

Iron Coated Sponge In Arsenic Removal

Tien Vinh Nguyen¹, Saravanamuthu Vigneswaran^{1*}, Huu Hao Ngo¹, Damoda Pokhrel², Thiruvenkatachari Viraraghavan²

¹ Faculty of Engineering, University of Technology, Sydney (UTS), PO Box 123, Broadway, NSW 2007, Australia

² Faculty of Engineering, University of Regina, Regina, Saskatchewan S4S 0A2, Canada

* Corresponding author. Tel.: +61-02-95142641; Fax: +61-02-95142633.

Email: s.vigneswaran@uts.edu.au

Arsenic (As) contamination in water has raised a grave concern in many regions of the world. Arsenic can lead to a number of health problems even at very low concentration. This paper presents the laboratory-scale experimental results on the specific treatment technology: iron coated sponge (IOCSp) adsorption in As removal. The results indicated that IOCSp could remove 47.3% to 65% of As (III) and As (V) after a 1 hour contact with IOCSp (initial As concentration = 260 µg/l; 0.15g sponge/100ml solution). A nine hour-adsorption led to a very high As removal efficiency (more than 92.4% removal for both As (III) and As (V)). Each gram of IOCSp adsorbed about 160µg of As (III) and As (V) upon a 9 hour - contact of IOCSp with the As solution. After adsorption, IOCSp can be easily regenerated by NaOH.

Fluid/Particle Separation Journal, Vol.16, No. 2, 2004,175 -184

KEY WORDS

Arsenic, water contamination, treatment technology, iron coated sponge (IOCSp)

INTRODUCTION

Arsenic present in ground water and surface water is recognized as a toxic metal that has fatal effects on human health and environment. Arsenic enters into aquifers and wells through natural activities, and to the water cycle as a result of anthropogenic activities (Thirunavukkarasu et al., 2001). Arsenic is found as organic or inorganic compounds mainly in 4 oxidation states (arsenite, monomethyl arsenic acid, dimethyl arsenic acid and arsenate). The inorganic arsenic compounds with trivalent species (arsenic III) are highly toxic.

Arsenic occurs in extremely high quantities in the ground water in Bangladesh and in a number of other Asian countries. Exposure to arsenic contaminated drinking water has caused serious health problems in a numbers of countries namely Bangladesh, Mexico, Taiwan, China, Chile, USA, Canada and India (Thirunavukkarasu et al., 2002; Williams et al., 1996). High arsenic levels have also been found in some parts of Australia. In rural of Victoria, arsenic concentrations is up to 16g/kg of soil on residential properties and as high as 0.008 mg/L and 0.22 mg/L in groundwater and surface water have been reported. These

exceed the National Health and Medical Research Council (NHMRC, Australia) guideline of 0.007 mg/L in drinking water and 300 mg/kg in soil. Medical research indicates that exposure to arsenic in drinking water causes urinary, bladder, lung and skin cancers, gastrointestinal disorders, muscular weakness, loss of appetites, nerve tissue injuries, and blackfoot disease (Chen et al., 1994, Altundogan et al., 2000). As a result, arsenic can lead to a significant economic and social cost to the community.

A number of physico – chemical processes are used in removing arsenic from water, namely coagulation, adsorption, ion exchange, and membrane processes such as nanofiltration and reverse osmosis etc. Flocculation/coagulation is the simplest conventional treatment process for arsenic removal in which chemicals are added to form precipitates or flocs that are removed by a subsequent sedimentation or filtration process. In a coagulation/flocculation process, arsenic removal is dependent on adsorption and co-precipitation of arsenic onto metal hydroxides. The most common flocculants/coagulants used are aluminum sulfate, ferrous sulfate, ferric chloride and ferric hydroxide.

The application of membrane to water treatment is being actively considered in many countries especially due to its capability in producing high quality water. As (V) can be effectively treated by reverse osmosis (RO) and nanofiltration (NF). Preoxidation of As (III) to As (V) followed by NF may achieve high rates of arsenic removal (Brandhuber and Amy., 1999). Powdered activated carbon (PAC) adsorption - microfiltration hybrid system was very effective in to water treatment (Ngo et al., 2002). This hybrid system consisted of a microfiltration module modified to incorporate in-line powdered activated carbon (PAC) addition.

