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**Simultaneous determination of arsenic and uranium by the Diffusive Gradients in Thin
Films technique using Lewatit FO 36: Optimization of elution protocol**

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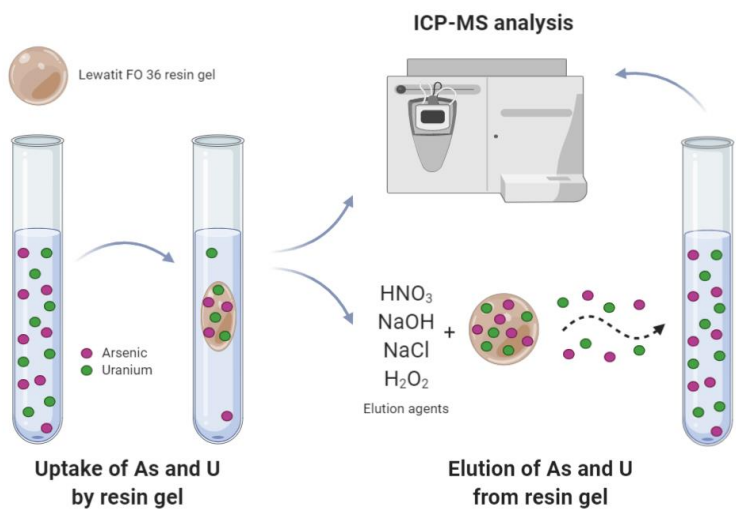
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Abbreviations

DGT, diffusive gradient in thin films technique; ET-AAS, electrothermal atomic absorption
spectrometry; ICP-MS, inductively coupled plasma mass spectrometry; MDL, method
detection limit



Abstract

The sorption ability of Lewatit FO 36-DGT resin gel, which has been developed for arsenic determination, towards uranium was tested by batch experiments within this study for the first time. Since the uptake efficiency of uranium was $99.0 \pm 0.4\%$ and the maximum uptake capacity was not achieved even at the U spike of $1250 \mu\text{g}$ in the solution, the Lewatit FO 36 resin seems to be a suitable binding phase for DGT resin gels for the determination of uranium. The resin gel also does not display any significant sorption selectivity in favour of one element over another. A novel protocol for simultaneous elution of arsenic and uranium from Lewatit FO 36 resin gel was therefore proposed in this study. The elution efficiencies of $90.3 \pm 3.9\%$ and $85.2 \pm 3.1\%$ for As and U, respectively, were obtained using 5 mL of 1 M NaOH at 70°C for 24 hours. The comparison with the original elution protocol using microwave-assisted elution by 0.25 M NaOH and 0.17 M NaCl at 130°C for 16 minutes indicates, that the novel elution protocol provides good results in the performance of arsenic elution and, in addition, allows simultaneous elution of uranium. Moreover, the elimination of NaCl from the elution process allows a fast and simple analysis of both elements using ICP-MS, and therefore, the Lewatit FO 36-DGT technique can become more commonplace among laboratories without the need to modify the analytical method as proposed in the original study.

Keywords

Diffusive gradients in thin films technique; arsenic; uranium; elution procedure

1 Introduction

The diffusive gradient in thin films (DGT) technique is considered to be an effective tool for *in-situ* determination of labile species of various contaminants in the environment. Although it has been successfully used for the determination of nutrients (ammonium, nitrate, phosphorus) or various organic compounds (antibiotics, bisphenols, pesticides, endocrine disruptors, pharmaceuticals, etc.) it is nowadays mostly used for its original purpose – determining the concentration of the labile species of trace metals [1, 2]. In our previously published work [3], a new resin gel utilizing Lewatit FO 36 was developed and evaluated for the determination of four bioavailable arsenic species (As(III), As(V), monomethylarsonic acid, dimethylarsinic acid) in the aquatic environment. But besides the high selectivity of iron oxide-hydroxide functional groups of Lewatit FO 36 for oxyanions, the resin also acts as a weakly basic ion exchanger thanks to tertiary amine functional groups ($-\text{CH}_2\text{-N}(\text{CH}_3)_2$). Therefore it can also bind natural organic matter such as tannins, lignins, negatively charged uranium complexes, chromate, and others [4]. Arsenic and uranium often occur simultaneously in mining environments [5-7]. Their simultaneous measurement by the DGT technique may be thus beneficial for environmental studies as it may improve understanding of geochemical cycling of these co-occurring contaminants and may contribute to the assessment of their potential bioavailability to biota.

