

BUET-UNU International Workshop on  
**Technologies for Arsenic  
Removal From Drinking Water**

*5 - 7 May 2001, Dhaka, Bangladesh*



# **Technologies for Arsenic Removal from Drinking Water**

A compilation of papers presented at the **International Workshop on Technologies for Arsenic Removal from Drinking Water** organized by Bangladesh University of Engineering and Technology (BUET), Dhaka, Bangladesh and The United Nations University (UNU), Tokyo, Japan

*Edited by:*

**M. Feroze Ahmed** Ph.D.

Professor

Department of Civil Engineering,  
BUET, Dhaka-1000, Bangladesh

**M. Ashraf Ali** Ph.D.

Associate Professor

Department of Civil Engineering,  
BUET, Dhaka-1000, Bangladesh

**Zafar Adeel** Ph.D.

Academic Programme Officer

Environment and Sustainable Development,  
The United Nations University, Tokyo, Japan

**Bangladesh University of Engineering and Technology, Dhaka**  
**The United Nations University, Tokyo**

## **Technologies for Arsenic Removal from Drinking Water**

A compilation of papers presented at the **International Workshop on Technologies for Arsenic Removal from Drinking Water**. The workshop is jointly organized by International Training Network (ITN) - Bangladesh University of Engineering and Technology (BUET) and Environment and Sustainable Development (ESD) Programme and International Network for Water, Environment and Health (INWEH) - The United Nations University (UNU), Tokyo, Japan.

The factual information and views expressed in the papers are those of the authors, not of the editors nor of the Universities they belong.

*Published by:*

The Editors on behalf of the Bangladesh University of Engineering and Technology and The United Nations University.

May, 2001

ISBN 984-31-1305-6

Copyright © 2000 by Publishers. This publication or any part of it can be reproduced in any form with permission of any of the publishers.

*Printed by:* Mati ar Manush,  
106 Fakirapool, Dhaka-1000  
Tel: 017-661841

*Cover by :* Color Graphic

## CONTENTS

<b>Author and Title</b>	<b>Page</b>
<b>Preface</b>	viii
<i>Richard Johnston and Han Heijnen</i> Safe Water Technology for Arsenic Removal	1
<i>Nahid Sharmin</i> Arsenic Removal Processes on Trial in Bangladesh	23
<i>Robert G.Robins, Tadahisa Nishimura and Pritom Singh</i> Removal of Arsenic from Drinking Water by Precipitation, Adsorption or Cementation	31
<i>R.Mamtaz and D.H.Bache</i> Low-cost Technique of Arsenic Removal from Water and Its Removal Mechanism	43
<i>B.N.Pal</i> Granular Ferric Hydroxide for Elimination of Arsenic from Drinking Water	59
<i>M.D.Hussain, M.A.Haque, M.M.Islam and M.A.Hossen</i> Approaches for Removal of Arsenic from Tubewell Water for Drinking Purpose	69
<i>J.C.Saha, K.Dikshit and M.Bandyopadhyay</i> Comparative Studies for Selection of Technologies for Arsenic Removal from Drinking Water	76
<i>Phillip Thomas Crisp and Ahmedul Hye Chowdhury</i> Design of A Low-cost Purification System for the Removal of Arsenic from Tubewell Water in Bangladesh and India	85

<i>M.Ashraf Ali, A.B.M.Badruzzaman, M.A.Jalil, M.Delwar Hossain, M.M.Hussainuzzaman, M.Badruzzaman, O.I.Mohammad and N.Akhter</i> Development of Low-cost Technologies for Removal of Arsenic from Groundwater	99
<i>Xiaoguang Meng and George P.Korfiatis</i> Removal of Arsenic from Bangladesh Well Water Using A Household Filtration System	121
<i>M.A.Jalil and Farooque Ahmed</i> Development of An Activated Alumina Based Household Arsenic Removal Unit	131
<i>Kiron Senapati and Iftekhar Alam</i> Apyron Arsenic Treatment Unit - Reliable Technology for Arsenic Safe Water	146
<i>Saraban Tahura, S.M.Shaidullah, Tofizur Rahman and Abul Hasnat Milton</i> Evaluation of An Arsenic Removal Household Device : Bucket Treatment Unit (BTU)	158
<i>A.K.M.Munir, S.B.Rasul, M.Habibuddowla, M.Alauddin, A.Hussam and A.H.Khan</i> Evaluation of Performance of Sono 3-Kolsi Filter for Arsenic Removal from Groundwater Using Zero Valent Iron Through Laboratory and Field Studies	171
<i>David Sutherland, Md. Obaidul Kabir and Naved Ahmed Chowdhury</i> Rapid Assessment of Technologies for Arsenic Removal at the Household Level	190
<i>Anisur Rahman Sarkar and Omar Twabur Rahman</i> In-situ Removal of Arsenic - Experiences of DPHE-Danida Pilot Project	201
<i>Nikita Eriksen-Hamel and Begum Kamrun Nahar Zinia</i> A Study of Arsenic Treatment Technologies and Leaching Characteristics of Arsenic Contaminated Sludge	207
<i>Roy K.Boerschke and Donna K.Stewart</i> Evaluation of Arsenic Mitigation Technologies for Use in Bangladesh	214

<i>D.Das, A.Chatterjee, G.Samanta, T.R.Chowdhury, B.K.Mandal, R.Dhar, C.R.Chanda, D.Lodh, P.P.Chowdhury, G.K.Basu, B.K.Biswas, U.K.Chowdhury, M.M.Rahman, K.Paul, and D. Chakroborti</i>	
<a href="#">A Simple Household Device to Remove Arsenic from Groundwater and Two Years Performance Report of Arsenic Removal Plant for Treating Groundwater with Community Participation</a>	231
<i>M.Feroze Ahmed</i>	
<a href="#">An Overview of Arsenic Removal Technologies in Bangladesh and India</a>	251
<i>Zafar Adeel</i>	
<a href="#">Policy Dimensions of the Arsenic Pollution Problem in Bangladesh</a>	270

## PREFACE

Arsenic contamination of groundwater in the alluvial aquifer underlying Bangladesh and India has been recognized as a major problem of catastrophic proportions. Groundwater extracted by shallow tubewells from this aquifer has been found to contain high levels of arsenic which are unsafe for drinking and cooking purposes. Thousands of people have already been identified to be affected by arsenic poisoning, in addition to the millions potentially under threat from drinking contaminated water. Provision of arsenic free water is urgently needed for immediate protection of health and well being of the people living in arsenic affected areas. In most situations, substitution of tubewell water by an alternative safe and reliable source of water supply is not an easy task. Treatment of arsenic-contaminated tubewell water is one prominent option in the acute arsenic affected areas in Bangladesh and India.

This publication comprises a compilation of papers presented at the BUET-UNU International workshop on *Technologies for Arsenic Removal from Drinking Water*. The papers describe a broad range of activities in the areas of research, development and evaluation of various arsenic removal technologies. It is anticipated that the information contained in this document will be useful in understanding the current technological developments in arsenic removal as well as their limitations. This effort is also useful in identifying the areas needing further improvement for successful implementation and adaptation of technologies to rural conditions. We hope that this publication of BUET-UNU workshop will be useful to the scientists, engineers, researchers, policy planners and decision-makers working for arsenic mitigation in various parts of the world, including Bangladesh and India.

The editors would like to express their sincere thanks and gratitude to all the contributors of this publication. The editors acknowledge the sincere efforts of Farhad Ahmed, Zobayer A. Shaurav, Miah M. Hussainuzzaman and others who directly or indirectly helped to publish this document.

**Editors**

# Safe Water Technology for Arsenic Removal

**Richard Johnston**

Consultant to UNICEF and WHO

and

**Han Heijnen**

WHO Environmental Health Advisor, Bangladesh

## ***Abstract***

*Arsenic contamination of drinking water has been reported from many parts of world. In some arsenic affected areas, substitution of drinking water source by a safe and easily available one may not be possible during part or all of the year, or may be very expensive. Arsenic removal may be a more appropriate water supply option in these situations. This paper describes some safe water technologies for arsenic removal.*

*Coagulation is the most common arsenic removal technology. As many Bangladesh waters contain arsenite, oxidation with chlorine or permanganate is required first. Coagulation with ferric chloride works best at pH below 8. Alum has a narrower effective range, from pH 6-8. Ion exchange resins are commercially produced synthetic materials that can remove some compounds from water. These resins only remove arsenate. Activated alumina, like ion exchange resins, is commercially available in coarse grains. Activated alumina beds usually have much longer run times than ion exchange resins, typically several tens of thousands of beds can be treated before arsenic breakthrough. Activated alumina works best in slightly acidic waters (pH 5.5 to 6). Membrane methods for arsenic removal include reverse osmosis and nanofiltration. Currently available membranes are more expensive than other arsenic removal options, and are more appropriate in municipal settings, where very low arsenic levels are required. Other techniques exist for arsenic removal, but are less well documented. When arsenic-rich water also contains high levels of dissolved iron, iron removal will also remove much of the arsenic. Introduction of zero-valent iron filings in three-pitcher filters to treat water in the home is showing great*



*promise. Many new materials are being tested for arsenic removal, from low-tech iron-coated sand and greensand to specially engineered synthetic resins.*

*In all cases, technologies should meet several basic technical criteria. The biggest challenges ahead lie however in applying the technologies described in poor, rural settings, and in enabling those communities to choose safe sources of water for drinking and cooking.*

## **INTRODUCTION**

In areas where the drinking water supply contains unsafe levels of arsenic, the immediate concern is finding a safe source of drinking water. There are two main options: finding a new safe source, and removing arsenic from the contaminated source. In either case, the drinking water supplied must be free from harmful levels of arsenic, but also from bacteriological contamination, and other chemical contaminants. This paper reviews available technologies for arsenic removal.

When arsenic contamination is identified, the immediate priority must be to find a safe alternate source of drinking and cooking water for affected communities. Alternate sources must be not only arsenic-free, but also microbiologically safe – it would be a serious mistake to revert back to unsafe use of surface water sources. In some cases, there may be no one technology that can provide communities with a sustainable, continuous, affordable, safe water supply. If a year-round safe water source is not currently available, it may be necessary as a short-term solution to use one source during wet seasons (e.g. groundwater, rainwater) and another during dry seasons (e.g. removing arsenic from contaminated water). If a completely satisfactory, arsenic-free water source cannot be established, the short-term goal should be to reduce arsenic levels in drinking water as much as possible, as quickly as possible, even if regulatory standards cannot be immediately met. It should be recalled that health effects of arsenic are dose-dependent, and a partial solution is better than no solution. The implementation of a temporary solution should not be used as a reason to delay design and implementation of a long-term plan.

In all cases, technologies should meet several basic technical criteria. Water supply options must first of all be able to produce water of the required quality, both chemical and bacteriological. Systems should also be able to supply water in adequate quantity, throughout different seasons. Technologies should be robust. It is important that operational safety be ensured. Finally, technologies should not have an undue adverse effect on the environment.

Technologies meeting these technical criteria can be evaluated under several socioeconomic criteria. First, the systems must be economically feasible. Introduction of new technologies requires institutional capacity including production and delivery of materials, training, and quality control monitoring. New options must be convenient, or people will not use them. Gender impacts

should be considered, so that the workload of women and girls is not unduly increased. New technologies require behavioral change on the part of the user, thus communication interventions should be considered. Finally, technologies must be socially acceptable to community members in order to be successful as a long-term safe water supply option.

## TECHNOLOGIES FOR ARSENIC REMOVAL

In some areas, arsenic-contaminated water will be abundant, and arsenic-free sources scarce or polluted with other compounds. In these areas it may be most efficient to remove arsenic from the contaminated water, at least as a short term measure. Many technologies have been developed for the removal of arsenic. Most of the documented experience has been with large municipal treatment plants, but some of the same technologies can be applied at community or household levels.

All of the technologies for arsenic removal rely on a few basic chemical processes, which are summarized below:

- Oxidation/reduction: reactions that reduce (add electrons to) or oxidize (remove electrons from) chemicals, altering their chemical form. These reactions do not remove arsenic from solution, but are often used to optimize other processes.
- Precipitation: Causing dissolved arsenic to form a low-solubility solid mineral, such as calcium arsenate. This solid can then be removed through sedimentation and filtration. When coagulants are added and form flocs, other dissolved compounds such as arsenic can become insoluble and form solids, this is known as coprecipitation. The solids formed may remain suspended, and require removal through solid/liquid separation processes, typically coagulation and filtration.
- Adsorption and ion exchange: various solid materials, including iron and aluminum hydroxide flocs, have a strong affinity for dissolved arsenic. Arsenic is strongly attracted to sorption sites on the surfaces of these solids, and is effectively removed from solution. Ion exchange can be considered as a special form of adsorption, though it is often considered separately. Ion exchange involves the reversible displacement of an ion adsorbed onto a solid surface by a dissolved ion. Other forms of adsorption involve stronger bonds, and are less easily reversed.
- Solid/liquid separation: precipitation, co-precipitation, adsorption, and ion exchange all transfer the contaminant from the dissolved to a solid phase. In some cases the solid is large and fixed (e.g. grains of ion exchange resin), and no solid/liquid separation is required. If the solids are formed *in situ* (through precipitation or coagulation) they must be

#### 4 *Technologies for Arsenic Removal from Drinking Water*

separated from the water. Gravity settling (also called sedimentation) can accomplish some of this, but filtration is more effective. Most commonly, sand filters are used for this purpose.

- Physical exclusion: some synthetic membranes are permeable to certain dissolved compounds but exclude others. These membranes can act as a molecular filter to remove dissolved arsenic, along with many other dissolved and particulate compounds.
- Biological removal processes: bacteria can play an important role in catalyzing many of the above processes. Relatively little is known about the potential for biological removal of arsenic from water.
- Boiling does not remove arsenic from water.

Most of the established technologies for arsenic removal make use of several of these processes, either at the same time or in sequence. All of the removal technologies have the added benefit of removing other undesirable compounds along with arsenic – depending on the technology, bacteria, turbidity, color, odor, hardness, phosphate, fluoride, nitrate, iron, manganese, and other metals can be removed.

Historically, the most common technologies for arsenic removal have been coagulation with metal salts, lime softening, and iron/manganese removal. Since the WHO Guideline Value for arsenic in drinking water was lowered from 50 to 10  $\mu\text{g/L}$  in 1993, several countries have lowered their drinking water standards, in some cases to 10  $\mu\text{g/L}$ . In January 2001, the USEPA lowered the U.S. drinking water standard from 50 to 10  $\mu\text{g/L}$  (only to postpone/reconsider this decision a few months later).

Coagulation processes are sometimes unable to efficiently remove arsenic to these low levels. As a result, various alternate technologies have been developed or adapted that are capable of removing arsenic to trace levels. These advanced treatment options include ion exchange, activated alumina, and membrane methods such as reverse osmosis and nanofiltration. While these technologies have all been shown to be effective in lab or pilot studies, there is still relatively little experience with full-scale treatment. In addition, a number of novel removal technologies are under development, some of which show great promise.

The main arsenic removal technologies are presented below, along with a brief description of how removal efficiency is affected by arsenic concentration and speciation, pH, and the presence of other dissolved constituents.

#### **Oxidation**

Most arsenic removal technologies are most effective at removing the pentavalent form of arsenic (arsenate), since the trivalent form (arsenite) is predominantly non-charged below pH 9.2. Therefore, many treatment systems

include an oxidation step to convert arsenite to arsenate. Oxidation alone does not remove arsenic from solution, and must be coupled with a removal process such as coagulation, adsorption or ion exchange.

Arsenite can be directly oxidized by a number of other chemicals, including gaseous chlorine, hypochlorite, ozone, permanganate, hydrogen peroxide, and Fenton's reagent ( $\text{H}_2\text{O}_2/\text{Fe}^{2+}$ ). Some solids such as manganese oxides can also oxidize arsenic. Ultraviolet radiation can catalyze the oxidization of arsenite in the presence of other oxidants, such as oxygen. Direct UV oxidation of arsenite is slow, but may be catalyzed by the presence of sulfite (Ghurye and Clifford, 2000), ferric iron (Emett and Khoe, 2001) or citrate (EAWAG, 1999). Chlorine is a rapid and effective oxidant, but may lead to reactions with organic matter, producing toxic trihalomethanes as a by-product. Chlorine is widely available globally, though if improperly stored it can lose its potency rapidly.

In Europe, and increasingly in the USA, ozone is being used as an oxidant. In developing countries, ozone has not been widely used. An ozone dose of 2 mg/L, contacted with the water for 1 minute prior to filtration, has been shown to be effective in oxidizing iron and manganese, at the same time removing arsenic and other metals to below detection limits (Nieminski and Evans, 1995). At a similar ozone dose, arsenite was shown to have a half-life of approximately 4 minutes (Kim and Nriagu, 2000). Ozone is also a potent disinfectant, but unlike chlorine, does not impart a lasting residual to treated water.

Permanganate effectively oxidizes arsenite, along with Fe(II) and Mn(II). It is a poor disinfectant, though it can produce a bacteriostatic effect. Potassium permanganate ( $\text{KMnO}_4$ ) is widely available in developing countries, where it is used as a topical antibiotic for minor cuts. It is relatively stable with a long shelf life. Residual manganese in treated water should not exceed the WHO guideline of 0.5 mg/L (WHO, 1993). Hydrogen peroxide may be an effective oxidant if the raw water contains high levels of dissolved iron, which often occur in conjunction with arsenic contamination.

### **Coagulation and Filtration**

The most heavily documented treatment methods for arsenic removal involve coagulation and filtration, either using metal salts or lime softening. This treatment can effectively remove many suspended and dissolved constituents from water besides arsenic, notably turbidity, iron, manganese, phosphate and fluoride. Significant reductions are also possible in odor, color, and potential for trihalomethane formation. Thus coagulation and filtration to remove arsenic will improve other water quality parameters, resulting in ancillary health and esthetic benefits. However, the optimal conditions vary for removal of different constituents, and coagulation to remove arsenic may not be optimal for removal of other compounds, notably phosphate and fluoride.

Arsenic removal with metal salts has been shown since at least 1934

(Buswell, 1943). The most commonly used metal salts are aluminum salts such as alum, and ferric salts such as ferric chloride or ferric sulfate. Ferrous sulfate has also been used, but is less effective (Jekel, 1994; Hering et al., 1996; Hering et al., 1997). Excellent arsenic removal is possible with either ferric or aluminum salts, with laboratories reporting over 99% removal under optimal conditions, and residual arsenic concentrations of less than 1 µg/L (Cheng et al., 1994). Full-scale plants typically report a somewhat lower efficiency, from 50% to over 90% removal.

During coagulation and filtration, arsenic is removed through three main mechanisms (Edwards, 1994):

- precipitation: the formation of the insoluble compounds  $\text{Al}(\text{AsO}_4)$  or  $\text{Fe}(\text{AsO}_4)$
- coprecipitation: the incorporation of soluble arsenic species into a growing metal hydroxide phase
- adsorption: the electrostatic binding of soluble arsenic to the external surfaces of the insoluble metal hydroxide.

All three of these mechanisms can independently contribute towards contaminant removal. In the case of arsenic removal, direct precipitation has not been shown to play an important role. However, coprecipitation and adsorption are both active arsenic removal mechanisms.

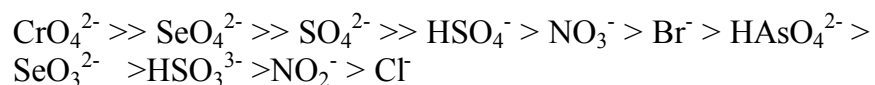
Numerous studies have shown that filtration is an important step to ensure efficient arsenic removal. After coagulation and simple sedimentation, HAO and HFO – along with their sorbed arsenic load – can remain suspended in colloidal form. Hering and others showed that coagulation and sedimentation without filtration achieved arsenate removal efficiencies of 30%; after filtration through a 1.0 micron filter, efficiency was improved to over 96%. Only marginal improvements were made by reducing the filter size to 0.1 micron (Hering et al., 1996). In field applications, some plants improve arsenic removal with two-stage filtration (Sancha, 1999b).

