

USE OF BIOMASS FOR REMOVAL OF ARSENIC COMPOUNDS

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Water contamination with arsenic compounds is a serious problem. One of the solutions is to develop new sorbents based on natural materials that would be cost-effective and environmentally friendly. New sorbents based on biomaterial impregnation with iron oxyhydroxides have been developed. Raw peat material, iron modified-peat, sand, iron modified-biomass (shingles, straw) were used for removal of arsenic compounds. The highest sorption capacity was observed for iron modified-peat. Kinetic studies indicated that most of arsenates were removed within 2 hours, and arsenate sorption on iron modified-peat was characterized by the pseudo-second order rate law.

Key words: *arsenic, peat, biomass sorbents, sorption model.*

INTRODUCTION

Arsenic is a well known toxic element and is present in natural water systems as a result of natural and anthropogenic activities. Natural arsenic contamination involves mobilization of natural arsenic-bearing deposits, biological activity and volcanic emission. Anthropogenic arsenic sources include discharges from various industries, such as smelting, petroleum refinery, glass manufacturing, fertilizer production and intensive application of arsenical insecticides and herbicides [1, 2]. The natural weathering processes contribute approximately 40,000 tons of arsenic to the environment annually, while the amount released by human activities is two times higher [3].

Nowadays arsenic polluted drinking water is one of the most serious environmental problems, and is especially significant in Bangladesh, India, and also in South America, United States and Europe [4–6].

Arsenic exists in natural waters in both inorganic and organic forms. Inorganic arsenic is the predominant form in polluted waters, and it exists in two oxidation states – As(III) and As(V). Arsenite (As(III)) is predominant in reduced conditions, while arsenate (As(V)) prevails in an oxidizing environment [7]. In the pH range of 3–9 the dominant species of As(III) is neutral H_3AsO_3 , while As(V) exists as negatively charged ions HAsO_4^{2-} and H_2AsO_4^- [6, 8]. The toxicity of arsenic compounds depends on its speciation, where As(III) is more toxic, soluble and mobile for biological systems than As(V) compounds [4, 6]. Organic forms of arsenic, for example monomethylarsenic acid (MMAA) and dimethylarsenic acid (DMAA) are rarely present in surface waters in comparison to inorganic forms. Organic arsenic species occur in natural waters as

a result of using organo-arsenic pesticides and through the biomethylation mechanism by microorganisms. Organic forms are also less toxic than inorganic forms of arsenic [3, 9].

Ingestion of arsenic contaminated water can cause important threats to the human health. Long-term uptake of arsenic-contaminated drinking water causes liver, lung, kidney, bladder, skin and nerve tissue injuries and cardiovascular problems [3, 4–6, 10].

In order to solve the problem of arsenic pollution, various treatment systems, for instance precipitation, adsorption, ion exchange and membrane processes have been used. Adsorption is considered to be one of the best methods because of its simplicity and potential of reuse, as well as its low cost and the ease of set up [2, 4, 5]. Most of the sorbents belong to one of three major groups – aluminium compounds, lanthanum compounds and iron compounds. There are studies in literature on goethite, hematite, iron coated sands, Fe loaded coral limestone, granular ferric hydroxide, ferrihydrite, pyrite, ferruginous manganese ore, manganese green sand, iron oxide impregnated activated alumina, naturally available red soil, modified (iron(III) loaded) industrial residue from orange juice processing, modified biomass, iron oxide coated polymeric materials and others [3, 6, 9, 11–16]. The solid phases loaded with Fe species may adsorb arsenates as well as arsenites, possibly due to formation of stable inner and outer sphere surface complexes as a result of interaction between As_2O_3 or AsO_4 with FeO_6 polyhedra [4]. There is also evidence for complex formation between arsenic oxyanions and ferric iron complexes of humic substances (HS). Spectroscopic evidence for ternary complex formation between As(V) and Fe(III)–HS complexes was given by Mikutta and Kretzschmar [17] using EXAFS (Extended X-ray Absorption Fine Structure).

Some of the sorbents are effective for removal of arsenates but are not useful for arsenites, as well as the sorption efficiency and costs are very variable, thus opportunities for finding new sorbents and new areas of sorbent application are open.