When using the DGT technique, the elution of analytes accumulated on the binding phase requires special attention as it may significantly contribute to the uncertainties of the DGT measurement [8]. Therefore, each novel binding phase undergoes thorough testing of elution procedures (with key variables of the used elution agent, its concentration, and volume together with the elution time and temperature) in order to achieve the highest elution yield with high reproducibility. The elution protocol of Lewatit FO 36 resin gel proposed in the

original study [3] utilizes the mixture of 0.17 M sodium chloride and 0.25 M sodium hydroxide as an elution agent (according to the recommendation of the resin manufacturer [4]) in combination with microwave-assisted extraction at 130 °C for 16 min. Although the obtained quantitative elution yield of arsenic content was $98.4 \pm 2.0\%$, the measurement of arsenic concentration in high chlorides matrix may be challenging due to the interference effect of chlorides during analysis. The proposed elution protocol is therefore not suitable for analysis by inductively coupled plasma mass spectrometry (ICP-MS), which is currently one of the most common analytical techniques for elemental analysis in laboratories.

Given that the Lewatit FO 36 resin has a great potential to be a suitable DGT binding phase for uranium, the uptake efficiency and uptake capacity of Lewatit FO 36 resin gel towards uranium were evaluated in this study. The selectivity of this DGT binding phase for a range of As and U concentrations in different ratios was evaluated as well to assess its suitability for application in a real environment. Due to the need for practical sample analysis by conventional ICP-MS, a new elution protocol for simultaneous measurement of both elements, As and U, was proposed and evaluated within this study.

2 Materials and methods

2.1 Reagents and chemicals

All chemicals were of analytical reagent or higher grade. Chemicals used for DGT gels production and the preparation protocol are described in a previous study [3]. Arsenic standard solution 1000 mg L^{-1} in 2% HNO_3 (Merck, Germany) and uranium standard solution 1000 mg L^{-1} in 2% HNO_3 (SPEX CertiPrep, UK) were used for the preparation of experimental solutions and for calibration of ICP-MS together with the internal standard of indium (Alfa Aesar, addition to a final concentration of $1 \text{ } \mu\text{g L}^{-1}$). The HNO_3 was used for

material cleaning (HNO₃ produced by distillation apparatus), gels extraction, and sample acidification (Optima Grade, Fisher Scientific, USA). The NaCl, NaOH, NaNO₃ (all Merck, Germany), and H₂O₂ (suprapure, Fisher Scientific, USA) were used for gel extraction. The pH was measured by multi-meter WTW 3430 and adjusted to a desired value by diluted HNO₃ or NaOH if necessary.

2.2 Uptake efficiency

Experimental solutions (0.01 M NaNO₃; pH = 5; spiked with 20 µg L⁻¹ of As and U) were prepared 24 hours before the start of the experiment so that the carbon content in the solution equilibrate with atmospheric CO₂. To evaluate the uptake efficiency of Lewatit FO 36 resin gel, a single resin gel disc (5 replicates) was immersed into 10 mL of experimental solution and shaken for 24 hours. The concentration of both elements in the experimental solution was determined at the beginning and end of the experiment by ICP-MS. The difference between the initial mass (M_i) and the remaining mass (M_r) of analytes in the solution indicated the total analyte mass accumulated on the resin gel disc (M_a). The efficiency of As and U uptake was expressed as the uptake factor (f_u), using **Eq. (1)**. A control experiment for evaluation of As and U sorption on the walls of tubes was performed as well.

$$f_u = (M_i - M_r)/M_i * 100\% \quad (1)$$

2.3 Elution efficiency

The gel discs removed from the experimental solution were rinsed with Milli-Q water and the accumulated As and U were eluted using various elution agents (HNO₃, NaOH, NaCl, H₂O₂) or their mixtures. The mixture of NaOH and H₂O₂ has already been successfully used as an elution agent for elution of As [9, 10] or U [11, 12] from other DGT resin gels. The molarity and volume of elution agents in combination with extraction temperature varied within

7 variants (**Table 1**) in order to achieve the highest possible efficiency of elution of both analytes. The tested molarity of elution agents and extraction conditions were selected with respect to the previous studies dealing with the elution of As and U from DGT resin gels [10, 11]. The extraction in the conventional drying oven at the temperature of 70 °C allows to increase the elution efficiency and at the same time does not disturb the material of the polypropylene extraction tubes [13]. Resin gel blanks (gel discs that were not deployed into the experimental solution) were eluted as well. After 24 hours of elution, the samples were centrifuged if necessary and diluted ten times by 2% (v/v) HNO₃ prior to analysis. The eluted mass of As and U (M_e) was used for the calculation of the elution factor (f_e) using **Eq. (2)**.

