The Removal of Phosphate and Arsenate from Aqueous Solution Using Silica Based Materials

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Abstract: Three silica modified materials (diethyl phenoxy ethyl amine silicate, L1, methylated diethyl phenoxy ethyl amine silicate, L2, and 25,27-bis[N-2(-hydroxy-1,1-bis hydroxymethyl-ethyl) amino-carbonyl(methoxy)-calix[4]arene-26,28-diol silica, L3) were synthesised. The extracting properties of L1 and L2 for the removal of phosphates and arsenates from aqueous medium were investigated taking into account several parameters such as mass of materials, anion salt concentration and the pH of the aqueous solution. Experimental data on the uptake of phosphate and arsenate from aqueous solution at 298 K against time were used to calculate the rate constants and the half-life of the extraction process by L1 and L2. The removal capacities of L1 and L2 for these anions from water were found to be 2.35 and 4.48 mmol/g respectively. Final conclusions are given.

Keywords: Water treatment, phosphate removal, arsenate removal, modified silicates, supramolecular receptors.

1. INTRODUCTION

Water pollution caused by human activities has been the main focus of scientists and technologists over the last decades. Large quantities of phosphates used in many industrial applications like fertilizers, detergents led to the production of phosphate-bearing wastes, which are usually discharged into municipal and industrial water effluent streams. Some well-known side effects of phosphates on human health are inhalation, ingestion, skin contact, eye contact. Phosphorus has been considered as a key element i) causing eutrophication, which leads to the development of aquatic plants, growth of algae, some of them being toxic and ii) to balance disturbance of organisms present in water which affects the fish and other aquatic life, microorganism and insect’s growth as well as it causes natural resorts degradation.

Development of technologies for phosphorus removal started in the 1950’s and fall under three categories: physical, chemical and biological. Physical methods have proved to be either too expensive like electro-dialysis or reverse osmosis [1], or inefficient removing only 10% of the total phosphorus [2]. Enhanced biological treatment can remove up to 97% of the total phosphorus, but this process can be highly variable due to operational difficulties [2]. Chemical treatment is widely used for the removal of phosphates. Research has been performed to utilize mechanically stable synthetic or natural solid matrices for many applications, such as chemical bonded phases in chromatography, extraction of ions by non-aqueous solvents and catalytic or ion-exchange reactions.

Among the different solid supports, silica gel has received great attention [3-4,5,6]. Immobilization of organic functional groups on a silica surface has been used to produce a variation of modified silica. In this process, an organic reagent containing the desired organic functional group is directly attached to the support to increase the main chain where other functional group can be added. The silica embed with Fe-EDA-SAMMS reported by Fryxell [6] showed a maximum capacity of 43.3 mg/g.

Previous research carried out for phosphate removal involves the use of active carbon adsorbents [7]. In 2012, Ravindhranath and co-workers [8] have reported the use of bio-sorbents for the removal of phosphates from water. The maximum percentage of extraction was achieved using bark ash of C. auriculata at a pH 10 in the presence of interfering cations (Mg²⁺, Cu²⁺, Zn²⁺, Fe²⁺ and Ni²⁺). Nano-size composite materials functionalized with amino groups were also used for phosphate extraction by Shen and co-workers [9]. The removal of arsenic species in water using the macrocycle known as calix[4] pyrrole has been
discussed by Danil de Namor and co-workers [10]. The removal capacity of this receptor for As(V) and As(III) was found to be 15.28 mg/g and 14.29 mg/g respectively.

The main point of interest in this paper is the development of silica based extracting agents for the removal of phosphate and arsenate anions from water. Several parameters such as the mass of the materials, concentration of the anion salt, pH of the aqueous solution as well as the kinetics of the extraction process were investigated.

2. MATERIALS AND METHODOLOGY

2.1. Chemicals

Silica (0.2-0.5 mm), 3-aminopropyltrimethoxysilane (97%), 18-crown-6 (99%), 2-diethylamino ethyl chloride hydrochloride (99.5%), ammonium hydroxide, magnesium sulfate, tri-n-ethylamine (99%), potassium carbonate, iodomethane (99%), ammonium molybdate (99%), deuterated chloroform, stannous chloride dihydrate, glycerine, potassium dihydrogen phosphate monobasic reagent ACS, sodium arsenate dibasic heptahydrate were all purchased from Aldrich Chemical Co.