Fixed bed treatment system such as adsorption and ion exchange are also used for arsenic removal in small-scale treatment systems because of their simplicity, ease of operation and handling, regeneration capacity and sludge free operation. Hydrous manganese and iron and aluminium oxides are considered the principal solid-phase components controlling the adsorption of arsenic in water (Yan-Chu, 1994).

Iron oxide plays an important role in removing arsenic from water and wastewater. An adsorption study with iron oxide coated sand indicated that a complete

removal of arsenic can be achieved in the influent was 75 µg/L despite the fact that the influent contained 800 mg/L sulfate (Thirunavukkarasu et al., 2001).

Oxidation/adsorption by manganese dioxide is an effective process for removing arsenic and arsenate from water, and a matrix, such as sand, coated with manganese dioxide showed promise as a medium for use in small systems or home treatment units (Bajpai, 1999)..

In this study, a new medium of metal oxide coated sponge was used to study its capability in removing arsenic from water. The metal oxide coated sponge used in this study had a high surface area and internal porosity for adsorption. Further, sponge can be easily compacted to an extremely small volume to facilitate disposal.

The optimum conditions for coating the sponge with metal oxide were experimentally evaluated. Then a

series of batch and dynamic experiments were carried out to evaluate the capacity and effectiveness of iron oxide coated sponge (IOCSp) in removing arsenic from water. The performance was compared with the experimental results obtained with iron coated sand (IOCS).

EXPERIMENTAL

All the experiments were conducted with synthetic water. Synthetic water was prepared by adding As in tap water to obtain an Arsenic concentration from 140ug to 590ug/l. The other components present in the water can be seen in the Table 1. The experiments were conducted at pH values of 6, 7 and 8. The pH of the synthetic water was adjusted to a designed value by using 1M HNO₃ and 1 M NaOH.

Table 1. Characteristics of the arsenic synthetic water used.

Parameters	Concentration
Arsenic (III)	0.14 – 0.59
Arsenic (V)	0.26 – 0.265
Iron	0.07
Manganese	0.02
Nitrate	1.7
Turbidity (NTU)	0.28
Chloride	12
Copper	0.001
Zinc	<0.005
Lead	<0.002
Barium	0.073
Chromium	<0.001
Chlorine (residual)	0.4

Note: All parameters except pH and turbidity are in mg/l

Experiment with uncoated sponge

Commercial polyurethane (PU) sponge was selected in this study mainly because of its specific characteristics such as high internal porosity and specific

surface and its cost effectiveness. The pore size of the sponge may be large or small and multitude of additives may be incorporated into the sponge. The properties of the polyurethane sponge are summarized in Table 2.

Table 2. Characteristics of the polyurethane sponge (Moe and Irvine, 2000)

Parameters	Value
Dry density (kg/m ³)	84
Density at 65% moisture content (kg/m ³)	113
Swelling in vertical direction when at 65% moisture content (%)	24
Swelling in horizontal direction when at 65% moisture content (%)	31
Swelling in volume when at 65% moisture content (%)	113
Porosity at 65% moisture content	0.85
Average single pore area (mm ²)	1.0
Surface area (m ² /m ³)	620

Experiments were conducted with uncoated sponge (haft-cylinder size with 3cm diameter and 1.5cm length). These sponges were put into 100ml As solution (total arsenic = 530 µg/l) and shaken for one to four days.

Optimization of iron coated sponge

The principal method for preparation of IOCSp is as follows:

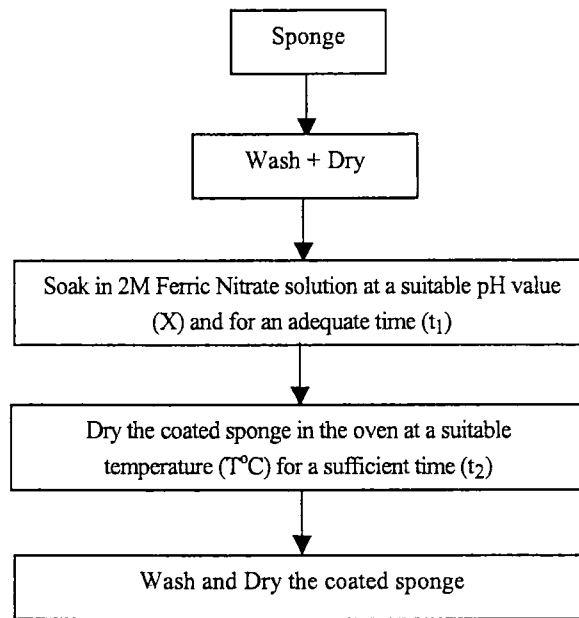


Figure 1. Procedure for optimization of coating of the sponge with iron oxide.

