

Removal of Arsenic from Bangladesh Well Water Using A Household Filtration System

Xiaoguang Meng and George P. Korfiatis

Center for Environmental Engineering

Stevens Institute of Technology, Hoboken NJ 07030, USA

Abstract

Field and laboratory tests were conducted to evaluate the effectiveness of a household filtration process and investigate the effects of phosphate and silicate on the removal of arsenic from Bangladesh groundwater by ferric hydroxides. Fe/As ratios of greater than 40 (mg/mg) were required to reduce arsenic to less than 50 $\mu\text{g/L}$ in Bangladesh well water due to the presence of elevated phosphate and silicate concentrations. The household filtration process included precipitation of arsenic by adding a packet of coagulants to 20 liters of well water and subsequent filtration of the water through a bucket sand filter. A field demonstration study has been performed to test the filtration systems in the households in Bangladesh since March 2000. Experimental results obtained from the participating families have proved that the household treatment process can remove arsenic from approximately 300 $\mu\text{g/L}$ in the well water to less than 50 $\mu\text{g/L}$. The participating families like this simple and affordable process and have used it to prepare clean water for drinking and cooking. A larger scale field test is currently underway.

INTRODUCTION

Millions of wells are drilled into Ganges alluvial deposits for public water supply in Bangladesh and West Bengal (Nickson et al., 1998; Das et al., 1996). The release of arsenic from the arsenic-bearing aquifer sediments may have polluted

more than 3 million of the approximately 5 million existing wells in Bangladesh, affecting up to 70 million people (Lepkowski, 1999). According to the data reported by the British Geological Survey (BGS, 1998), among the 9037 wells tested, 22 percent have arsenic concentrations in the range of 100 to 250 $\mu\text{g/L}$. The divalent iron concentration is in the range of 0.2-12 mg/L and is positively correlated with arsenic concentration in the groundwater. Groundwater in Bangladesh also contains fairly high concentrations of phosphate (0.2-3 mg-P/L), silicate (6-28 mg-Si/L), and bicarbonate (10-671 mg/L).

A variety of technologies have been used for the treatment of arsenic in water, including conventional co-precipitation with ferric chloride, lime softening, filtration using exchange resins and adsorbents such as activated alumina, and membrane filtration processes (Sorg and Logsdon, 1978; Hering et al., 1996; McNeill and Edwards, 1997). High iron concentration may hinder the application of the adsorbents, exchange resins, and membranes in treating Bangladesh well water. Ferrous iron will be oxidized and form a ferric hydroxide coating on the media surface or block the pores of membranes. In addition, high anion concentrations will reduce the capacity of the media for arsenic removal.

Co-precipitation with ferric chloride is an effective and economical technique for removing arsenic from water (Gulledge and O'Conner, 1973; Cheng et al., 1994; Hering et al., 1996; McNeill and Edwards, 1995). Iron hydroxides formed from the ferric salts have a high adsorption capacity for arsenate [As(V)]. Arsenite [As(III)], which is more difficult to remove than As(V), can be oxidized rapidly to As(V) by oxidizing agents such as hypochlorite, permanganate, and hydrogen peroxide. However, elevated phosphate and silicate concentrations in Bangladesh groundwater may dramatically decrease the effectiveness of arsenic removal by the co-precipitation treatment. It has been reported that phosphate enhances the mobility of As(V) in soils contaminated with lead arsenate (Peryea and Kammereck, 1997). Silicate and carbonate decrease the removal of SO_4^{2-} , SeO_3^{2-} , PO_4^{3-} , and CrO_4^{2-} by iron hydroxides (Meng and Letterman, 1996; van Geen et al., 1994; Goldberg, 1985; Zachara et al., 1987). Experimental results have demonstrated that silicate affects adversely the removal of As(III) and As(V) by co-precipitation with ferric chloride (Meng et al., 2000).

In the present study, co-precipitation tests were conducted to evaluate the effects of phosphate and silicate on the removal of arsenic from Bangladesh well waters. A household co-precipitation and filtration process was tested in Kachua Thana, Chandpur district, Bangladesh, an area where the groundwater is severely impacted by arsenic contamination. Some members of the participating families had already developed skin lesions and cancers due to arsenic poisoning. The field test results demonstrated that the household filtration process offers a simple and reliable solution for the arsenic problem in Bangladesh.