New sorbents based on natural materials have a similar efficiency to synthetic sorbents. Sorbents based on natural materials are cheap, environmentally friendly and recyclable. A prospective matrix for such sorbent development is peat – an abundant resource in Northern Europe and elsewhere. The aim of this study was to synthesize iron modified biomaterials and investigate application possibilities of iron modified biomaterials for arsenic adsorption.

EXPERIMENTAL

Analytical quality reagents (Merck Co., Sigma-Aldrich Co., Fluka Chemie AG, RdH Laborchemikalien GmbH Co.) were used without further purification. For the preparation of solutions, high purity water Millipore Elix 3 (Millipore Co.), 10–15 M Ω /cm, was used throughout.

Sodium arsenate ($Na_2HAsO_4 \cdot 7H_2O$) from Sigma-Aldrich was purchased as analytical grade chemical. Peat was obtained from Dizais Veikenieks Bog (Latvia), Gagu Bog (Latvia) as well as Silu Bog (Latvia) and chemically modified. Modification involved precipitation of iron hydroxides on the surface of peat, followed by thermal treatment [5, 18, 19]. Arsenic sorption onto modified biomass was also investigated. Iron modified-shingles, iron modified-straw and iron modified-sands were used for adsorption of arsenic.

Peat modification with iron compounds

The method was based on peat impregnation with iron hydroxide, where 67.55 g (0.25 mol) of $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$ were dissolved in 250 mL of distilled water, 250 mL of 3 M NaOH were added and left for 2–4 hours. Then the precipitates that formed were rinsed and decanted in a 1 L vessel. A dispersion of $\text{Fe}(\text{OH})_3$ was mixed in with 100 g of homogenized peat. After filtration, the reaction product was rinsed with approximately 0.5 L of deionized water, filtered, dried and heated for 4 hours at 60 °C.

Biomass modification with iron compounds

Biomass modification was based on material impregnation with iron hydroxide, similarly to peat modification. For this purpose, 67.55 g (0.25 mol) of $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$ were dissolved in 250 mL of distilled water, treated with 250 mL of 3 M NaOH and leaving for 3 hours. Then the formed precipitates were rinsed and decanted into a 1 L vessel. A dispersion of $\text{Fe}(\text{OH})_3$ was mixed in with 100 g of homogenized biomass (shingles, straw, sands). After filtration, the reaction product was rinsed with approximately 0.5 L deionized water, filtered, dried and heated for 4 hours at 60 °C.

Synthesis of iron hydroxide

Iron hydroxide was used for comparison, by dissolving 67.55 g (0.25 mol) of $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$ in 250 mL distilled water, adding 250 mL 3 M NaOH and leaving for 3 hours. Then reaction mixture was rinsed and decanted in a 1 L vessel. After that, the product was dried and heated for 4 h at 60 °C.

Characterization of sorbents

Iron concentration in the studied sorbents was determined by using atomic absorption spectrometer Perkin-Elmer Analyst 200 with flame atomization.

Fourier transformation infrared spectra were obtained for all sorbents, using Perkin-Elmer Spectrum BX FT-IR spectrometer, and data processing was performed with Spectrum v 5.3.1 software. Samples were pressed in KBr pellets and the spectra recorded in the range of 4000–400 cm^{-1} with a 4 cm^{-1} resolution.

Sorption experiments

$\text{Na}_2\text{HAsO}_4 \cdot 7\text{H}_2\text{O}$ was used for arsenic stock solution preparation at concentrations of 300, 200, 100, 50, 25, 10 and 5 mg/L. In a 100 mL glass bottle with 0.5 g of sorbent, 40 mL of arsenic solution was added. Bottles were shaken for 24 h at room temperature. The peat suspension was then filtered and arsenic was analyzed in the filtrate, using Perkin-Elmer Analyst 200 atomic absorption spectrophotometer (AAS) with flame atomization.

Sorption kinetics

Sorption experiments were made in the same way as previously described. The initial arsenic concentration was 100 mg/L. Arsenic stock solution was made of $\text{Na}_2\text{HAsO}_4 \cdot 7\text{H}_2\text{O}$. In a 100 mL glass bottle, 40 mL of arsenic solution was added to 0.5 g of sorbent. Bottles were shaken and the arsenic content in the solution phase was detected after 0.2, 0.5, 0.7, 0.8, 1.0, 1.3, 2.0, 3.0, 4.0, 5.0, 6.0, 7.0 and 24.0 h, using AAS.