The experiments were conducted at various operating conditions to find the optimum condition for coating on sponge with the iron oxide. The conditions studied are: (i) pH value of coating solution (pH from 1, 2 ... to 12); (ii) time of contact between iron oxide and the sponge t_1 (5, 10, 15, 20, 30 minutes and up to 10 hours);

(iii) coating temperature $T^{\circ}C$ (110^oC, 220^oC); and (iv) time of drying of sponge after the coating t_2 (8h, 12h, 14h, 18h, 20h). The optimum coating conditions for preparing IOCSp were be found and applied in the subsequent batch and dynamic experiments.

Batch kinetic studies

Batch adsorption kinetic studies were conducted with the IOCSp prepared at the optimum coating conditions to investigate the removal of both As (III) and As(V) from the synthetic water.

The IOCSp was first cut into half-cylinder pieces each with 1.5 cm in length and 3 cm in diameter. They weighed 0.15g each. The IOCSp was then placed into 250ml Erlenmeyer flasks containing the synthetic water. The flasks were sealed with laboratory film. The samples were placed on a mechanical shaker and shaken at 175rpm. Samples from the flask were collected at regular time intervals and analyzed for residual As.

IOCSp tray studies

The laboratory - scale IOCSp tray experimental set-up is shown in Figure 2. This system consists of a synthetic water feeding system and a tray with IOCSp placed on it.

The tray was designed to hold 10 rows of semi circular sponges each with a length of 19.5cm and diameter of 3cm. Each row of sponge weighs of 1.92g. The tray was placed at an angle of inclination of 10° to the horizontal to facilitate the water flow in gravitational mode. The tray had

an influent chamber which helped to evenly distribute the water across the cross-section of the tray. In the first set of experiments, synthetic water (spiked with the As (III) concentration of $144.5 \mu\text{g/l}$) was pumped through the tray using a peristaltic pump at a flow rate 15.6 mL/min. The water at the outlet was sampled for As (III). After that, the IOCSp was regenerated with 0.3M NaOH solution before running the second cycle with higher influent As (III) concentration (260 to $280 \mu\text{g/l}$) in order to study the effect of influent concentration. The operation time of experiment was 30 hours.

Similar experiments were conducted with As (V) solution with a determined As (V) concentration of 260 - $265 \mu\text{g/l}$. In these experiments, the IOCSp was also regenerated with 0.3M NaOH solution. In the experiments with As (V) solution, the tray contained only 7 rows (weight = 13.4g) of semi circular IOCSp. The angle of inclination of the tray was decreased to 6° to increase a contact time between IOCSp and water when the water passes through each row of IOCSp.

The arsenic concentration in the effluent was measured using a graphite furnace atomic absorption spectrometry (GFAAS).