EXPERIMENTAL METHODS

Material

Batch co-precipitation tests were conducted in three types of water samples: 1) Groundwater collected from wells in the Kishoreganj, Munshiganj, and Chandpur districts in Bangladesh (B-GW); 2) Groundwater collected from a well in New Hampshire (NH); and 3) Simulated Bangladesh groundwater (SB) prepared by dissolving sodium, calcium, and magnesium chloride in DI water. The chemical composition of the waters used in the tests is summarized in Table 1. The water samples were used to evaluate the effects of phosphate and silicate on arsenic removal by co-precipitation with ferric chloride. The NH sample represented groundwater with low phosphate concentration. Total arsenic concentration in the B-GW samples varied from 280 to 600 $\mu\text{g/L}$. Approximately 75 to 93 percent of the arsenic in B-GW samples were present as As(III) species. As(III) was added to the NH and the SB samples to reach a total arsenic concentration of 400 $\mu\text{g/L}$, which was the average arsenic concentration in the B-GW samples used in the co-precipitation tests. Phosphate and silicate were added to the SB and the NH samples to assess the anion effects. After the addition of silicate and phosphate, the spiked SB and NH samples were aged at a neutral pH for a week before they were used in the co-precipitation experiments. The samples were aged so that the spiked silicate and phosphate could form species similar to those in the B-GW samples.

Table 1: Chemical composition of the waters used in co-precipitation tests

Waters	As ($\mu\text{g/L}$)	Fe ($\mu\text{g/L}$)	P ($\mu\text{g/L}$)	Si (mg/L)	Na (mg/L)	Ca (mg/L)	Mg (mg/L)
B-GW	280-600	4.7-7.7	1.6-2.7	14-20	15-78	65-151	14-42
NH	70, 400*	0.7	0.02, 1.9*	6.6, 18*	13	16	2.9
SB	400	0	0, 1.9*	0, 18*	50	100	20

*Total chemical concentration in the spiked NH and SB samples.

Batch Co-precipitation Tests

Co-precipitation tests were conducted with all three types of water samples. Hypochlorite solution was added to the water samples to oxidize As(III) and Fe(II). A residual chlorine content of approximately 1 mg/L was maintained by the addition of the hypochlorite solution during approximately 5 minutes of mixing. Different amounts of ferric solution (Fe(III)=0, 5, 10, 20 mg/L) were added to the oxidized water samples to co-precipitate arsenic. After the samples were mixed for 30 minutes, the final pH values were measured and the samples were filtered through a 0.4- μm pore size membrane filter. The filtered water

samples were acidified with nitric acid and then analyzed for the residual arsenic and iron concentrations using a Furnace Atomic Absorption Spectrometer (FAAS) (Varian SpectrAA-400) and inductively coupled plasma (ICP) emission spectrometer.

Field Tests of Household Filtration Process

A household system was developed for removal of arsenic from the well water based on the principles of the co-precipitation and filtration. For convenient application of the chemicals, the iron coagulants were sealed in small plastic packets. According to batch co-precipitation results, each packet of chemicals could treat 20 L of well water with arsenic concentration of 500 µg/L or less. The household filters were made of 20-liter plastic buckets with a few inches of filter sand packed at the bottom of the filter. To produce clean drinking water, well water was collected into a 20-liter bucket followed by addition of a packet of the chemicals. After the water was mixed with the chemicals for a few minutes, it was poured into the bucket filter and passed through the sand bed by gravity for the removal of the precipitates. Clean water was collected from a tube connected to the bottom of the bucket filter.

A field demonstration study was performed in seven families in Kachua Thana, Chandpur District, Bangladesh in March and April 2000. A list of ten families using contaminated wells was provided by the Earth-Identity Project (a Non-Government Organization in Bangladesh). Seven of the families volunteered to participate in the study. A set of chemical packets and bucket filters were distributed to the participating families. During the demonstration study, the families used the filtration system every day. Filtered water samples were collected from the families three times a week and were analyzed for total arsenic. Well water and the filtered water samples in one family were also analyzed for standard water quality parameters.

RESULTS AND DISCUSSION

Arsenic Removal by Batch Co-precipitation

The results in Figure 1 show the removal of arsenic from the three types of waters by the oxidation and co-precipitation treatment. The original Fe/As ratio in the B-GW samples ranged between 13 and 22. When Fe(II) and As(III) in the B-GW samples were oxidized by NaClO and subsequently formed ferric hydroxide precipitates, less than 70 percent of the arsenic was removed. The residual arsenic in the treated B-GW samples was greater than 100 µg/L. Speciation analysis of the arsenic in the filtered water showed that As(III) was completely oxidized to As(V) by the hypochlorite. More than 97 percent of the

iron was removed by the oxidation and filtration process. It is clear from these results that the amount of the iron in B-GW samples was not enough to reduce arsenic to less than 50 $\mu\text{g/L}$, which is the drinking water standard in Bangladesh.