$$f_e = (M_e/M_a) * 100\% \quad (2)$$

2.4 Diffusion coefficient of U towards Lewatit FO 36

Since resin gels utilizing Lewatit FO 36 resin were originally developed for the determination of arsenic, its diffusion coefficient was determined in the previous study [3]. But diffusion coefficient of U towards this resin gel was determined within this study by the time-dependence experiment. The DGTs were deployed in 2 L of well-stirred 0.01 M NaNO₃ spiked with 20 µg L⁻¹ of U (with the addition of 0.983 mM L⁻¹ NaHCO₃ to buffer the solution to pH 7.56 [14]) and a duplicates of DGT units were retrieved from the solution after 2, 4, 8, 24, 48 h. The diffusion coefficient (D , cm² s⁻¹) was calculated from the slope of a linear regression of the U mass accumulated on a resin gel and normalized for the solution concentration (M/c) as a function of time using **Eq. (3)**, where Δg is the thickness of diffusive layer consisting of diffusive gel and membrane filter (0.080 + 0.0125 cm), and A is the exposed area (3.14 cm²). The diffusion coefficient was corrected to the temperature using the Stokes-Einstein relation [15].

$$D = slope * \Delta g/A \quad (3)$$

2.5 Uptake capacity of the Lewatit FO 36 resin gel

The uptake capacity is commonly determined by exposing a resin gel to a high concentration of analyte until equilibrium is reached. A single Lewatit FO 36 resin gel disc (3 replicates) was immersed into 5 mL of 0.01 M NaNO₃ solution (pH 5.0) with U concentration range of 0.1–250 mg L⁻¹ and let shaken for 24 h. The gels were subsequently eluted using the new elution protocol proposed in this study. The U mass eluted from the gel disc (M_e) was compared to the mass that was expected to be accumulated on the gel disc (M_a) based on the difference between the initial and remaining U mass in the solution. This enabled us to validate the results and evaluate whether the elution efficiency is independent of the amount of metal bound on the gel disc. Since the new elution protocol was also tested for As, the same experiment was performed with both elements in parallel.

2.6 Selectivity of the Lewatit FO 36 resin gel for arsenic and uranium

To evaluate whether the Lewatit FO 36 resin gel favour one of the tested elements over the other, the series of solutions with As + U spike of various concentrations and ratios were prepared (**Table 2**). The concentration ranges were chosen concerning the average concentrations of As and U in the natural environment that are generally quite low (< 10 µg L⁻¹ in freshwater and 1.5 µg L⁻¹ in seawater for As [16], and 0.3 µg L⁻¹ in freshwater and 3.3 µg L⁻¹ in seawater for U [17, 18]). The variant **j** (10 mg L⁻¹ of each element) then represented extreme conditions. A single Lewatit FO 36 resin gel disc (3 replicates) was immersed into 10 mL of each solution prepared in 0.01 M NaNO₃ (pH 5.0) and the tubes were shaken for 24 h. The uptake efficiency of both elements was calculated by the difference between the initial and remaining masses in the solution as described in

Section 2.2. The elution of the gels using the new elution protocol proposed in this study was performed as well.

2.7 Analytical methods and data analysis

Arsenic and uranium concentration in all samples was determined by the sector field inductively coupled plasma mass spectrometry (SF-ICP-MS, Element II, Thermo Fisher Scientific Bremen GmbH, Germany), for instrumental parameters see Supplementary Information. The accuracy of sample analysis was verified by the analysis of reference samples (river water SLRS6, National Research Council Canada). Arsenic and uranium concentration in the certified reference material (SLRS-6) was $108 \pm 4\%$ and $103 \pm 5\%$ of certified values, respectively. Analysis of blank resin gels (5 replicates) was performed for the determination of the method detection limit (MDL). Analytical software STATISTICA13 (StatSoft, Czech Republic) was used for data analysis. One-way analysis of variance (ANOVA test) was used to determine the statistically significant differences between DGT performances. A statistically significant difference of the results was declared when p-value was below the level of significance $\alpha = 0.05$. The Tukey's Honest Significant Difference post-hoc test was performed to identify statistically different results.

