Use of ferric impregnated volcanic ash for arsenate(V) adsorption from contaminated water with various mineralization degrees

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Abstract

Ferric impregnated volcanic ash (FVA) which consisted mainly of different forms iron and aluminum oxide minerals was developed for arsenate (V) removal from the aqueous medium. The adsorption experiments were conducted in both DI water samples and the actual water (*Lake Kasumigaura*, Japan) to investigate the effects of solution mineralization degree on the As(V) removal. Kinetic and equilibrium studies conducted in actual water revealed that the mineralization of water greatly elevated the As(V) adsorption on FVA. The experiment performed in DI water indicated that the existence of multivalence metallic cations significantly enhanced the As(V) adsorption ability, whereas competing anions such as fluoride and phosphate greatly decreased the As(V) adsorption. It is suggested that FVA is a cost-effective adsorbent for As(V) removal in low-level phosphate and fluoride solution. It was important to conduct the batch experiment using the actual water to investigate the arsenic removal on adsorbents.

Keywords: Arsenate (V) adsorption, Actual water, Water mineralization, Ferric impregnated volcanic ash, Langmuir isotherm.

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1. Introduction

Arsenate in water is a widespread toxic contaminant which might cause many chronic and carcinogenic public health problems, such as cancer and skin diseases [1]. It was reported that over 70 countries were suffering from natural arsenic pollution, posing a serious health hazard to an estimated 150 million people world-wide [2]. Among them, more than 70% populations lived in Asia, especially in South and South-east of Bangladesh, China, and India [3, 4]. Maximum Contaminant Level (MCL) of arsenic in drinking water, suggested by World Health Organization (WHO) in 1996, is 10 μg /L [5]. This standard has been adopted by European Union and USA in 1998 and 2001 [6, 7]. However, the standard is fivefold higher than that of WHO in China, India and some other developing countries where a high risk of arsenic poisoning exists [2]. There is urgent need for develop a cost- effective technology for arsenic removal for aqueous medium.

Several methods are available for arsenic removal from aqueous medium, including adsorption, ion exchange, lime softening, reverse osmosis, coagulation, and precipitation [8 -10]. Given its advantages and limitations, the adsorption has been recognized as a favorable technology which has the advantages of convenient process, high removal efficiency, regeneration potential and sludge free. Many former studies had investigated agricultural products, industrial by-products/wastes, soils and clay minerals as promising adsorbents for arsenic, such as, red mud or fly ash [11, 12]. They had built a win-win system for waste utilization and disposal of environmental accumulated hazard due to their high alkalinity and large amount.

Volcanic ash (VA), as a similar environmental load to red mud and fly ash, is one of the major hazards from volcanic eruptions. Significant accumulations of volcanic

ash ashfall can lead to the immediate destruction of most of the local ecosystem, as well as damage on man-made structures, such as, severely damage jet engines, abrade surfaces, clog air filters, obstruct surface transportation, and shut down major airports [13]. Volcanic ash mainly consisted of different forms of iron and aluminum oxide minerals, which were contribute to arsenic adsorption [11, 12]. In this study, volcanic ash was first used for arsenic removal from aqueous medium. We loaded iron (hydro)oxides on the surface of volcanic ash through ferric impregnation and moderate temperature coating treatments, in order to enhance the arsenic affinity to adsorbent.

Arsenic sorption was commonly studied in terms of the effects of adsorbent (dosage and particle size) and solution properties (initial concentration, pH, and temperature). However, less attention was paid to the solution mineralization, which was believed it also showed great influence on the arsenic adsorption [14,16-19]. Guo et al. [17] reported the presence of phosphate greatly impeded the adsorption of arsenate, and Sun et al. [18] showed that the presence of high-level nitrate anion can accelerate arsenate removal while phosphate provides a competitive effect. Xu et al. [14] and Roberts et al. [19] also studied effects of anions on As removal. But there are comparatively few studies published on the effect of cations on As removal. Besides, the batch experiments are usually carried out with deionized water and influence of water chemistry is not well studied. Given the fact that degree of water mineralization varies in most contaminated aqueous systems, it is important to investigate arsenic removal based on actual waters instead of deionized water.

The purpose of present study was to develop and investigate ferric impregnated volcanic ash (FVA) as an alternate As(V) adsorbent. The effects of mineralization degree (ion competition and ionic strength) on the arsenic removal efficiency were

systematically researched. Kinetic and equilibrium studies of arsenic removal in actual waters by FVA were discussed.

2. Materials and methods

2.1. Materials

Volcanic ash was provided by Makino Store, Kiyosu, Japan. The chemical composition was analyzed through the semi-quantitative elemental analysis and element mapping by energy dispersive X-ray spectrometry (EDX). The result was listed in Table 1 and it shows that volcanic ash is primarily a mixture of Si, Fe and Al oxides. 5g samples were crushed and sieved to obtain fractions of particle size smaller than 150 mesh, and then impregnated with ferric solution ($FeCl_3$, 20g/l) in a water thermostat (50 °C). The impregnated samples were calcined in a muffle furnace at 300°C for 1 h, and the cooling samples were re-sieved through a 150-mesh screen for future study.