When the Fe/As ratio was increased to greater than 40 by adding ferric chloride to the B-GW samples, the arsenic removal was increased to more than 85 percent (Figure 1). The wide fluctuation of the arsenic removal data was attributed to variations in phosphate and silicate concentrations in the B-GW samples. In general, a Fe/As ratio of greater than 40 was required to reduce arsenic concentration to less than 50 $\mu\text{g/L}$. For an arsenic concentration of 500 $\mu\text{g/L}$, approximately 20 mg/L of Fe(III) was required to treat the well water.

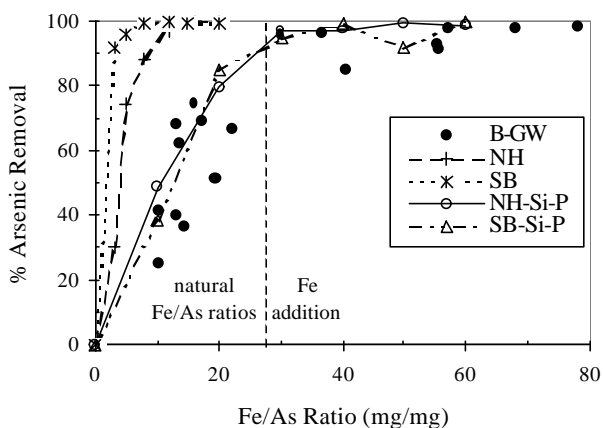


Figure 1: Removal of As by co-precipitation as a function of Fe/As ratio. Water samples are provided in Table 1. Samples “NH-Si-P” and “SB-Si-P” contained 18 mg-Si/L and 1.9 mg-P/L.

In contrast to the high Fe/As ratio needed for the treatment of Bangladesh water, Fe/As ratios of less than 12 were sufficient to obtain nearly 100 percent of arsenic removal from the NH and the SB samples (Figure 1). The total arsenic concentration in the NH and SB samples was 400 $\mu\text{g/L}$. The NH samples contained 0.02 mg-P/L and 6.6 mg-Si/L (Table 1). No phosphate or silicate was present in the SB sample. When phosphate and silicate stock solutions were added to both NH and SB samples to reach 1.9 mg-P/L and 18 mg-Si/L (i.e. the average concentrations in the Bangladesh water samples), the removal of arsenic from the samples decreased dramatically and reached similar removal efficiency as those observed for B-GW samples (data labeled “NH-Si-P” and “SB-Si-P”).

Although the concentrations of the other ions in the B-GW, NH-Si-P, and SB-Si-P samples were quite different, the profiles of the arsenic removal from

the samples were very similar. The results indicate that phosphate and silicate in the Bangladesh well water were the major anions affecting the removal of As(V) by co-precipitation with ferric chloride. A high Fe/As ratio had to be used to achieve substantial arsenic removal from Bangladesh well water due to the presence of elevated phosphate and silicate concentrations.

The effects of phosphate and silicate on arsenic removal were further investigated by conducting additional co-precipitation experiments. The results are shown in Figure 2. The addition of only silicate to the SB sample decreased moderately the removal of arsenic (data labeled “SB-Si”). When only phosphate was added to the SB sample, it had a drastic effect on arsenic removal. When both silicate and phosphate were present, the removal of As(V) was further decreased. Those effects are attributed to the competition of the anions with As(V) for ferric hydroxide sorption sites. As(V), silicate, and phosphate are adsorbed on ferric hydroxide through the formation of surface complexes with the surface hydroxyl groups (Meng et al., 2000; Goldberg, 1985).

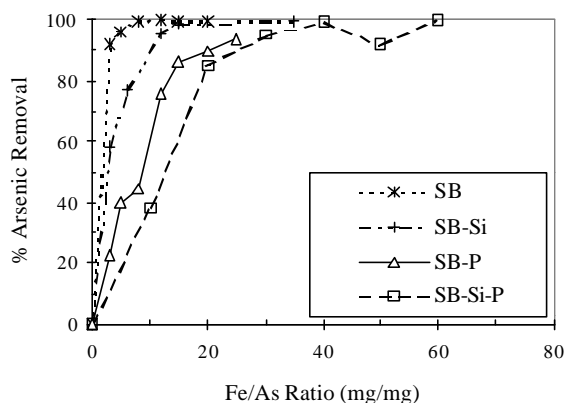


Figure 2 : Effects of phosphate and silicate on As removal by co-precipitation. The “SB-Si”, “SB-P”, and “SB-Si-P” samples were amended with 18 mg-Si/L or/and 1.9 mg-P/L.