3 Results and discussion

3.1 Uptake and elution efficiency

The average uptake efficiency of arsenic and uranium towards Lewatit FO 36 resin gel ($n = 15$) was $98.7 \pm 0.6\%$ and $99.0 \pm 0.4\%$, respectively. No sorption of As and U onto the tube walls was observed within the control experiment. The previous study showed excellent sorption ability of Lewatit FO 36 resin gel towards arsenic whose As(III) and As(V) compounds are predominantly neutral or anionic in the pH range > 4 [3]. In terms of uranium,

it is mostly present in the natural surface water under oxic conditions in the hexavalent oxidation state U(VI), while under anoxic conditions in groundwater (e.g. in confined aquifers) it is present in tetravalent oxidation state U(IV). Other oxidation states (trivalent and pentavalent) of uranium are generally not relevant for ecotoxicological studies because they are considered unstable in the natural environment [17]. Hexavalent compounds are also highly soluble and mobile and are present either as free uranyl ion (UO_2^{2+}) or complexed with ligands such as OH^- , Cl^- , CO_3^{2-} , PO_4^{3-} , F^- , SO_4^{2-} [19]. However, both free uranyl ion and the most common carbonate complexes are predominantly neutral or anionic in the same pH range as arsenic and are therefore bound by functional groups of Lewatit FO 36 resin.

Comparison of elution efficiencies of all tested elution agents is given in **Fig. 1**. Concentrated HNO_3 (**A**) was an effective elution agent for uranium (although with a large standard deviation of 8.3%) but as already demonstrated in the original study by Smolíková et al. [3], it is not a suitable eluent for arsenic elution from Lewatit FO 36 resin gel. The elution mixture of 0.25 M NaOH and 0.17 M NaCl, originally proposed in the mentioned study, provided unsatisfactory recoveries of both elements (**B**), but the results pointed out the strong effect of the temperature on the elution efficiency. In the original protocol using this elution agent in combination with microwave-assisted extraction (130 °C for 16 min), the elution efficiency of arsenic was 34.8% higher compared to the result in this study, where only the temperature of 70 °C was used. The resulting elution efficiency was therefore insufficient for DGT calculations since the minimum generally accepted value of f_e should be at least 80% as it is a typical value for metals [2]. Even though the higher temperature of microwave-assisted extraction allows achieving higher elution efficiency, its practical use may be restrictive due to the low number of samples processed in one batch and generally higher demands on laboratory equipment. Therefore, the extraction of DGT resin gels in a conventional drying oven at 70 °C is generally preferred and was used in this study

as well. To avoid the use of chloride-containing eluents which cause interferences during analyses, the mixture of NaOH and H₂O₂ (**C**, **D**, **E**) was used. There is a statistically significant difference ($p < 0.05$) of elution efficiency between variant **C** and variants **D**, **E** for both elements. But whereas the use of a higher temperature and elution agent volume reduced the elution efficiency of uranium, the elution efficiency of arsenic was conversely increased. Therefore, the higher temperature and volume of the elution agent seems to be crucial for the elution of arsenic. On the other hand, a statistically significant improvement in the elution efficiency of uranium between variants **D** and **E** ($p < 0.05$) suggests that a higher ratio of elution agents in favour of NaOH to H₂O₂ (from 1:1 to 2:1) can increase the uranium elution despite the negative effect of higher temperature. The presence of H₂O₂ at the higher temperature, therefore, seems to have a negative effect on the elution of uranium from Lewatit FO 36 resin gel. For this reason, a simple 1M NaOH was used as the other variant of the elution agent. As evident from the obtained results, laboratory temperature and eluent volume of 1 mL were insufficient for elution of both elements (**F**). The elevated extraction temperature (70 °C) and a higher volume of eluent (5 mL) (**G**) nevertheless provided excellent elution efficiency of As ($90.3 \pm 3.9\%$) and U ($85.2 \pm 3.1\%$). Since there was no statistical difference ($p > 0.05$) in the elution efficiencies of As in variants **D**, **E**, and **G**, it is obvious that H₂O₂ has no role in the elution process of arsenic from Lewatit FO 36 resin gel. Even though the elution efficiency of arsenic is 8.0% lower compared to the one of the original study [3], the advantages of simultaneous elution of both elements and the possibility of analysing the samples by ICP-MS are undoubtedly more beneficial. Moreover, the elution factors of both elements are higher than the minimum generally accepted value of 80% and, in addition, with excellent repeatability with deviations below 5%. For the results of statistical analysis see Supplementary Information.

3.2 Diffusion coefficient of U towards Lewatit FO 36

The diffusion coefficient of U calculated within this study from the time-dependence experiment (**Fig. 2**) was $4.38 \pm 0.06 \times 10^{-6} \text{ cm}^2 \text{ s}^{-1}$ (0.01 M NaNO₃ solution, pH 7.56, at 25 °C), which is in good agreement with the average value of $D = 4.44 \pm 0.22 \times 10^{-6} \text{ cm}^2 \text{ s}^{-1}$ obtained by Drozdak et al. [12] for Chelex, Metsorb, and Diphonix resin gels. Drozdak et al. [12] also demonstrated in their study that the diffusion coefficients of U may vary in the literature, with differences being given by the used DGT binding phase in combination with the experimental conditions (solution composition and pH). This causes the changes in uranium speciation in solution (such as the formation of anionic uranyl carbonates species), resulting in a lower affinity towards the resin or lower uptake kinetics.