Ethanol (HPLC), chloroform, dichloromethane, dried toluene, acetonitrile, concentrated sulfuric acid, formaldehyde (37%), hydrochloric acid, ammonium hydroxide, phenol (99%) were purchased from Fisher.

2.2. Synthesis of Modified Silica, L1

The synthetic procedure is shown in Scheme 1. Thus silica (0.2-0.5 mm) was first activated by drying at high temperature overnight. Dried silica gel (10 g) was transferred into a round-bottomed flask and dried toluene (150 cm³) was added followed by 3-aminopropyltrimethoxysilane (7.6 cm³). The mixture was refluxed overnight at 100-120 °C. The solution was cooled, filtered off, washed with toluene and dried overnight. Microanalysis was carried out at the University of Surrey for L1: Found %: C, 7.83; H, 1.95; N, 2.09.

2.2.1. Synthesis of Diethyl Phenoxy Ethylamine

The synthetic procedure is shown in Scheme 2. Diethyl phenoxy ethyl amine was synthesised by dissolving phenol (5 g, 53.12 mmol) in dried acetonitrile (150 cm³) followed by the addition of potassium carbonate (29 g, 212.50 mmol) and 18-crown-6 (2.8 g, 10.63 mmol). The mixture was stirred for one hour. Then 2-diethylamino ethyl chloride hydrochloride (18.28 g, 206.24 mmol) was added and the mixture was refluxed at 70-80 °C for 24 hours.

Once the reaction was complete, acetonitrile was removed in vacuo. The resulting compound was dissolved in dichloromethane and the organic layer was extracted using ammonium hydroxide. The organic phase was dried over magnesium sulfate before being dried in vacuo.

2.2.2. Attachment of Diethyl Phenoxy Ethyl Amine to the Silicate

The synthetic procedure is shown in Scheme 3. Thus diethyl phenoxy ethyl amine (3 g, 15 mmol) was placed in a 250 cm³ round bottom flask and an ethanol/chloroform mixture (100: 100) was added followed by tri-n-ethylamine (2.1 cm³, 15 mmol) and

Scheme 1: Synthetic procedure used for the preparation of modified silica, L1.

Scheme 2: Synthetic procedure used for the preparation of diethyl phenoxy ethyl amine.

Scheme 3: Synthetic procedure used for the preparation of diethyl phenoxy ethyl amine silicate.
formaldehyde (2.4 cm³, 30 mmol). The mixture was stirred for one hour, then the modified silica L1 (5 g, 7.5 mmol) was added and the solution was refluxed for 24 hours at 60-70 °C. The solution was cooled down; the solid was recovered by filtration, washed with ethanol/chloroform and dried overnight. Microanalysis was carried out at the University of Surrey: Found %: C, 8.12; H, 1.76; N, 1.20.

2.2.3. Synthesis of the Methylated Diethyl Phenoxy Ethyl Amine Silicate Compound, L2

The synthetic procedure is shown in Scheme 4. Thus phenoxy silicate compound (5 g, 7.5 mmol) was placed in a 250 cm³ round bottom flask and dried acetonitrile (150 cm³) was added. This was followed by the addition of potassium carbonate (6.22 g, 45 mmol) and 18-crown-6 (1.18 g, 4.5 mmol). The solution was stirred for one hour. Then iodomethane (0.93 cm³, 15 mmol) was added and the solution was refluxed at 60-70 °C for 24 hours under a nitrogen atmosphere. The solution was cooled down, the solid recovered by filtration, washed with ethanol/chloroform and dried overnight. Microanalysis was carried out at the University of Surrey: found %: C, 6.46; H, 1.48; N, 1.51.

2.2.3. Synthesis of the Methylated Diethyl Phenoxy Ethyl Amine Silicate Compound, L2

The synthetic procedure is shown in Scheme 4. Thus phenoxy silicate compound (5 g, 7.5 mmol) was placed in a 250 cm³ round bottom flask and dried acetonitrile (150 cm³) was added. This was followed by the addition of potassium carbonate (6.22 g, 45 mmol) and 18-crown-6 (1.18 g, 4.5 mmol). The solution was stirred for one hour. Then iodomethane (0.93 cm³, 15 mmol) was added and the solution was refluxed at 60-70 °C for 24 hours under a nitrogen atmosphere. The solution was cooled down, the solid recovered by filtration, washed with ethanol/chloroform and dried overnight. Microanalysis was carried out at the University of Surrey: found %: C, 6.46; H, 1.48; N, 1.51.