Table 1
Chemical analysis of VA and FVA

Composition (wt %)	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	MnO	pH_{zpc}
VA	51.30	38.05	7.67	1.94	0.78	0.26	6.9 ± 0.5
FVA	48.40	36.53	12.75	1.62	0.46	0.24	5.5 ± 0.5

As(V) stock solutions (1000mg/L) were prepared by dissolving sodium hydrogen arsenate ($Na_2HAsO_4{\cdot}7H_2O$, Wako Pure Chemical Industries) in deionized water (DI) of pH 6.9. The coexisting ions were provided by analytical grade chemicals (KCl, $CaCl_2$, $FeCl_3$, NaCl, NaF, $NaNO_3$, Na_2SO_4, and Na_3PO_4, Wako Pure Chemical Industries), and the solution ionic strength was adjusted to 0.001, 0.01 and 0.1 M with NaCl, which were used to produce various water mineralization degrees.

Furthermore, two actual water samples, named W1 to W2, with different compositions have been selected in order to test the influence of water mineralization on As(V) removal in real water solution. W1 is a tap water sample from our

laboratory; W2 is a surface layer water sample taken from *Lake Kasumigaura*, the second largest lake in Japan. The chemical compositions information was shown in Table 2. In all the samples the arsenic concentration was below the detection limits (1μg /L) determined by an inductively coupled plasma atomic emission spectrometer.

Table 2
Chemical compositions and characteristics of the water samples

Water sample		W0	W1	W2
Composition		Deionised water	Tap water	Lake water
Sodium	mg L^{-1}	0.6	26.9	43.4
Magnesium	mg L^{-1}	<0.1	6.7	6.2
Calcium	mg L^{-1}	0.4	22.0	28.7
Potassium	mg L^{-1}	0.3	6.7	15.1
Fluoride	mg L^{-1}	0.5	0.2	0.2
Sulfate	mg L^{-1}	0.2	22.8	35.4
Chloride	mg L^{-1}	0.2	50.1	119.2
Nitrate	mg L^{-1}	<0.1	2.4	8.6
Phosphate	mg L^{-1}	<0.1	<0.1	1.0
pH	pH unit	6.72	7.19	7.87

2.2. Methods

2.2.1. Analysis methods

The prepared FVA was analyzed in order to determine its physicochemical and mineralogical properties. Specific surface area and pore size distributions were determined by a gravimetric Brunauer–Emmett–Teller (BET) specific surface analysis device (Coulter SA3100, US). The morphological features of FVA and VA were analyzed by a scanning electron microscope (SEM, JSM-6700F, JEOL, Japan). Mineralogical phase characterization was carried out using the quantitative X-ray diffraction (XRD, RINT2200, Rigaku, Japan). The anions of water samples were measured by an ion chromatography (IC7000, AS9-HC column, Yokogawa, Japan) and major cations in water samples and As(V) concentrations were determined by an inductively coupled plasma atomic emission spectrometer (ICP-AES, ICPS-7500, Shimadzu, Japan). The point of zero charge (pH_{pzc}) of FVA was estimated by using

batch equilibrium techniques described by Chutia et al. [20].

2.2.2. Batch experiments

Batch adsorptions contained two sets of experiments: kinetic and isotherm experiment. In order to know the static adsorption rate, kinetic experiments were carried out with the actual and DI water samples in a water thermostat (20 ± 0.5°C) without any agitations for 48h. 300 ml of synthetic As(V) solution (10 mg/L) was impregnated in the conical flask, with 10 g/L FVA. After centrifuging at 3000 rpm, the supernatant was filtered through a 0.45 μm membrane filter and used to measure As(V) concentration by ICP-AES.

Isotherm experiments were performed to examine arsenic adsorption capacity on FVA in the water of different mineralization degrees, such as DI water (W0), tap water (W1) and lake water samples (W2). A 50 ml polyethylene centrifuge tube filled with 50 ml of As(V) (in concentrations ranging from 5 to 100mg/L) water samples and 10 g/L FVA were used to carry out the isotherm experiment. Considering that the plateau equilibrium need a long time, all isotherm tests were taken under an agitation speed of 200 rpm to shorten the equilibrium time.

Adsorption were conducted in both actual and DI water samples for investigating the relationship between the degree of water mineralization and As(V) removal. For the DI water, we adjusted the ionic strength of the solution or added other coexisting ions to simulate various mineralization degrees. The solution ionic strength was adjusted to 0.001, 0.01, and 0.1 M by adding the analytical grade NaCl. Coexisting ion tests were performed using As(V) solutions of 50 mg/L containing 5, and 50 mg/L of cations, including K^+, Ca^{2+}, and Fe^{3+} (as $FeCl_3$); and anions, including NO_3^-, F^-, SO_4^{2-} and PO_4^{3-}. These ions represented univalent, bivalent and trivalent ions, respectively.

3. Results and Discussion

3.1. Characterization of the prepared FVA

As shown in Fig. 1, the BET specific surface area of FVA was 147.13 sq.m/g. The BJH (Barrett–Joyner–Halenda) pore size distribution revealed that the observed pore sizes mostly varied between 2 and 50 nm (63.59%), according to the IUPAC classification which is typical for mesoporous materials. Fig. 2a and 2b are SEM images of FVA and VA in the initial Fe^{3+} of 20g/L. The FVA initially forms a rough surface structure. Long-time (48h) solution erosion during impregnation appears to smooth the surface structure somewhat. It is also found that a few acicular and prismatic particles appeared on the surface after impregnation, which elevated the adsorption site. According to XRD analyses (Fig. 2c), the acicular and prismatic particles were identified as the boehmite (JCPDS 74-1895) and goethite (JCPDS 81-0463).