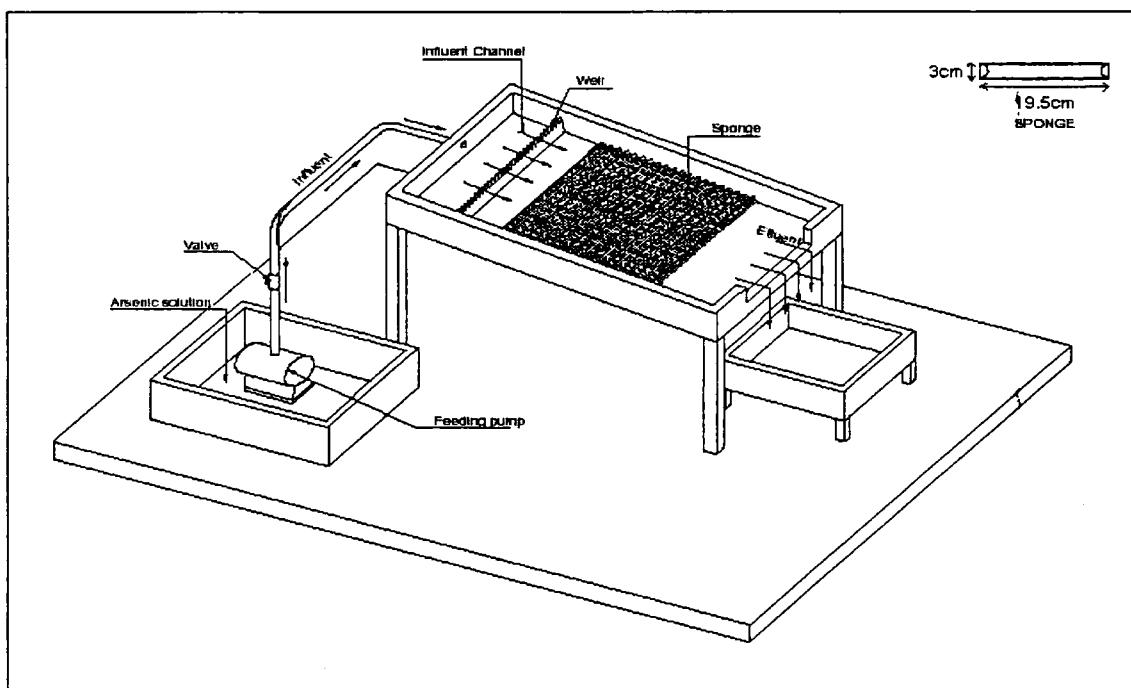


Figure 2 Experimental set-up used in IOCSp tray experiments.

Column studies

Experiments were conducted to study the removal of As in synthetic water. A glass column of 19 mm diameter and 400 mm height was used in the studies. The

synthetic water was run through the packed column at a flow rate 8 mL/minute. The column was packed with a 4g (57 mL) of the IOCSp. The column tests were conducted in the down-flow mode and at the normal pH (7.4-7.6) of the synthetic water.

RESULTS AND DISCUSSION

Performance of iron coated sponge (IOCSp) in Arsenic removal

a. Uncoated sponge in removing arsenic

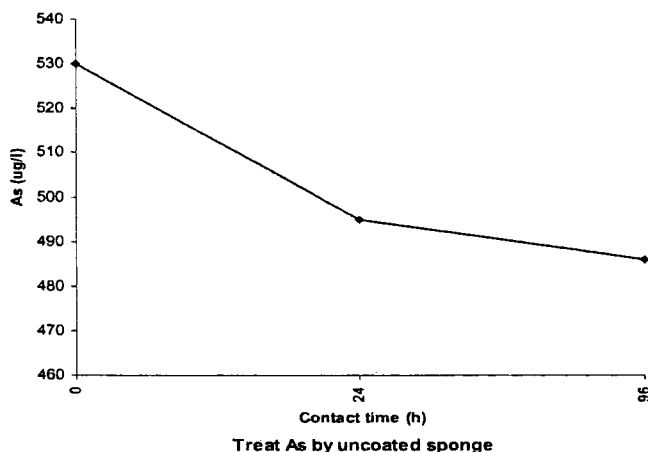


Figure 3: Arsenic removal by uncoated sponge.

The experimental results showed that uncoated sponge had a low capacity in arsenic removal, approximately 10% with Arsenic solution of 530µg/l (see figure 3) or only 23.3µg and 29.3µg/g sponge after 24h and 96h contact respectively.

b. Optimization of preparation conditions of IOCSp

Experimental results showed that sponge could not be coated in an adequate manner when the soaking time (t_1) was less than 1 hour. The sponge was damaged when it was coated at a temperature of 220°C and above. Experimental results also showed that sponge could not be coated well at a pH above 5 and was damaged when drying time was more than 34 hours.

From a series of experiments, the optimum conditions for coating the sponge with iron oxide was found to be: pH of 4, t_1 of 10 hours, T^0 of 110°C and t_2 of 20 hours. Then optimum conditions were used for the sponge preparation in the subsequent batch and dynamic experiments.

c. Adsorption kinetics

Figures 4 and 5 present the removal of As (III) and As (V) as a function of adsorption time of IOCSp respectively. The results showed that IOCSp could remove 47.3% to 65% of As (III) and As (V) after a 1 hour contact with IOCSp. A nine - hour adsorption led to a very high amount of As adsorption (less than 18µg/L of As remaining in the water). In these experiments, 0.15g of IOCSp was placed in a flask containing 100ml of As solution. Each gram of IOCSp adsorbed about 160µg of As (III) and As (V) upon a 9 hours contact of IOCSp with the As solution (Figures 4b and 5b).