RESULTS AND DISCUSSION

Due to widespread arsenic pollution of waters and good perspectives of iron containing sorbents, the possibility to obtain iron modified biomass for use in arsenic removal was examined. The synthesis method of iron modified biomass was based on biomass impregnation with iron hydroxide and certain reaction conditions were selected considering results of our previous studies [20].

Characterization of sorbents

Fourier transformation infrared spectra (FT-IR) and iron content were estimated to characterize the obtained sorbents. The type, age, elemental content, cation exchange capacity (CEC) and content of carboxylic groups (COOH, meq/g) were determined for the raw peat material used in this study (Table 1).

Table 1. Characterization of raw peat material used in this study

Parameters	Peat Bog Dizais Veikenieks (Latvia), depth 25–52 cm	Peat Bog Gagu (Latvia), depth 50–60 cm	Peat Bog Silu (Latvia), depth 12.5–25 cm
Peat type	High-type <i>fuscum</i> peat	High-type cotton grass-sphagnum peat	High-type cotton grass-sphagnum peat
Peat age, ¹⁴ C years	730 ± 50	–	–
Elemental composition	C, %	48.19	48.54
	H, %	5.53	5.54
	N, %	0.66	1.15
CEC, cmol/kg	6.6	7.5	–

Iron content was determined for all sorbents that were modified with iron compounds. Modification results indicated that the modification method was effective, because the iron content was significantly enhanced after modification. For example, the peat layer (25–52 cm) from Dizais Veikenieks Bog contained 0.095 mg Fe/g [21], but after modification the Fe content reached 43±1 mg/g. Moreover, raw peat (Gagu) contained 0.28±0.01 mg Fe/g and raw peat (Silu) – 0.42±0.02 mg Fe/g. Although biomass modification with iron compounds was based on a single method, the determined iron content was quite variable – Fe content reached 28±9 mg/g for modified straw, 24±5 mg/g for modified shingles and 15±4 mg/g for modified sand. The main reason could be the different matrix in each case.

The Fourier transform infrared (FT-IR) spectra showed structural changes due to the modification, when comparing raw and modified peat samples. The FT-IR spectra of all iron modified peat samples from D. Veikenieks, Gagu, and Silu Bog, as well as one FT-IR spectrum of raw peat material from Silu Bog are shown in Fig. 1. All studied materials had a common feature – a broad band at 3600–3300 cm⁻¹ corresponding to phenolic and carboxylic acid hydroxyl groups. Major changes of modified peat and unmodified peat FT-IR spectra could be observed at wavenumbers from 1700 to 450 cm⁻¹. As it can be seen in Fig. 1 the intensity of several functional group signals varies after the formation of Fe complexes, thus indicating that structural changes have occurred in the

molecule due to interaction with the metal. And it has also been proven in other studies. Rodriguez-Lucena *et al.* [22] suggested that the bands at 2940, 2830, 1715, 1470, 1500 and 1050 cm^{-1} are less intense after the complexation with iron compounds. The lower intensity of separate bands involving CH, carbonyl and carboxyl stretching, CH deformation, aromatic ring vibrations, C=C aromatic skeletal vibrations and the vibrations of C–O, C–C and C–OH may be related to the formation of Fe phenolates and carboxylates. However, the band at $\sim 1600 \text{ cm}^{-1}$ was characteristic for all studied materials, but it was more intense for iron modified peat. This agreed with previous studies, possibly the reason could be iron inclusion into structure that in FT-IR spectra caused stretching of unconjugated carbonyl-carboxyl groups. However, hydrogen bond valence vibrations of hydroxyl groups could be observed at 3570–3200 cm^{-1} , and was obvious for all studied materials. The FT-IR signal at 1430 cm^{-1} characterized methyl C–H asymmetric/symmetric bending, but aromatic C–H bending signal could be observed at 1225–950 cm^{-1} [23].

