.

2.4.2 Column method

50 mg SA-SBA-15 was packed into a self-made PTFE column (60 mm × 4.0 mm i.d.). The column was cleaned by 2 M HCl followed by water washing until acid free. Sample solution of Pb(II) was then passed through the column at a flow rate of 3.0 mL min⁻¹. After water washing to remove the loosely adsorbed metal ions, the retained Pb(II) ions on the sorbent were eluted from the column using a mixed solution of 2 M HCl and 5% CS(NH₂)₂ and analysed by AAS.

2.5 Calibration for various heavy metals

For the determination of metal ions with AAS, various parameters (viz. wavelength, slit width, lamp current, etc) were set at the optimum level, as recommended by the manufacturer. The linear working range and calibrate equations for measurement under optimum conditions were listed in Table 1.
3. Results and discussion

3.1 Characterization of sinapinaldehyde modified SBA-15 (SA-SBA-15)

FTIR was used to characterize the modification process. Fig. 2 shows the FTIR spectra of the as synthesized SBA-15, NH$_2$-SBA-15, SA-SBA-15 and SA-SBA-15 after lead adsorption. The spectrum of SBA-15 (Fig. 2a) shows typical bands at 3747 and 961 cm$^{-1}$ due to the presence of silanol groups. The peaks at 3435 and 1629 cm$^{-1}$ correspond to the stretching vibration of the –OH groups, and the peaks at 1090, 805 and 465 cm$^{-1}$ are attributed to the Si–O–Si bonds [26]. After modification of amine groups, the FTIR spectrum of NH$_2$-SBA-15 (Fig. 2b) shows new peaks at 2937 and 798 cm$^{-1}$, which are attributed to the stretching and bending vibrations of C–H, respectively. A band at 1635 cm$^{-1}$, corresponding to the bending vibration of N–H, is also identified. The peaks at 3747 and 961 cm$^{-1}$ that correspond to the silanol groups have been weakened considerably and the characteristic bands of the immobilized aminopropyl groups (NH$_2$-SBA-15 spectrum) increase after modification with APS, indicating that the reaction between the hydroxyl groups of the mesoporous silica network with the ethoxy groups of APS has taken place [16,27].

The spectrum of SA-SBA-15 (Fig. 2c) reveals new peak at 1636 cm$^{-1}$, corresponding to the C=C stretching that can be attributed to the aromatic bond in SA. The peak at 1514 cm$^{-1}$ can be assigned to the stretching vibration of C–O. The peaks at 1416 cm$^{-1}$ and 1466 cm$^{-1}$ are attributed to the stretching vibration of O–H and C=N, respectively [28]. The small peak at 1331 cm$^{-1}$ is due to νC–N and the peak at 949 cm$^{-1}$ appears as a result of the δC–H of the benzene ring. All of these peaks support the assertion that the modification of SBA-15 with SA has been successfully accomplished.

The spectrum of SA-SBA-15 after lead adsorption (Fig. 2d) shows some significant shifts in some peaks, which assigned to C–N, O–H, C–O and C=C stretching vibration, respectively. Obviously, the C–N stretching vibration peak becomes sharp and shifts from 1331 to 1385 cm$^{-1}$, which suggest that the nitrogen atoms are the main adsorption sites for Pb(II). In addition, a new peak appears at 2427 cm$^{-1}$ which can be attributed to the formation of hydrogen bonds between the surface hydroxyl groups and nitrogen or hydrogen atoms. These results indicate that the functional groups of C–N, O–H, C–O and C=C in the SA molecule may participate in binding the Pb(II) ions.
The SEM images of the ‘as-synthesized’ SBA-15, SA-SBA-15 and Pb(II) loaded SA-SBA-15 are shown in Fig. 3. As seen in Fig. 3a, SBA-15 has a rope-like framework structure, with relatively uniform sizes and regular diameters. The diameter of the rope is in the range between 300 to 410 nm. After modification with SA, the macrostructure of the rope-like framework remains the same with the exception that the rope diameter increases to 625–720 nm, as showed in Fig. 3b.