### **Ion-Exchange Resins**

Synthetic ion exchange resins are widely used in water treatment to remove many undesirable dissolved solids, most commonly hardness, from water. These resins are based on a cross-linked polymer skeleton, called the ‘matrix’. Most commonly, this matrix is composed of polystyrene cross-linked with divinylbenzene. Charged functional groups are attached to the matrix through covalent bonding, and fall into four groups (Clifford, 1999):

- Strongly acidic (e.g. sulfonate,  $-\text{SO}_3^-$ )
- Weakly acidic (e.g. carboxylate,  $-\text{COO}^-$ )
- Strongly basic [e.g. quaternary amine,  $-\text{N}^+(\text{CH}_3)_3$ ]
- Weakly basic [e.g. tertiary amine,  $-\text{N}(\text{CH}_3)_2$ ]

The acidic resins are negatively charged, and can be loaded with cations (e.g.  $\text{Na}^+$ ), which are easily displaced by other cations during water treatment. This type of cation exchange is most commonly applied to soften hard waters. Conversely, strongly basic resins can be pretreated with anions, such as  $\text{Cl}^-$ , and used to remove a wide range of negatively charged species. Clifford gives the following relative affinities of some common anions for a type 1 strong-base anion resins (Clifford, 1999):



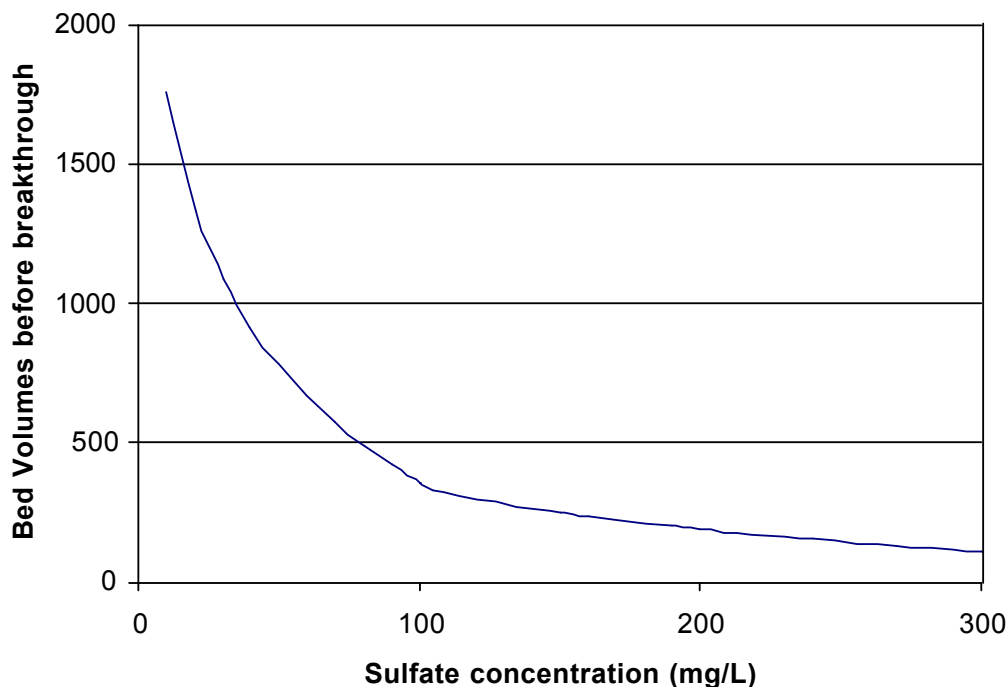
Different resins will have differing selectivity sequences, and resins have been developed specifically to optimize removal of sulfate, nitrate, and organic matter. Various strong-base anion exchange resins are commercially available which can effectively remove arsenate from solution, producing effluent with less than 1  $\mu\text{g/L}$  arsenic. Arsenite, being uncharged, is not removed. Analysts have taken advantage of this specificity to develop procedures for analytical differentiation of arsenite and arsenate (e.g. Ficklin, 1983; Edwards et al., 1998). Therefore, unless arsenic is present exclusively as arsenate, an oxidation step will be a necessary precursor to arsenic removal.

Conventional sulfate-selective resins are particularly suited for arsenate removal. Nitrate-selective resins also remove arsenic, but arsenic breakthrough occurs earlier. Most commonly, resins are pretreated with hydrochloric acid, to establish chloride ions at the surface, which are easily displaced by arsenic (Ghurye et al., 1999), though the resin can be primed with other anions such as bromide or acetate (Edwards et al., 1998). Packed beds are commonly designed to have an Empty Bed Contact Time (EBCT) of 1.5 to 3 minutes.

Arsenate removal is relatively independent of pH and influent concentration. On the other hand, competing anions, especially sulfate, have a strong effect. The number of bed volumes that can be treated before arsenic breakthrough (defined as 10% of the influent concentration) can be roughly estimated with two simple formulas: (Clifford and Majano, 1993; cited in Chen et al., 1999).

$$\begin{aligned} \text{For } [\text{SO}_4^{2-}] < 120 \text{ mg/L: Bed Volumes} &= -606 * \ln[\text{SO}_4^{2-}] + 3,150 \\ \text{For } [\text{SO}_4^{2-}] > 120 \text{ mg/L: Bed Volumes} &= -200 * \ln[\text{SO}_4^{2-}] + 1,250 \end{aligned}$$

where  $[\text{SO}_4^{2-}]$  is the initial sulfate concentration in mg/L. In low-sulfate waters, ion exchange resin can easily remove over 95% of arsenate, and treat from several hundreds to over a thousand bed volumes before arsenic breakthrough occurs. Accordingly, the USEPA recommends that ion exchange resins not be used in waters with  $>120$  mg/L sulfate or  $>500$  mg/L TDS, and will be most effective in waters with even lower sulfate levels ( $<25$  mg/L) (USEPA, 2000).



**Figure 1 : Bed volumes treated with ion exchange resin**

Ion exchange capacity, analogous to the adsorption capacity discussed in the previous section, is a measure of the number of exchange sites, and is usually measured in milliequivalents (meq) per mL (wet volume, including pore spaces). The operating capacity measures actual performance of resins under environmental conditions, and is always less than the advertised exchange capacity, due to incomplete regeneration and contaminant leakage.

### **Activated Alumina**

Activated alumina is a granulated form of aluminum oxide ( $\text{Al}_2\text{O}_3$ ) with very high internal surface area, in the range of 200-300  $\text{m}^2/\text{g}$ . This high surface area gives the material a very large number of sites where sorption can occur, and activated alumina has been widely used for removal of fluoride. In the early 1970s Bellack accidentally discovered that activated alumina could remove arsenic from water (Bellack, 1971; Sorg and Logsdon, 1978).

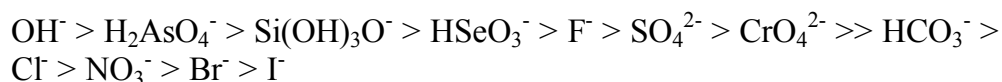
The mechanisms of arsenic removal are similar to those of a weak base ion exchange resin, and are often collectively referred to as 'adsorption', though ligand exchange and chemisorption are technically more appropriate terms (Clifford, 1999). The kinetics of arsenic removal onto the alumina surface are slower than those of ion exchange resins, and some arsenic leakage is often noted in activated alumina systems.

Arsenic removal efficiency is excellent (typically > 95%), for both arsenate and arsenite, but arsenic capacity varies significantly, and is controlled primarily by pH and influent arsenic concentration and speciation. Arsenate removal capacity is best in the narrow range from pH 5.5 to 6.0, where the alumina surfaces are protonated, but acid anions are not yet concentrated enough to compete with arsenic for sorption sites (Trussell et al., 1980; Rosenblum and Clifford, 1984; Clifford, 1999). Typically, activated alumina has a point of zero charge (PZC), below which the surface is positively charged, and above which the surface bears a negative charge, at pH 8.2. Arsenic removal capacity drops sharply as the PZC is approached, and above pH 8.5, is reduced to only 2-5% of capacity at optimal pH (Clifford, 1999). For neutral and basic waters, therefore, pH adjustment may be necessary for effective arsenic removal.

Fine (28-48 mesh) particles of activated alumina are typically used for arsenic removal, with an Empty Bed Contact Time of five to eight minutes (Rubel and Woosely, 1979). When operated in the optimal pH range, activated alumina beds have much longer run times than ion exchange resins. The number of bed volumes that can be treated at optimal pH before arsenate breaks through is mainly controlled by the influent arsenic concentration

Frank and Clifford reported an arsenate capacity (at pH 6) of about 1.6 g/L of activated alumina, consistent with an earlier reported capacity of 4 mg/g, assuming a bulk density of 0.5 kg/L (Gupta and Chen, 1978). Fox reported a somewhat lower capacity of 1 mg/g, but this is likely due to the elevated pH (7.4-8.0) of the influent water (Fox, 1989).

The sorption sites on the activated alumina surface are also attractive to a number of anions other than arsenate: Clifford reports the selectivity sequence of activated alumina in the pH range of 5.5 to 8.5 as (Clifford, 1999):



Trussell and others reported a similar selectivity sequence, but included phosphate as the second most preferred anion, after hydroxyl, and placed fluoride above arsenate in the sequence (Trussell et al., 1980). Because of activated alumina's strong selectivity for arsenate, competing anions pose less of a problem than with ion exchange resins. Sulfate, and to a lesser extent, chloride, have been shown to reduce capacity, but the competition effect is not as dramatic as with ion exchange resins (Rosenblum and Clifford, 1984). Phosphate and fluoride are also sorbed onto activated alumina, producing improvements in drinking water quality, but at the same time reducing arsenic removal potential.

Activated alumina can be regenerated by flushing with a solution of 4% sodium hydroxide, which displaces arsenic from the alumina surface, followed by flushing with acid, to re-establish a positive charge on the grain surfaces.



Regeneration is more difficult, and less complete (generally 50-80%) than with ion exchange resins (Clifford, 1986).

The advantages of activated alumina are that simple removal systems can be developed at community or household levels that require no chemical addition. Since activated alumina can treat thousands of bed volumes before breakthrough, filters could be operated for months before the media need to be changed or regenerated. Activated alumina will also remove selenite, fluoride, sulfate, and chromate. Disadvantages include the possibility that the media will be fouled or clogged by precipitated iron, the relatively narrow pH range for optimal operation, and the relative difficulty of regeneration. Also, compared with ion exchange resins, a significantly longer Empty Bed Contact Time is required.

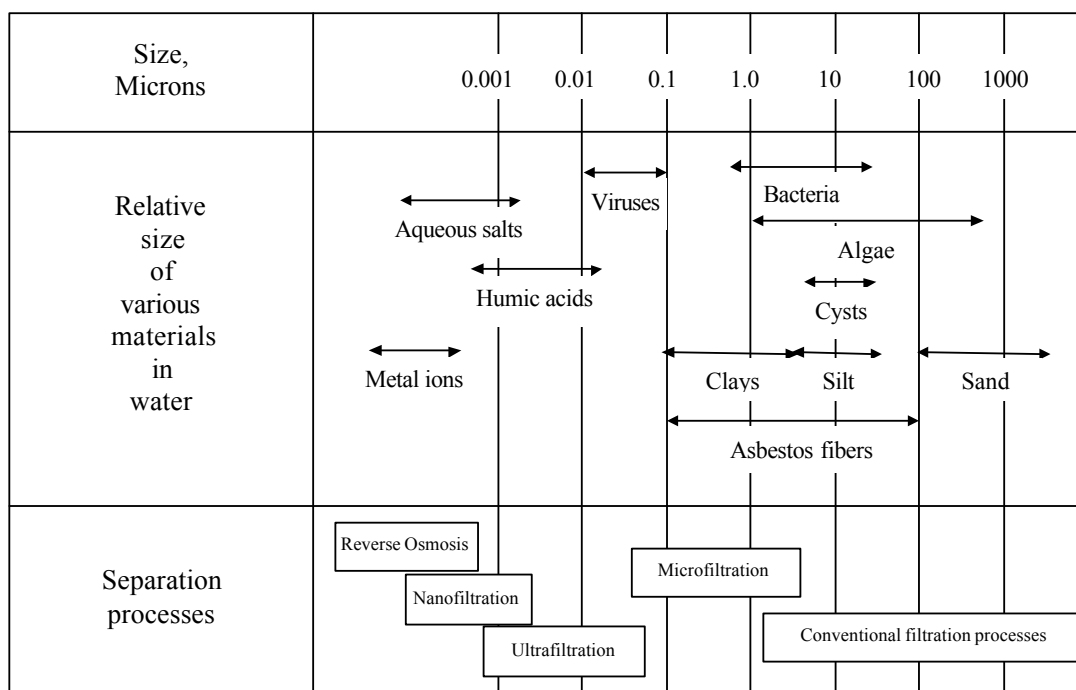
### **Membrane Methods**

Synthetic membranes are available which are selectively permeable: the structure of the membrane is such that some molecules can pass through, while others are excluded, or rejected. Membrane filtration has the advantage of removing many contaminants from water, including bacteria, salts, and various heavy metals.

Two classes of membrane filtration can be considered: low-pressure membranes, such as microfiltration and ultrafiltration; and high-pressure membranes such as nanofiltration and reverse osmosis. Low-pressure membranes have larger nominal pore sizes, and are operated at pressures of 10-30 psi. The tighter high-pressure membranes are typically operated at pressures from 75 to 250 psi, or even higher (Letterman, 1999).

From Figure 2, it is clear that reverse osmosis (RO) and nanofiltration (NF) membranes have pore sizes appropriate for removal of dissolved arsenic, which is in the 'metal ion' size range. Both RO and NF membranes are most often operated in lateral configurations, in which only a small amount of the raw water (10-15%) passes through the membrane as permeate. In household systems, where only a small amount of treated water is required for cooking and drinking, this low recovery rate may be acceptable. Municipal systems achieve higher recovery rates (80 to over 90%) by using multiple membrane units in series.

In recent years, a new generation of RO and NF membranes have been developed that are less expensive and operate at lower pressures, yet allow improved flux and are capable of efficient rejection of both arsenate and arsenite. Waypa and others have showed that some of the new membranes, operated at pressures ranging from 40-400 psi, were able to reject from 96-99% of both arsenate and arsenite in spiked natural waters. The authors attribute this rejection of arsenite to the relatively large molecular weight of both arsenate and arsenic, rather than charge repulsion. At these high arsenic rejection rates, membrane filtration can result in extremely low arsenic levels in treated water.



**Figure 2 : Pore size of various membranes, and size of materials subject to filtration (Redrawn after Letterman, 1999)**

Arsenic removal was found to be independent of pH and the presence of co-occurring solutes, but was somewhat improved at lower temperatures. Interestingly, the NF membrane tested performed comparably to the RO membranes, even though the operating pressure was much lower (40-120 psi, compared to 200-400 psi) (Waypa et al., 1997). Membrane filtration requires a relatively high-quality influent water. Membranes can be fouled by colloidal matter in the raw water, particularly organic matter. Iron and manganese can also lead to scaling and membrane fouling. To prevent fouling, reverse osmosis filters are almost always preceded by a filtration step.

Membrane filtration has the advantage of lowering the concentrations of many other components in addition to arsenic. Even ultrafiltration (UF) membranes are able to remove over 99.9% of bacteria, *Giardia* and viruses. Also, the membrane itself does not accumulate arsenic, so disposal of used membranes would be simple. Operation and maintenance requirements are minimal: no chemicals need be added, and maintenance would consist of ensuring a reasonably constant pressure, and periodically wiping the membrane clean. The main disadvantages are low water recovery rates (typically only 10-20% of the raw water passes through the membrane), the need to operate at high pressures,

relatively high capital and operating costs, and the risk of membrane fouling. Also, particularly with RO, the treated water has very low levels of dissolved solids, and can be very corrosive, and deficient in minerals which can be important micronutrients for humans.

### **Emerging Technologies**

In recent years, a tremendous amount of research has been conducted to identify novel technologies for arsenic removal, particularly low-cost, low-tech systems that can be applied in rural areas. Most of these technologies rely on oxidation of arsenite, followed by filtration through some sort of porous material, where arsenic is removed through adsorption and coprecipitation. Many of these systems make use of iron compounds, which have a very strong affinity for arsenic. A brief review of some of the most documented technologies is given below.

#### ***Fe-Mn Oxidation***

Conventional iron and manganese removal can result in significant arsenic removal, through coprecipitation and sorption onto ferric or manganic hydroxides. The mechanisms involved are the same as in coagulation and filtration. Most low-cost technologies for arsenic and manganese removal rely on aeration and filtration through porous media such as sand and gravel. Any technology that effectively removes iron and manganese could be evaluated to see if arsenic is also removed effectively. In this respect arsenic removal is more convenient than that of fluoride, which does not undergo oxidation, and is not removed by coprecipitation with iron.

In Bangladesh and West Bengal, elevated arsenic concentrations are often associated with high iron and manganese levels. One survey in Bangladesh found that over 80% of arsenic-affected tubewells ( $>50 \mu\text{g/L}$ ) also contained iron levels of 2 mg/L or more. However, iron alone is not a good indicator of arsenic: 30% of the wells with safe levels of arsenic also had 2 mg/L iron or more (DPHE/BGS/MML, 1999). Because of the link between arsenic and iron levels, and the affinity of arsenic for iron hydroxides, there have been calls for a simple solution to arsenic contamination: simple storage of pumped water to allow iron to settle out, scavenging arsenic in the process. While this is an appealing idea, successful application of this type of 'passive Fe-Mn oxidation' is not simple, for several reasons:

- iron removal is not always easily accomplished. Some waters contain iron in a form that is slow to oxidize, or may be complexed with organic material that impedes oxidation and filtration. Precipitation may not occur if alkalinity is low;
- without a filtration step, much of the iron can remain suspended as

colloidal matter, even after oxidation;

- arsenite is not as strongly bound to iron as arsenate, if the waters contain mostly arsenite arsenic removal will be less efficient; and
- when water is stored in household containers, there is a high risk of bacterial contamination.

When considering passive Fe-Mn oxidation, particularly at the household level, careful pilot studies should be made using the local waters and local storage conditions, in order to assess the effectiveness of this technique, and the possibility of pathogenic contamination. It should be noted that chlorine addition would improve oxidation of both iron and arsenic, and would provide protection against bacterial growth. However, as discussed above, chlorination at the household level involves difficulties in ensuring the correct dose, and the potency of the chlorine agent.

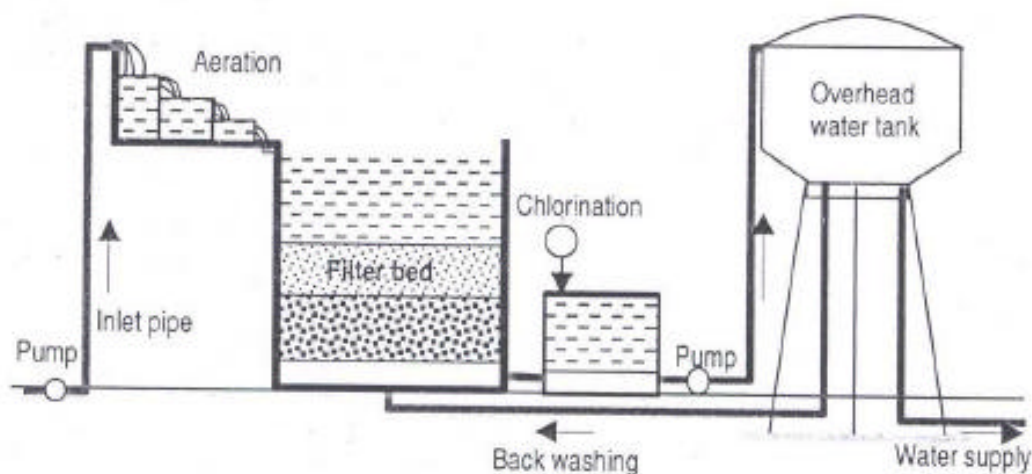
With support from the Dutch Government, the Department of Public Health Engineering of Bangladesh has constructed three arsenic removal plants in small municipalities. These plants are basically iron removal plants, and add no chemicals, but pump groundwater over a series of cascades to aerate the water. Filtration then removes the resulting iron and arsenic precipitate, and the water is chlorinated and stored in an elevated tank for distribution. Water stored in the tank is periodically used to backwash the filters. The waste water is stored in sludge ponds, and sludge is removed once or twice annually. Arsenic removal efficiency varies considerably, and seems to improve with higher iron levels:

**Table 1 : Arsenic Removal in Three 18-DTP Plants**

Municipality	Influent iron (mg/L)	Iron removal efficiency (%)	Influent arsenic ( $\mu\text{g/L}$ )	Arsenic removal efficiency (%)
Satkira Razzak	3.4	95	57.0	51
Satkira Polash	5.8	95	67.5	67
Manikganj	7.6	99	84.8	72

Source: (18-DTP, 1999)

Although removal rates are not very high, in all cases it is effective enough to bring waters into compliance with the Bangladesh drinking water standard of 50  $\mu\text{g/L}$ . Plant managers experimented with addition of coagulants (4 mg/L  $\text{FeCl}_3$ ) and oxidants (0.9 mg/L bleaching powder), but found that arsenic removal efficiency was not significantly improved.