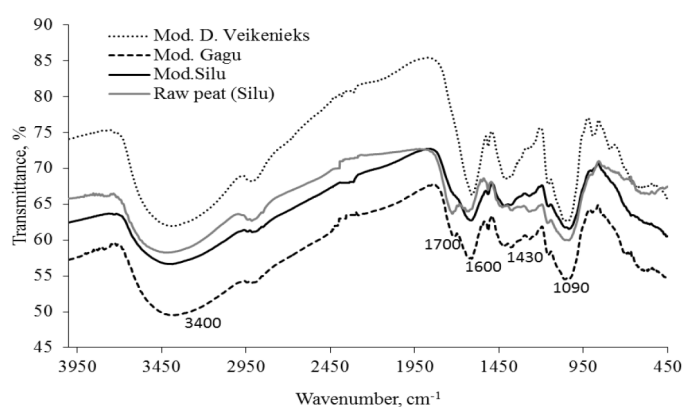


Fig. 1. FT-IR spectra of iron modified-peat and raw peat material.

FT-IR spectrometry is one of the methods that are used to characterize modification products, although FT-IR spectra show structural differences useful for comparing modified and unmodified materials, it does not allow a full characterization of modification results.

For unmodified biomass, the main functional groups that bind arsenic could be carboxylic and amino groups, while the As–O–Fe bond could support interaction between arsenic and iron-modified biomass. Examples of possible functional groups of raw peat material that bind arsenic could be amino groups, vicinal hydroxyl groups and carboxyl groups. Vicinal hydroxyl groups and carboxyl groups may be present also in straw and shingles, which possibly may interact with arsenic.

Sorption isotherms

Sorption isotherms characterize the equilibrium partitioning between sorbed and desorbed phase, providing information about sorption process. Sorption experiments were carried out using unmodified materials – different peat materials, sand, straw, shingles as well as iron modified-biomass sorbents. Inorganic form of arsenic–sodium arsenate dibasic heptahydrate ($\text{Na}_2\text{HAsO}_4 \cdot 7\text{H}_2\text{O}$) was used to investigate arsenic removal.

The obtained arsenic sorption isotherms were compared with the sorption models of Langmuir and Freundlich. The obtained data best fitted to the Langmuir isotherm model (Eq. 1):

$$q_e = \frac{q_m K_a C_e}{1 + K_a C_e} \quad (1)$$

The constants q_m and K_a of the Langmuir equation can be determined from a linearized form of the Langmuir equation (Eq. 2):

$$\frac{C_e}{q_e} = \frac{1}{q_m K_a} + \frac{C_e}{q_m} \quad (2)$$

where C_e – the equilibrium concentration, mg/L;
 q_e – the amount of arsenic sorbed onto solid phase, mg/g;
 q_m – q_e for a complete monolayer, mg/g;
 K_a – sorption equilibrium constant, L/mg [24].

We have found that sorption capacity depended on used biomass sorbent, although the reaction conditions were similar. The highest sorption capacity was observed for iron modified-peat sorbents, while the iron modified-shingles and iron modified-straw showed similar results, but iron modified-sand was not useful for removal of arsenic compounds. Iron hydroxide was used for comparison. The main reason was to synthesize new sorbents based on natural material that could be used in arsenic polluted waters, and therefore it was important to compare the sorption capacity of synthesized iron hydroxide and biomass that was modified by impregnation with iron hydroxide. Sorption isotherms of iron hydroxide and iron modified-biomass sorbents are shown in Fig. 2.

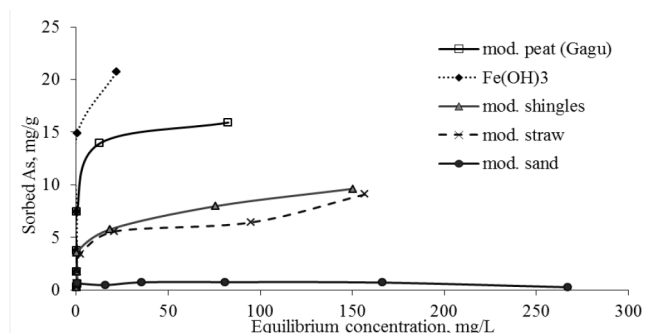


Fig. 2. Arsenic removal using iron modified biomass and iron hydroxide, sorption time 24 h at room temperature.

For better understanding of arsenic removal efficiency, comparison of sorption capacities has been used (Fig. 3). Iron hydroxide adsorbed more than 99% of arsenic when the initial arsenic concentration reached 100 mg/L, but the adsorption decreased to 92% when the initial arsenic concentration exceeded 280 mg/L (Fig. 3). However, iron modified-peat (Gagu) may adsorb 98% at the initial concentration of 100 mg/L, and the adsorbed amount of arsenic decreased to 70% when the initial arsenic concentration reached 270 mg/L. The amount adsorbed on modified shingles and modified straw exceeded accordingly 95%

and 99%, if the initial arsenic concentration was 45 mg/L, but the weakest sorbent – modified sand could be used effectively if arsenic concentration does not exceed 10 mg/L.