3.2 Effect of solution pH on the adsorption of Pb(II)

The effect of solution pH on the adsorption of Pb(II) was carried out using the batch method. 25 mg SA-SBA-15 was added into a series of 1.0 μg mL⁻¹ Pb(II) solutions (10 mL) with different pH values (pH 1.0–7.0). As seen in the data presented in Fig. 4, the low pH conditions (pH < 4.0) are not favourable for Pb(II) extraction and high extraction rates (> 95%) can be achieved in the pH range of 4.0–7.0. In the whole pH range between 1.0 and 7.0, Pb species mainly exist as Pb(II) with two positive charge. There are some [Pb(OH)]⁺ form at pH 6.8 but with a low percentage of ~7%. In lower pHs (pH < 4.0), the N and O atoms of the surface coating that are the main binding sites to Pb(II), tend to protonate and become positively charged which could prevent the approaching and binding Pb(II) with the same charge resulting in the low adsorption rate. While in weak acidic solutions (pH 4.0–7.0), the binding sites are less protonated thus higher extraction rates are obtained in this pH range. However, higher pH levels (pH>7.0) are not considered as appropriate conditions for metal ion adsorption as hydroxides may complex and precipitate the metal ions [29]. Thus, a pH of 4.0 was selected as optimal for the adsorption of Pb(II).

3.3 Effect of the shaking time on extraction yield

The adsorption of metal ions onto the solid phase extractant is a biphasic transfer process. A high level of contact between the metal ions and the extractant is crucial in order to achieve efficient adsorption. SA-SBA-15 is a porous material, and hence a mass transfer limitation may exist in the adsorption process. Although shaking could facilitate the mass transfer, it would be useful to ascertain the rate at which Pb(II) adsorption reaches an equilibrium. In this work, different shaking time (range from 2 to 30 min) was studied for the percentage extraction of Pb(II) by the sorbent following the batch method. The results showed that the
95% uptake of Pb(II) was achieved after 10 min. This is a little longer than the time taken for equilibration to be reached for Pb(II) adsorbing onto nonporous silica-based sorbent, as reported in our previous work [30,31]. This result suggests that it takes a certain period of time for the metal ions to reach the sides of the sorbent, with a further adsorbing time required to reach a quantitative recovery state.

### 3.4 Effect of elution condition and regeneration of sorbent

Once Pb(II) was adsorbed onto the sorbent, it was necessary to recover the Pb(II) for further measurement and sorbent recycle. The elution recovery of Pb(II) from SA-SBA-15 was studied using various concentrations of HCl and HNO₃ as well as a mixed solution of HCl and CS(NH₂)₂. Less than 60% of Pb(II) recovery was obtained by using HCl and HNO₃ as the eluent. The highest degree of recovery was obtained when 2 M HCl and CS(NH₂)₂ was used. This mixture solution is most effective in recovering the Pb(II) since it has a double effect: the hydrogen ions from HCl could compete for the adsorption sites on the SA-SBA-15 and the N and S atoms of CS(NH₂)₂ could interact with the adsorbed Pb(II) ions. It is likely that the interaction between CS(NH₂)₂ and Pb(II) is stronger than that between SA-SBA-15 and Pb(II). As a result, the coordination linkage of chelated Pb(II) could be disrupted by the presence of the CS(NH₂)₂, causing the subsequent release of the Pb(II) ions from the adsorption sites into the surrounding medium. Due to its important role in the elution process, the thiourea concentration in the mixture is another factor that influences the extent of recovery of the Pb(II). It was found that the recovery increases from 67.0% to 99.8% when the amount of CS(NH₂)₂ in the HCl and CS(NH₂)₂ mixture is increased from 1% to 5%. In this case, 5 mL of 2 M HCl + 5% CS(NH₂)₂ was found to be sufficient for the complete elution of the Pb(II).