3.3 Uptake capacity of the Lewatit FO 36 resin gel

Generally, a high uptake capacity of the DGT binding phase towards the studied analyte is required to avoid its saturation during *in-situ* deployment. Very high uptake capacity of the Lewatit FO 36 resin gel towards As was demonstrated in the original study [3], and therefore, the uptake capacity towards U was investigated as well.

The expected U mass accumulated per gel disc (based on the difference between the initial and remaining mass in the solution) plotted versus the U concentration in the original solution is shown in **Fig. 3A**. The Lewatit FO 36 resin gel effectively accumulated uranium even though the U mass in the initial solution was 1250 µg which proves its very high uptake capacity. Given that the saturation of resin gel was not achieved, the total uptake capacity of Lewatit FO 36 towards uranium has not been established. In comparison with other binding phases used for the determination of U, the uptake capacity of Lewatit FO 36 is comparable or much higher than the capacities reported by Drozdak et al. [12, 20]. In these studies, the maximum uptake capacities of PIWBA, Chelex-100, and Metsorb resins were determined as

99.9–249.9 μg of U per gel disc. The best results were so far achieved with Diphonix resin, the capacity of which was not fulfilled even when the U spike was up to 2500 μg .

However, even though the uptake capacity of the Lewatit FO 36 resin gel was demonstrated to be very high, important information regarding the efficiency of the elution protocol proposed in this study was revealed. The results of U mass eluted from the gels showed that the elution efficiency is dependent on the amount of U accumulated on the resin gel disc and is actually able to release only up to 112.2 ± 8.7 μg of accumulated U (**Fig. 3A**). To verify the data for As, the uptake capacity test and subsequent elution of the gels were performed in the same way (**Fig. 3B**). The results showed that only 122.3 ± 8.4 μg of accumulated As was released from the gel during elution even though the accumulated mass was much higher. Since the total masses of both analytes eluted from gels are very similar, it seems that the elution agent (1 M NaOH at 70 °C) reached its maximum elution capacity. Based on the results of different volumes of eluent and especially elution temperature, the authors believe, that increasing the eluent volume or extraction temperature may increase the elution efficiency. Nevertheless, with respect to the practical use of DGTs and also the average concentrations of arsenic (< 10 $\mu\text{g L}^{-1}$ in freshwater and 1.5 $\mu\text{g L}^{-1}$ in seawater [16]) and uranium (0.3 $\mu\text{g L}^{-1}$ in freshwater and 3.3 $\mu\text{g L}^{-1}$ in seawater [17, 18]), the obtained results still suggest the possible deployment over long time periods in natural waters. Regarding the most common deployment period (24 h), the Lewatit FO 36-DGTs can be applied in natural waters with concentrations up to 6.51 mg L^{-1} of As or 8.73 mg L^{-1} of U¹.

¹ The maximum As/U concentration in natural waters for DGT application calculated for $M_{\text{As}} = 122.3$ $\mu\text{g As}$; $M_{\text{U}} = 112.2$ μg ; $\Delta g = 0.0925$ cm ; $A = 3.14$ cm^2 ; $t = 24$ h ; $D_{\text{As}} = 6.41 \times 10^{-6}$ $\text{cm}^2 \text{s}^{-1}$; $D_{\text{U}} = 4.38 \times 10^{-6}$ $\text{cm}^2 \text{s}^{-1}$.

Therefore, the potential distortion of the results can occur only in the case of application in an environment where the concentrations of both elements would be extremely high.

3.4 Selectivity of the Lewatit FO 36 resin gel for arsenic and uranium

Although the uptake capacity of both studied elements was determined to be very high, a series of experiments evaluating the influence of the simultaneous presence of As and U on the course of their sorption was performed at different concentration ratios (**Fig. 4**). The results showed that even at the highest concentration ratio of As and U (variant **j** with 10:10 mg L⁻¹), the uptake efficiency of both elements was $97.9 \pm 0.7\%$ and $95.9 \pm 1.4\%$, respectively. With respect to the results obtained in Section 3.3, the elution of the gels was performed as well in order to validate the elution efficiency when both analytes are accumulated at the same time. The resulting eluted masses of variants **a–i** corresponded overall to 94.6–105.5% of the masses accumulated on the gels. However, this result was expected given the fact that the As and U spike in the most concentrated variant **i** was only 1 µg of each element. On the contrary in the variant **j**, where the As and U spike corresponded to 100 µg of each element, the total accumulated mass (200 µg) on the gel disc exceeded the maximum mass that can be released from the gel using the proposed elution protocol as stated in Section 3.3. Thus, the elution efficiencies obtained for variant **j** were $50.3 \pm 5.5\%$ for As and $67.7 \pm 9.1\%$ for U. When expressing these results as total masses, this corresponds to 48.9 ± 5.4 µg of As and 63.9 ± 8.6 µg of U and therefore ~113 µg as a sum of eluted analytes. This result thus confirms the observations from the previous experiment and indicates the insufficient strength of the eluent when the total mass of the accumulated analytes exceeds ~110 µg.