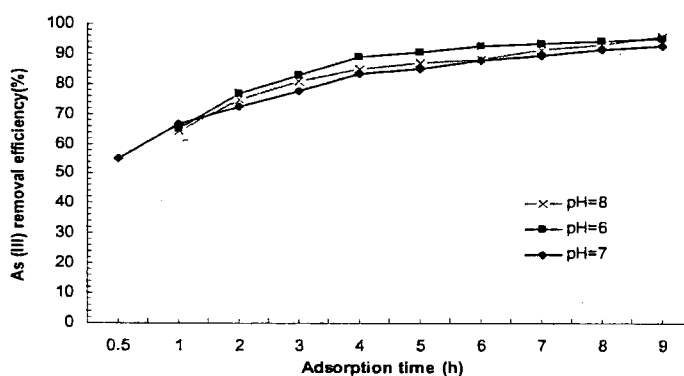


Figure 4(a). Removal efficiency of As (III) as a function of adsorption time. (Initial As (III) concentration = 260 µg/L; IOCSp's weight = 0.15g, Temperature = 20°C, volume of As solution = 100mL)

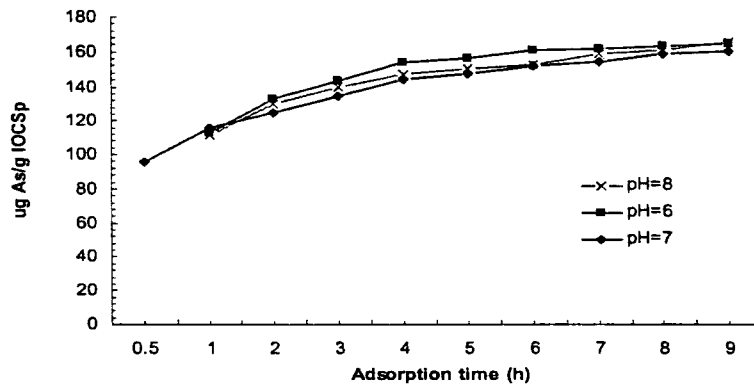


Figure 4(b). Amount of As (III) adsorbed onto a unit weight of IOCSp. (Initial As(III) concentration=260 $\mu\text{g/L}$; IOCSp's weight=0.15g, volume of As solution=100mL)

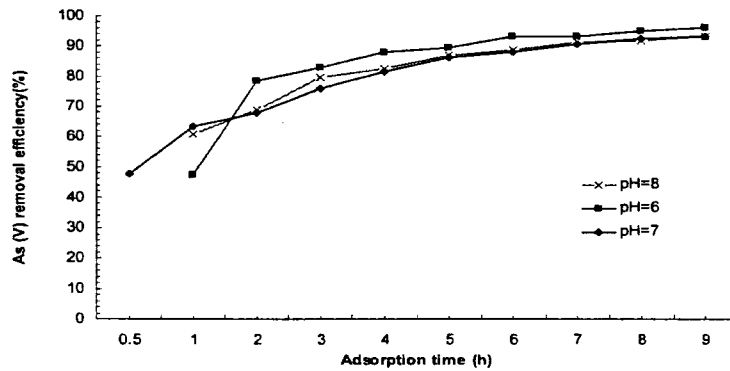


Figure 5(a). Removal efficiency of As (V) as a function of adsorption time (Initial As (V) concentration = 260 $\mu\text{g/L}$; IOCSp's weight = 0.15g, Temperature = 20 $^{\circ}\text{C}$, volume of As solution = 100mL)