Source: (Ahmed and Rahman, 2000)

**Figure 3 : 18-DTP Arsenic Removal Plant**

### ***Sorption onto other metal oxides***

Besides activated alumina, other metal oxides have strong affinities for arsenic, and can serve as effective sorbents, and in some cases as oxidants. Quartz is very poor at removing arsenic under most environmental conditions, because the mineral surface is negatively charged above a pH of 2. However, quartz sand, or indeed any other granular media, can be made highly sorptive by coating the grains with metal oxides. In recent years many researchers have used this principle to develop low-cost arsenic removal methods using locally available materials. Vaishya showed that sand from the Ganges river, which presumably is rich in iron coatings, could remove arsenite from solution, with a reported capacity of 0.024 mg/g. Removal was found to be pH-dependent, and best from pH 7-9 (Vaishya and Agarwal, 1993). Joshi and Chaudhuri showed that iron oxide coated sand (IOCS) is able to remove both arsenite and arsenate. A simple fixed bed unit was able to treat about 160-190 bed volumes of water containing 1000 µg/L arsenite and 150-165 bed volumes of water with 1000 µg/L arsenate. Flushing with 0.2 N sodium hydroxide regenerates the media. The authors propose that this media would be very useful for domestic arsenic removal units (Joshi and Chaudhuri, 1996).

A similar coated sand material can be prepared using manganese dioxide instead of iron. Since MnO<sub>2</sub> is a good oxidant, this material can remove arsenite as well as arsenate. In fact, the treated sand was able to remove 80% of a 1 mg/L solution of arsenite within two hours, but slightly less than 70% of an equivalent solution of arsenate. A prototype household unit was developed, which could treat about 150 bed volumes of 1 mg/L arsenic (half arsenite and half arsenate)

before breakthrough (Bajpai and Chaudhuri, 1999).

Greensand is a granular material composed of the mineral glauconite, which has been coated with manganese oxide. It is a natural zeolite, and has strong ion exchange properties, and will remove iron, manganese, arsenic, sulfide, and many other anions. Like manganese dioxide coated sand, greensand surface is strongly oxidizing, and is thus able to remove both arsenite and arsenate. The media is typically recharged by application of potassium permanganate, which not only reestablishes the oxidizing environment, but deposits a fresh layer of manganese oxide on grain surfaces (Ficek, 1996). Viraraghavan and others showed that greensand could reduce arsenite levels from 200  $\mu\text{g/L}$  by about 40% in the absence of iron. When ferrous iron was also present, arsenite removal improved to above 80% (Subramanian et al., 1997; Viraraghavan et al., 1999). Little information is available about the capacity of greensand for arsenic removal, or the effects of pH or competing anions on arsenic removal.

Several proprietary iron-based adsorption materials have been developed recently. Granular ferric hydroxides are being used in full scale systems in Germany (Driehaus et al., 1998), and similar materials have been developed in Canada and the United States. These materials generally have high removal efficiency and capacity.

### ***Sorption onto reduced metals***

Most of the above processes rely on arsenate adsorption onto surfaces of metal oxides. However, arsenic also has a strong affinity to reduced metal surfaces, such as sulfides. A few researchers have taken advantage of this property to remove arsenic through reduction and sorption.

Lackovic and others have demonstrated that zero-valent iron filings can be used either in situ or ex situ to reduce arsenate, and produce ferrous iron. The ferrous ions precipitate out with sulfide, which is also added to the system. Arsenite is removed either through coprecipitation or adsorption onto pyrite. This system is promising for use in rural areas, because of the low cost of materials, and the simple operation. However, treated water is very high in ferrous iron, and must undergo iron removal treatment before distribution or consumption (Lackovic et al., 2000).

A similar system using zero-valent iron to treat water stored in individual homes was tested in Bangladesh and West Bengal (the so-called: three kolshi filter). Arsenic removal was approximately 95% for highly contaminated waters, containing 2000  $\mu\text{g/L}$  arsenic in the presence of sulfate at pH 7. Removal is rapid, but if batches are left for too long, dissolved iron concentrations become unacceptably high (Ramaswami et al., 2000).

### ***Ion exchange and adsorption***

Ion exchange resins developed for removal of anions such as sulfate and nitrate have proven to be reasonably effective at removing arsenic, as discussed above. As materials engineering becomes more advanced, researchers are increasingly able to design novel ion-exchange materials with surficial properties that are particularly specific to arsenate. In particular, several researchers have found that copper-doped materials have a strong, specific affinity for arsenate (e.g. Rajakovic and Mitrovic, 1992; Ramana and Sengupta, 1992; Lorenzen et al., 1995). Fryxell and others have developed a novel mesoporous silica sorbent which makes use of Cu(II)-based functional groups. This material has a higher ion exchange capacity (75 mg As/g) than conventional resins, and shows a stronger affinity for arsenate and chromate than for sulfate or nitrate. Therefore, unlike the conventional resins, these materials will not release chromatographic peaks of arsenic when exposed to high levels of sulfate (Fryxell et al., 1999).

While conventional synthetic ion exchange resins are the most commonly used media in ion exchange, costs are relatively high (\$USD 2-5 per liter of wet resin). A variety of naturally occurring materials also have high ion exchange capacities, sometimes after chemical pretreatment. Many of these materials are not pure ion exchangers: some arsenic removal is through less reversible chemisorption. Especially in developing countries, researchers have been evaluating the potential of these materials for use as low-cost arsenic removal systems.

Zeolites are naturally occurring minerals with a crystalline structure characterized by large internal pore spaces. Accordingly, they have very large surface areas, and ion exchange capacities: zeolites were used extensively for water softening, before the development of synthetic resins with faster exchange rates, higher capacity, and longer life. A few arsenic removal studies have been conducted with zeolites.

Natural zeolite minerals such as clinoptilolite and chabazite have a strong affinity for both arsenite and arsenate. A chabazite filter was able to remove 1000 µg/L arsenate from over 235 bed volumes before arsenic was detected in the effluent (Bonnin, 1997). Adsorption of arsenate onto natural zeolites can be improved by organically modifying the zeolite structure (Misaelides et al., 1998).

Chitosan and chitin are natural polyaminosaccharides occurring in crustacean shells, that have good ion exchange properties. Shellfish wastes containing chitosan have been used to remove arsenic from water contaminated by mining wastes (Luong and Brown, 1984). Elson and others investigated a mixture of chitosan and chitin, and found a relatively low arsenic removal capacity of about 0.01 mg As/g (Elson et al., 1980).

### ***In Situ arsenic immobilization***

When arsenic is mobilized in groundwater under reducing conditions, it is possible to immobilize the arsenic by creating oxidized conditions in the subsurface. In Germany, in order to remediate an aquifer containing high-arsenite, high ferrous iron, low-pH groundwater, Matthes injected 29 tons of potassium permanganate directly into 17 contaminated wells, oxidizing arsenite, which coprecipitated out with ferric oxides. Mean arsenic concentrations were reduced by over 99%, from 13,600 to 60  $\mu\text{g/L}$  (Matthes, 1981). More recently, atmospheric oxygen was used to reduce arsenic concentrations *in situ* from approximately 20 to 5  $\mu\text{g/L}$ , while iron and manganese levels were also lowered (Rott and Friedle, 1999). Under reducing conditions, and in the presence of sulfur, arsenic can precipitate out of solution and form relatively insoluble arsenic sulfides.

*In situ* immobilization has the great advantage of not producing any wastes that must be disposed of. However, experience is limited, and the technique should be considered with caution. Oxidants are by definition reactive compounds, and may have unforeseen effects on subsurface ecological systems, as well as on the water chemistry. Care must also be taken to avoid contaminating the subsurface by introducing microbes from the surface. Also, at some point pore spaces can become clogged with precipitates, particularly if dissolved iron and manganese levels are high in the untreated water.

## **SUMMARY**

The Table 2 summarizes some of the key technologies for arsenic removal, with special reference to experiences gained from field level application. Research needs are also identified. Arsenic removal efficiency will vary according to many site-specific chemical, geographic, and economic conditions, so actual applications may vary from the generalizations listed below. Because of the many factors that can affect arsenic removal efficiency (including arsenic concentration, speciation, pH and co-occurring solutes), any technology should be tested using the actual water to be treated, before implementation of arsenic removal systems at the field scale.



**Table 2 : Summary of Technologies for Arsenic Removal**

Technology	Removal Efficiency		Institutional experience and issues
	As (III)	As (V)	
Coagulation with iron salts	++	+++	Well proven at central level, piloted at community and household levels. Phosphate and silicate may reduce arsenic removal rates. Generates arsenic-rich sludge. Relatively inexpensive.
Coagulation with alum	-	+++	Proven at central level, piloted at household levels. Phosphate and silicate may reduce arsenic removal rates. Optimal over a relatively narrow pH range. Generates arsenic-rich sludge. Relatively inexpensive
Lime softening	+	+++	Proven effective in laboratories and at pilot scale. Efficiency of this chemical process should be largely independent of scale. Chiefly seen in central systems in conjunction with water softening. Disadvantages include extreme pH and large volume of waste generated. Relatively inexpensive, but more expensive than coagulation with iron salts or alum because of larger doses required, and waste handling.
Ion exchange resins	-	+++	Pilot scale in central and household systems, mostly in industrialized countries. Interference from sulfate and TDS. High adsorption capacity, but long-term performance of regenerated media needs documentation. Waters rich in iron and manganese may require pre-treatment to prevent media clogging. Moderately expensive. Regeneration produces arsenic-rich brine.
Activated alumina	+/ ++	+++	Pilot scale in community and household systems, in industrialized and developing countries. Arsenite removal is poorly understood, but capacity is much less than for arsenate. Regeneration requires strong acid and base, and produces arsenic-rich waste. Long-term performance of regenerated media needs documentation. Waters rich in iron and manganese may require pre-treatment to prevent media clogging. Moderately expensive.
Membrane methods	-/ +++	+++	Shown effective in laboratory studies in industrialized countries. Research needed on removal of arsenite, and efficiency at high recovery rates, especially with low-pressure membranes. Pretreatment usually required. Relatively expensive, especially if operated at high pressures.
Fe-Mn oxidation	?	+/ ++/ +++	Small-scale application in central systems, limited studies in community and household levels. More research needed on which hydrochemical conditions are conducive for good arsenic removal. Inexpensive.
Porous media sorbents (iron oxide coated sand, greensand, etc.)	+/ ++	++/ +++	Shown effective in laboratory studies in industrialized and developing countries. Need to be evaluated under different environmental conditions, and in field settings. Simple media are inexpensive, advanced media can be relatively expensive.

Technology	Removal Efficiency		Institutional experience and issues
	As (III)	As (V)	
In-situ immobilization	++	+++	Very limited experience. Long-term sustainability and other effects of chemical injection not well documented. Major advantage is no arsenic-rich wastes are generated at the surface, major disadvantage is the possibility of aquifer clogging. Should be relatively inexpensive.

Key:+++ Consistently > 90% removal  
 ++ Generally 60 – 90% removal  
 + Generally 30 – 60% removal  
 - < 30% removal  
 ? Insufficient information

## REFERENCES

- 18-DTP 1999 *Arsenic in 18-DTP*, 18 District Town Project, Dhaka, December 1999.
- Ahmed, M. and Rahman, M.M. 2000 *Water Supply and Sanitation - Rural and Low-Income Urban Communities*, ITB-Bangladesh Centre for Water Supply and Waste Management, Dhaka, Bangladesh.
- Bajpai, S. and Chaudhuri, M. 1999 “Removal of arsenic from ground water by manganese dioxide-coated sand.” *Journal of Environmental Engineering*, 125(8), 782-784.
- Bellack, E. 1971 “Arsenic removal from potable water.” *Journal of the American Water Works Association*, 63(7), 454.
- Bonin, D. 1997 *Arsenic removal from water utilizing natural zeolites*. Proceedings, AWWA Annual Conference. American Water Works Association, Denver, CO.
- Buswell, A.M. 1943 “War problems in analysis and treatment.” *Journal American Water Works Association*, 35(10), 1303.
- Chen, H.-W., Frey, M.M., Clifford, D., McNeill, L.S. and Edwards, M. 1999 “Arsenic treatment considerations.” *Journal of the American Water Works Association*, 91(3), 74-85.
- Cheng, R.C., Liang, S., Wang, H.C. and Beuhler, M.D. 1994 “Enhanced coagulation for arsenic removal.” *Journal of the American Water Works Association*, 86(9), 79-90.
- Clifford, D. 1986 “Removing dissolved inorganic contaminants from water.” *Environmental Science and Technology*, 20, 1072-1080.
- Clifford, D. 1999 Ion exchange and inorganic adsorption. In: A. Letterman [Ed.] Water Quality and Treatment, American Water Works Association, McGraw Hill, New York.

- Clifford, D. and Majano, R. 1993 "Computer prediction of ion exchange." *Journal of the American Water Works Association*, 85(4), 20.
- DPHE/BGS/MML 1999 *Groundwater Studies for Arsenic Contamination in Bangladesh. Phase 1: Rapid Investigation Phase, Final Report*. Report prepared for the Department of Public Health Engineering by Mott MacDonald Ltd. and British Geological Survey under assignment from the Department for International Development (UK), Department of Public Health Engineering, Government of Bangladesh, British Geological Survey and Mott MacDonald Ltd. (UK), Dhaka, Bangladesh.
- Driehaus, W., Jekel, M. and Hildebrandt, U. 1998 "Granular ferric hydroxide; a new adsorbent for the removal of arsenic from natural water." *Aqua*, 47(1), 30-35.
- EAWAG 1999 "SODIS." <http://www.sodis.ch/>, Access Date January, 2000.
- Edwards, M. 1994 "Chemistry of arsenic removal during coagulation and Fe-Mn oxidation." *Journal of American Water Works Association*, 86(9), 64-78.
- Edwards, M., Patel, S., McNeill, L., Chen, H.-W., Frey, M., Eaton, A.D., Antweiler, R.C. and Taylor, H.E. 1998 "Considerations in arsenic analysis and speciation." *Journal of the American Water Works Association*, 90(3), 103-113.
- Elson, C., Davies, D. and Hayes, E. 1980 "Removal of arsenic from contaminated drinking water by a chitosan/chitin mixture." *Water Resources*, 14, 1307.
- Emett, M.T. and Khoe, G.H. 2001 "Photochemical oxidation of arsenic by oxygen and iron in acidic solutions." *Water Research*, 35(3), 649-656.
- Ficek, K.J. 1996 "Remove heavy metals with greensand/permanganate." *Water Technology*, 19(4), 84-88.
- Ficklin, W.H. 1983 "Separation of As(III) and As(V) in groundwaters by ion-exchange." *Talanta*, 30(5), 371.
- Fox, K.R. 1989 "Field experience with Point-of-Use treatment systems for arsenic removal." *Journal of the American Water Works Association*, 81(2), 94-101.
- Frank, P. and Clifford, D. 1986 *Arsenic(III) oxidation and removal from drinking water*. EPA-600/S2-86/021, USEPA, Washington.
- Fryxell, G.E., Liu, J., Hauser, T.A., Nie, Z., Ferris, K.F., Mattigod, S., Gong, M. and Hallen, R.T. 1999 "Design and synthesis of selective mesoporous anion traps." *Chemical Materials*, 11, 2148-2154.
- Ghurye, G., Clifford, D. and Tripp, A. 1999 "Combined arsenic and nitrate removal by ion exchange." *Journal of the American Water Works Association*, 91(10), 85-96.
- Ghurye, G. and Clifford, D. 2000 *Laboratory study on the oxidation of As III to As V*. Proceedings, AWWA Water Quality Technology Conference.
- Gupta, S. and Chen, K. 1978 "Arsenic removal by adsorption." *J. Water Poll.*

*Contr. Fed.*, 50, 493-506.

- Hering, J.G., Chen, P.Y., Wilkie, J.A., Elimelech, M. and Liang, S. 1996 "Arsenic removal by ferric chloride." *Journal American Water Works Association*, 88(4), 155-167.
- Hering, J.G., Chen, P.-Y., Wilkie, J.A. and Elimelech, M. 1997 "Arsenic removal from drinking water during coagulation." *Journal of Environmental Engineering*, 123(8), 800-807.
- Jekel, M.R. 1994 Removal of arsenic in drinking water treatment. In: J. O. Nriagu [Ed.] Arsenic in the Environment, Part I: Cycling and Characterization, John Wiley & Sons, Inc., New York.
- Joshi, A. and Chaudhuri, M. 1996 "Removal of arsenic from ground water by iron oxide-coated sand." *Journal of Environmental Engineering*, 122(8), 769-772.
- Kim, M.-J. and Nriagu, J. 2000 "Oxidation of arsenite in groundwater using ozone and oxygen." *Science of the total environment*, 247, 71-79.
- Lackovic, J.A., Nikolaidis, N.P. and Dobbs, G. 2000 "Inorganic arsenic removal by zero-valent iron." *Environmental Engineering Science*, 17(1), 29-39.
- Letterman, A. [Ed.] 1999 *Water quality and treatment: a handbook of community water supplies*. American Water Works Association, McGraw-Hill, New York.
- Lorenzen, L., Vandeventer, J. and Landi, W. 1995 "Factors Affecting The Mechanism Of The Adsorption Of Arsenic Species On Activated Carbon." *Minerals Engineering*, 8(4-5), 557-569.
- Luong, H.V. and Brown, E.J. 1984 Removal of arsenic from contaminated water with partially deacetylated shellfish waste. NTIS PB85-214716/AS, USGS, September.
- Matthess, G. 1981 "In situ treatment of arsenic contaminated groundwater." *Science of the Total Environment*, 21(99), 99-104.
- Misaelides, P., Nikashina, V.A., Godelitsas, A., Gembitskii, P.A. and Kats, E.M. 1998 "Sorption of As(V)-anions from aqueous solutions by organo-modified natural zeolitic materials." *Journal of Radioanalytical and Nuclear Chemistry*, 227(1-2), 183-186.
- Nieminski, E. and Evans, D. 1995 "Pilot testing of trace metals removal with ozone at Snowbird Ski Resort." *Ozone Science Engineering*, 17(3), 297-309.
- Rajakovic, V. and Mitrovicm, M. 1992 "Arsenic removal from water by chemisorption filters." *Environmental Pollution*, 75(3), 279-287.
- Ramana, A. and Sengupta, A. 1992 *Journal of Environmental Engineering*, 118, 755.
- Ramaswami, A., Isleyen, M. and Tawachsupa, S. 2000 *Zero-valent iron for treatment of high arsenic water*. Proceedings, 4th International Conference on Arsenic Exposure and Health Effects. SEGHS, San Diego, CA.
- Rashid, H. 1991 "Geography of Bangladesh." 2nd ed., University Press, Dhaka.

- Rosenblum, E. and Clifford, D. 1984 *The equilibrium capacity of activated alumina*. EPA-600/S2-83-107, USEPA, Washington.
- Rott, U. and Friedle, M. 1999 Eco-friendly and cost-efficient Removal of Arsenic, Iron and Manganese by means of Subterranean Groundwater Treatment. Proceedings, IWSA XXII World Congress and Exhibition, Buenos Aires, Argentina.
- Rubel, F.J. and Woosely, R.D. 1979 "The removal of fluoride from drinking water by activated alumina." *Journal of the American Water Works Association*, 71(1), 45-48.
- Sancha, A.M. 1999b *Removal of arsenic from drinking water supplies*. Proceedings, IWSA XXII World Congress and Exhibition, Buenos Aires, Argentina.
- Sorg, T.J. and Logsdon, G.S. 1978 "Treatment technology to meet the interim primary drinking water regulations for inorganics: part 2." *Journal of the American Water Works Association*, 70(7), 379-393.
- Subramanian, K.S., Viraraghavan, T., Phommavong, T. and Tanjore, S. 1997 "Manganese greensand for removal of arsenic in drinking water." *Water Quality Research Journal of Canada*, 32(3), 551-561.
- Trussell, R.R., Trussell, A. and Kreft, P. 1980 *Selenium removal from groundwater using activated alumina*. 600/2-80-153, USEPA, Cincinnati, OH.
- Vaishya, R.C. and Agarwal, I.C. 1993 "Removal of arsenic(III) from contaminated ground waters by Ganga sand." *Journal of Indian Water Works Association*, 25(3), 249-253.
- Viraraghavan, T., Subramanian, K. and Aruldoss, J. 1999 "Arsenic in drinking water - Problems and solutions." *Water Science and Technology*, 40(2), 69-76.
- Waypa, J., Elimelech, M. and Hering, J. 1997 "Arsenic removal by RO and NF membranes." *Journal of the American Water Works Association*, 89(10), 102-114.