After Pb(II) was recovered from the sorbent, the sorbent was treated with Milli-Q water until neutral equilibration was reached. Sequential adsorption–desorption cycle was repeated by means of the same sorbent according to the column method. The results showed that the recovery of Pb(II) using the recycled sorbent could be maintained at 95% level at the 3rd cycle. Thus, the adsorption–desorption cycle could be repeated at least three times for the same sorbent in the column.
3.5 Maximum sample volume and enrichment factor
In order to explore the possibility of concentrating low concentrations of analytes from large volumes of solution, the role that sample volume played on the extent of retention of metal ions was also investigated. Using the column method, different volumes of Milli-Q water at pH 4.0 were spiked with Pb(II) of 1.0 µg. The results showed that in order to keep the recovery of Pb(II) above 95%, a maximum sample volume could be used is 400 mL. Thus when 5 mL of 2 M HCl + 5% CS(NH₂)₂ was used as eluent, the enrichment factor of SA-SBA-15 for Pb(II) was calculated to be 80. This value is close or higher than some other silica-based materials that have been reported (e.g., enrichment factor 30 [32], 50 [33], 75[30], 100 [31,34]). As generally methods with larger enrichment factors provide more accurate results with lower errors, the SA-SBA-15 material developed in this work is a good candidate as a sorbent for extracting trace Pb(II).

3.6 Adsorption capacity of the functionalized SBA-15
The static adsorption capacity of SA-SBA-15 was tested according to the batch method. A series of 10 mL Pb(II) ions solutions (50–300 µg mL⁻¹) were adjusted to the appropriate pH 4, and shaking to reach adsorption equilibrium after adding the SA-SBA-15 sorbents (50 mg) at optimum conditions. The Pb(II) ions in the supernatant were determined by AAS. As shown in Fig. 5, the amount of Pb(II) adsorbed per unit mass of sorbent increases with increasing concentration of Pb(II) until a plateau is reached. This plateau represents the adsorption capacity of SA-SBA-15, which was found to be 33.6 mg g⁻¹. The data presented in Table 2 compares the adsorption capacity of a few SBA-15 based silica materials used for the solid phase extraction of Pb(II) [35,36]. It is noteworthy that among these functionalized SBA-15 silica materials that have been used for the extraction of lead ions, our SA modified SBA-15 exhibits the highest adsorption capacity.

The adsorption capacity of SA-SBA-15 towards other common metal ions, namely Cr(III), Fe(III), Co(II), Ni(II), Cu(II), Zn(II), Cd(II) and Hg(II) at pH 4 were also tested. Under the same adsorption condition, the recovery rates for 1.0 µg mL⁻¹ Cr(III), Zn(II), Ni(II), Hg(II), Cd(II) ions were in the range of 10–30%, and 50–72% recovery were obtained for extracting Cu(II), Co(II) and Fe(III). However, when co-existing with Pb(II) in a solution, these ions have little interfere on the enrichment or determination of Pb(II). Results of
analysing solutions containing 1.0 µg mL\(^{-1}\) of Pb(II) and these ‘interfering’ ions indicate that the presence of 2000-fold excesses of K(I), Na(I), Mg(II) and Ca(II), and 100–fold excesses of Cr(III), Fe(III), Co(II), Ni(II), Cu(II), Zn(II), Cd(II), Hg(II) had a negligible effect on the extraction of Pb(II).

The enhanced adsorption capacity and better selectivity towards Pb(II) compared with other metal ions indicates that SA-SBA-15 has a higher binding affinity towards lead ions. The main reason we believe is due to the unique chemical structure of SA (see Fig.1) and the surface chemistry of SA-SBA-15. SA possesses functional groups with well incorporated donor atoms (N and O) which could interact with lead ions to form metal complexes in a stable ring structure [23]. Moreover, the OH- and CH\(_3\)O- groups contained in SA-SBA-15 are hard Lewis bases, and hence hard Lewis acid metal cations such as Pb(II) tend to bind to these functional groups.

3.7 Analytical precision, detection limit and analysis of lead in water samples
Eight portions of standard solutions were analyzed using the column method under the same conditions. The relative standard deviation (R.S.D.) of the method was lower than 2.0%, which indicated that the method showed good precision for the analysis of trace Pb(II) in aqueous samples. According to the IUPAC definition, the detection limit of this method was calculated based on three times the standard deviation of eight runs of the blank solution. The detection limit (3\(\sigma\)) of the proposed method was determined to be 1.3 µg L\(^{-1}\).