2.3. The Synthetic Procedure


Scheme 4: Synthetic procedure used for the preparation of methylated diethyl phenoxy ethyl amine silicate, L2.


2.3.1. Deterbutylation of p-Tert-Butyl Calix[4] Arene, 1

Into a dry 500 cm\(^3\) three-necked bottomed flask equipped with a condenser, p-tert-butyl calix[4]arene (5.15 g, 7.93 mmol) and phenol (4.5 g, 47.58 mmol) were mixed together in dry toluene (100 cm\(^3\)) under a nitrogen atmosphere. The mixture was stirred for one hour. Then, aluminium chloride (7.4 g, 55.51 mmol) was added slowly to the solution under vigorous stirring. The reaction mixture was heated to 50\(^\circ\)C [11].

The reaction was monitored by TLC using a developing solvent system formed by a hexane:ethyl acetate (8:2) mixture. The reaction was stopped after about 5 hours. The organic phase was separated and dried with sodium bicarbonate and then with distilled water. The dichloromethane, extracted with a saturated solution of magnesium sulphate, then filtered. Dichloromethane was removed under reduced pressure. The solid afforded was dissolved in anhydrous K\(_2\)CO\(_3\) (8.73 g, 63.2 mmol) and anhydrous K\(_2\)CO\(_3\) (8.73 g, 63.2 mmol) were suspended [12]. The mixture was stirred for thirty minutes at room temperature. Then ethyl bromoacetate (5.6 cm\(^3\), 50.52 mmol) was added from a glass syringe into a dry 500 cm\(^3\) three-necked bottomed flask equipped with a condenser, a solution of 1 (5.36 g, 12.63 mmol) in dry acetonitrile, 18-crown-6 (0.66 g) and anhydrous K\(_2\)CO\(_3\) (8.73 g, 63.2 mmol) were suspended [12]. The mixture was stirred for thirty minutes at room temperature. Then ethyl bromoacetate (5.6 cm\(^3\), 50.52 mmol) was added from a glass syringe through a seal septa surba. The reaction mixture was refluxed at 60\(^\circ\)C for a period of 5 hours.

The reaction was followed by Thin Layer Chromatography (TLC) using a hexane: ethyl acetate (8:2) mixture. The solvent was removed under reduced pressure. The solid afforded was dissolved in dichloromethane, extracted with a saturated solution of sodium bicarbonate and then with distilled water. The organic phase was separated and dried with magnesium sulphate, then filtered. Dichloromethane was removed by rotary evaporation and the solid obtained was recrystallized from hot ethanol. The solution was left overnight and the crystals were dried over calcium chloride under vacuum at 100\(^\circ\)C. The product was obtained in 70 % yield and was characterised by Proton Nuclear Magnetic Resonance (\(^1\)H NMR).

- \(^1\)H NMR (300 MHz, CDCl\(_3\)), \(\delta\) (ppm), J (Hz) \(\delta = 10.195\) (s, 1H, H-5) \(\delta = 7.056\) (d, 2H, H-1), 6.731 (t, 1H, H-2), 4.255 (br, 2H, H-4), 3.515 (br, 1H, H-3).

2.3.2. Preparation of the 25, 27-Bis (Ethylene Ethanoate) Calix[4] Arene 26, 28 Diol Derivative, 2

A solution of 3 (0.2 g, 0.37 mmol) and 2-ethoxyethoxy carbonyl-1-2-dihydroquinoline (EEDQ) (0.28 g, 1.1 mmol) in freshly distilled pyridine (10 cm\(^3\)) were suspended in 250 cm\(^3\) three-necked-bottom flask equipped with a magnetic stirrer and a condenser. The mixture was left to stir at room temperature for 2 hours under a nitrogen atmosphere. Then tris [hydroxymethyl] aminomethane (0.18 g, 1.5 mmol) was added and the mixture was refluxed for a period of 18 hours.

Subsequently the solvent was removed in vacuo and an oily residue was obtained. It was then washed with ethyl ether in order to remove the excess of EEDQ. The crude material was dissolved in chloroform and extracted with distilled water several times to remove the excess of tris [hydroxymethyl]
aminomethane. The organic layer was collected and dried over MgSO₄. Then the solvent was removed in vacuo to afford a crude product which was washed again with ethyl ether. The remaining material was dissolved in an ethanol: dichloromethane (90:10) mixture and left overnight. The crystals obtained were dried over calcium chloride at 80°C under vacuum. L3 was obtained in 90% yield and was characterised by ¹H NMR, and elemental analysis.