# **Arsenic Removal Processes on Trial in Bangladesh**

**Nahid Sharmin**

Department of Chemical Engineering,  
Bangladesh University of Engineering and Technology, Dhaka 1000, Bangladesh

## ***Abstract***

*Arsenic in groundwater is present in excess of the safe limit set for Bangladesh. It is now recognized that arsenic is a serious health hazard. It reviews some of the arsenic removal technologies being tried and tested in Bangladesh.*

## **INTRODUCTION**

The rural people of Bangladesh are mostly dependent on hand tubewells for drinking water. The groundwater was, in the past, considered to be a source of safe drinking water. Unfortunately it is now established that this water contains arsenic at concentrations higher than the safe limit set for drinking purpose. This paper reviews some of the arsenic removal technologies so far tried and tested in Bangladesh.

## **DRINKING WATER IN RURAL BANGLADESH**

Until 1970s most rural people obtained and consumed water from the hand-dug wells, ponds, rivers or canals. These waters were usually consumed directly without any treatment. So epidemics of diarrhea and other water-borne diseases were very common. Hundreds of people particularly the infants died only because of drinking these unsafe waters. The idea of tapping groundwater, which seemed to be clean, plentiful and pathogen-free under anaerobic condition, was accepted and hand tubewells were considered reliable means for extracting

groundwater at an affordable cost. Approximately 90 percent of the rural population of Bangladesh get their drinking water from around 4-5 million tubewells that have been sunk over the last 30 years.

## DRINKING WATER STANDARDS

Table 1 lists the standards set for drinking water by USEPA, WHO and Bangladesh. The standard set by Bangladesh is less stringent in respect of parameters such as iron, chloride, hardness, sulfate, TDS and Arsenic. Canada and other countries have set 0.01 ppm limit for Arsenic.

**Table 1: Drinking water quality standards**

Parameter	USEPA (2000) (mg/l)	WHO (1993) (mg/l)	Bangladesh (GoB, 1997) (mg/l)
pH	6.5-8.5	7-8.5	6.5-8.5
Iron	0.3	0.3	0.3-1.0
Chloride	250	250	150-600
Hardness (as CaCO <sub>3</sub> )	100-500	-	200-500
Sulfate	250	250	400
Manganese	0.1	0.05	0.1
Fluoride	2.0	1.5	1.0
Nitrate	10	50	10
Arsenic	0.01	0.01	0.05
TDS	400-500	1000	1000

## ARSENIC IN DRINKING WATER IN BANGLADESH AND RELATED PROBLEMS

DPHE in 1993 detected arsenic in groundwater at Barogharia of Chapai Nawabganj district (the western part of Bangladesh) following reports of extensive contamination of groundwater by arsenic in West Bengal, India. As per the latest statistics, out of 64 districts groundwater of 59 districts in Bangladesh contains arsenic. And out of these 59 districts worst affected parts of Bangladesh are the southern and the northeastern districts (DPHE/BGS, 1999). The access to safe drinking water in Bangladesh has declined by 17 percent in last three years due to the presence of arsenic in groundwater.

Arsenic is a cumulative substance, which slowly passes out of the body through the urine, hair, fingernails/toe nails, and skin. It takes around 8-14 years after starting to drink arsenic contaminated water for symptoms to appear. This period depends on the amount of arsenic ingested, the length of exposure and immunity level of the person. Symptoms of the initial stage of the disease are skin pigmentation, eye infections, trachea and cancer. Although arsenicosis, the disease caused by arsenic contamination, is not an infectious, contagious or hereditary, it creates social problems for the victims and their families.

### **ARSENIC REMOVAL TECHNOLOGIES BEING TRIED IN BANGLADESH**

Technologies for removal of arsenic from drinking water already exist as incidences of arsenic contamination in groundwater have already been reported from various parts of the world. The removal technology usually relies on its very strong adsorption to iron and aluminum oxides, and if sufficient of these are added, the arsenic concentration can be reduced to a level as low as the standard set for Bangladesh.

Several technologies are currently being promoted for application in Bangladesh. They claim to be effective in removing arsenic from tubewell water. These are all new and in development stage. The effectiveness, viability and sustainability of the technologies under field conditions in Bangladesh are yet to be ascertained before their adoption and scale-up thereof. Some of the technologies so far tried both in laboratory and at field level are discussed below.

Auto-attenuation, which needs collection of groundwater from the wells and allowing it stand for a specific period of time, was tried in Rajshahi and Meherpur. Groundwater having high concentration of dissolved iron, is readily oxidized and forms ferric precipitates. The auto-oxidation of  $Fe^{2+}$  to  $Fe^{3+}$  generates favorable substrate with surface reactive sites for the adsorption of uncharged As(III) as well as anionic As(V) species. The test result showed that it needs further modifications for high-arsenic groundwater.

Nikolaidis et al. (1997) suggested a simple filter, which is a tube filled with sand and iron fillings (zero-valent iron) and is designed to fit in a well outlet. It can be an effective low-cost tool.  $BaSO_4$  is to be added if not present in water. In the presence of  $BaSO_4$ , iron oxidizes and reacts with arsenic to form arsenopyrite that precipitates out and remains trapped in the filter. Laboratory experiments show 97% removal for initial arsenic concentration of 45 to 8600  $\mu\text{g/l}$ .

Joshi and Chowdhury (1996) developed a home arsenic removal unit using iron-coated sand. The unit was able to produce 600 – 700 l of water at a flow rate of 6 l/h maintaining an arsenic concentration of 0.01 mg/l for an initial arsenic concentration of 1.0 mg/l.



Parknikar (1998) describes two types of metal-microbiological interactions that can be used for arsenic removal: i) microbial oxidation of As(III) to As(V) and its subsequent precipitation, and ii) bio-accumulation of arsenic by microbial biomass. The oxidation method can be operated in an immobilized reactor reservoir. A cheap source of organic substrate like sugarcane juice can be added along with iron fillings (Panikar, 1998). Iron fillings promote development of iron – oxidizing bacteria that oxidize iron at a rate  $50 \times 10^3$  times faster than chemical oxidation of iron. Arsenic is then adsorbed on the ferric iron. Treated overflow of water typically contain arsenic  $< 0.05$  mg/l for initial concentration up to 4.0 mg/l.

Lehimans et al. (1998) conducted pilot studies to adopt biological filtration for removal of As(III), the oxidation state where arsenic is the most delicate to treat. For concentration as high as 400  $\mu\text{g/l}$ , upto 90% reduction was achieved. An initial level of 75  $\mu\text{g/l}$  even allows a final concentration below 10  $\mu\text{g/l}$ . In addition, complete iron removal was achieved. They conclude that under optimized pH, temperature and oxygenation condition and with a sufficient initial iron concentration, biological filtration allows simultaneous elimination of As(III) and iron.

SORAS is a simple method that uses irradiation of water with sunlight in PET or other UV transparent bottles to reduce arsenic level from drinking water (Wegelin et al., 2000). The process is developed by Swiss Federal Institute of Environmental Science and Technology, Switzerland and Swiss Agency for Development and Cooperation (SDC), Bangladesh. The method is based on photochemical oxidation of As (III) followed by precipitation or filtration of As (V) adsorbed on Fe (III) oxides. Field tests in Bangladesh show removal efficiency between 45-78% with an average of 67%. Concerning the Bangladesh guideline value of 50  $\mu\text{g/l}$ , SORAS can treat raw water having an arsenic concentration below 100 – 150  $\mu\text{g/l}$ .

Khair (1999) found Bijaypur clay from Mymensingh and processed cellulosic materials like delignified jute, bleached sawdust and pulped newspaper to be capable of adsorbing both As(III) and As(V) in solutions acidified with vinegar or hydrochloric acid. Iron (III) hydroxide-coated newspaper pulp in lab-scale adsorption filters coagulated arsenic. The material showed potential for use in small-scale home treatment units. Workable exposure length, flow rate and extractant volume demonstrated arsenic removal at least or even below 0.050 mg/l. The sludge was regenerated by sodium hydroxide elution.

Laterite has been tested as an adsorbent and proved to be a promising low-cost remedial technique to safeguard drinking water (Larsson et al., 1999). Laterite is vesicular clayey residuum occurring abundantly in the tropical regions. Adsorption experiments showed that the removal efficiency varied between 50 and 90% for 5 g of added laterite per 100 ml water under an

equilibrium period of 20 minutes (Larsson et al., 1999). Modification of laterite by treating with 0.01 M HNO<sub>3</sub> increased the adsorption capacity of laterite due to an increased specific surface area (Larsson et al., 1999).

Chatterjee et al. (1999) patented a filter and tablet system to remove arsenic from water. The tablet contains Fe<sup>3+</sup> salts, an oxidizing agent and activated charcoal. The filter was made by using fly ash, clay, charcoal etc. The system is made up of two jars. For 20 liter of water, using one tablet, 95 – 100% removal of arsenic was achieved.

Adsorbing Colloid Flotation (ACF) with ferric hydroxide as the co-precipitant, anionic surfactant sodium dodecyl sulfate (SDS) as the collector and nitrogen micro-bubbles has been shown to be effective in removing arsenic from low concentration of arsenic aqueous solution. When pH is in the range of 4 – 5, 99.5% arsenic removal efficiency can be achieved.

The Bucket Treatment Unit was developed by DPHE-Danida and is being under the Arsenic Mitigation Pilot Project. This project was launched in Lakshpur and Chaumuhini Pourashavas in the coastal region of Bangladesh. The system can treat any kind of tubewell water, regardless of the arsenic concentration, and to an arsenic level below Bangladesh's standard of 0.05 mg/l.

BCSIR (1999) has developed a low cost arsenic filter. The technology consists of adding a floc forming composition to the arsenic contaminated water followed by stirring and settling. The chemicals are composed of iron oxide, alum, activated charcoal and calcium carbonate, which are to be mixed in definite proportions, homogenized and micronized. After settling the water is passed through a filter bed composed of sand and some iron bearing minerals of definite particle size range, which are to be activated by suitable chemical and heat treatment. The dose of the floc forming composition depends on the extent of arsenic contamination. Water containing upto 2.7 ppm arsenic could be purified below safe limit set by WHO.

Project Earth Industries, USA, developed a arsenic removal unit which is used with a hand pump tube-well. The Unit was tested at Sonargaon, Naraynganj, where groundwater arsenic concentration is very high. The principal component of the Arsenic Removal Unit consists of an adsorption media. The removal mechanism involves adsorption of arsenic onto the media surface as tubewell water flows through it. Along with arsenic a number of other anions and cations (including iron) also get adsorbed on it.

Shin Nihon co. Ltd. of Japan developed a house holds arsenic removal unit, which is a cylindrical container made of plastic and fitted with a tap close to the bottom for outflow. The container is filled with READ-F adsorbent resin. The inlet of the tap is fitted with a screen to block the entry of the resin into the tap. The adsorbent is always kept under water to retain its effectiveness. This is an effective system in removing arsenic from drinking water containing a low level of iron.

Coolmart Water Purifier, Korea, developed another purification unit, which consists of a series of beds containing activated carbon, silver-activated carbon, bio-mineral sand, zeolite and silica sand through which water passes. A laboratory tests of the system shows that around 25 litres of water containing 300 ppb of arsenic and 0.1mg/l of iron could be treated by the purifier satisfying the Bangladesh drinking water standard for arsenic.

Allergy Environmental Research and Skin Care Institute (AARSCI), Integrated Quality and Environmental Management (IQM) etc. have developed simple cost effective filters. AARSCI used indigenous materials such as coconut coir, coconut shells and husk, along with small amount of alum to prepare the filter bed. IQM prepared the filtering bed using the clay pots, sunlight, air, iron, sand or ferrous salts and alum. Another filter developed by US company called Arsen: X filter, which has been tested successfully in the Sadar thana of Kishoreganj. This filter not only removed arsenic, but also reduced other contaminants including fluoride and lead and it can be safely land-filled or recycled as non hazardous material. 100 percent removal of arsenic from water is accompanied by a unique bonding of arsenic into molecular structure of the filter and therefore, it does not disassociate.

Tetrahedron has developed a filter medium based on anionic resin. The filter has already been tested successfully. They claimed that the bed can easily be regenerated using Sodium Chloride solution, which is available in our country and the filter can be used for ten years.

## CONCLUSIONS

To save millions of people from arsenic poisoning it is important to detect the arsenic concentration in groundwater and also to provide a suitable, user friendly and cost effective arsenic removal process for the rural people of Bangladesh. Unfortunately, the very first step towards prevention and arsenic testing is in great chaos. The instruments are expensive and require skilled person to operate. There is no licensing authority to supervise the testing procedure in Bangladesh. At present, very few laboratories can provide reliable result. On the other hand removal technologies so far tried for the rural people have potential but not tested thoroughly for adoption. Most of the rural people are illiterate. They developed the habit of drinking hand tubewells water during the last 30 years. So any change in their behavioral needs more friendly approach and technology.

## ACKNOWLEDGEMENT

The author gratefully acknowledges her gratitude to Dr. A. K. M. A. Quader, Professor of Chemical Engineering, Bangladesh University of Engineering and Technology for his encouragement during the preparation of this paper. The author is also grateful to the authority of Bangladesh Council of Scientific and Industrial Research (BCSIR), Dhaka for granting her study-leave in order to pursue her Ph.D. degree at BUET.

## REFERENCES

- BCSIR (1999), Report on arsenic contamination of groundwater of Bangladesh and its removal by flocculation and filtration method, Bangladesh Council of Scientific and Industrial Research, Dhaka, Bangladesh.
- Chatterjee, A., Das, D., Mandal, B. K., Chowdhury, T. R., Samanta, G. and Chakraborti, D. (1999), Arsenic in groundwater in six districts of West Bengal, India: The biggest arsenic calamity in the World. Part 1. Arsenic species in drinking water and urine of affected people. *Analyst*, 120, p. 643-650.
- DPHE/BGS (1999), Main Report. Groundwater studies for Arsenic contamination in Bangladesh. Phase-I, British Geological Survey, Mott MacDonald Ltd, UK, 1999
- DPHE-Danida (2000) Fourth Quarterly Progress report of DPHE-Danida Arsenic Mitigation Pilot Project in Noakhali, Bangladesh, February 2000.
- GoB (1997), Environment Conservation Regulation 1997, Government of Peoples' Republic of Bangladesh, 1997.
- Joshi, A. and Chaudhuri, M. (1996), "Removal of Arsenic from Ground Water by Iron Oxide-Coated Sand", *ASCE Journal of Environmental Engineering*, 122(8), p. 769-771.
- Khair, A. (1999), Arsenic removal from drinking water by low-cost materials, Paper presented at the International Conference on Arsenic in Bangladesh Groundwater: World's Greatest Arsenic Calamity, USA, February 27-28.
- Larsson, M., Leiss, A., Bhattacharya, P., Jacks, G. and Chatterjee, D (1999), Arseniferous groundwater in the Bengal Delta Plains: Appraisal of the low-cost remediation techniques, Paper presented at the International Conference on Arsenic in Bangladesh Groundwater: World's Greatest Arsenic Calamity, USA, February 27-28.
- Lehimans, G. F. et al. (1998), Use of biological processes for Arsenic removal (Available at <http://www.saur.co.uk/poster.html>).

- Nikolaidis, N. P., Lackovic, J. and Dobbs, G. (1997), Arsenic remediation technology – AsRT (Available at <http://www.eng2.uconn.edu/nikos/asrt-brochure.html>)
- Parknikar, K. M., (1998), Potential application of microbiological processes for the removal of arsenic from groundwater. A paper presented in the International Conference on Arsenic Pollution of Groundwater in Bangladesh: Causes, Effects and Remedies, February 8-12, Dhaka, Bangladesh.
- USEPA (2000) Drinking Water Quality Standards, United States Environmental Protection Agency (Available at <http://www.epa.gov/safewater/ars/arsenic/treat1.html>).
- Wegelin, M., Gechter, D., Hug, S., Mahmud, A., Motaleb, A. (2000) SORAS-a simple arsenic removal process (Available at [http://phys4.harvard.edu/~wilson/mitigation/SORAS\\_Paper.html](http://phys4.harvard.edu/~wilson/mitigation/SORAS_Paper.html)).
- WHO (1993) Guidelines for drinking-water quality, Second Edition, Volume 2, health criteria and other supporting information, WHO, Geneva

## Removal of Arsenic from Drinking Water by Precipitation, Adsorption or Cementation

**Robert G. Robins**

AquaMin Science Consortium, Lindfield, Australia,

**Tadahisa Nishimura**

Institute for Advanced Mineral Processing (IAMP),  
Tohoku University, Sendai, Japan.

**and**

**Pritam Singh**

Division of Science, Murdoch University, Perth Western ,Australia.

### *Abstract*

*The removal of arsenic from process solutions and effluents has been practised by the mineral process industries for many years. More recently, because of the recognition that arsenic at low concentrations in drinking water causes severe health effects, the technologies that have been used in the mineral industry are being applied to that situation. Removal of arsenic in process solutions can be accomplished for most present day product specifications but the stability of solid and liquid waste materials for long-term disposal or discharge may not meet the regulatory requirements of the future. In the case of drinking water treatment where the requirement is to reduce arsenic to a few parts per billion, the applicable technologies are limited. This paper mentions briefly the aqueous inorganic chemistry of arsenic and the most common methods that have been applied commercially in the mineral industry for arsenic removal, recovery, and disposal. Some techniques, which have been used only in the laboratory, or otherwise suggested as means of eliminating or recovering arsenic from solution, are also outlined. Low cost removal of arsenic from drinking water is likely to be confined to precipitation, adsorption or cementation, but the sludges created present stability concerns. This paper reviews some of the work done in relation*

*to the mineral industry where there is also application to drinking water. Disposal of stable residues is critical in both situations, and the testing methods for assessing stability need careful consideration.*

## INTRODUCTION

The material, which is mentioned only briefly in this paper, is discussed in greater detail in the publications cited in the paper. Although there are many other excellent relevant references the authors have chosen the papers with which they are most familiar, for convenience and reliability, and these are not necessarily the earliest chronological references. The references also relate mostly to literature on extractive metallurgy and not water treatment since we believe that this work has not been adequately cited by publications in the latter field. There are many statements in this paper originating from much unpublished work.

The various unit processes that have been considered to deal with arsenic in hydrometallurgical processes include: oxidation-reduction, precipitation and thermal precipitation, co-precipitation, adsorption, electrolysis and cementation, solvent extraction, ion exchange, membrane separations, precipitate and ion flotation, and biological processing. All of these methods are not considered here, but are detailed in some of the references at the end of this paper (Robins, 1985b, 1987b; Twidwell et al., 1999). Here we will consider only precipitation, adsorption and cementation, which are the processes that are more generally adopted, particularly in relation to drinking water in situations where costs must be given priority.

The aqueous solution chemistry of arsenic which relates to hydrometallurgical processes has been extensively covered in the literature, and the use of thermodynamic stability diagrams to describe the chemistry has been widely adopted (Nishimura et al., 1978, 1980, 1988, 1989, 1991, 1992, 1993; Robins, 1982, 1983, 1985b; Itoh et al., 1989). The important oxidation states of arsenic are -3, 0, +3, and +5, and all have been utilised in some way in hydrometallurgy. The removal of arsenic from solution has relied mostly on precipitation and adsorption processes and it has been considered that arsenic(V) is the oxidation state that leads to the most effective removal by precipitation since the simple metal arsenates generally have lower solubility than the arsenites. The general assumption that arsenic(V) is always more easily removed from solution is not correct. Current work has identified mixed oxidation state compounds and also the element and its alloys (formed by either cementation or electrolysis) to be appropriate low solubility materials. Arsenic complexation in solution has had little attention, and it seems that only complexes of arsenic(V) with iron(III) have been studied (Khoe and Robins, 1988; Robins, 1990). Oxidation of arsenic(III) in solution to arsenic(V), and reduction of arsenic(V) to arsenic(III) has been

investigated (Tozawa and Nishimura, 1976, 1984; Nishimura and Tozawa, 1988a, 1988b) as part of the overall chemistry relating to hydrometallurgy. Oxidants such as air and oxygen, chlorine and hypochlorite, hydrogen peroxide, permanganate, ozone, and  $\text{SO}_2/\text{O}_2$  have been investigated, both with and without catalysts. Photochemical oxidation of As(III) to As(V) is a recent innovation (Khoe et al., 2000; Zhang, et al., 2000; Emmett and Khoe, 2001). The removal of arsenic from gold process solutions has been of understandable interest over the years, and has perhaps been investigated more than for other hydrometallurgical processes (Robins and Tozawa, 1982; Robins, 1984; Robins and Jayaweera, 1992; Nishimura and Robins, 2000).