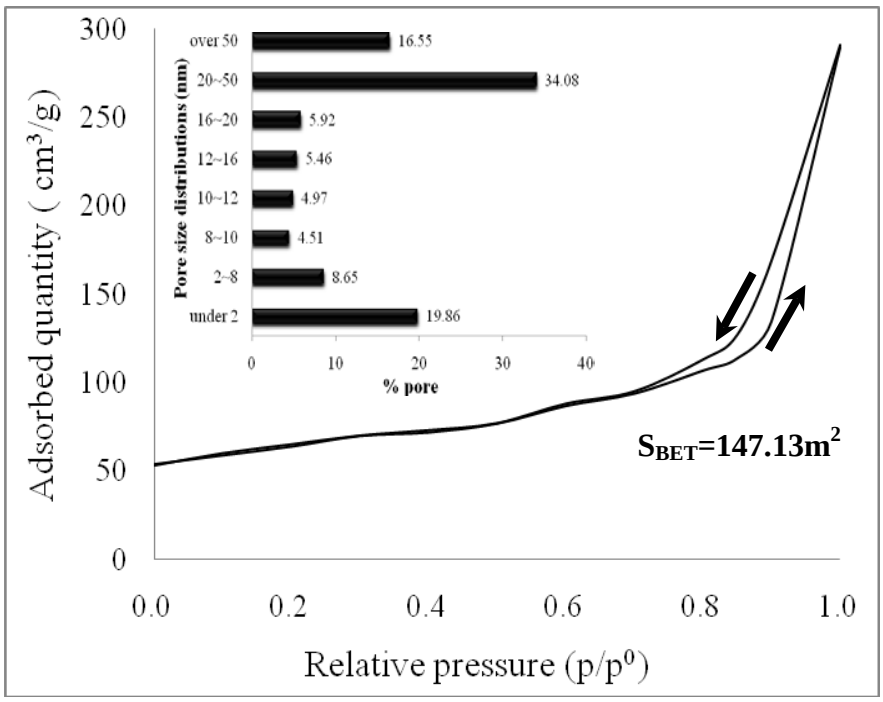

Fig. 1. N_2 adsorption /desorption isotherm (77k) curve and pore size distributions of FVA (insert).

Local chemical composition of FVA is determined by SEM-EDX, together with

XRD pattern. As the results shown in Table 1, FVA mainly consist of the salic mineral (aluminum oxides: 36.5%, silicon dioxide: 48.4%), comparing with VA, the iron proportion increased to 12.75% due to the ferric impregnation. Fig. 2c shows the XRD patterns of VA and FVA in initial As (V) of 100mg/L (W0). It revealed that the peaks of the acicular and prismatic were increase after the impregnation in ferric solution.