We conclude that iron hydroxide and iron modified-peat (Gagu) are the most effective sorbents for arsenic removal, and it is possible to use them for highly arsenic polluted waters. On the contrary, it can be proposed that iron modified shingles and iron modified straw could be applied only if arsenic concentrations are low.

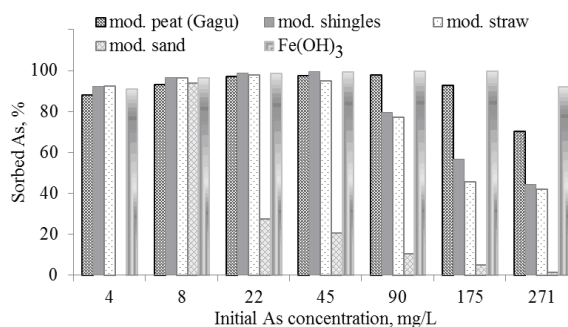


Fig. 3. Arsenic (V) sorption onto iron modified biomass and iron hydroxide (sorption time 24 h, room temperature).

Biosorption has been demonstrated to be a useful alternative to conventional treatment systems for the removal of arsenic and other metalloids and metals from aqueous solution. The pre-treatment and modification of biomaterials are used very often, in order to enhance sorption capacity. A wide variety of different materials has been used to remove As(III) and As(V) from water, with variable efficiency. For example, maximum removal efficiency of As(III) using naturally available red soil was 98% at an adsorbent dose of 45 g/L with the initial As(III) concentration of 1 mg/L in batch studies, and 95% at 25 g/L adsorbent dose at the same conditions [6]. In this study, the adsorbent dose was 12.5 g/L, and to compare sorption capacity and sorbent amount, removal efficiency using red soil was 65% at an adsorbent dose 10 mg/L and 79% at an adsorbent dose 15 mg/L [6]. Other studies indicate that the sorption capacity of As(III) by using iron oxide impregnated activated alumina was 378 mg/kg, if the initial arsenic concentration was 1.4 mg/L [11]. The maximum sorption capacity of As(V) was 0.94 mol/kg and of As(III) 0.91 mol/kg using modified (iron(III) loaded) orange juice industrial residue [12]. Guo *et al.* [13] showed that the sorption capacity was 97.7 µg/g for siderite coated sand and 51.9 µg/g for hematite coated sand but Thirunavukkarasu *et al.* [3] found that the sorption capacity of the iron oxide coated sands and ferrihydrite used for arsenic removal from natural waters was 18.3 µg/g and 285 µg/g, respectively. In addition, Manna and Gosh [15] found that the sorption capacity of As(III) reached 66 g/kg using FeOOH. Comparatively high sorption capacity of As(V) was obtained using modified biomasses (*P. chrysogenum*) – 37.85 mg/g for HDTMA-Br modified mycan biomass, 56.07 mg/g for magnafloc-modified biomass and 33.31 mg/g for dodecylamine-modified biomass [14].

To summarize, the sorption capacity of sorbents synthesized in this study are comparable with that of other biomaterials, but serious consideration must be given to conditions such as the sorbent amount, arsenic concentration, pH and

others factors, that noticeably influence sorption capacity, thus the ability to compare efficiency of different sorbents.

Since the iron modified peat had the highest sorption capacity in comparison to other iron modified-biomass materials used in this study, different peat materials were chosen to investigate possible use for arsenic removal.

The Fig. 4 proves that the modification of peat enhanced the sorption capacity. The reason could be the formation of As–O–Fe bonds during the arsenic sorption process onto iron-saturated peat materials. Probably the iron content and its chemical form were the main reasons for the obtained results. Modified peat sorbents had a noticeably higher Fe content in comparison to raw peat material.