## PRECIPITATION

The insolubility of certain inorganic arsenic(V) compounds is the basis of many hydrometallurgical arsenic removal processes, and the insoluble product is often a disposal material. The most common methods of removing arsenic from aqueous process streams are by precipitation as arsenic(III) sulfide, calcium arsenate, or ferric arsenate, but it has been shown that all of these materials are unstable under certain conditions and therefore not suitable for direct disposal to uncontained tailings as they will produce leachate containing arsenic (Robins and Tozawa, 1982; Robins, 1984; Nishimura et al., 1985).

The sulfide  $\text{As}_2\text{S}_3$  has its lowest solubility below  $\text{pH}=4$ , but that solubility is significantly higher than has been generally accepted (Young and Robins, 2000). The sulfide is not usually a form that is disposed in residues as it is easily oxidised and increasingly soluble above  $\text{pH}=4$ . There have been unsuccessful attempts to use  $\text{As}_2\text{S}_3$  in landfill in which acidic-anaerobic conditions are maintained, and also in cement cast admixes. Recent work on biological formation of arsenic sulfides may have an application in treating process residues, but containment of waste material remains a problem.

There are a number of calcium arsenates that can be precipitated from arsenic(V) solutions, by lime addition to high  $\text{pH}$  (Nishimura et al., 1983; Nishimura and Tozawa, 1984; Nishimura and Robins, 1998). Lime addition in excess can reduce arsenic concentrations in solution to  $<0.01$  mg/L, but those calcium arsenates which are precipitated at  $\text{pH}>8$  are not stable with respect to the  $\text{CO}_2$  in the atmosphere, which converts them into calcium carbonate, releasing arsenic to solution in balance with appropriate cations (Nishimura et al., 1983).

Arsenic(V) can also be precipitated from process solutions below about  $\text{pH}=2$  with iron(III) to form ferric arsenate,  $\text{FeAsO}_4 \cdot 2\text{H}_2\text{O}$ , which is white to very pale green in color. At ambient precipitation temperatures the compound is very small in crystal particle size ( $<10\text{nm}$ ) and is "2-Line" X-ray amorphous (Robins, 1990),



but these particles tend to agglomerate to about 100nm and the material is difficult to de-water by conventional operations. At temperatures above about 90°C the precipitated compound is crystalline (>100nm) and has a solubility about 2 orders of magnitude lower than the amorphous material (which is the particle size effect). The "amorphous" ferric arsenate exhibits incongruent solubility at about pH=1 (where [As] is about 500 mg/L) and at higher pH will convert very slowly to an arsenic bearing ferrioxyhydroxide, which initially forms around the surfaces of the ferric arsenate tending to stabilise the material and colouring it yellow to brown (Robins, 1990). Crystalline ferric arsenate (*scorodite*) has an incongruent solubility point at about pH=2 and is comparatively slow to convert to the arsenic bearing ferrioxyhydroxide at higher pH, and for material of larger crystal particle size, this may take some years (Robins, 1990). Crystals of  $\text{FeAsO}_4 \cdot 2\text{H}_2\text{O}$  do not grow to appreciable size (greater than about 1 mm) as they have a relatively high positive surface potential right up to the pH of the incongruent point. Ferric arsenate of either form is not thermodynamically stable in the neutral to high pH region (the kinetics of decomposition being related to particle size and solution composition, and being controlled by diffusion through the product). The materials may pass conventional leach tests (such as the TCLP) and are not suited for direct uncontained disposal, but perhaps would satisfy a "slow release criteria" if regulatory authorities would give this option its deserved consideration. Ferric arsenate is also not stable in alkaline cement cast admixes.

There are other metal arsenates, such as those of Fe(II), Zn(II), Cu(II) and Pb(II) (Robins, 1985b), which are less soluble and more stable in the neutral pH region than the calcium arsenates or ferric arsenate, but these have not been seriously considered as disposal forms. Iron(II) arsenate is of particular interest as a low solubility material (Khoe et al., 1990) and this compound has recently been the basis of a process developed and successfully demonstrated in a variety of applications (Twidwell et al., 1999). Barium(II) arsenate was proposed as being an extremely insoluble arsenate, but this was shown (Robins, 1985a; Nishimura et al., 1989) to be incorrect. More complex compounds, such as the apatite structured calcium phosphate-arsenate have recently been demonstrated to be of low solubility (including being stable to atmospheric  $\text{CO}_2$ ) and of appropriate stability for disposal considerations (Twidwell et al., 1999). Ferric arsenite sulfate is also of recent interest and may prove to be useful in stabilising arsenic(III) (Nishimura and Umetsu, 2000). One of the most insoluble arsenic compounds is lead(II) chloroarsenate (the mineral form being *mimetite*) which has been studied in detail (Comba et al., 1988).

Very little attention has been given to mixed oxidation state materials (both Fe(II)-Fe(III) and As(III)-As(V) combination compounds have been tentatively identified, and the authors are currently conducting a comprehensive study of these systems. The Fe(II)-Fe(III) hydroxy sulfate (known as "green rust") has been shown to incorporate arsenic into the structure at pH<7 (Nishimura and Robins,

2000) and is worthy of further study.

### ADSORPTION OF ARSENIC ON FERRIHYDRITE

Over many years there has been much attention directed to the removal of arsenic from hydrometallurgical process solutions and waste waters by precipitation and co-precipitation with iron(III). At relatively high concentrations of iron(III) and arsenic(V) ( $>$  about 0.001M) and at low pH, the precipitation results in the formation of ferric arsenate,  $\text{FeAsO}_4 \cdot 2\text{H}_2\text{O}$ , as above. At lower concentrations of arsenic(V) and higher iron(III) concentrations the co-precipitation of arsenic with ferrioxihydroxide (*ferrihydrate*) occurs and this is probably the most effective method of removal of arsenic from aqueous solutions, and leads to a solid phase which can be stable at least for a year or so. The solid co-precipitate has been referred to as "basic ferric arsenate" and in 1985 a controversy commenced (Robins et al., 1991) as to whether the co-precipitated material was in fact a compound of iron(III) and arsenic(V) or simply an adsorptive binding of arsenic with ferrioxihydroxide (*ferrihydrate*). There was at that stage sufficient evidence to support the latter contention, but the use of the term "basic ferric arsenate" still exists and formulae such as " $\text{FeAsO}_4 \cdot x\text{Fe}(\text{OH})_3$ " are used.

A number of studies have indicated that various complexes are formed in the adsorption of As(V) on *ferrihydrate* (Manceau, 1995; Sun and Doner, 1996; Fendorf et al., 1997). EXAFS studies on arsenic bearing *ferrihydrate* formed at  $\text{pH} > 7$ , have shown that arsenic(V) is adsorbed to *ferrihydrate* as a strongly bonded inner-sphere complex with either monodentate or bidentate attachment (Waychunas et al., 1993, 1995). It has also been reported that monodentate attachment predominates near the optimal  $\text{pH} = 4-5$  for adsorption.

The adsorption of arsenic(III) on *ferrihydrate* has also been investigated but the optimal adsorption in this case occurs at  $\text{pH} 8-9$  (Nishimura and Umetsu, 2000), and although it seems an efficient process there is no evidence that the adsorbed species is in fact arsenic(III). It may be that during the process, oxidation of arsenic(III) will occur with some ease, being balanced by the reduction of Fe(III) to Fe(II) in the *ferrihydrate* structure, as has been shown in preliminary experiments by the authors. It is well known that Fe(II) substitution in *ferrihydrate* does occur.

Very little attention has been given to the possibility of modifying the *ferrihydrate* structure to improve its adsorptive capacity for arsenic in solution. It is well known that many cations will incorporate into the *goethite* structure (Schwertmann and Cornel, 1996; Jambor and Dutrizac, 1998), and therefore possibly into a precursor *ferrihydrate*. The authors have been investigating the co-precipitation of both Al(III) and Mn(III) with Fe(III) to form an aluminic *ferrihydrate* and a manganic *ferrihydrate* respectively. Both materials are showing

considerably better capacity for arsenic adsorption. The control of potential is important in this adsorption process. The effective oxidation of As(III) by manganese substituted *goethite* has been studied by XANES spectroscopy (Sun et al., 1999), and the implications are obvious in relation to adsorption mechanisms.

There is also little work reported on the adsorption of arsenic from solutions initially below say 50 micrograms/kg. This region of concentration is presently of immediate interest in relation to drinking water, where US EPA has introduced a MCL of 5 micrograms/kg (January 2001).

## **CEMENTATION**

It is well known that iron and other metals will replace arsenic from solution to produce arsenic as the element or as an alloy (Tozawa et al., 1992; Twidwell et al., 1999). This method of removing arsenic from solution to levels <2 mg/kg has been demonstrated on ground water at a commercial site at a pilot scale of 1-5 US gallons per minute. Cementation has also been suggested, and may be appropriate, for the removal of arsenic from drinking water.

## **TESTING FOR LONG TERM STABILITY**

Testing methods for evaluating the stability of hazardous waste residues have been defined by the US EPA in several "Background Document for Toxicity Characteristic Leaching Procedure" publications. The test methods do not adequately assess the long term stability of arsenical residues. Improved test methods must be designed which also include a characterisation of physical properties and chemical components (mineralogy) so that more accurate predictions of behaviour can be made.

## **THERMODYNAMIC MODELING**

The stability of arsenic species can be characterised by their free energies of formation. Many of the papers referenced below have free energy of formation data for arsenic species, and some contain thermodynamic stability diagrams, which have been invaluable to the authors in gaining a better understanding of these systems. Few of the reputable thermodynamic data bases have sufficient relevant data for modelling aqueous arsenic systems, but the published paper (Itagaki et al., 1986) is one of the most comprehensive single sources.

## CONCLUSIONS

There have not been any significant and innovative improvements in the methods for removing arsenic from process and effluent solutions, or indeed from drinking water, in the last decade or so. The current needs to remove arsenic from drinking water is now a world problem, apart from the well publicised and critical situation in Bangladesh (Nickson et al., 1998; Nordstrom, 2000), and so must be addressed as a matter of great urgency

## REFERENCES

- Comba, P. G., D. R. Dahnke, L. G. Twidwell, Arsenic Removal from Process and Wastewaters. In: Arsenic Metallurgy Fundamentals and Applications, Eds., R. G. Reddy, J. L. Hendrix and P. B. Queneau. TMS, Warrendale PA. Pp. 305-319, 1988.
- Emett, M. T. and Khoe, G. H. Photochemical Oxidation of Arsenic by Oxygen and Iron in Acid Solutions. *Water Research*, Vol. 35, Issue 2, pp. 649-656, 2001.
- Fendorf, S. M. Eick, J. Grossl, P. R. and Sparks, D. L. Arsenate and Chromate Retention Mechanisms on Goethite. I Surface Structure. *Env. Sci. and Technol.* 31, pp. 315-320, 1997.
- Fuller, C.C. Davis, J.A. Waychunas, G.A. and Rea, B.A. Surface Chemistry of Ferrihydrite: II Kinetics of Arsenate Adsorption and Coprecipitation *Geochimica et Cosmochimica Acta*, 57. Pp. 2271-2282, 1993.
- Jambor, J. L. and Dutrizac, J. E. Occurrence and Constitution of Natural and Synthetic Ferrihydrite, a Widespread Iron Oxyhydroxide. *Chem. Revs.*, 98, pp. 2549-2585, 1998.
- Khoe, G. H., Emmett, M. T., Zaw. M. and Prasad, P. Removal of Arsenic Using Advanced Oxidation Processes. In: *Minor Metals 2000*. Ed. C. A. Young. SME, Littleton CO. pp. 31-38, 2000.
- Khoe, G.H., Huang, J.C.Y. and Robins R.G. Precipitation Chemistry of the Aqueous Ferrous Arsenate System. In: *EPD Congress '91*. Ed. D. R. Faskell. TMS, Warrendale PA, pp 103-105, 1991.
- Khoe, G.H. and Robins, R.G. The Complexation of Iron(III) with Sulphate, Phosphate or Arsenate, *J. Chem. Soc., Dalton Trans.*, 1988, pp. 2015-2021, 1988.
- Itagaki, K. and Nishimura, T. Thermodynamic Properties of Compound and Aqueous Species of Va Elements. *Metallurgical Review of MMIJ*, 3 (2), pp. 29-48, 1986.
- Itoh, C. T. Nishimura, T. and Tozawa, K. Equilibria of the System Sr(II)-As(III,V)-H<sub>2</sub>O at 25°C. *Bull. Res. Inst. Min. Dress. Metall. Tohoku Univ.*, 45 (1), pp. 1-12, 1989.

- Manceau, A. The Mechanism of Anion Adsorption on Iron Oxides: Evidence for the Bonding of Arsenate Tetrahedra on Free  $\text{Fe}(\text{O},\text{OH})_6$  Edges. *Geochimica et Cosmochimica Acta*, 59, pp. 3647-3653, 1995.
- Nickson, R. McArthur, J. Burgess, W. Ahmed, K. M. Ravenscroft, P. and Rahman, M. Arsenic Poisoning of Bangladesh Groundwater. *Nature*, 395, September, p 338, 1998.
- Nishimura, T. Tozawa, K. and Robins, R. G. The Calcium-Arsenic-Water System, Proceedings MMIJ /Aus.IMM Joint Symposium, Sendai, Japan. Paper JD-2-1, pp. 105-120, 1983.
- Nishimura, T. and Tozawa, K. On the Solubility Products of Ferric, Calcium and Magnesium Arsenates. *Bull. Res. Inst. Min. Dress. Metall. Tohoku Univ.*, 34 (1), pp.19-26, 1978.
- Nishimura, T. and K.Tozawa, K. The Eh-pH Diagrams for the Systems Cu-As- $\text{H}_2\text{O}$  and Cu-As- $\text{NH}_3\text{-H}_2\text{O}$ . *Bull. Res. Inst. Min. Dress. Metall. Tohoku Univ.*, 36 (1), pp.81-90, 1980.
- Nishimura, T. and Tozawa, K. The Eh-pH Diagrams for the Systems M(Ni,Co)-As- $\text{H}_2\text{O}$  and M(Ni,Co)-As- $\text{NH}_3\text{-H}_2\text{O}$ . *Bull. Res. Inst. Min. Dress. Metall. Tohoku Univ.*, 36 (2), pp.141-152, 1980.
- Nishimura and Tozawa, K. The Reaction for the Removal of As(III) and As(V) from Aqueous Solutions by adding Calcium Hydroxide. *J. Min. Met. Inst. Japan*, 100, pp. 1085-1091, 1984.
- Nishimura, T. Itoh, C. T. Tozawa, K. and Robins, R G. The Calcium-Arsenic-Water-Air System. Proceedings of Impurity Control and Disposal. 15th Annual Hydrometallurgical Meeting of CIM, Vancouver, Canada, pp. 2/1-2/19, August 1985.
- Nishimura, T. and Tozawa, K. Removal of Arsenic from Waste Water by Addition of Calcium Hydroxide and Stabilization of Arsenic-Bearing Precipitate by Calcination. Proceedings of Impurity Control and Disposal. 15th Annual Hydrometallurgical Meeting of CIM, Vancouver, Canada, pp. 3/1-3/18, August 1984.
- Nishimura, T. and Tozawa, K. Behavior of Antimony and Arsenic in Sulfuric Acid Solution. *Metallurgical Review of MMIJ*, 3 (2), pp. 131-145, 1986.
- Nishimura, T. Itoh, C. T. and Tozawa, K. Stabilities and Solubilities of Metal Arsenites and Arsenates in Water and Effect of Sulfate and Carbonate Ions on Their Solubilities. In: *Arsenic Metallurgy Fundamentals and Applications*. Eds. R.G.Reddy, J.L.Hendrix and P.B.Queneau, TMS, Warrendale PA, pp. 77-98, 1988.
- Nishimura, T. and Tozawa, K. Kinetics of Reduction of Arsenic(V) with Sulfur Dioxide in Sulfuric Acid Solutions. *Bull. Res. Inst. Min. Dress. Metall. Tohoku Univ.*, 44 (1), pp.77-88, 1988.
- Nishimura, T. and Tozawa, K. Kinetics of Oxidation of Arsenious Acid with Aqueous Ozone. *J.Min.Met.Inst.Japan*, 44(1), pp.549-153, 1988.

- Nishimura, T. Itoh, C. T. and Tozawa, K. Equilibria of the System Ba(II)-As(III,V)-H<sub>2</sub>O at 25°C. Bull. Res. Inst. Min. Dress. Metall. Tohoku Univ., 45 (2), pp.105-116, 1989.
- Nishimura, T. Itoh, C. T. and Tozawa, K. Equilibria of the System Zn(II)-As(III,V)-H<sub>2</sub>O at 25°C. Bull. Res. Inst. Min. Dress. Metall. Tohoku Univ., 47, pp.113-122, 1991.
- Nishimura, T. Itoh, C. T. and Tozawa, K. Equilibria of the System Cu(II)-As(III,V)-H<sub>2</sub>O at 25°C. Bull. Res. Inst. Min. Dress. Metall. Tohoku Univ., 48, pp.197-106, 1992.
- Nishimura, T. Itoh, C. T. and Tozawa, K. Equilibria of the Systems Co(II)-As(III,V)-H<sub>2</sub>O and Ni(II)-As(III,V)-H<sub>2</sub>O at 25°C. Bull. Res. Inst. Min. Dress. Metall. Tohoku Univ., 49, pp.61-70, 1993.
- Nishimura, T. and Umetsu, Y. Removal of Arsenic(III), Arsenic(V) with Manganese from Aqueous Solution by Ozonation. In: Impurity Control and Disposal in Hydrometallurgical Processes. Eds. B.Harris and E. Krause, The Metallurgical Society of CIM, pp. 91-100, 1994.
- Nishimura, T. and Tozawa, K. Kinetics of Reducton of Arsenic(V) with Sulfur Dioxide Gas in Aqueous Sulfuric Acid Solution. Metall. Review of MMIJ, 13 (1), pp.113-127, 1996.
- Nishimura, T. Wang, Q. and Umetsu, Y. Removal of Arsenic from Process Liquors by Oxidation of Iron(II), Arsenic(III) and Sulfur(IV) with Oxygen. In: Iron Control and Disposal. Eds. J.E.Dutrizac and G.B.Harris. CIM, Montreal Quebec, pp. 535-548, 1996.
- Nishimura, T. and Robins, R. G. A Re-evaluation of the Solubility and Stability Regions of Calcium Arsenites and Calcium Arsenates in Aqueous Solution at 25°C. Mineral Proc and Extr. Met. Reviews, 18 pp. 283-308, 1998.
- Nishimura, T. and Robins, R. G. Removal of Arsenic in the Gold-Cyanide Process. In: Minor Metals 2000. Ed. C. A. Young. SME, Littleton CO, pp. 135-140, 2000.
- Nishimura, T. and Umetsu, Y. Chemistry on Elimination of Arsenic, Antimony and Selenium from Aqueous Solutions with Iron(III) Species. In: Minor Metals 2000, Ed. C. A. Young. SME, Littleton CO, pp. 105-112, 2000.
- Nordstrom, D. K. An Overview of Arsenic Mass-Poisoning in Bangladesh and West Bengal, India. In: Minor Metals 2000. Ed. C. A. Young. SME, Littleton CO. pp. 21-30, 2000.
- Robins, R.G. The Solubility of Metal Arsenates. Proc. MMIJ-AIME Joint Meeting, Tokyo, Paper D-1-3, pp. 25-43, 1981.
- Robins, R.G. The Solubility of Metal Arsenates. Metallurgical Trans. B, 12, pp. 103-109, 1981.