Although the silicate concentration in the SB-Si sample was ten times higher than the concentration of phosphate in the SB-P sample, it had a weaker effect on As(V) removal than phosphate had. The results suggested that the affinity of silicate for ferric hydroxide was much weaker than As(V) and phosphate. When well water in family #1 was treated, phosphate concentration was reduced from 2.7 to 0.04 mg-P/L, representing a removal of 86 $\mu\text{M-P}$. Silicate concentration only decreased from 14.5 mg/L to 13.1 mg/L, indicating a removal of 58 $\mu\text{M-Si}$. Total Fe concentration used for the treatment of the water was 428 μM . If a surface site density of 0.9-mol sites/mol Fe was assumed in the co-precipitation system (Meng and Letterman, 1993), the total adsorptive sites in the treatment

system would be 385 μM . The adsorbed phosphate and silicate occupied 22 and 15 percent of the adsorptive sites, respectively.

Arsenic Removal by Household Filtration Process

The household filtration system was first tested for the treatment of contaminated water in a well located in the Munshiganj district of Bangladesh. The field test results showed that the initial flow rate through the bucket filter was approximately 1.5 L/min (Figure 3). After 200 L (10 buckets) of water was filtered, the filtration rate decreased to about 0.4 L/min because the sand bed was clogged gradually by the precipitated solids. In the initial filtration stage, the arsenic concentration was removed from 485 $\mu\text{g/L}$ in the well water to 15 $\mu\text{g/L}$ (Figure 3). The residual arsenic concentration decreased to 5 $\mu\text{g/L}$ when 200 L of water was treated. Since the filtration was at a low hydraulic head, no particle and arsenic breakthrough occurred in the filtration process. When the flow rate became very low, the filter sand was washed with well water and used again.

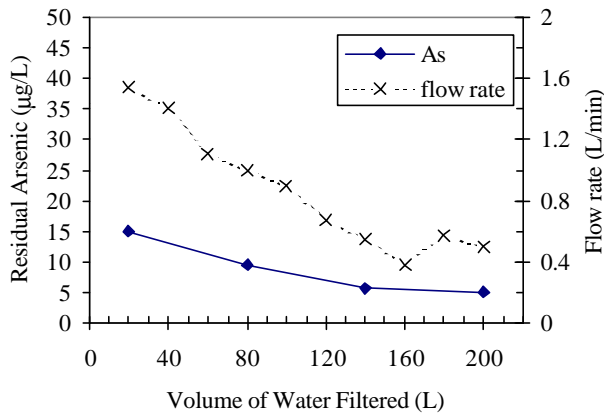


Figure 3: Performance of the bucket filter for treatment of water in a well in Munshiganj district.

During the field demonstration study, each family filtered approximately three buckets (60 liters) of water daily. Field analysis indicated that residual chlorine content in the treated water was usually less than 2 mg/L. Most of the families washed the filter sand about twice a week. Approximately two buckets (40 liters) of well water were used to wash the clogged sand filter. The families used the filters consistently to treat well water for drinking and cooking.

Figure 4 shows arsenic concentrations in the well water and the average arsenic concentrations in the filtered water samples collected during 35 days of the demonstration study. The arsenic concentration in the untreated well water

ranged from 87 to 313 $\mu\text{g/L}$. The average arsenic concentration in the filtered water ranged from 1.9 to 21.8 $\mu\text{g/L}$.

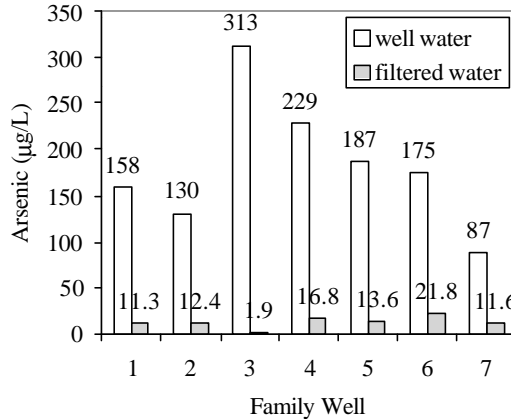


Figure 4: Comparison of arsenic concentrations in well water and the average arsenic concentration in the filtered water.

CONCLUSIONS

The field demonstration results showed that the household filtration process could effectively remove arsenic from Bangladesh well water. The household co-precipitation and filtration process was proved reliable and easy to use. Based on a daily consumption of 50 liters of filtered water, it is estimated that the chemical costs are less than US\$4 annually for a family. The co-precipitation results indicate that elevated phosphate and silicate concentrations in Bangladesh well water dramatically decreased adsorption of arsenic by ferric hydroxides. A Fe/As mass ratio of greater than 40 was required to reduce arsenic concentration to less than 50 $\mu\text{g/L}$ in the well water.