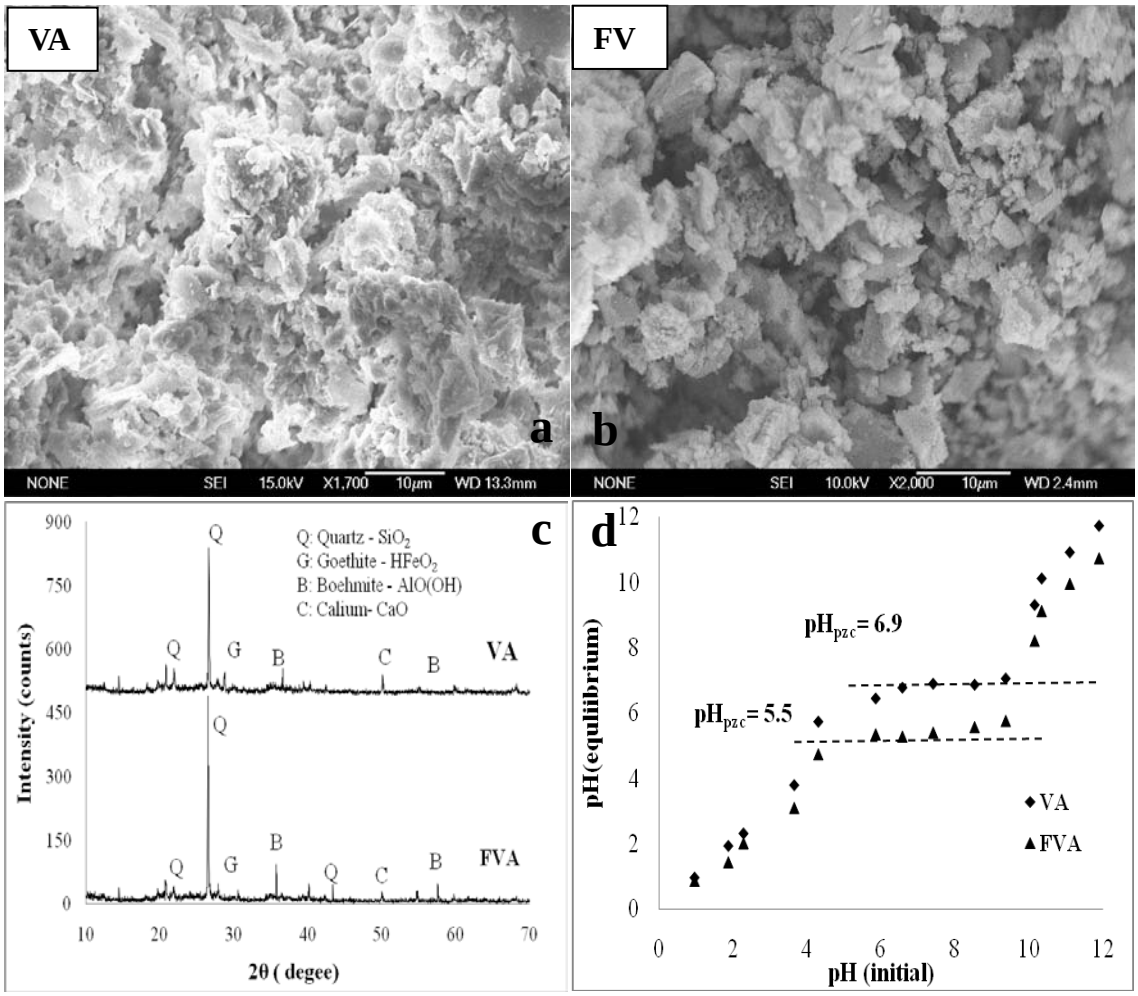

Fig. 2. SEM images (a:VA; b: FVA), XRD analysis (c) and pH_{pzc} (d) of volcanic ash before and after impregnation in ferric solution.

3.2. Batch adsorption study

3.2.1. Determination of pH_{PZC} and effect of solution pH on arsenic removal

The pH value of solution where the net surface charge of adsorbent is zero is defined as pH_{PZC}. As indicated in Fig. 2d, a plot of pH values of filtered solution after

equilibrium (pH_{final}) as a function of initial pH values ($pH_{initial}$) provides pH_{PZC} of the adsorbents by the common plateau of constant pH to the ordinate at around ~6.9 and ~5.5 for VA and FVA, respectively. As a typical lewis acid, $FeCl_3$ solution varied the sorbability of the electrolytes and degree of H^+ and OH^- ions adsorption, and hence decrease the value of pH_{PZC} [21].

It is reported that adsorption anionic pollutant adsorption from aqueous medium depends heavily on the protonation pH range of the predominant metallic oxidic group, which affects the surface charge of the adsorbent particles and the ionization degree [22]. As indicated in Fig. 3, experiment data of arsenic adsorption on VA and FVA show a increase trend in As(V) removal efficiency with the declining of initial solution pH. It can be interpreted that the surface of adsorbents were partially positively charged at $pH < pH_{pzc}$, which provided more adsorption sites for the predominant arsenic species ($H_2AsO_4^-$ or $HAsO_4^{2-}$). The decrease of adsorption efficiency at pH < 4 was probably due to the adsorbent loss caused by the solubilization and/or degradation.

3.2.2. Adsorption behavior on VA and FVA

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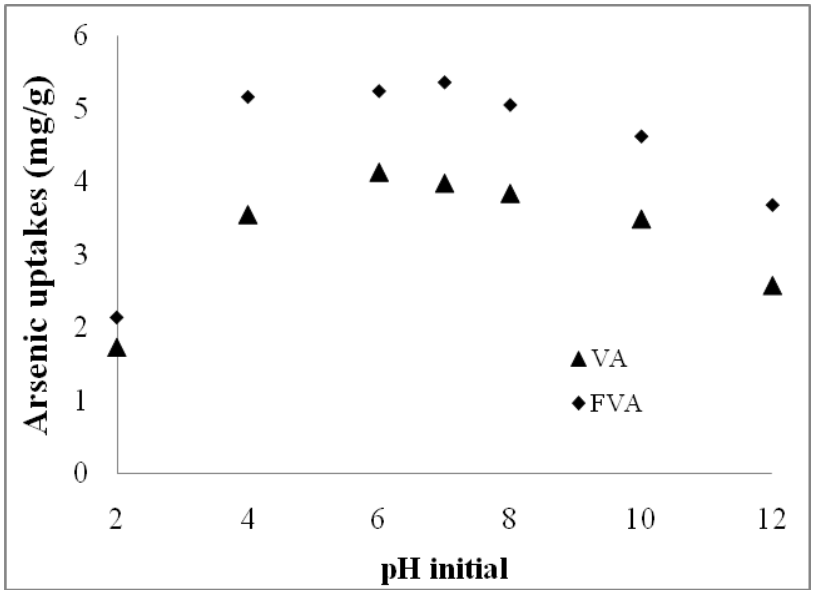

Fig. 3. Effect of pH on As (V) adsorption by FVA, (initial As = 50mg/L; FVA dosage = 10 g /L; contact time = 48 h; T = 20°C).

The experimental results (Fig. 3) show the iron impregnated onto volcanic ash greatly elevated the As (V) removal ability under all investigated pH condition. Recently, many previous studies focused on ferric based absorbents or ferric-arsenic co-precipitation for arsenic removal [16, 23]. However, in this study, the adsorption elevation may not only due to iron-arsenic co-precipitation caused by the formation of iron (hydro)oxides, but also due to the decline of pH_{PZC} resulting in a enhancement of electrostatic attraction at neutral pH.

3.2.3. Effects of water mineralization

The effects of water mineralization, mainly focused on the coexisting ions and ionic strength, on the arsenic removal efficiency was studied. The effect of coexisting ions on As(V) removal by FVA is presented in Fig. 4. The presence of sulfate and nitrate did not perceptibly interfere with As(V) removal even at the higher concentration of 50 mg/L (85.6% to 84.7% and 85.2%, respectively). However, both fluoride and phosphate exhibited obvious adverse effects on As(V) removal. The adsorption efficiency decreased quickly from 85.6% to 57.4% with an increase of fluoride concentration from 5 to 50 mg/L. The competitive ability of phosphate was much higher than that of fluoride, As(V) removal dramatically decreased from 85.6% to 29.6% with an increase of phosphate concentration from 5 to 50 mg/L. This phenomenon suggested that some adsorption sites on the surface of FVA can be occupied by the arsenate, phosphate and fluoride; and that the adsorption sites had a stronger effect on phosphate than on arsenate or fluoride. Sun et al. [18] reported that phosphate evidently inhibited arsenate removal due to competition between arsenate and phosphate species.