- ¹H NMR (500 MHz, DMSO-d₆), δ (ppm), J (Hz), δ= 8.08 (s, 1H, H-9), 7.93 (s, 1H, H-7), 6.99 (d, 1H, J= 7.6, H-1), 7.15 (d, 2H, J= 7.5, H-5), 6.61 (t, 1H, H-2, J= 7.5), 6.78 (t, 1H, J= 7.5, H-6), 4.74 (t, 3H, J= 5.7, H-11), 4.50 (s, 2H, H-8), 4.31 (d, 1H, J= 13.1, H-4), 3.69 (d, 6H, J= 5.7, H-10), 3.43 (d, 1H, J= 13.2, H-3).

- ¹H NMR (500 MHz, CD₃OD), δ (ppm), J (Hz), δ= 7.16 (d, 2H, H-5), 6.93 (d, 2H, H-1), 6.78 (t, 1H, J= 7.5, H-6), 6.73 (t, 1H, J= 7.5, H-2), 4.59 (s, 2H, H-8), 4.36 (d, 1H, J= 13.46, H-4), 3.92 (s, 6H, H-10), 3.49 (d, 1H, J= 1.54, H-3).

- Elemental analysis was carried out in duplicate at the University of Surrey. Found and calculated results were in good agreement.

Calculated %: C, 64.33; H, 6.21; N, 3.75; Found %: C, 64.30; H, 6.25; N= 3.71.

2.4. Attachment of L3 to 3-Aminopropylidimethylsilylated Silica, L3MSi

The procedure used is generally described in Scheme 9. Thus L3 (41.88 g, 2.53 mmol) was dissolved in THF (20 cm³) followed by the addition of ethanoic acid (2.5 cm³), modified silica (1g, 1.5 mmol) and formaldehyde (0.5 cm³, 37 %). The reaction mixture was left under stirring for one hour at room temperature and then it was heated to 35°C and left under stirring for 24 hours. The solvent was removed under vacuum and the residue was washed using water and methanol. Elemental analysis was carried out in duplicate at the University of Surrey. Found results were as follows, % C= 8.59, % H= 1.57, % N= 1.60.

2.5. Quantitative Determination of Dihydrogen Phosphate and Arsenate in Solution

Procedures used for the analytical determination of phosphate and arsenate species are those reported in the literature [13-14, 15].

2.5.1. Determination of the Optimum Amount of L1 and L2 for the Uptake of Arsenate from Aqueous Solution

The optimum amount of material was determined by fixing the concentration of phosphate and arsenate species at 1.00 × 10⁻¹ mol dm⁻³ and 1.00 × 10⁻⁴ mol dm⁻³ respectively and using different amounts of materials, (ranging from 0.003 to 0.200 g) a fixed volume (10 cm³) of the ionic species was added to test tubes. For the analytical determination of arsenate in aqueous solution the same procedure described above was used.

2.5.2. Effect of pH on the Uptake of Phosphate and Arsenate Species by L1 and L2 at 298 K

The effect of pH on the removal process was investigated by adding a volume (10 cm³) of an aqueous solution of known concentration of phosphate species (1.00 × 10⁻¹ mol dm⁻³) to the tests tubes containing a fixed amount of material L1 (0.03 g) and L2 (0.009 g). For arsenate species (1.00 × 10⁻⁴ mol dm⁻³) the amount of L1 and L2 used were 0.07 and 0.01 g respectively. The pH of solutions of phosphate and arsenate species in the 2 to10 range were adjusted with hydrochloric acid (HCl) or ammonium hydroxide (NH₄OH) using a digital micro-processor pH-meter equipped with a glass electrode. Two standards buffer solutions at pHs 4.0 and 7.0 were used for calibration. Then the procedure in section 2.5.3 was applied. The percentage of removal was calculated using eq. 1.

\[
\% \text{Extracted} = \frac{(c_i - c_{eq}) \times 100}{c_i} \quad (1)
\]

In eq. 1, cᵢ and cₑₐₑ are the initial and the equilibrium concentrations (mmol dm⁻³) of phosphate and arsenate ions in solution respectively.
2.5.3. Kinetics of Phosphate and Arsenate Extraction from Aqueous Solutions at 298 K