ACKNOWLEDGEMENTS

The authors wish to thank Harold J. Raveché, the President of Stevens Institute of Technology, Ms. Nasrine R. Karim and Ms. Hiroko Kawahara of the Earth Identity Project in Bangladesh and the Government of Bangladesh for the continuing support of this project. We thank Mahmoud Wazne and Chuanyong Jing for assistance with laboratory experiments.

REFERENCES

- BGS (1998) Groundwater Studies for Arsenic Contamination in Bangladesh, British Geological Survey and Mott MacDonald Ltd (UK).
- Cheng, R. C.; Liang, S.; Wang, H. C. and Beuhler, M. D. (1994) Enhanced Coagulation for Arsenic Removal. *Jour. AWWA* **86**(9),79-90.
- Das, D., Samanta, G., Mandal, B. K., Chowdhury, T. R., Chanda, C. R., Chowdhury, P. P., Basu, G. K. and Chakraborti, D. (1996) Arsenic in Ground Water in Six Districts of West Bengal, India. *Environmental Geochemistry Health*, **18**, 5-15.
- Hering, J. G., Chen, P. Y.; Wilkie, J. A.; Elimelech, M. and Liang, S. (1996) Arsenic Removal by Ferric Chloride. *J. AWWA* **88**(4),155-167.
- Goldberg, S. (1985) Chemical Modeling of Anions Competition on Goethite Using the Constant Capacitance Model. *Soil Sci. Soc. Am. J.* **49**, 851-856.
- Gulledge, J. H. and O'Conner, J. T. (1973) Removal of Arsenic(V) from Water by Adsorption on Aluminum and Ferric Hydroxides. *Jour. AWWA* **65**(8), 548-552.
- Lepkowski, W. (1999) Arsenic Crisis Spurs Scientists. *CEN* (May 17, 1999) 45-49.
- McNeill, L. S. and Edwards, M. (1995) Soluble Arsenic Removal at Water Treatment Plants. *Jour. AWWA* **87**(4), 105-113.
- McNeill, L. S. and Edwards, M. (1997) Arsenic Removal during Precipitative Softening. *J. Environ. Eng.* **123**, 453-460.
- Meng, X. G., Bang, S. B. and Korfiatis, G. P. (2000) Effects of Silicate, Sulfate, and Carbonate on Arsenic Removal by Ferric Chloride, *Water Research*, **34**, 1255-1261.
- Meng, X. G. and Letterman, R. D. (1993) Effect of Component Oxide Interaction on the Adsorption Properties of Mixed Oxides. *Environ. Sci. Technol.* **27**, 970-975.
- Meng, X. G. and Letterman, R. D. (1996) Modeling Cadmium and Sulfate Adsorption on Fe(OH)₃/SiO₂ Mixed Oxides. *Water Res.* **30**, 2148-2154.
- Nickson, R., McArthur, J., Burgess, W. and Ahmed, K. M. (1998) Arsenic Poisoning of Bangladesh Groundwater. *Nature* **395**, 338.
- Peryea, F. J. and Kammereck, R. (1997) Phosphate-Enhanced Movement of Arsenic out of Lead Arsenate Contaminated Topsoil and Through Uncontaminated Subsoil. *Water Air Soil Pollut.* **93**, 243-254.
- Sadiq, M. (1997). Arsenic Chemistry in Soils: An Overview of Thermodynamic Predictions and Field Observations. *Water Air Soil Pollution* **93**, 117-136.
- Sorg, T. J. and Logsdon, G. S. (1978). Treatment Technology to Meet the Interim Primary Drinking Water Regulations for Inorganics: Part 2. *Jour. AWWA* **70**(7), 379-393.

The U.S. Environmental Protection Agency, Test Methods for Evaluating Solid Waste, Physical/Chemical Methods, SW-846, 3rd edition, Method 1311, U. S. EPA, Washington, DC, 1992.

Van Geen, A., Robertson, A. P. and Leckie, J. O. (1994). Complexation of Carbonate Species at the Goethite Surface: Implications for Adsorption of Metal Ions in Natural Waters. . *Geochim. Cosmochim. Acta* **58**, 2073 - 2086.

Zachara, J. M.; Girvin, D. C.; Schmidt, R. L. and Resch, C. T. (1987) Chromate Adsorption on Amorphous Iron Oxyhydroxide in the Presence of Major Groundwater Ions. *Environ. Sci. Technol.* **21**, 589-594.