3.5 *Method detection limit*

The blank values of Lewatit FO 36 resin gel eluted by 5 mL of 1 M NaOH, was calculated as 0.21 ± 0.04 ng for As, and 0.16 ± 0.02 ng for U. The MDL was calculated for 24 h deployment using the thickness of the diffusion layer (0.0925 cm), exposed area (3.14 cm^2) and the diffusion coefficient of As and U towards Lewatit FO 36 ($6.41 \times 10^{-6} \text{ cm}^2 \text{ s}^{-1}$ [3] and $4.38 \times 10^{-6} \text{ cm}^2 \text{ s}^{-1}$, respectively). The calculation was made from three times the standard deviations of resin gel blank values. The resulting MDLs were $0.04 \mu\text{g L}^{-1}$ for As and $0.02 \mu\text{g L}^{-1}$ for U.

4 **Conclusions**

The excellent sorption abilities of Lewatit FO 36-DGT resin gel towards uranium and arsenic were demonstrated within this study by quantitative uptake efficiency of $98.7 \pm 0.6\%$ for As and $99.0 \pm 0.4\%$ for U. Moreover, the resin gel has extremely high uptake capacity for U that was not saturated even at a U spike of $1250 \mu\text{g}$ in the solution. It has also been shown that the resin gel does not show signs of selectivity in favour of one element over another. These results suggest that this novel resin gel can be used for the simultaneous determination of both elements in the real aquatic environment. An optimized elution procedure for the simultaneous elution of As and U from Lewatit FO 36 resin gel using 5 mL of 1 M NaOH at 70°C resulted in an elution efficiency of $90.3 \pm 3.9\%$ for As and $85.2 \pm 3.1\%$ for U. The elimination of NaCl from the original elution protocol allows simple analysis of samples by ICP-MS and therefore enables the widespread use of the new Lewatit FO 36 resin gel in many laboratories. Although the results revealed that the proposed elution protocol may be insufficient for elution of accumulated masses over $\sim 110 \mu\text{g}$ per gel disc or higher, with respect to common concentrations of both studied elements in the natural environments, this

would be a problem only under extreme conditions. However, our results pointed to the need for thorough testing in the introduction of new elution procedures, which should always be verified in terms of both uptake and elution efficiency over concentration ranges.

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388

389 **Table 1** Variants of the tested elution protocols.

Variant	Elution agent	Elution volume	Elution temperature
A	Concentrated HNO ₃	1 mL	70 °C
B	0.25 M NaOH + 0.17 M NaCl	1 mL	70 °C
C	1 M NaOH + 1 M H ₂ O ₂	1 mL	18 °C*
D	1 M NaOH + 1 M H ₂ O ₂	5 mL	70 °C
E	2 M NaOH + 1 M H ₂ O ₂	2.5 mL	70 °C
F	1 M NaOH	1 mL	18 °C*
G	1 M NaOH	5 mL	70 °C

390 * Laboratory temperature.

391

392 **Table 2** Arsenic and uranium concentration ratios for evaluation of Lewatit FO 36 selectivity.

Variant	a	b	c	d	e	f	g	h	i	j
As (µg L ⁻¹)	1	1	1	10	10	10	100	100	100	10,000
U (µg L ⁻¹)	1	10	100	1	10	100	1	10	100	10,000