Milli-Q water, tap water, natural water from Swan River (Perth, Australia) and bottled mineral water (Perrier) were analyzed using the batch method. Recovery testing was carried out by adding 0.5 µg mL\(^{-1}\) and 1.0 µg mL\(^{-1}\) Pb(II) to these water samples. The results are given in Table 3. It can be seen that the recoveries of Pb(II) are in the range of 92–103% which is reasonable for trace analysis. These results highlight that the proposed method would be suitable for the preconcentration of Pb(II) at the trace level for a range of water samples.

4. Conclusions
The present study has demonstrated a straightforward method to prepare sinapinaldehyde modified SBA-15 (SA-SBA-15) and its application as a sorbent for the extraction and determination of Pb(II) in water samples. The sorbent exhibited excellent selectivity, fast adsorption equilibrium, easy elution and a high adsorption capacity for Pb(II). Most common coexisting ions do not appear to interfere with the pre-concentration and analysis of Pb(II) under the conditions used in this study. In addition, the reliable method was successfully applied to the analysis of Pb(II) in a number of water samples with satisfactory results.

Acknowledgments

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Reference

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(2012).
**Table and Figure Captions**

Table 1 The linear working range and calibrate equations used in analysis of trace elements

Table 2 Comparison of pH and the maximum capacities of some functionalized mesoporous silica materials used for solid phase extraction of Pb(II).

Table 3 Analytical results for the determination of Pb(II) in water samples.

Fig. 1. Schematic representation of the synthesis of SA-SBA-15.

Fig. 2. FTIR spectra of SBA-15 (a), NH₂-SBA-15 (b), SA-SBA-15 (c) and Pb(II) loaded SA-SBA-15 (d).

Fig. 3 SEM images of SBA-15 (a) and SA-SBA-15 (b).

Fig. 4 Effect of pH on the recovery of Pb(II) in 10 mL 1.0 μg mL⁻¹ Pb(II) solution.

Fig. 5 Effect of initial concentration (C₀) of Pb(II) on the adsorption capacity (Q) of SA-SBA-15 sorbent.
### Table 1 The linear working range and calibrate equations used in analysis of trace elements

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<th>Elements</th>
<th>Linear working range (µg mL⁻¹)</th>
<th>Calibration equations for elements</th>
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<td>Pb(II)</td>
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<td>Zn(II)</td>
<td>0.01-1.0</td>
<td>( y = 0.3249x + 0.0269, R^2 = 0.976 )</td>
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<td>Cd(II)</td>
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<td>0.03-1.0</td>
<td>( y = 0.1747x + 0.0021, R^2 = 0.999 )</td>
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<td>Co(II)</td>
<td>0.05-1.0</td>
<td>( y = 0.1236x + 0.001, R^2 = 0.999 )</td>
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<tr>
<td>Hg(II)</td>
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<td>Fe(III),</td>
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<td>Cr(III)</td>
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<td>Ni(II)</td>
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<td>( y = 0.0127x + 0.0015, R^2 = 0.966 )</td>
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Table 2 Comparison of pH and the maximum capacities of some functionalized mesoporous silica materials used for solid phase extraction of Pb(II).

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Table 3: Analytical results for the determination of Pb(II) in water samples.

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<td>0.49</td>
<td>98±0.2</td>
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<sup>a</sup>Average of three determinations ± standard deviation

<sup>b</sup>Not detectable
Fig. 1. Schematic representation of the synthesis of SA-SBA-15.
Fig. 2. FTIR spectra of SBA-15 (a), NH$_2$-SBA-15 (b), SA-SBA-15 (c) and Pb(II) loaded SA-SBA-15 (d).
Fig. 3 SEM images of SBA-15 (a) and SA-SBA-15 (b).
Fig. 4. Effect of solution pH on the recovery of Pb(II) in 10 mL 1.0 μg mL$^{-1}$ Pb(II) solution.
Fig. 5. Effect of initial concentration ($C_0$) of Pb(II) on the adsorption capacity ($Q$) of SA-SBA-15 sorbent.