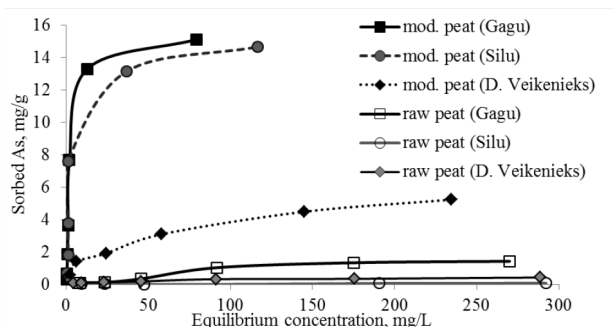


Fig. 4. Arsenic removal using modified and raw peat material (sorption time 24 h at room temperature).

As previously mentioned, iron modified-peat (Gagu) may adsorb almost 100% at the initial As concentration of 100 mg/L, but the adsorbed amount of arsenic decreased to 70% when the initial arsenic concentration reached 270 mg/L, a similar trend was observed also for modified peat (Silu), but 75% was the highest adsorbed percentage of arsenic for modified peat (D. Veikenieks) at the initial arsenic concentration 10 mg/L. However, the usefulness of iron modified-peat could cover partially treated waters, as a polishing step, in cases where most of arsenic has been removed and some additional treatment might be required.

The differences in sorption capacity for iron modified-peat sorbents may be explained by the different chemical forms of iron that may originate in the aging and drying processes.

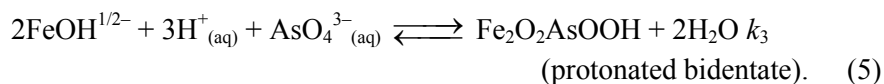
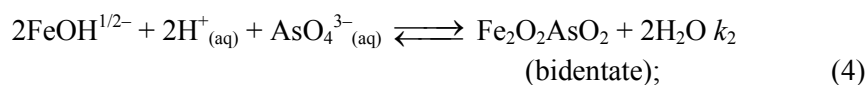
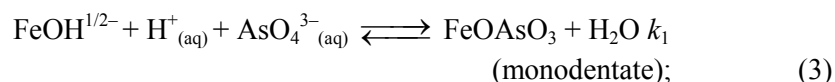
Kinetic study

Sorption kinetics can give valuable insights into sorption process pathways and mechanisms. The kinetics of arsenic adsorption on iron modified peat was studied as a function of time at room temperature. The results of our kinetic study indicated that the majority of As(V) was removed within two hours (using modified peat (Silu) as sorbent), and the adsorbed percentage of arsenic exceeded 90% after 5 hours.

Several models were used to describe the kinetics of sorption process, according to the pseudo first and pseudo second order equations. The pseudo first order equation of Lagergren was based on solid capacity, and the pseudo

second order equation was based on solid phase sorption [25, 26]. The determination coefficients were 0.991 and 0.9997, using the pseudo first and pseudo second order equations accordingly. The kinetics of arsenate ion sorption on modified peat was based on the assumption of the pseudo second order mechanism, and the rate limiting step could be chemisorption [27].

Previous spectroscopic studies of arsenic adsorption onto goethite and ferrihydrite, using EXAFS and XANES, indicated that arsenate and also arsenite was bound on these surfaces as inner sphere complexes [9]. However, later it was proven that arsenites on Fe oxides may form outer sphere surface complexes as well. More detailed mechanism for As(V) adsorption on surface of hydrous ferric oxides was proposed based on published spectroscopic data (Eq. 3–5) [9].



Equations (3–5) suggest that arsenic is mainly adsorbed on iron oxides through specific adsorption mechanism (chemisorption), where arsenic is directly bound with surface functional groups. This assumption gives appropriate information about mechanisms for the removal of arsenic using hydrous ferric oxides. Katsoyiannis and Zouboulis [9] suggested that physicochemical properties of iron oxides after coating on the surface of polymeric materials do not change; therefore the sorption mechanism would be similar. Since iron modified peat was used as sorbent for arsenic, and sorbent contained iron oxyhydroxide, the mechanism of sorption could be as shown in the Eq. (3–5).