Batch equilibrium experiments were performed to evaluate the time required to attain equilibrium. Times between 30 minutes and 1440 minutes were investigated. The other parameters such as mass of the materials (0.03 and 0.009 g for L1 and L2 respectively for phosphate extraction and 0.07 and 0.01 g for L1 and L2 respectively for arsenate extraction), the concentration (phosphate $1.00 \times 10^{-1}$ mol dm$^{-3}$, arsenate $1.00 \times 10^{-4}$ mol dm$^{-3}$), pH (~5), temperature (298 K) and the time of agitation (2 minutes) were kept constant. The same procedure described previously (Section 2.5) for the analytical determination of phosphate in the aqueous solution was applied. The equilibrium concentrations of the anion versus the equilibration time at 298 K were plotted.

2.5.4. Determination of the Uptake Capacity of the Materials

In order to estimate the uptake capacity of the materials for the dihydrogen phosphate and arsenate from aqueous solutions, batch experiments were carried out at 298 K by varying the concentrations of phosphate and arsenate ($1.00 \times 10^{-3} - 1.00 \times 10^{-1}$ mol dm$^{-3}$) and ($3.00 \times 10^{-5} - 1.00 \times 10^{-4}$ mol dm$^{-3}$) respectively with a fixed mass of the materials (0.03 and 0.009 g for L1 and L2 respectively for phosphate extraction and 0.07 and 0.01 g for L1 and L2 respectively for arsenate extraction). The uptake capacity, $q_{eq}$ (mmol g$^{-1}$), per unit mass of material was calculated using the following equation,

$$q_{eq} = \frac{(c_i - c_{eq}) \times v}{m}$$

(eq. 2)

In eq. 2, $m$ is the mass of the material (g), and $v$ is the volume of the solution (cm$^3$).

3. RESULTS AND DISCUSSION

3.1. Extraction of Phosphate and Arsenate Species from Water Using L1 and L2

3.1.1. Determination of Optimum Amount of L1 and L2 for the Uptake of Arsenate Species from Water at 298 K

Different masses of L1 and L2 were used for the determination of the optimum mass of dihydrogen arsenate species from water. A representative example is given in Figure 3.1 for arsenate where the percentages of extraction by L1 and L2 were found to be 15 and 23 % respectively.

![Figure 3.1: Effect of mass on the uptake of arsenate species from aqueous solution by the L1 and L2 at 298 K.](image)

The increase in the amount of the anion extracted from aqueous solution by an increase of the mass of material can be explained on the basis of an increase in the number of active sites for a fixed initial concentration of the anion salts in solution. It means that at a given mass of the material and concentration of the anion in aqueous solution, the material is saturated. The optimal masses of the material to be used for the removal of arsenate species from water is 0.01g. Similar masses are required for phosphate’s removal.

Preliminary experiments carried out with the macrocycle grafted into the silica, L3-MSi showed that using a much lower concentration of phosphates than that used with L1 and L2 ($1x 10^{-4}$ mol.dm$^{-3}$) the % E was found to be about 51% which is most encouraging. Further work is in progress.

3.1.2. The pH Effect on the Uptake of Phosphate and Arsenate Species from Water by L1 and L2 at 298 K

Figure 3.2 shows the effect of the pH of the solution on the percentages of phosphate and arsenate species removed from aqueous solution by these materials at 298 K.

In analysing the data the dissociation of these species must be considered (eqs. 3-5) [16-17] as well the number of donor atoms of the ligand able to interact with the anion salt. As far as phosphates are concerned the pK$_{a1}$ value for the first dissociation of phosphoric acid in water at 298 K is 2.12 while for
The Removal of Phosphate and Arsenate from Aqueous Solution

The removal of phosphate and arsenate from aqueous solution is 2.24. At pH 2.12, the speciation in solution are ~ phosphoric acid (50 %) and dihydrogen phosphate (50 %), while at pH 2.24, equal amounts of arsenic acid and dihydrogen arsenate are present in solution. However at these pHs, protonation of the amino functionalities of the ligands would take place and therefore a low percentage of extraction is observed. At pH 4.66, the predominant species in solution are dihydrogen phosphate and dihydrogen arsenate given that the pKₐ₂ of the latter in water at 298 K is 6.96, thus a higher interaction between L1 and these anions takes place leading to the maximum % E extraction of phosphate when L1 is the receptor but for L2 the higher extraction occurs at pH 6.2 when a higher proportion of the monohydrogen phosphate anion is present in solution relative to those at pH 4.66. For arsenate species the results show that the percentage of arsenate removed from aqueous solution by L1 and L2 reaches a maximum at pH 7.1 and 7.8 for L1 and L2 respectively when monohydrogen arsenate rather than dihydrogen arsenate are the predominant species in solution. However it should be noted that as the pH increases and the percentages of the divalent anion increase, the percentage of extraction decreases.