- Robins, R.G. and Tozawa, K. Arsenic Removal from Gold Processing Waste Waters: The Potential Ineffectiveness of Lime. *Can. Min. & Met. Bull.*, April, pp. 171-174, 1982.
- Robins, R.G. The Stabilities of Arsenic(V) and Arsenic(III) Compounds in Aqueous Metal Extraction Systems. In: *Hydrometallurgy, Research Development and Plant Practice*. Eds. K. Osseo-Assare and J. D. Miller, TMS, Warrendale PA, pp. 291-310, 1982.
- Robins, R.G. The Stability of Arsenic in Gold Mine Processing Wastes. In: *Precious Metals: Mining Extraction and Processing*. Eds. V. Kudryk et al., AIME Warrendale PA, pp. 241-249, 1984.
- Robins, R.G. The Stability of Barium Arsenate: Sheritt's Barium Arsenate Process. *Metallurgical Transactions B*, 16, pp. 404-406, 1985a.
- Robins, R.G. The Aqueous Chemistry of Arsenic in Relation to Hydrometallurgical Processes. *Proceedings, Impurity Control and Disposal. CIM Annual Meeting, Vancouver, Canada, Paper No. 1*, pp. 1/1-1/26, August 1985b.
- Robins, R.G. The Solubility and Stability of Scorodite,  $\text{FeAsO}_4 \cdot 2\text{H}_2\text{O}$ ; Discussion. *Amer. Mineral.*, 72: pp. 842-844, 1987a.
- Robins, R.G. Arsenic Hydrometallurgy. In: *Arsenic Metallurgy Fundamentals and Applications*. Eds. R. G. Reddy, J. L. Hendrix and P. B. Queneau, TMS, Warrendale PA, pp. 215-247, 1987b.
- Robins, R.G. Huang, J.C.Y., Nishimura, T. and Khoe, G.H. The Adsorption of Arsenate Ion by Ferric Hydroxide. *Ibid.* pp. 99-112, 1987.
- Robins, R.G. and Glastras, M.V. The Precipitation of Arsenic from Aqueous Solution in Relation to disposal from Hydrometallurgical Processes. In: *Proceedings, Research and Development in Extractive Metallurgy, Aus.I.M.M.*, May 1987.
- Robins, R.G. The Stability and Solubility of Ferric Arsenate: An Update. In: *EPD Congress '90*. Ed. D. R. Gaskell. TMS, Warrendale PA, pp. 93-104, 1990.
- Robins, R.G. and Jayaweera L.D. Arsenic in Gold Processing. *Mineral Processing and Extractive Metallurgy Review*, 9, pp. 255-271, 1992.
- Robins, R.G. Wong, P.L.M. Nishimura, T., Khoe, G.H. and Huang, J.C.Y. Basic Ferric Arsenates - Non Existent. In: *EPD Congress 1992*. Ed. J. P. Hager. TMS Warrendale PA, pp. 31-39, 1991.
- Schwertmann, U. and Cornell R. M. *The Iron Oxides. Structure, Properties, Reactions, Occurrences and Uses*. VCH, Weinheim Germany, 1996.
- Sun, X. and Doner, H. E. An Investigation of Arsenate and Arsenite Bonding Structures on Goethite by FTIR. *Soil Science*, 161, pp. 865-872, 1996.
- Sun, X. Doner, H. E. and Zavarin, M. Spectroscopy Study of Arsenite [As(III)] Oxidation on Mn-Substituted Goethite. *Clays and Clay Minerals*, 47(4), pp. 474-480, 1999.

- Tozawa, K. and Nishimura, T. Oxidation of As(III) in Aqueous Solution. *J. Min. Met. Inst. Japan*, 92, pp. 809-814, 1976.
- Tozawa, K. Nishimura, T. and Umetsu, Y. Removal of Arsenic from Aqueous Solutions. *Proc. 16th CIM Conference of Metallurgist, Vancouver, Canada*, pp. 1-11, August 1977.
- Tozawa, K. Umetsu, Y. and Nishimura, T. Hydrometallurgical Recovery or Removal of Arsenic From Copper Smelter By-Products. Paper presented at 107th AIME Annual Meeting, Denver, USA, TMS Paper Selection A, pp. 1-23, February 1978.
- Tozawa, K. and Nishimura, T. The Eh-pH Diagram for the System As-S-H<sub>2</sub>O. *Bull. Res. Inst. Min. Dress. Metall. Tohoku Univ.*, 34 (1), pp. 74-79, 1978.
- Tozawa, K. Umetsu, Y. and Nishimura, T. A Hydrometallurgical Treatment of Arsenic-Bearing Intermediate Products in Smelters: Recovery of Valuable Metals and Arsenic Trioxide. *Bull. Res. Inst. Min. Dress. Metall. Tohoku Univ.*, 35 (2), pp. 127-135, 1979.
- Tozawa, K. and Nishimura, T. Oxidation of As(III) to As(V) in Aqueous Solutions. *Metallurgical Review of MMIJ*, 1 (I), pp. 76-87, 1984.
- Tozawa, K. Nishimura, T. Akahori, M. and Malaga, M. A. Comparison between Purification Processes for Zinc Leach Solutions with Arsenic and Antimony Trioxides. *Hydrometallurgy*, 30, pp.445-461, 1992.
- Twidwell, L. G. and Mehta, A. Disposal of Arsenic Bearing Copper Smelter Flue Dust. *Nuclear and Chemical Waste Management*, 5(4), January, 1986.
- Twidwell, L. G. Bowler, T. O. Plessas, K. O. Removal of Arsenic from Wastewaters and Stabilization of Arsenic Bearing Waste Solids, EPA Workshop: Arsenic and Mercury, July 17, 18, 1992, Washington, DC, EPA/600/R-92-105, pp. 46-50, 1992.
- Twidwell, L.G. Plessas, K.O. Comba, P. G. Dahnke, D. R. Removal of Arsenic from Wastewaters and Stabilization of Arsenic Bearing Waste Solids: Summary of Experimental Results, *J. Haz. Mat.*, 36, pp. 69-80, 1994.
- Twidwell, L.G. Plessas, K. O. Comba, P. G. Dahnke, D. R. Part Seven Waste Disposal and Utilization and Stabilization of Arsenic Bearing Waste Solids: Summary of Experimental Studies. *Min. Proc. and Extractive Met.*, 15, pp. 237-246, 1995.
- Twidwell, L.G., McCloskey, J. Miranda, P and Gale, M. Technologies and Potential Technologies for Removing Arsenic from Process and Wastewater. *Proc. REWAS'99, San Sabastian, Spain, September 5-9, 1999.*
- Waychunas, G.A. Rea, B.A. Fuller, C.C. and Davis, J.A. Surface Chemistry of Ferrihydrite: I EXAFS Studies of the Geometry of Coprecipitated and Adsorbed Arsenate. *Geochimica et Cosmochimica Acta*, 57, pp. 2251-2269, 1993.



- Waychunas, G. A. Rea, B. A. Davis J. A. and Fuller, C. C. Geometry of Sorbed Arsenate on Ferrihydrite Crystalline FeOOH: Re-evaluation of EXAFS Results and Topological Factors in Predicting Geometry, and Evidence for Monodentate Complexes. *Ibid*, 59, pp. 3655-3661, 1995.
- Young, C. A. and Robins, R. G. The Solubility of  $As_2S_3$  in Relation to the Precipitation of Arsenic from Process Solutions. In: *Minor Metals 2000*. Ed. C. A. Young. SME, Littleton CO. pp. 381-391, 2000.
- Zhang, W., Singh, P and Muir, D. M. Kinetics of Oxidation of As(III) with  $SO_2/O_2$  and UV Light. *Ibid.*, pp. 333-343, 2000.

# Low-cost Technique of Arsenic Removal from Water and Its Removal Mechanism

**R. Mamtaz**

Department of Civil Engineering, Bangladesh University of Engineering and Technology, Dhaka-1000, Bangladesh

And

**D.H. Bache**

Department of Civil Engineering, University of Strathclyde, UK

## ***Abstract***

*This study examines the potential of removing arsenic from water by coprecipitation with naturally occurring iron. The experimental study examined the sensitivity of removal of arsenic in response to manual mixing and prolonged settlement. It was found that about 88% arsenic removal could be achieved after 24 h settlement. It has also demonstrated that provided the iron levels are sufficiently high (say 1.2 mg/l), simple shaking of a container and allowing the iron-arsenic complex to settle out for 3 days could reduce the concentration of arsenic from 0.10 mg/l to Bangladesh standard (0.05 mg/l). There was evidence that adsorption may be the dominating trapping mechanism when Fe/As weight ratio was  $\geq 10$ .*

## **INTRODUCTION**

In recent years there has been widespread coverage in the media about the problems of arsenic in Bangladesh's drinking water. This has been an unforeseen consequence of a large-scale programme to replace contaminated surface water sources by 'safe' groundwater. The programme led to the installation of about 4 million tubewells, never suspecting the presence of arsenic in the aquifers carrying the groundwater.

Arsenic in groundwater was first detected in 1993 following reports of many people suffering from arsenical skin diseases. Further investigations showed the extent of the problem with large areas of the country's water supply being affected and millions of people are at serious risk of arsenic poisoning.

Technology for arsenic removal from water already exists (Kartinen and Martin, 1995). However, the socio-economic conditions which prevail in Bangladesh, do not permit implementation of this type of technology on grounds of cost. The task was to develop technology, which could be implemented at household level and at virtually zero cost.

A related problem in the groundwater in Bangladesh and some other parts of the world is the presence of iron. While this not a health hazard, it is usually removed because of taste and staining problems. It is well known that iron hydroxide adsorbs arsenic (Ferguson and Gavis, 1972). In this study an attempt was made to exploit the naturally occurring iron as a means of arsenic removal through the development of simple practices based on adsorption-coprecipitation and settlement.

## **BACKGROUND**

### **Groundwater in Bangladesh: Arsenic and Iron**

The presence of arsenic in groundwater in Bangladesh is the most serious health hazard the country has ever faced. A recent study carried out by BGS and MotMacdonald (1999) shows many areas within Bangladesh with arsenic concentration greater than 0.05 mg/l implying that millions of people are at serious risk of arsenic poisoning. According to EGIS (1997) report the concentration of arsenic generally varies from 0.02 to 0.5 mg/l (exceeding the WHO standard of 0.01 mg/l and Bangladesh Standard of 0.05 mg/l). Regarding the iron concentration, about 65% of the area of Bangladesh contain dissolved iron in excess of 2 mg/l and in many areas concentration is as high as 15 mg/l (Ahmed et al, 1998). While arsenic and iron pose individual problems, their association in groundwater has the potential of providing a simple means of removing arsenic by coprecipitation and adsorption.

### **Arsenic Chemistry and Its Removal**

Arsenic occurs in waters in several different forms depending on the pH and redox potential  $E_h$ . Arsenate (As(V)) and arsenite (As(III)) are the primary forms of arsenic found in natural waters (Ferguson and Anderson, 1974). The thermodynamically stable forms are As(V) in oxygenated surface water and As(III) in reducing groundwater. The latter is of the concern in this study.

However, both forms can occur together in both environments due to the slow oxidation and reduction kinetics (Edwards, 1994).

From previous studies (Jekel 1994, Shen, 1973; Sorg and Logsdon, 1978; Edwards, 1994; Cheng et al, 1994; Hering et al, 1996), it is already known that coagulation-precipitation is a very effective and most frequently applied technique in arsenic removal. In this technique, addition of coagulant facilitates the conversion of soluble arsenic species into insoluble products through coprecipitation and adsorption

Adsorption of arsenic onto preformed  $\text{Fe}(\text{OH})_3$  has also been shown to be an effective method for removing arsenic (Hering et al, 1996; Driehaus et al, 1998). Like coagulation, removal of As(III) by adsorption is less than that of As(V). However arsenic removal during coagulation with  $\text{FeCl}_3$  is more efficient than arsenic adsorption onto preformed hydrous ferric oxide (Hering et al, 1997).

Settlement is a well-known mechanism in the context of iron precipitation and iron removal. Depending on the initial iron concentration in the raw water, Ghosh and O'Connor (1966) indicated that a 1 h design period was 'inadequate for complete iron precipitation'. It suggests that where arsenic removal depends on iron precipitation, the settling time must exert a major influence on the removal process. A study carried out by Shen (1973) with just arsenic-containing water showed that sedimentation could only remove 8.7% arsenic after 24 h settlement. A drawback of Ghosh and O'Connor (1966) is the lack of settling time. In the case of Shen's (1973) sedimentation, the study is restricted to arsenic and provides no insight into the potential influence of iron and the removal efficiency.

## Materials and Methods

Laboratory nano-pure water was used for the preparation of the standard and sample waters. The chemicals employed for the experiments were general purpose grade (GPR) and used without any purification. Solutions of arsenic (As(III)) were prepared from concentrated stock solution of arsenic trioxide,  $\text{As}_2\text{O}_3$ , (1 mg/ml) in 0.5 M/l HCl supplied by BDH, UK for use in the tests. In common with other studies (Shen, 1973; Edwards, 1994; Cheng et al, 1994) iron presence was based on preparing  $\text{FeCl}_3$  solution.

All experiments were performed with a constant ionic strength of 0.01 M/l  $\text{NaNO}_3$  and 0.1 g/l  $\text{NaHCO}_3$  to provide necessary alkalinity. pH was maintained by adding 0.1 M NaOH. All glassware was cleaned by soaking 10%  $\text{HNO}_3$  and rinsed three times with nano-pure water. Blank tests (without Fe) confirmed that no arsenic was lost through adsorption onto the glassware. Each type of test was carried out in (at least) triplicate.

Arsenic was measured by Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES) method. In the ICP-AES method, all samples and

standards were acidified according to the standard methods (APHA, AWWA and WEF, 1995).

Values of the parameters such as arsenic, pH and iron/arsenic ratios were chosen to be representative of the range found in Bangladesh (EGIS, 1997). The As(III) form of arsenic was selected for the experimental investigation, as it is the form of arsenic likely to be found in groundwater (DFID et al, 2000). Experiments were carried out with initial As(III) concentration of 0.2 mg/l, Fe dosages of 4.0 mg/l and pH 7.5.

Additional detail on methods included in the subsequent text to support specific parts of the experimental programme.

## **EXPERIMENTS AND RESULTS**

### **Mixing, Filtration and Settlement**

Mixing is a necessary stage in order to ensure aeration and to induce flocculation as well as assuring dispersion of the chemicals. At village level, shaking is a straightforward means of achieving mixing. This was compared with mechanical mixing, the latter being included for reference purposes. Similarly filtration was introduced for reference purposes, but the prime focus of the study was to exploit sedimentation as a means of achieving solid-liquid separation following the initial As-Fe interaction.

Mechanical mixing was applied to 1 litre sample water (0.01M/l NaNO<sub>3</sub> and 0.1 g/l NaHCO<sub>3</sub>) containing 0.2 mg/l As(III), 4.0 mg/l Fe at pH 7.5. Sample containing in a 2-litre capacity conical glass flask was mixed in an orbital shaker (KL2) at a rapid rate (410 rpm) for 5 min, at a slow rate (100 rpm) for 25 min and allowed to settle. In the series based on manual mixing, samples were shaken vigorously for periods in the range of 15 s to 5 min and then allowed to settle. After 2 h settlement, two sets of supernatant were collected at a depth of 20 mm from the top surface from each type of samples (both mechanical and manually mixed samples). One set of sample was analysed for residual As(III) concentration with filtration through 0.45 µm filter papers and another set was analysed for the same conditions but without filtration. Table 1 presents the effects of mixing condition and filtration on As(III) removal at different mixing time.

For the filtered samples, shown in Table 1, it is observed that the removal efficiency is insensitive to the mixing regime, whereas for the unfiltered samples, removal depends on mixing type and time. In the latter case, the duration of mixing probably enhances flocculation, because it seems likely that the larger removal rates are associated with larger particle sizes. It is seen that 5 min manual mixing is almost as effective as mechanical mixing.

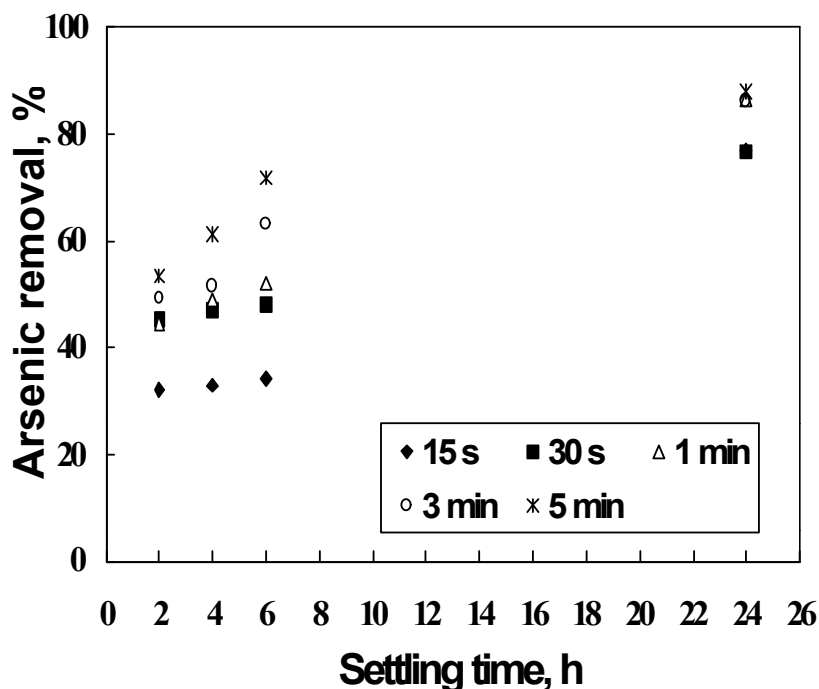
**Table 1: As(III) removal at different mixing conditions of filtered and unfiltered samples after 2 h settlement (Initial As(III) 0.2 mg/l, Fe 4.0 mg/l and pH 7.5)**

Test condition	Mean As(III) removal, %	
	Filtered	Unfiltered
Manual mixing:		
15 s manual mixing	63.7	32.2
30 s manual mixing	63.6	45.4
1 min manual mixing	64.3	44.5
3 min manual mixing	64.0	49.3
5 min manual mixing	63.6	53.5
Mechanical mixing	68.5	60.4

To investigate the effects of settlement on As(III) removal, tests were carried out following the same procedure in manual mixing method, the samples being allowed to settle for 24 h. Supernatant was collected at specified time intervals, 2, 4, 6 and 24 h and analysed for residual As(III) concentration without filtration. Fig. 1 shows the effects of settling time on As(III) removal for manually mixed unfiltered samples at varying mixing times. In Figure 1 it is evident that at shorter settling times say 2-6 h, the removal is fairly sensitive to the mixing time. In contrast, at longer settling time (24 h) the removal is less sensitive to the initial stage of mixing.

### **Insight into the Removal Mechanism**

From the experiments described above, it was evident that manual mixing followed by settlement was reasonably effective for reducing the levels of arsenic in the presence of iron. Having gained this experience, further experiments were conducted to discover more about the interaction between As(III) and Fe(III). Experiments were carried out with 1.0 litre sample water in a 2 litre capacity conical glass flask at Fe dosage of 4.0 mg/l, As(III) concentration ranging from 0.1–7.5 mg/l and pH 7.5. The flask was shaken manually for 1 min and then transferred to a 1.0 litre capacity cylinder (432 mm height) to settle for 1 day. After 24 h, the supernatant was collected from the mid depth of the cylinder and the residual arsenic was measured. The removal of As(III) was determined from the difference between As(III) added and the measured residual.