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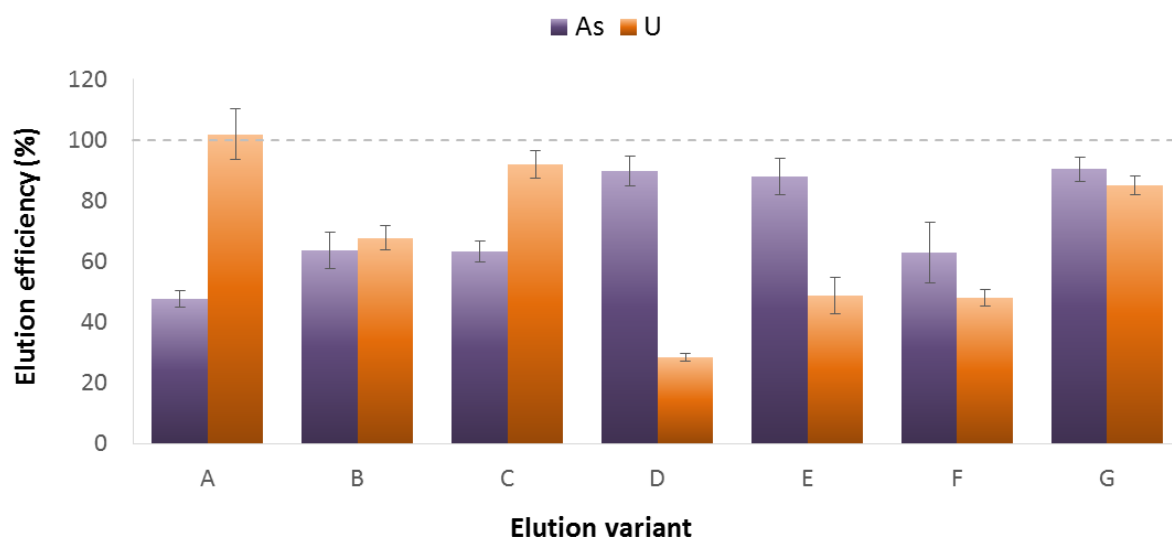


Fig. 1 Comparison of elution efficiency of each elution agent variant: **A** – concentrated $\text{HNO}_3/70^\circ\text{C}$; **B** – $0.25\text{ M NaOH} + 0.17\text{ M NaCl}/70^\circ\text{C}$; **C** – $1\text{ M NaOH} + 1\text{ M H}_2\text{O}_2/18^\circ\text{C}$; **D** – $1\text{ M NaOH} + 1\text{ M H}_2\text{O}_2/70^\circ\text{C}/5\text{ mL}$; **E** – $2\text{ M NaOH} + 1\text{ M H}_2\text{O}_2/70^\circ\text{C}/2.5\text{ mL}$; **F** – $1\text{ M NaOH}/18^\circ\text{C}$; **G** – $1\text{ M NaOH}/70^\circ\text{C}/5\text{ mL}$ (error bars for $n = 5$).

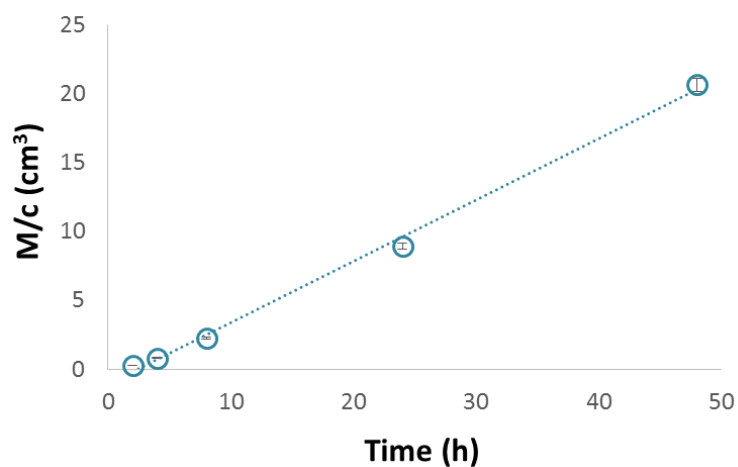
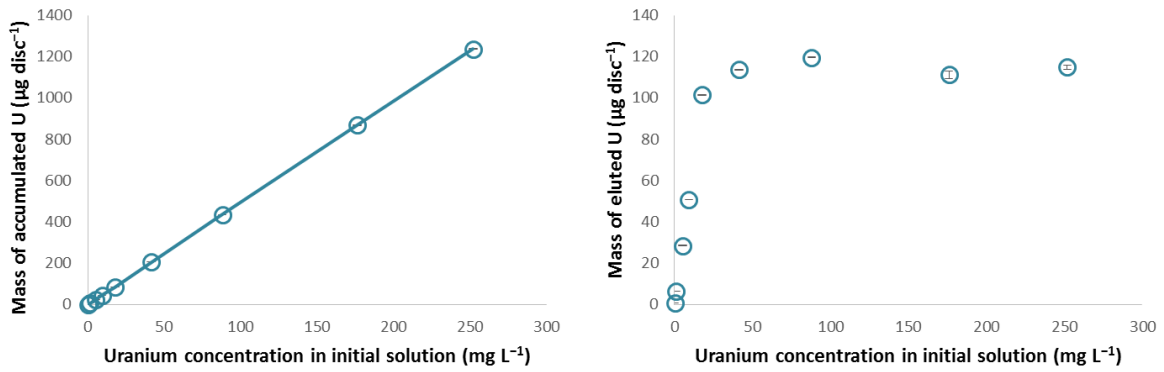


Fig. 2 Time-dependence experiment of U uptake by Lewatit FO 36 resin gel (deployment solution of 0.01 M NaNO_3 ; U $20\text{ }\mu\text{g L}^{-1}$; pH 7.56; $n = 3$).