At pH 9.5, the dominant species are HPO₄²⁻, less hydrogen atom will be available for the interaction with the active donor atoms of the legend, thus the uptake of phosphate by L1 and L2 decreases.

\[ H_3PO_4 \overset{pK_{a1}}{\leftrightarrow} H_2PO_4^- + H^+ \quad pK_{a1}=2.12 \quad \text{eq. 3} \]

\[ H_2PO_4^- \overset{pK_{a2}}{\leftrightarrow} HPO_4^{2-} + H^+ \quad pK_{a2}=6.82 \quad \text{eq. 4} \]

\[ HPO_4^{2-} \overset{pK_{a3}}{\leftrightarrow} PO_4^{3-} + H^+ \quad pK_{a3}=12.38 \quad \text{eq. 5} \]

3.1.3. Kinetics of Extraction of Phosphates and Arsenates by L1 and L2 from Aqueous Solution at 298 K

The kinetics of the process is a relevant factor to consider. Batch equilibrium experiments were performed at 298 K to evaluate the kinetics of the extraction process. In doing so the optimum amount of material and the pH of the solution were kept constant for both anions. The outcome of these experiments is shown in Figure 3.3 in which the capacities of the materials (mmol/g) are plotted against the contact time. The rate of extraction of these species and the half-life of these processes were calculated from the obtained data over a region from zero to maximum. Regarding phosphates, the maximum removal of the species by L1 was attained within the first 2 hours. However, the results showed a higher uptake of phosphates by L2 where the species maximal removal was obtained in 4 hours after which it remained constant. As far as arsenate is concerned, the obtained curves show that higher removal of the species was established by L2 within 4 hours whereas L1 showed a lower extraction of As(V) in the same duration (4 hours).

![Figure 3.2: Percentage of extraction of phosphate and arsenate species plotted against the pH using L1 and L2.](image)

![Figure 3.3: Determination of the optimum time for the uptake of H₂PO₄⁻ and H₂AsO₄⁻ anions by L1 and L2 from aqueous solution at 298 K.](image)
As shown in Figure 3.3, the experimental data for both species (phosphate and arsenate) was fitted to a simple exponential model as the rate of the uptake of each species by L1 and L2 is proportional to the distance from equilibrium (i.e. pseudo first-order process). By fitting the data points, the obtained rate to equilibrium (k) for phosphate removal by L1 is 0.03 and 0.01 by L2 with half-life of 24 minutes (L1) and 58 minutes (L2). On the other hand, the fits of the data for arsenate removal with L1 and L2 show rate constants of 0.01 respectively with half-life for extraction of 110 and 52 minutes.

3.1.4. Phosphate and Arsenate Uptake Capacities of L1 and L2 at 298 K

Batch experiments were carried out to determine the uptake capacities of L1 and L2 for phosphates and arsenates. Thus the uptake in mmol/g of material against the molar concentration of the anion salts are shown in Figure 3.4. Thus L1 and L2 are able to take up 2.35 mmol and 4.48 mmol of phosphate /g of material respectively while the uptake of L1 and L2 materials for arsenate is substantially reduced to values of 7.33x10⁻³ and 3.64 x10⁻² mmol/g respectively.

CONCLUSIONS

From the above discussion the following conclusions are drawn;

a) The outcome of extraction studies indicate that silica based materials are suitable decontaminating agents for the removal and recovery of H₂PO₄⁻ ions from aqueous media. The uptake of H₂PO₄⁻ ions by these materials was influenced by experimental parameters such as initial concentration, mass and pH of the aqueous solution. The observed capacity of L1 and L2 to extract H₂PO₄⁻ from aqueous solutions was 2.35 and 4.48 mmol/ g respectively.

b) As for the extraction of arsenate, the materials showed uptake capacities of 7.33x10⁻³ and 3.64 x10⁻² mmol g⁻¹ for L1 and L2 respectively. On the other hand, both silica based materials showed an increase in the arsenate uptake up to pH 7.8, after which the capacity of these materials for this anion decreased.

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