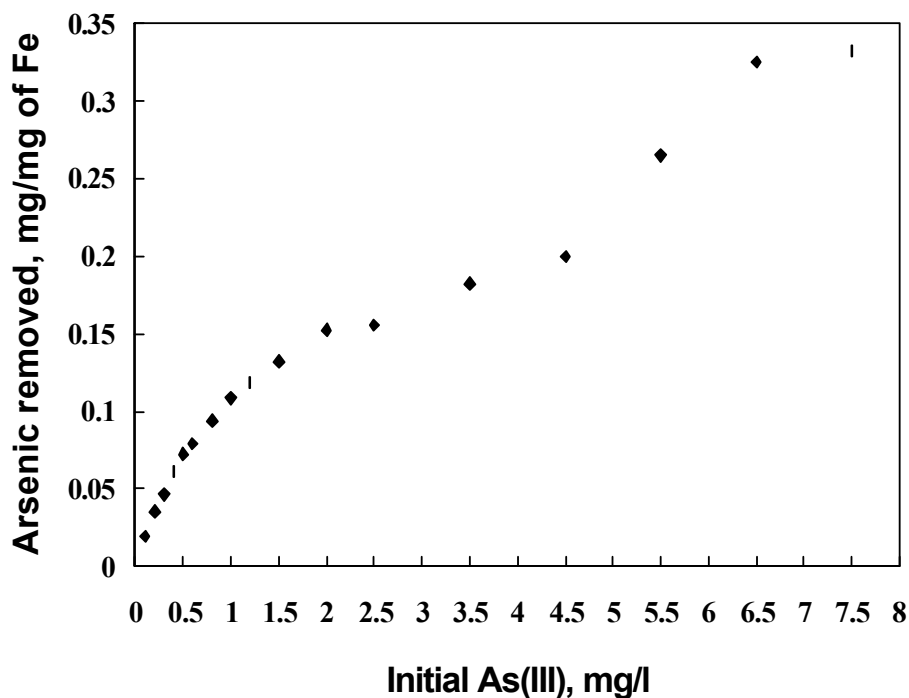
**Figure 1 : Effects of settlement on arsenic removal for manually mixed unfiltered samples at varying mixing time with initial As(III) concentration of 0.2 mg/l, Fe 4.0 mg/l and pH 7.5.**

Results of this test are plotted in Figure 2. When the initial As(III) is between 1.6 to 2.8 corresponding to As/Fe ratio (by weight) in the range of 0.4 to 0.7, it is seen that removal becomes less sensitive to initial arsenic concentration with a removal density  $\sim 0.15$  mg As/mg Fe over this range. However further increase of As/Fe ratio lead to higher removals.

In this type of test, the removal depends on a series of mechanisms i.e. contact between Fe and As (influenced by molecular diffusion), floc formation (influenced by shaking) and solid-liquid separation by sedimentation. In order to gain an insight into the data corresponding to removal at 24 h, the results were plotted in the same form as an adsorption isotherm (Figures 3 and 4). Here it is recognised that the resultant trend refers the combination of processes rather than just adsorption. This form of plot has the benefit of identifying the removal ratio (mg(As)/g(Fe)) corresponding to the residual level of arsenic — the latter needing to comply with target water quality standards. Figures 3 and 4 also show adsorption data from Pierce and Moore (1982) study. Pierce and Moore (1982) investigated the behaviour of As(III) removal by purely adsorption onto pre-

prepared amorphous  $\text{Fe}(\text{OH})_3$ . They found that for a certain range of initial As(III) concentration (0.05–1.0 mg/l), the adsorption reaches a saturation point. At higher initial As(III) concentration (2.5–50 mg/l), the adsorption of As(III) per unit mass of adsorbent increased linearly with increasing equilibrium concentration.

Before commenting on the behavioural features shown in Figures 3 and 4, it is necessary to provide some of the background behind adsorption plots. Pierce

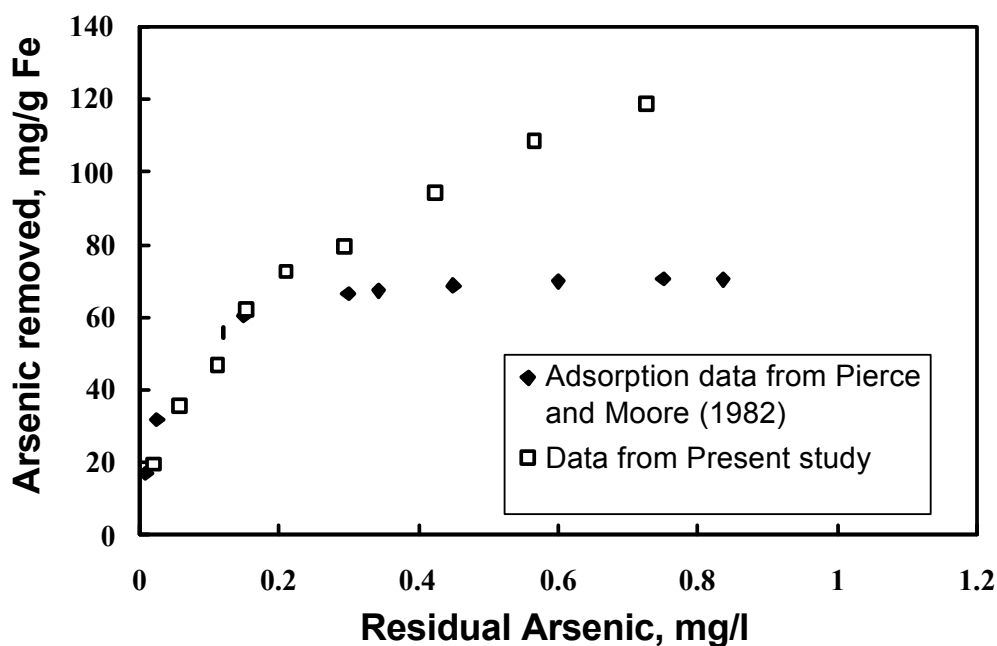


**Figure 2 : Removal density of arsenic using  $\text{FeCl}_3$  with 1 min manual mixing and 1 day settlement with initial As(III) concentration over the range of 0.1 – 7.5 mg/l, Fe 4.0 mg/l and pH 7.5.**

and Moore (1982) data refers to adsorption at pH 7.0 whereas the pH in the current study was 7.5. The differences in between the separate studies are not considered to be significant as it is known that around neutral pH range, the As(III) removal by coagulation is largely unaffected by pH (Edwards, 1994). The adsorption tests reported by Pierce and Moore (1982) were carried out for 24 h continuous mixing by magnetic stirrers and then supernatants were centrifuged and analysed for arsenic concentration. The present work was also carried out for 24 h settlement, the supernatant being analysed for residual arsenic concentration without filtration.



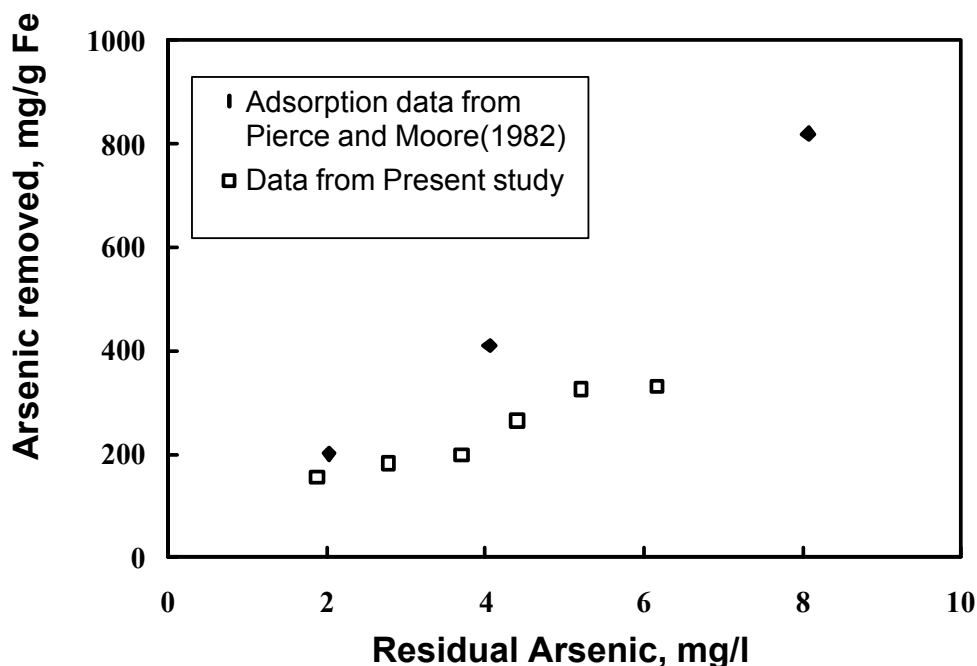
In Figure 3 there is a remarkable similarity between the trends (removal/adsorbed) in the domain  $\text{As}(\text{mg})/\text{g Fe} < 60$ . This may be a coincidence or alternatively may point to the role of adsorption as the dominating removal mechanism when Fe/As weight ratio is  $\geq 10$ . In the case of the adsorption-centrifugation combination (Pierce and Moore, 1982), saturation occurs at an adsorption density of around 70 mg As(III)/g Fe whereas higher levels of removal (about 130 mg As(III)/g Fe) are achieved by the coprecipitation-sedimentation technique for the stated range of initial As(III) concentration.



**Figure 3 :** A comparison of arsenic removal density as a function of residual arsenic concentration by adsorption-coprecipitation and sedimentation with  $\text{FeCl}_3$  at pH 7.5 and adsorption onto pre-formed  $\text{Fe}(\text{OH})_3$  at pH 7.0 for initial As(III) concentration of 0.05-1.0 mg/l and contact time 24 h.

Figure 4 shows the comparison at higher initial As(III) concentration and displays a very different form of behaviour. In contrast to Figure 3, the removal density obtained by adsorption study (Pierce and Moore, 1982) is higher than those obtained by the present study for the stated range of initial As(III) concentration (Figure 4). The different nature of the removal density of the present study might be due to the differences in experimental procedure. Pierce's work was carried out by introducing preformed ferric hydroxide to the solution and not by neutralising an acid solution that contains both Fe and As, whereas the

latter procedure was adopted in the present study. Further, at higher initial dosage of As(III) ( $\geq 2.5$  mg/l), a large amount of 0.1M NaOH was required to maintain pH 7.5 constant. Here, it is conceivable that the NaOH might change or reorder the internal properties of adsorption surface sites.



**Figure 4 :** A comparison of arsenic removal density as a function of residual arsenic concentration by adsorption-coprecipitation and sedimentation with  $\text{FeCl}_3$  at pH 7.5 and adsorption onto preformed  $\text{Fe}(\text{OH})_3$  at pH 7.0 for initial As(III) concentration of 2.5 - 10 mg/l and contact time 24 h

#### **Implication of Iron Concentration on Reducing the Level of Arsenic**

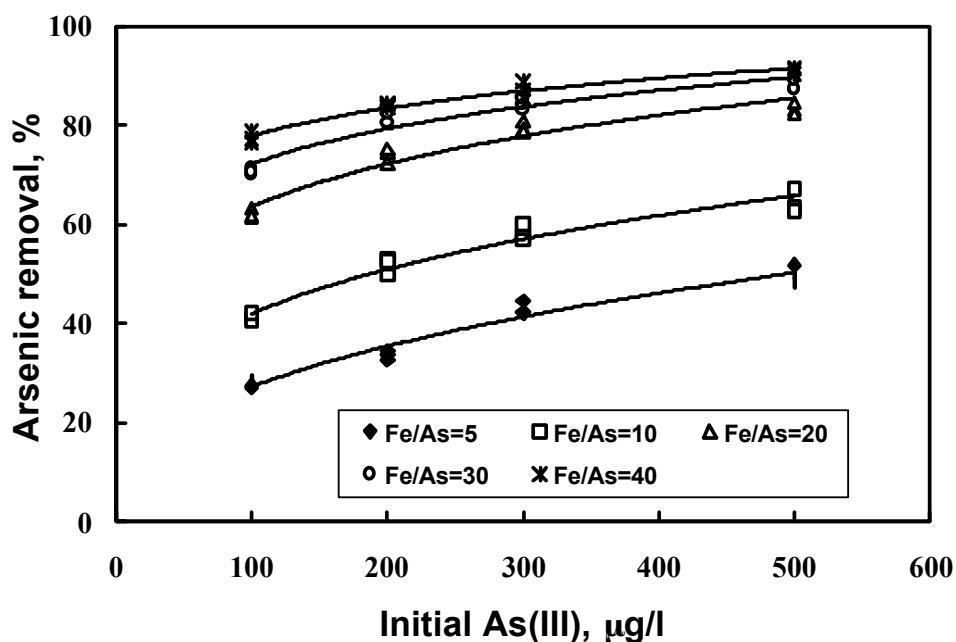
A series of tests was conducted with varying As(III) concentration ranging from 0.1 mg/l to 0.5 mg/l and Fe/As ratios (by weight) ranging from 5 to 40 at pH 7.5. The sample was mixed for 1.0 min manually and transferred to a measuring glass cylinder (432-mm height) to settle for 3 days. After 3 day settlement, the supernatant was collected and the residual arsenic was measured.

The influence of Fe/As ratio on the As(III) removal is presented in Fig. 5. The trend in Figure 5 shows that the effectiveness of As(III) removal is strongly influenced by the Fe/As ratio and is also sensitive to initial As(III) concentration. The trends are reasonably similar for the different values of the Fe/As ratios. In

Mamtaz (2000), it was shown that the data was adequately represented by the empirical equation:

$$\text{As(III) removal (\%)} = 3.98 (\text{Initial As(III)})^{0.22} (\text{Fe/As})^{0.39} (\text{pH})^{0.24} \quad (1)$$

where As(III) is expressed in  $\mu\text{g/l}$ . This equation is valid for As(III) concentration of 0.1 to 0.5 mg/l, Fe/As ratio (by weight) 5 to 40 and pH 5 to 8 and a settling time of 3 d.



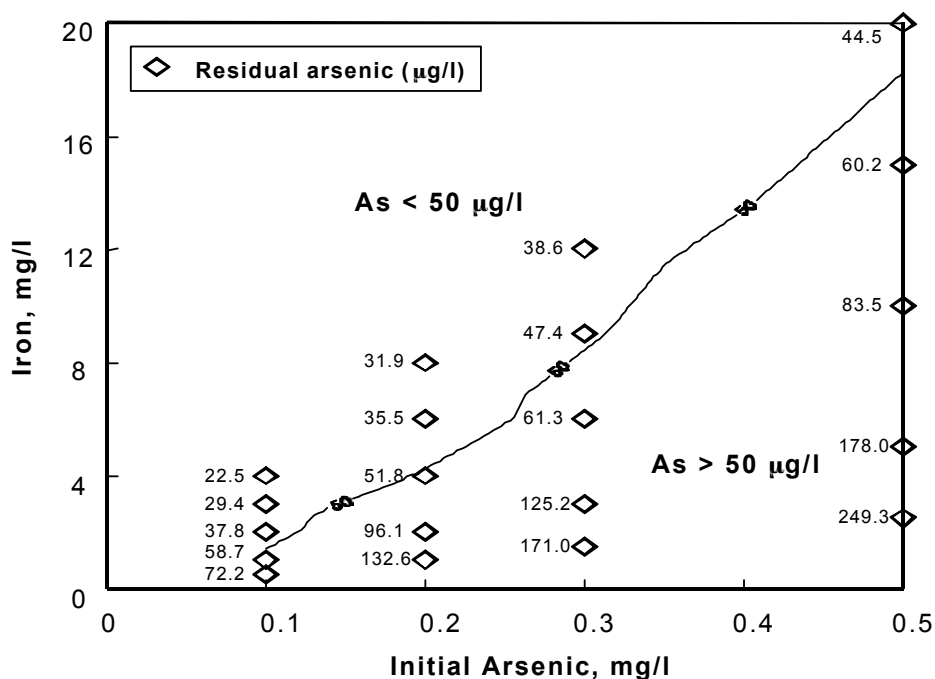
**Figure 5 : Effects of arsenic removal at different Fe/As weight ratios and initial As(III) concentration at pH 7.5 after 3 day settlement.**

The present paper focuses on a different aspect of the data shown in Figure 5. From the experimental results of Fe/As ratio (by weight) tests at different initial As(III) concentration at pH 7.5 and 3 day settling (Figure 5), it is possible to calculate the minimum amount of Fe required for reducing the arsenic level to the Bangladesh standard (0.05 mg/l) for a given As(III) concentration. A contour analysis allows one to identify the 50  $\mu\text{g/l}$  isoconcentration line of residual arsenic for the data shown in Figure 6. This was well represented by the empirical relationship as follows (Figure7):

$$\text{Fe} = 66 \text{As}^{1.75} \quad (2)$$

where, Fe and As concentrations are in mg/l.

In essence, eqn. 2 shows the necessary iron concentration to allow reduction of the arsenic to achieve the Bangladesh standard ( $50 \mu\text{g/l}$ ) for a given level of arsenic. For example, when the arsenic level is  $0.10 \text{ mg/l}$ , the minimum amount of iron requirement is  $1.2 \text{ mg/l}$  at pH 7.5 and with 3 day settlement to attain the Bangladesh limit ( $0.05 \text{ mg/l}$ ). It is noted that Figure 6 and 7 and Equation 2 are tied to 3 days settlement. Had a different time scale been used, the trends would have been different because of the dependence of the removal rate on the settling time.



**Figure 6 : Contour line showing the boundary of the zone complying with Bangladesh standard ( $50 \mu\text{g/l}$ ) for residual arsenic concentration at pH 7.5 after 3 day settlement.**

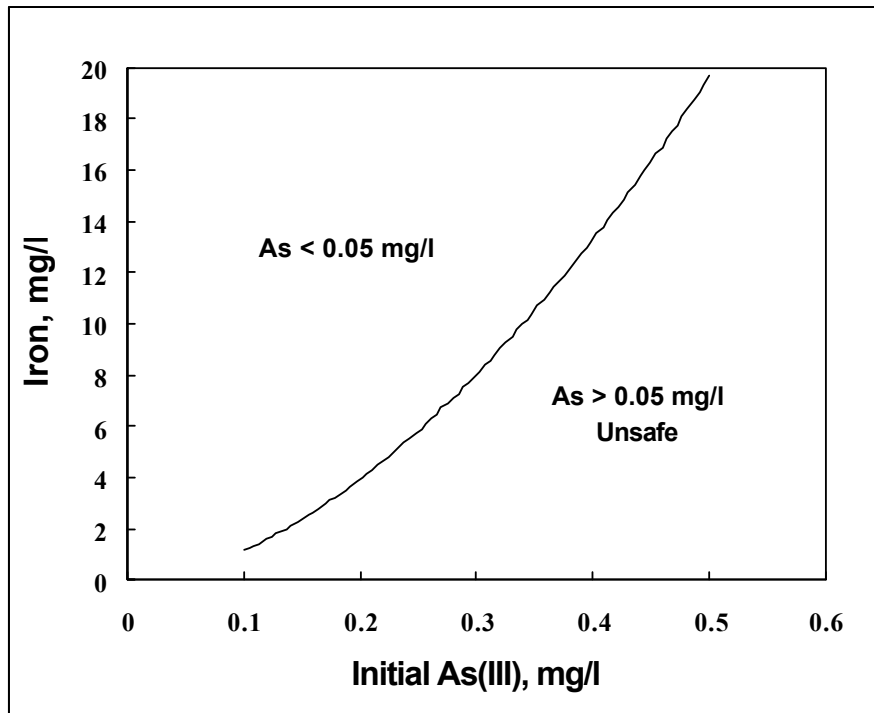


Figure 7 : Amount of minimum Fe required for a given arsenic concentration at pH 7.5 after 3 days settlement to comply with the Bangladesh Standard for arsenic (0.05 mg/l).

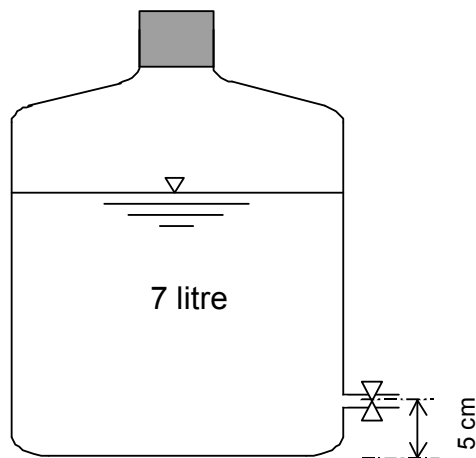


Figure 8 : Container to be used for arsenic removal

## DISCUSSION

The principal achievement in this study has been the demonstration that adsorption and coprecipitation with iron followed by settlement can remove significant amounts of arsenic provided that there is sufficient iron and a sufficient settling time ( $\geq 3$  d). As such the method has considerable promise as a low-cost technique because of the total absence of added chemicals.

A surprising aspect of the study (see Table 1 and Figure 1) was that manual mixing and sedimentation was capable of achieving higher rates of removal than mechanical mixing and filtration through a 0.45  $\mu\text{m}$  filter paper. The reasons for this are not clear and require further investigation. At early time ( $< 6$  h) manual shaking was shown to influence the separation process presumably arising from the enhancement of the size of the microflocs which were just visible to the naked eye. Simple increases in size are not necessarily responsible for increased settling because experience shows that flocs are fractal structures, larger sizes tending to lower effective density (Gregory, 1989).