All of the investigated coexisting cations enhanced the As(V) removal ability on FVA (Fig. 4). The As(V) adsorption efficiency significantly elevated from 85.6% to

93.6% with the addition of 5 mg/L of Fe^{3+}. The univalent cation K^{+}, and bivalent cation Ca^{2+} showed a similar trend but with an inferior effect compared with trivalent cation Fe^{3+}. It can be stated that the ferric ion was prone to form hydroxylated complex, like ferric hydroxide that can provide higher affinity to As(V), thereby activate the adsorption ability of FVA. Zhang et al. [24] reported that metallic cations can link the adsorbent particle with arsenate, forming a metal–arsenate complex or a metal–H_2O–arsenate complex.

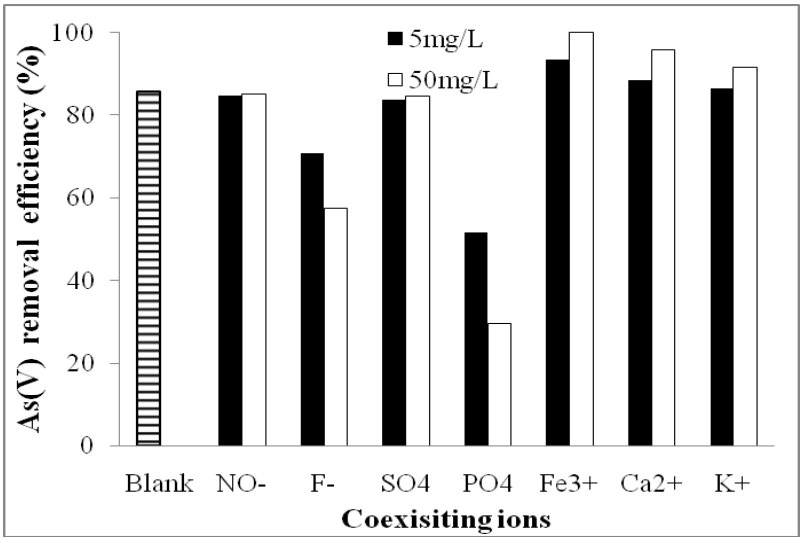

Fig. 4. Effect of coexisting ions on As(V) adsorption: (initial As = 50 mg/L; FVA dosage = 10 g/L; contact time = 24 h; T = 20°C; initial pH = 6.9, agitation speed = 200 rpm, the coexisting ions concentration: 5 and 50 mg/L.)

The ionic strength gave a slight effect on As(V) sorption with FVA (Table 3). When the solution ionic strength was increased from 0.001 to 0.1M, the As(V) uptake increased only from 5.35 to 5.82 mg/g. However, the obtained data were all higher than that of a blank experiment with DI water. These trends were indicative of an inner-sphere sorption mechanism for As(V), which probably meant an exchange of aqueous ligand for surface hydroxyl complexes might be generated on the surface of inner-sphere. These trends are consistent with the results reported by Goldberg et al. [25] and Fuller et al. [26], in which arsenate sorption onto mineral surfaces was due to the formation of inner sphere complexes.

Table 3

Effect of solution ionic strength on As(V) adsorption by FVA

20°C	ionic strength			
Ionic strength	0	0.001M	0.01M	0.1M
As(V) Uptake (mg/g)	5.31	5.35	5.48	5.82
Electric Conductivity (us/cm)	< 1	138.8	1.24×10^3	12.57×10^3

Initial As = 50 mg/L; dosage = 10 g/L; contact time = 24 h; pH = 6.9, agitation speed = 200 rpm.

Fig.5 shows that As(V) adsorption efficiency with < 150 mesh FVA in DI water at 35°C was 87.64% which is higher than that with < 150 mesh FVA at 20°C (85.6%), > 14 mesh FVA at 35°C (77.54%) and > 14 meshes FVA at 20°C (75.21%). However, the experiment performed under the conditions above in the actual water sample (W1 and W2) showed a greatly elevated arsenic removal efficiency, demonstrating that reaction between the $HAsO_4^{2-}$ and the coexisting ions in actual water sample can enhance the sorptive properties of FVA. The arsenic adsorption in the higher mineralized water W2 resulted in the higher As(V) removal efficiency. It is suggested that the water mineralization might be the key factor in determining the As(V) adsorption performance comparing to the surface area of adsorbents and adsorption temperature.