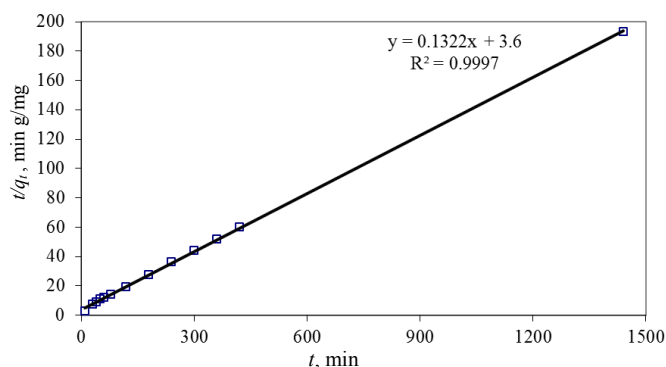


Fig. 5. Pseudo second order sorption kinetics of As(V) onto iron modified peat (Silu) at the initial As(V) concentration of 100 mg/L, where q_t is the amount of As(V) adsorbed on the modified peat surface at any given time t (mg/g).

The rate of pseudo-second order reaction may depend on the amount of solute adsorbed and the amount adsorbed at equilibrium. The integrated rate law for a pseudo second order reaction is shown in the Eq. (6) [24].

$$q_t = \frac{t}{(1/kq_e^2) + (t/q_e)}, \quad (6)$$

where k – the rate constant of sorption, mg/(g·min);

q_e – the amount of arsenate adsorbed onto modified peat at equilibrium, mg/g;

q_t – the amount of arsenate adsorbed on the surface of modified peat at any given time t , mg/g.

The linear form of Eq. (6) is:

$$\frac{t}{q_t} = \frac{1}{kq_e^2} + \frac{t}{q_e}. \quad (7)$$

Eq. (7) can be transformed to obtain Eq. (8):

$$\frac{q_t}{t} = \frac{h}{1+kq_e t}, \quad (8)$$

where $h = kq_e^2$, and h characterizes the initial sorption rate as q/t , when $t \rightarrow 0$ [16].

Therefore, a plot of t/q_t against t (Fig. 5) reveals a linear relationship with the slope of $1/q_e$ and the intercept of $1/kq_e^2$. The amount of arsenate sorbed onto modified peat at equilibrium (q_e) was 7.57 mg/g, and the rate constant (k) of sorption process was 0.005 mg/(g·min), while the initial sorption rate (h) reached 0.27 mg/(g·min).

We conclude that modified peat is able to remove arsenic from water, and more than 90% were removed within 5 hours. The sorption data had the best fit to a pseudo second order mechanism, and the rate limiting step could be chemisorption.

CONCLUSIONS

Biosorbent impregnation with iron compounds significantly enhanced the sorption capacity and made them useful for removal of arsenic compounds. Iron hydroxide and iron modified-peat (from the Gagu Bog) were the most effective sorbents for arsenic removal, and it is possible to use them for waters highly polluted with arsenic. On the contrary, it can be proposed that iron modified shingles and iron modified straw could be applied for low level arsenic removal. Sorption capacity of iron modified biomass was comparable to that of bio-materials investigated by other researchers, but the conditions were important, such as the sorbent amount used, arsenic concentration, pH and others factors, that noticeably influenced the sorption capacity, thus the relative efficiency of various sorbents.

Kinetic results indicate that modified peat was able to remove arsenic from water, and more than 90% of arsenic was removed within 5 hours. The sorption data had the best fit to the pseudo second order mechanism, and the rate limiting step could be chemisorption.

Acknowledgements

This work has been supported by the Latvian National Research Programme NatRes and by the European Social Fund within the project "Support for Doctoral Studies at the University of Latvia".

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BIOMASAS IZMANTOŠANA ARSĒNA SAVIENOJUMU SORBCIJAI

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K O P S A V I L K U M S

Ūdens piesārņojums ar arsēna savienojumiem ir viena no nopietnākajām vides problēmām. Tās atrisināšanai no dabas materiāliem tiek izstrādāti jauni sorbenti, kas būtu videi draudzīgi un ekonomiski izdevīgi. Pētījuma autori radījuši jaunus sorbentus, kuru pamatā ir biomateriālu impregnēšana ar dzelzs oksihidroksīdiem. Arsēna sorbcijai tika izmantota neapstrādāta kūdra, ar dzelzi modificēta kūdra, kā arī ar dzelzi modificētas smiltis un biomasa (skaidas, salmi). Konstatēts, ka augstākā sorbcijas kapacitāte sasniegta, par sorbentu izmantojot modificētu kūdru. Veiktie kinētikas pētījumi liecina, ka lielākā daļa arsenātu modificēta kūdrā tiek sorbēti 2 stundu laikā un sorbcijas procesu apraksta pseido-otrās pakāpes mehānisms.