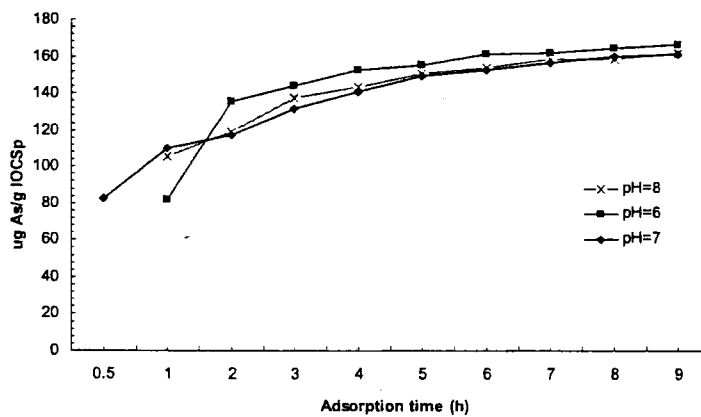


Figure 5(b). Amount of As (V) adsorbed onto a unit weight of IOCSp. (Initial As (V) concentration = 260 $\mu\text{g/L}$; IOCSp's weight = 0.15g, volume = 100mL)

d. IOCSp Sponge tray experiments

The results on the removal of both As (III) and As (V) using IOCSp tray system are presented in Figures 6 to 7.

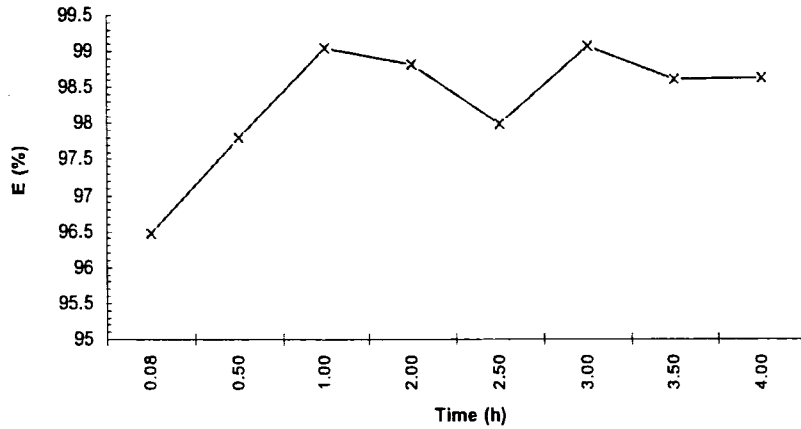


Figure 6 (a). Experimental results with IOCSp tray system, cycle 1. (Initial As (III) concentration = 144.5 µg/l; IOCSp weight = 19.2g)

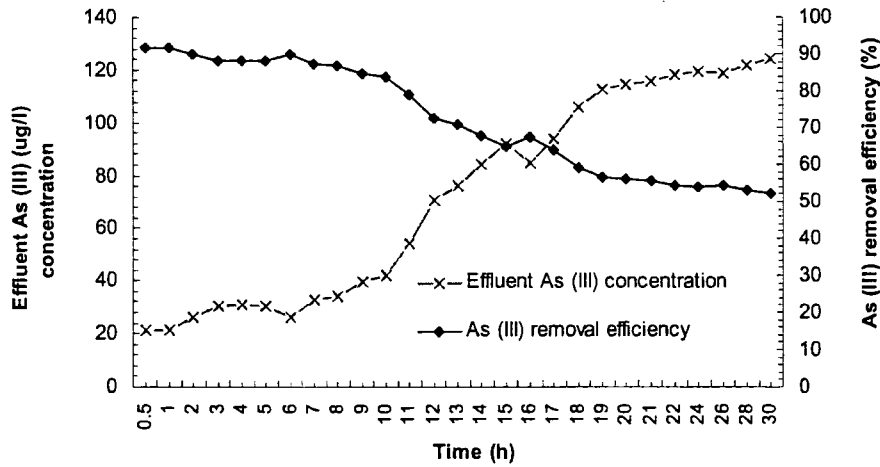


Figure 6(b): Arsenic (III) removal efficiency with the regenerated IOCSp tray system, cycle 2. (Initial As (III) concentration = 260 µg/l; IOCSp's weight = 19.2g)

The results of the first set of experiments showed that the tray can remove arsenic to a value of less than 20µg/l. In the second series of experiments, after the IOCSp in the tray was regenerated by 0.3M of NaOH, the IOCSp could continue to adsorb nearly 10 L of As (III) (concentration = 260µg/l) to a value less than 50µg/l. After 30 hours running with 28 liters As solution, efficiency decreased gradually to a value of 52.3% (123.9µg/l in the effluent) (Figure 6(b)).