A



B

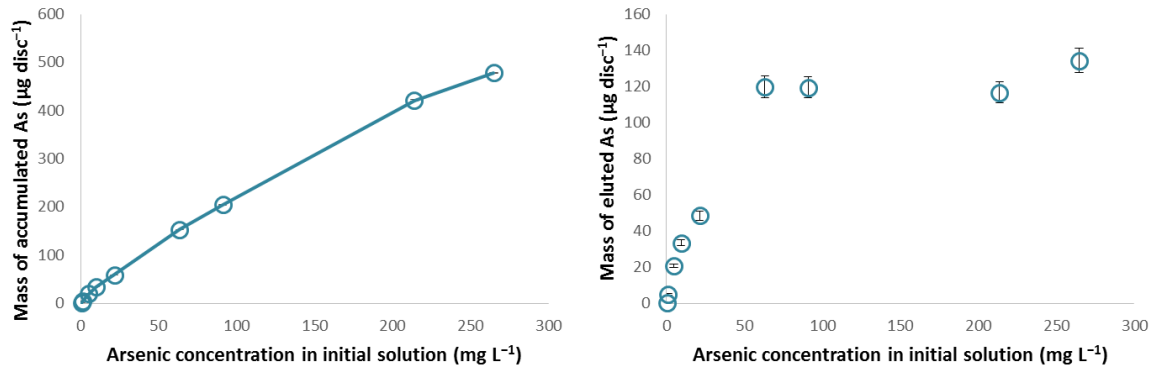


Fig. 3 Uptake capacity and elution efficiency of new elution protocol over the high concentration range of uranium (A) and arsenic (B) (error bars for $n = 3$).

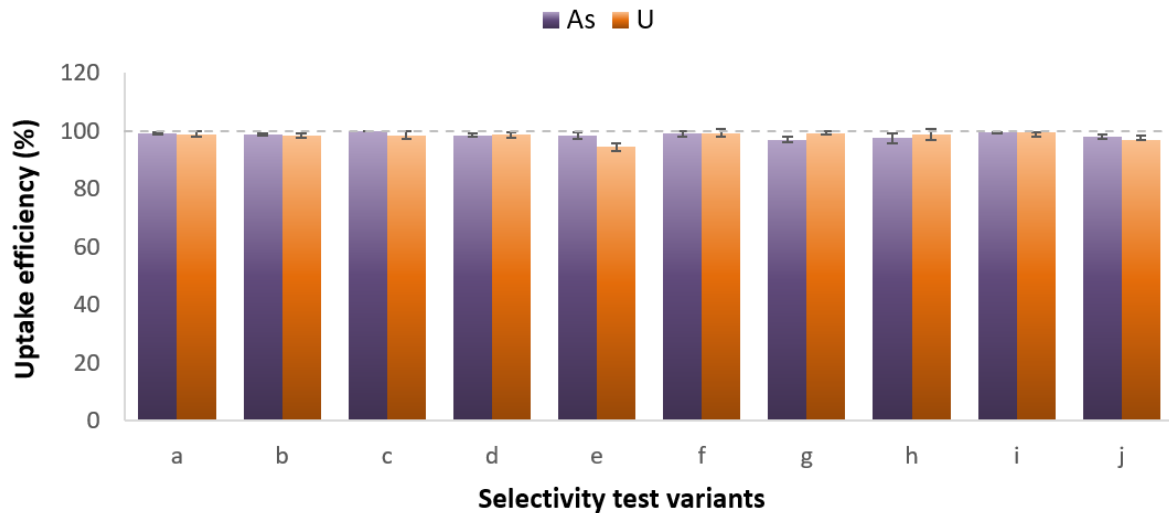


Fig. 4 Evaluation of the Lewatit FO 36 resin gel selectivity for As and U at different concentration ratios: a – 1:1; b – 1:10; c – 1:100; d – 10:1; e – 10:10; f – 10:100; g – 100:1; h – 100:10; i – 100:100; j – 10,000:10,000 (concentrations in $\mu\text{g L}^{-1}$; error bars for $n = 3$).