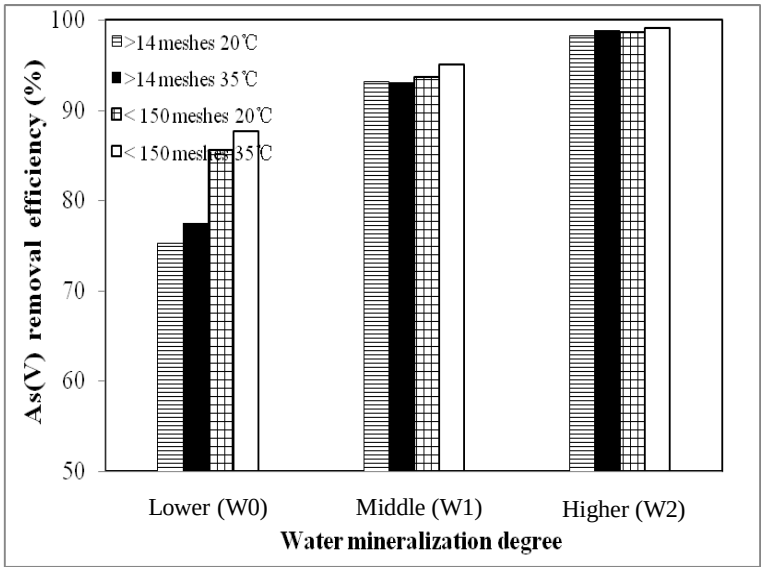

Fig. 5. Comparison effects of water mineralization, adsorption temperature and particle size of FVA on As (V) adsorption (initial As = 50 mg/L; FVA dosage = 10 g/L; initial pH = 6.9, agitation speed = 200 rpm)

All of the above results indicate that the mineralization of aqueous medium show

a marked effects on the arsenic adsorption. Therefore, it is important to investigate arsenic removal based on actual waters rather than deionized water.

3.2.4. Adsorption rate in different water samples

Based on the research above, actual and DI water samples were applied in kinetic study. In this experiment, the pseudo-first-order, pseudo-second-order, and intraparticle diffusion models were used to discuss kinetic parameters of As(V) adsorption on FVA. The experiment data showed As(V) adsorption pseudo-equilibrium was achieved after approximately 48 h. Such a long adsorption time probably indicated that adsorption could be due to not only the surface adsorption on the particles but also chemisorption between the mineral matter and the $HAsO_4^{2-}$ in actual water. The experiment data best fitted in intraparticle diffusion equation:

$$q_t = k_i t^{0.5} + C \qquad (1)$$

where q_t is the As(V) adsorption amount at time t, k_i is the intra-particle diffusion rate constant (mg/g/h$^{-0.5}$) which can be calculated from the slopes of linear plot (q_t versus $t^{0.5}$) and C is the intercept depicting the boundary layer effect.

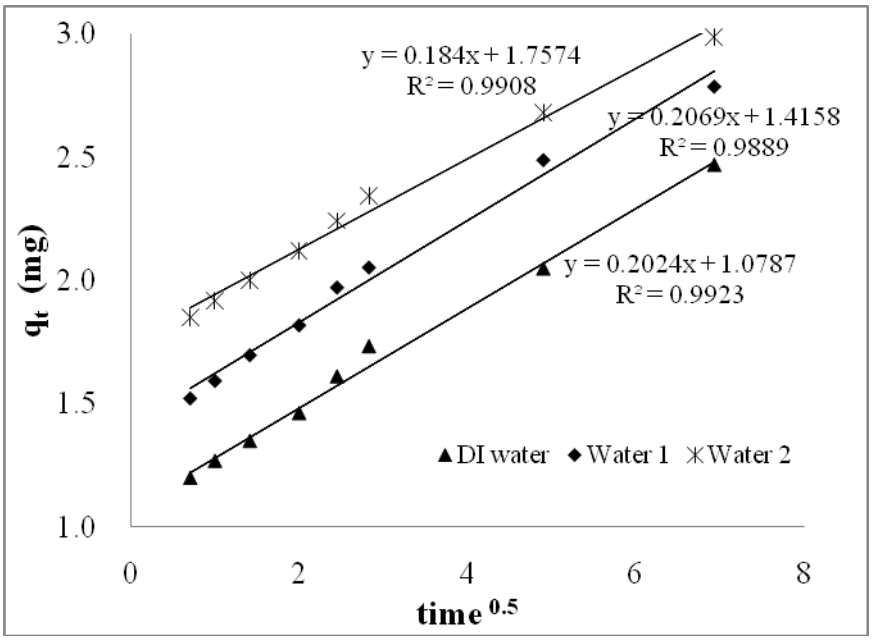

Fig. 6. Intraparticle diffusion plot for arsenic As (V) adsorption on FVA in different water samples (initial As= 10 mg/L; FVA dosage = 10 g/L; contact time = 48 h; T = 20 ± 0.5°C; initial pH = 6.9, agitation speed = 200 rpm).

The larger intercept from the higher initial concentration indicated that chemisorption provides a greater contribution than surface adsorption, which was probably due to the accompanying reaction caused by complex composition of the nature adsorbent and actual water. As Ciardelli et al. [27] described the arsenic uptake efficiency can be increased by coprecipitation with ferric oxyhydroxides and calcium carbonate existed in the aqueous medium. Fig. 6 also shows that the plots do not pass through the origin, which indicated the intraparticle diffusion was not only the rate controlling step [28], and both the surface adsorption and intraparticle diffusion contributed to the mechanism of arsenic adsorption.