In the study with As (V), after 6 hours of running, the As(V) concentration in the effluent reached to the value of 49.2µg/L. This value was nearly 110µg/l after 28hours running (Figure 7(a)).

After IOCSp in the tray was regenerated by 0.3M of NaOH, IOCSp continued to adsorb As(V) to a value less than 20µg/l even after 6hours of running time (Figure 7(b)).

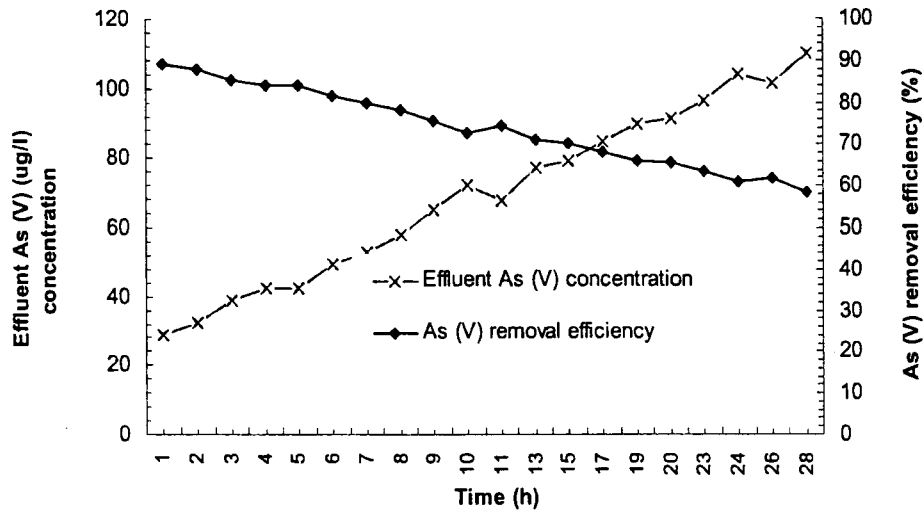


Figure 7(a): Experimental results with IOCSp tray system, cycle 1. (Initial As (V) concentration = 265 µg/l; IOCSp's weight = 13.4g)

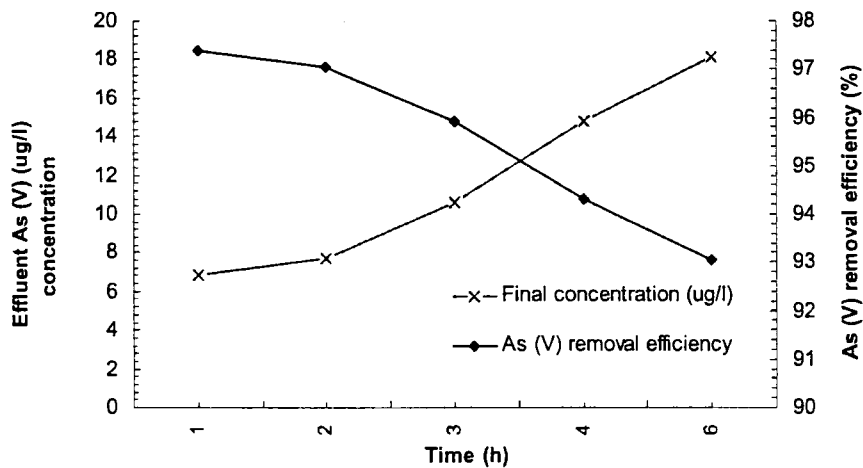


Figure 7 (b): Arsenic (V) removal efficiency with the regenerated IOCSp tray system, cycle 2. (Initial As (V) concentration = 265 µg/l; IOCSp's weight = 13.4g)

e. IOCSp Sponge column experiments

The results on the removal of As using IOCSp column system are presented in Figure 8.

The initial results with IOCSp column showed that up to 287 bed volume, the As effluent concentration still lower than 20ug/l with removal efficiency is more than 94%.

Comparison of removal efficiency between IOCSp and iron coated sand (IOCS)

The Table 3 below presents the comparison of removal efficiency between IOCSp and IOCS as a function of weight. IOCS is the iron coated sand and the coating methods are discussed in detail elsewhere (Thirunavukkarasu et al, 2001).

The density of IOCS was very much higher than that of IOCSp and one cannot assume that IOCSp is better than IOCS from the results obtained (as the comparison was made based on the unit weight of the material).

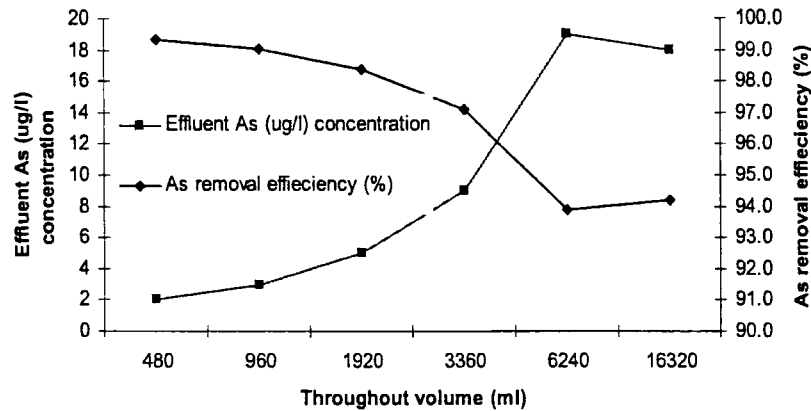


Figure 8. Arsenic removal efficiency with the IOCSp column. (Initial As = 310 µg/L; flow rate = 8mL/minute, Q = 1.7m³/m².h, IOCSp's = 4g, volume of IOCSp = 57ml)

Table 3. Comparison of removal efficiency between IOCSp and IOCS.

No	Adsorbed Time (hour)	As (III)			As (V)		
		µg As/g IOCSp	µg As/g IOCS	IOCSp/IOCS	µg As/g IOCSp	µg As/g IOCS	IOCSp/IOCS
1	1	115.9	9.7	12.0	109.7	8.2	13.5
2	2	125.1	13.2	9.5	117.2	13.0	9.0
3	3	134.5	20.2	6.7	131.7	17.7	7.5
4	4	144.2	20.4	7.1	141.0	20.1	7.0
5	5	146.8	20.9	7.0	149.1	21.6	6.9
6	6	151.7	22.5	6.7	152.2	23.0	6.6
7	7	154.2	23.5	6.6	156.6	23.2	6.8
8	8	158.0	24.1	6.5	159.8	24.1	6.6

CONCLUSIONS

The initial experimental results showed that iron coated sponge (IOCSp) has high removal efficiency in removing both As (III) and As (V) from water. Based on weight of media, Arsenic adsorption capacity of IOCSp has a high As adsorption capacity and can be an excellent material to remove Arsenic.

ACKNOWLEDGEMENTS

This research was mainly funded by Australian Research Council (ARC) Discovery Grant (2004-2006) and ARC International Linkage Grant (2003-2004). Mr. T. V. Nguyen also likes to show his thankful to Vietnamese Ministry of Education and Training in supporting his scholarship.

REFERENCES

Altundogan, H. S., Altundogan, S., Tumen, F. And Bildik, M., Arsenic removal from aqueous solutions by adsorption on red mud, Waste Management, 20 (8), 2000, 761-767.

Bajpai, S. and Chaudhuri, M., Removal of arsenic from ground water by manganese dioxide-coated sand, Journal of Environmental Engineering, 8, 1999, 782-784.

Brewster, M.D., Removing Arsenic from Contaminated Wastewater, Water Environment & Technology, 4 (11), 1992, 54-57.

Chen, S. L., Dzung, S. R. and Yang, M. H., Arsenic species in ground waters of the blackfoot diseases area, Taiwan, Journal of Environmental Science and Technology, 28, 1994, 877-881.

Chen, H.-W., Frey, M.M., Clifford, D., McNeill, L.S. and Edwards, M., Arsenic treatment considerations, Journal of the American Water Works Association, 91(3), 1999, 74-85.

Cheng, R.C., Liang, S., Wang, H.C. and Beuhler, M.D., Enhanced coagulation for arsenic removal, Journal of the American Water Works Association, 86(9), 1994, 79-90.

Gulledge, J.H. and O'Connor, J.T., Removal of As(V) from water by adsorption on aluminum and ferric hydroxides, Journal of the American Water Works Association, 65(8), 1973, 548-552.