3.2.5. Isotherm study

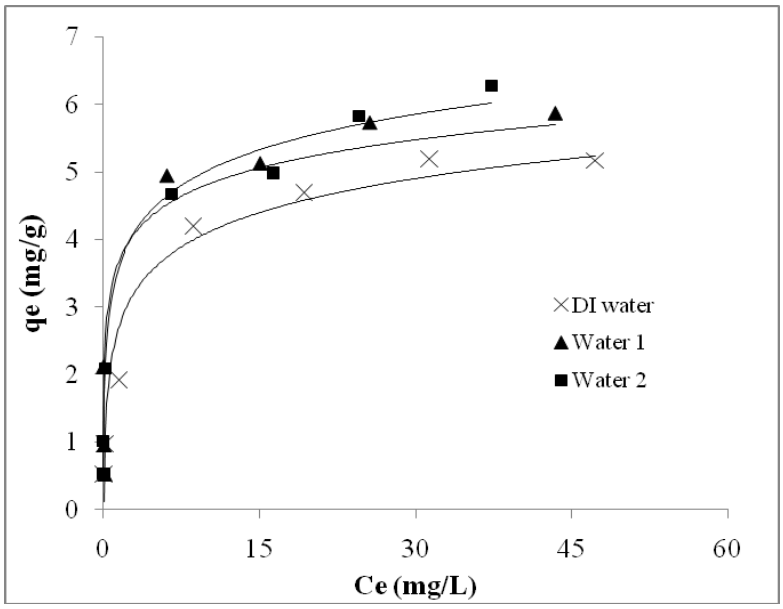

Fig. 7. Langmuir plots for As(V) adsorption on FVA in different water samples (initial As: varied from 5 to 100 mg/L; FVA dosage = 10 g/L; contact time = 24 h; T = 20 ± 0.5°C; initial pH = 6.9, agitation speed = 200 rpm).

The As(V) adsorption were carried out in different water samples with an initial arsenic concentration of 5, 10, 20, 50, and 100 mg/L (Fig. 7). The experiment data from all water samples fitted the Langmuir isotherm well, which indicates that the reaction is a reversible monolayer phenomenon [29] and the adsorbents have the regeneration potential. The linearized forms of Langmuir isotherm equation is:

$1/q_e = (1/Q*b*Ce) + 1/Q,$ (2)

where q_e is the amount of solute adsorbed (mg/g) at equilibrium and C_e is the equilibrium concentration (mg/L), The values of the empirical constants Q and b, denoting the monolayer capacity and energy of adsorption, were calculated from the slope and intercept of plot between C_e/q_e and C_e. Fig. 7 and Table 4 show that the As(V) adsorption on FVA in water sample W2 results in the highest removal capacity of 6.13 mg/g (estimated by Langmuir isotherm), followed by 5.92 mg/g in W1 and 5.30 mg/g in W0. The experimental data is 5.98, 5.88 and 5.34 mg/g, respectively, which is in agreement with the calculated ones, further confirming that the adsorption on FVA well fit to Langmuir isotherm.

As the composition of water samples shown in Table 1, the mineralization degree is very low for water sample W0, while it is moderate for samples W1, being higher the concentrations of Na^+, Ca^{2+}, Cl^- and SO_4^{2-} in the latter. The water sample W2 is higher mineralized, with high contents of Na^+, Ca^{2+}, K^+, Mg^{2+}, Cl^-, NO_3^- and SO_4^{2-}. The mineralization degree increase through waters W0 to W2 (Table 1), and the general trend of the arsenic adsorption efficiency is to grow in the same way, that indicated the mineralization degree of water samples elevated the As(V) removal efficiency on FVA. This result can also be proved by the effect of coexisting ions on the As(V) removal researched above, the anions in the studied water samples mainly consisted of Cl^-, NO_3^- and SO_4^{2-}, which evidently had no significant effect on the As(V) removal in the current concentrations limit. However, the dominated coexisting bivalence cations, such as Ca^{2+} and Mg^{2+}, enhanced the As(V) adsorption efficiency conclusively.

Table 4

Langmuir Isotherm parameters for As(V) adsorption on FVA in different water samples

Water sample	Langmuir constants		
	Correlation coefficient r^2 (%)	Q (mg/g)	b (L/μmol)
DI water	0.9973	5.3008	1.2811
Water 1	0.9977	5.9210	0.9822
Water 2	0.9894	6.1361	1.0554

Initial As: varied from 5 to 100 mg/L; dosage = 10 g/L; contact time = 24 h; T = 20 ± 0.5°C; pH = 6.9, agitation speed = 200 rpm.

It has been reported that the adsorption of As(V) by neutralized red mud [11], hematite [17], and synthetic zeolites [20], follow Langmuir isotherm. The maximum As(V) uptake, as estimated by Langmuir equation, of these adsorbents are 0.69, 0.20 and 34.8 mg/g, respectively. It is evident that FVA is more effective than neutralized red mud and hematite. In this connection, synthetic zeolite seem to be more advantageous adsorbents but the FVA is an attractive material in view of being inexpensive and effect in a large pH range.

3.5. Possible mechanism of arsenic adsorption

Fig. 8a shows a SEM picture for the adsorbed FVA, and its corresponding element mapping as revealed by EDX. It further confirms that FVA is primarily a mixture of Si, Fe and Al oxides. Fig. 8 shows Si, Al and O evenly distributed on the surface, iron is seen to be very well-dispersed all throughout the FVA (Fig. 8c). Comparison with As mapping (Fig. 8d) suggests that iron is closely associated with As, which implied that the As was bound with iron oxide. This suggests that the amount of As adsorbed on the surface of FVA possibly depended on the iron content of the particle surface.

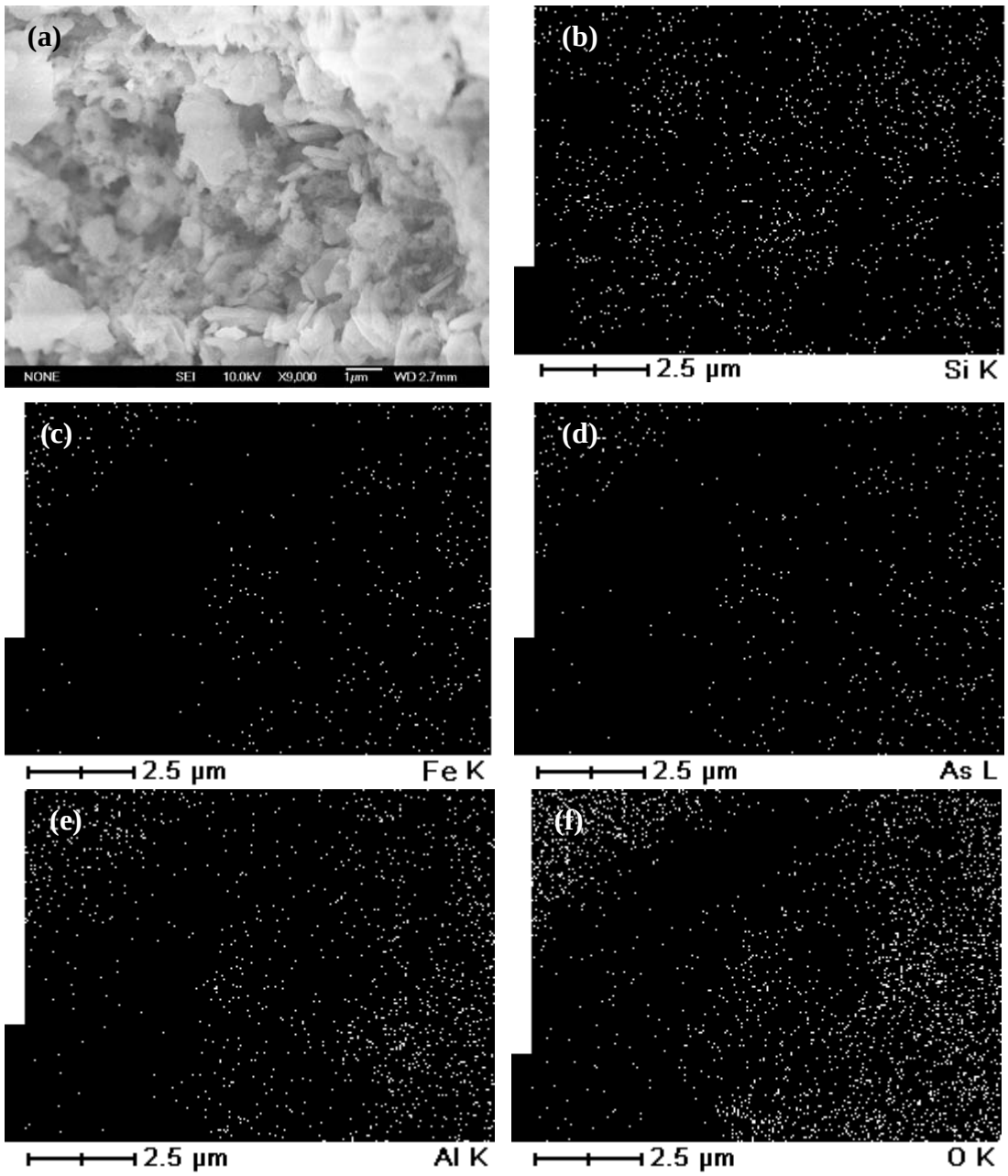

Fig.8. SEM images of adsorbed FVA (a), and mapping of elements: (b) Si, (c) Fe, (d) As, (e) Al and (f) O, as seen by EDX (energy dispersion of X-rays).

Based on the available data, the mechanism of As removal by FVA could not be explained in full detail, though it is evident that it involves electrostatic attraction and surface complexation processes between the As species in solution and Fe(II) and/or Fe(III)-hydroxides in the solid materials. We assumed the possible mechanism as below.

$$Fe\text{-}OH + H_2AsO_4^- \rightarrow Fe\text{-}OAsO_3H + OH^-$$

$$Fe\text{-}OH + HAsO_4^{2-} \rightarrow Fe{-}O_2AsO_2H^- + OH^-$$

$$2FeOH + HAsO_4^{2-} \rightarrow 2FeO{-}AsO_2H + 2OH^-$$

The adsorption of As(V) onto FVA occurred by ligand exchange reactions, and most of the hydroxide groups are involved in ligand exchange reactions. During the adsorption, the arsenate oxyanion present in the aqueous solution would replace the hydroxyl ions in the iron crystal lattice without disturbing the crystal structure of the compound. This type of substitution is iso-electronic in nature, as reported by Maliyekkal and Shukla [30]. The cumulative hydroxide group release per amount of arsenic adsorbed was related with amount of arsenic adsorbed [31]. The amount of goethite on the surface of FVA is proportional to the removal of arsenic. As shown in Fig. 7, the Langmuir Isotherm Model fits the experimental data well, because iron-hydroxide plays as an adsorption site for arsenic. The intraparticle diffusion analysis also indicated that chemisorption provides a greater contribution than surface adsorption, to the adsorption process.

4. Conclusions

Ferric impregnated volcanic ash (FVA) is a cost-effective adsorbent for arsenic removal from water solution, especially form low-level phosphate and fluoride solution. The relationship between water mineralization degree and As(V) removal was attributed to the competitive or elevated effect of coexisting ions on FVA and ionic strength in the surrounding aqueous medium. The kinetic and isotherm studies conducted in actual water revealed that the mineralization of water showed great influence on the arsenic adsorption. It is suggested that the deionized batch experiment should not be applied directly to all cases. It was important to conduct the adsorption experiment using the actual water. Further research is underway to examine the adsorbent stability and whether the FVA can maintain its capability after

several regenerations and reuse cycles.

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