In contrast to the experiences with settlement in this study, Shen (1973) regarded sedimentation as an ineffective method for removing arsenic. The major difference between the current study and Shen's study is that Shen (1973) carried out sedimentation test *without* the presence of iron or any adsorbent. This emphasises the advantage that is gained by coprecipitation to enhance arsenic removal.

When comparing the removal mechanism of the present study with other studies, the main limitation is that preparation techniques such as manual shaking and settlement have no direct equivalents. An additional complication is the time-dependence of the removal process. Hence, it is difficult to make direct comparisons with other studies. In Figure 2, it was evident that the removal density did not reach a saturation point of the range of As(III) concentration tested (0.1-7.5 mg/l). Ferguson and Anderson (1974) also reported that arsenite adsorption did not reach a state of saturation; they observed a maximum adsorption density at 0.4 mole As /mole Fe. Pierce and Moore (1982) suggested that a multisite adsorption occurred in arsenic adsorption onto  $\text{Fe}(\text{OH})_3$  at higher initial arsenic concentration i.e. arsenic can penetrate into oxide surface which is theoretically possible for an open permeable structure of amorphous  $\text{Fe}(\text{OH})_3$ .

The coincidence of the trends plotted in Fig. 3 is intriguing. At first sight it suggests that adsorption is responsible for the removal of arsenic up to the initial arsenic concentration of 0.4 mg/l (corresponding residual concentration is  $\sim 0.15$  mg/l). However without further scrutiny to examine the time-dependence (in our study), this interpretation must remain speculative. Nevertheless it should be pointed out that just as our own data is linked to a time-dependent process, this

aspect is also true of the Pierce and Moore (1982) study wherein centrifugation after 24 h adsorption is used as the separation technique. According to Hering et al (1996) adsorption is a dominant mechanism in the arsenic removal by coagulation. Some comparative studies of As(V) adsorption on preformed Fe(OH)<sub>3</sub> and coprecipitation showed that higher removal densities (mole As/mole Fe) could be achieved by coprecipitation when compared with adsorption, this effect being most pronounced at high As-Fe ratios (Fuller et al, 1993; Edwards, 1994). Clearly this subject requires further investigation.

The prime objective of this work was to ascertain whether the As/Fe interaction offered sufficient promise for arsenic removal (a practical system being described in the Appendix). It is believed that in spite of a lack of understanding of the underlying mechanisms, the method is potentially very useful. A necessary condition is the sufficiency of iron. Relationship of the type shown by Equation 2 is likely to be useful for discerning the minimum iron concentration.

## **ARSENIC REMOVAL AT VILLAGE LEVEL**

A simple and practical method that can be adopted at village level for reducing the level of arsenic in contaminated groundwater in Bangladesh is described below. This method applies to water in, which there is a sufficient iron concentration to form iron-arsenic precipitates.

For iron concentration between 1.0 and 20.0 mg/l and arsenic concentration between 0.1 to 0.5 mg/l, there is a reasonable expectation that after following the procedure described below, the water will comply with the Bangladesh Water Quality Standard for arsenic (0.05 mg/l).

- Fill a clean container of 10 litre capacity (Fig. 8) with about 7 litre water to be treated leaving an air space
- Shake the container for 1 minute
- Allow 3 days for particle settling
- Take out treated water through the tap, not exceeding a flow-rate of 0.5 litre/min (Mamtaz and Bache, 2000).

## **CONCLUSIONS**

Manual flocculation followed by sedimentation appears to be a promising method for removing arsenic from groundwater containing naturally occurring iron. Over prolonged periods of settlement ( $\geq 24$  h), removal of up to 88% was achieved (Fig. 1). Provided the iron levels are sufficiently high (say  $\geq 1.2$  mg/l),

it has been demonstrated that simple shaking of a container and allowing the arsenic-iron complex to settle out for 3 days could reduce the concentration of arsenic from 0.10 mg/l to the Bangladesh standard (0.05 mg/l).

Evidence (Fig. 3) suggests that adsorption may be the primary mechanism controlling the As(III) removal by the techniques employed in this study and when the Fe/As weight ratio is  $\geq 10$ . However this aspect requires further scrutiny.

## REFERENCES

- Ahmed, M. F., Ali, M..A. and Hossain, M. D. 1998 Groundwater treatment for arsenic-iron removal. *International conference on arsenic pollution of ground water in Bangladesh: causes, effects and remedies*, Dhaka, Bangladesh.
- APHA, AWWA, and WEF. 1995 19th edition *Standard methods for the examination of water and wastewater*. Washington, DC.
- BGS and MottMacdonald Ltd. UK. 1999 Phase I, Groundwater studies of arsenic contamination in Bangladesh. *Executive summary, Main report*, for Govt. of Bangladesh, Ministry of local Govt. Rural Development Co-operatives, Dept. of Public Health Engineering (DPHE) and Dept. for International Development (DFID-UK).
- Cheng, C. R., Liang, S., Wang, H-C and Beuhler, M. D. 1994 Enhanced coagulation for arsenic removal. *J. American Water Works Association*. **86** (9), 79-90.
- Department for Internatinal Development (UK), British Geological Survey (UK), Govt. of Peoples Republic of Bangladesh, Ministry of Local Govt. and Co-operatives, Dept. of Public Health Engineering Groundwater studies of arsenic contamination in Bangladesh. *Final report Summery, June 7, 2000*.
- Driehaus, W., Jekel, M. R. and Hilderbrandt, U. 1998 Granular ferric hydroxide- a new adsorbent for the removal of arsenic from natural water. *J Water Supply Research and Technology-AQUA*. **47** (1), 30-35.
- Edwards, M. 1994 Chemistry of arsenic removal during coagulation and Fe-Mn oxidation. *J. American Water Works Association*. **86** (9), 64-78.
- EGIS (ENVIRONMENT AND GIS SUPPORT PROJECT FOR WATER SECTOR PLANNING). 1997 Spatial Information System for Arsenic Mitigation Programs. *Draft Report*, Ministry of Water resources, Government of Bangladesh.
- Ferguson, J. F. and Anderson, M. A. 1974 Chemical form of arsenic in water supplies and their removal. *In Chemistry of Water Supply, Treatment and Distribution (Edited by Rubin A.J.)*, Ann Arbor Science, Ann Arbor, MI. 137-158.



- Ferguson, J. F. and Gavis, J. 1972 A review of arsenic cycle in natural waters. *J. Water Research.* **6**, 1259-1274.
- Fuller, C. C., Davis, J. A. and Waychunas, G. A. 1993 Surface chemistry of Ferrihydrite: Part 2, Kinetics of arsenic adsorption and coprecipitation. *Geochim. Cosmochim. Acta.* **57** (10), 2271-2282
- Ghosh, M. M. and O'Connor, J. T. 1966 Precipitation of iron in aerated groundwater. *J. Sanitary Eng. Div. ASCE*, 90 SAi, 199.
- Gregory, J. 1989 Fundamentals of Flocculation. *CRC critical reviews in Environmental Control.* **19** (3), 185-230.
- Hering, J. G., Chen, P-Y, Wilkie, J. A. and Elimelech, M. 1997 Arsenic removal during coagulation. *J. Environmental Engineering, ASCE.* **123** (8), 800-807.
- Hering, J. G., Chen, P-Y., Wilkie, J. A., Elimelech, M. and Liang, S. 1996 Arsenic removal by ferric chloride. *J. American Water Works Association.* **88** (4), 155-167.
- Jekel, M. R. 1994 Removal of arsenic in drinking water treatment. *Arsenic in the Environment, Part I: Cycling and Characterisation (edited by Jerome O. Nriagu), John Wiley and Sons, Inc.* **26**, 119-132.
- Kartinen, E. O. and Martin, C. J. 1995 An overview of arsenic removal processes. *J. Desalination.* **103**, 79-88.
- Mamtaz, R. 2000 Low-cost technology for removal of arsenic from water: with particular reference to Bangladesh. *PhD thesis*, University of Starthclyde, UK.
- Mamtaz, R. and Bache, D. H. 2000 Low-cost separation of arsenic from water: with special reference to Bangladesh. *J. Chartered Institute of Water and Environmental Management (in press).*
- Pierce, M. L. and Moore, C. B. 1982 Adsorption of As(III) and As(V) on amorphous iron hydroxide. *J. Water Research.* **16**, 1247.
- Shen, Y. S. 1973 Study of arsenic removal from drinking water. *J. American Water Works Association.* **65** (8), 543-548.
- Sorg, T. J. and Logsdon, G. S. 1978 Treatment technology to meet the interim primary drinking water regulations for inorganics: part 2. *J. American Water Works Association.* **70**, 379-393.

# Granular Ferric Hydroxide for Elimination of Arsenic from Drinking Water

**B. N. Pal**

M/S Pal Trockner [P] Ltd.  
25/1B Ibrahimpur Road, Calcutta-700 032

## INTRODUCTION

Arsenic is a naturally occurring element that is tasteless and odorless. As a compound of underground rock and soil, arsenic works its way into groundwater and enters food chains through either drinking water or eating plants and cereals that have absorbed the mineral. Daily consumption of water with greater than 0.01 mg/L of arsenic, less than 0.2 % of the fatal dose, can lead to problems with the skin and circulatory and nervous systems. If arsenic builds up to higher toxic levels, open lesions, organ damages (such as deafness), neural disorders and organ cancer, often fatal, can result.

Groundwater is the preferred source of drinking water in rural areas, particularly in developing countries, because treatment of the same, including disinfection, is often not required and its extraction system can be placed near consumers. The groundwater of vast areas in the Ganges Delta – in West Bengal and Bangladesh – is highly contaminated by arsenic. Of all the 18 districts of West Bengal together having 341 blocks, 10 districts with 69 blocks have already been identified as severe arsenic contaminated areas, which include many places around Calcutta, such as Barasat, Habra etc. in North 24-Parganas. The problem of arsenic contamination of groundwater is more serious in Bangladesh, where the groundwater in 59 of the 64 districts is contaminated with arsenic and about two-third of the population is exposed to “the biggest mass – poisoning case the world has ever known” (Washington Post). The water from deep wells in these areas may not be initially contaminated by arsenic, but there is every reason to fear that in course of time the contaminated groundwater from upper level may ultimately affect the water of the lower level too.

The most common valence states of arsenic in geogenic raw water sources are As(V) or arsenate and As(III) or arsenite. In the pH range of 4 to 10, the prevalent As(III) species are neutral in charge, while the As(V) compounds are negatively charged. The removal efficiency for As(III) is poor compared to that for As(V) by any of the of the conventional technologies for elimination of arsenic from water. For effective removal of arsenic form water a complete oxidation of As(III) to As(V) is required. [1]

## CONVENTIONAL ARSENIC REMOVAL SYSTEMS

Some important works on evaluating treatment methods for removal of arsenic have been carried out recently. However, all these studies indicate that only As(V) can be removed from water effectively . If As(III) is present in source water, oxidation of the same is essential.

- Removal of arsenic by coagulation with ferric salts, followed by filtration (co-precipitation), is the best known technique. This technique allows doses of ferric salts below 10 mg/L and achieves residual arsenic concentrations below 10  $\mu$ g/L. [2]
- Lime softening for reducing carbonate hardness is also an efficient process for removal of As(V) .
- Further, the conventional Iron-Manganese removal processes can be utilized for removal of arsenic from groundwater containing naturally occurring iron and/or manganese. Iron coagulation/filtration and iron addition with direct filtration methods can significantly reduce arsenic while removing the iron and manganese from the source water. But the biggest problem with the systems is the safe separation of the precipitate and the disposal of the contaminated coagulant sludge. The coagulation technique is not appropriate for small water facilities, because of high cost and need for well-trained operators.
- Ion exchange can remove As(V) from water. However, high levels of TDS, selenium , sulfate, fluoride and nitrate contained in water can affect the life of resin. Disposal of highly concentrated spent regenerant is a serious problem. As (III) is hardly removable by ion exchange method.

- Reverse osmosis and nano-filtration may deliver satisfactory removal efficiencies, but water rejection is very high in these technologies and the discharge of reject water is also a concern.
- Adsorption of arsenic on Activated Alumina in fixed bed is a simpler but less effective technology. [3] The presence of phosphate, sulfate, fluoride and chloride in raw water may reduce the adsorption capacity of Activated Alumina substantially. Chemical handling requirements to make this technique attractive may make the process too complex. The highly concentrated spent regenerant may create disposal problem. Activated Alumina cannot be effectively applied for removal of As(III).

### **ADSORPTION OF ARSENIC WITH GRANULAR FERRIC HYDROXIDE (ADSORPAS®)**

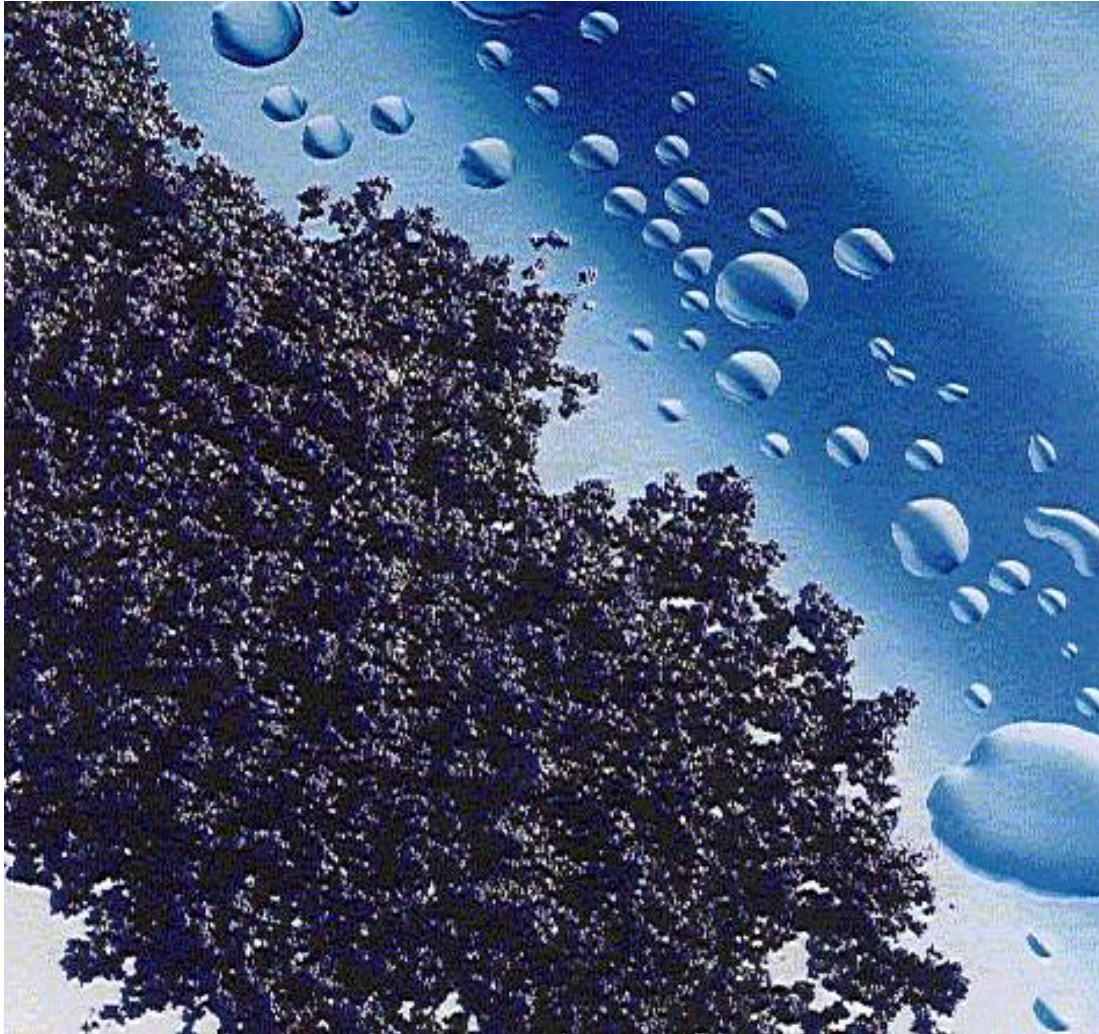
The requirements for an acceptable technique for removal of arsenic from drinking water are:

- high efficiency
- safe technology to ensure the maintaining of the maximum contaminant level,
- simple operation
- minimum residual mass.

Fixed bed Granular Ferric Hydroxide (AdsorpAs®) reactors satisfy all these requirements. This technology combines the high arsenic removal efficiency of the coagulation–precipitation process with the advantage of simple operation of the fixed bed adsorption technology.

### **Granular Ferric Hydroxide – A High Performance Adsorbent**

Granular Ferric Hydroxide (AdsorpAs®) is an adsorbent, developed at the Technical University of Berlin, Germany, Department of Water Quality Control, especially for selective removal of arsenic from natural water. Studies on the adsorption of both arsenic forms on amorphous ferric hydroxide had determined that such a material should have 5 to 10 times higher efficiency than Activated Alumina [4]. Also in the coagulation- filtration process ferric salts show better removal efficiency than alum at equal dosage. So it is expected that a granular activated ferric oxide or ferric hydroxide should have higher capacity for the adsorption of arsenic from water than Activated Alumina in a fixed bed system.



**Figure 1 : Granular Ferric hydroxide ( AdsorpAs®)**

Granular Ferric Hydroxide (AdsorpAs®) is poorly crystallized  $\alpha$ - FeOOH manufactured from a ferric chloride solution by neutralization and precipitation with sodium hydroxide. As no drying procedure is included in its preparation, all the pores are completely filled with water, leading to a high density of available adsorption sites and thus to a high adsorption capacity [5]. The main application of AdsorpAs® is the adsorptive removal of arsenate, arsenite and phosphate from natural water as well as wastewater. It can, however, be applied also for the removal of various other dissolved substances in water, e.g. fluoride, molybdenum, selenium, antimony etc.



**Figure 2 : AdsorpAs® - synthetically manufactured Iron Hydroxide having a porosity of about 75% and specific surface of 250 – 300 m<sup>2</sup> /g.**

**Material Properties**

Chemical composition:

Active substance	Fe(OH) <sub>3</sub> and (α-FeOOH)	:	52-57 %
Water content		:	43-48 %

Adsorption Density:

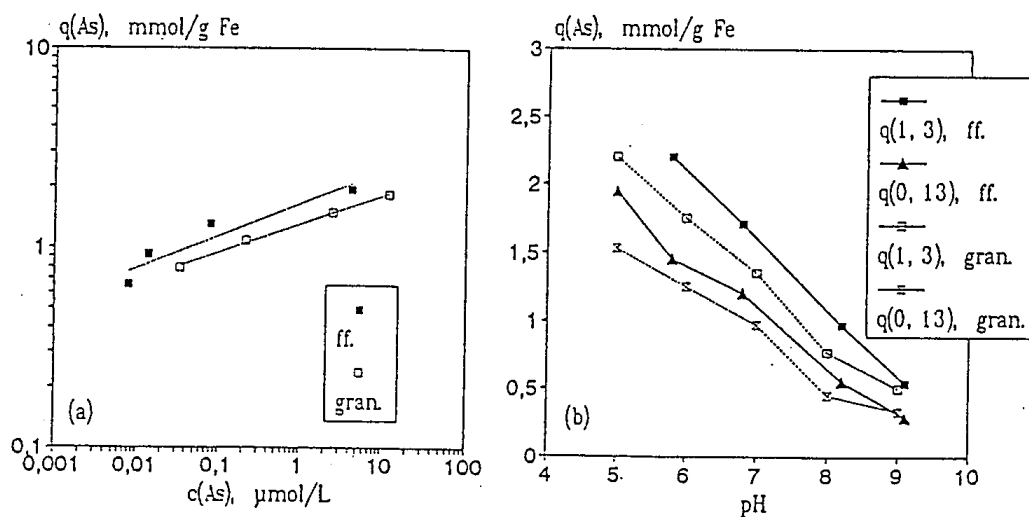
AsO <sub>4</sub> <sup>3-</sup> - Arsenic	:	typical 28 g/dm <sup>3</sup> adsorber bed,	45g/kg dry weight
Phosphorus	:	typical 10g/dm <sup>3</sup> adsorber bed,	16g/kg dry weight

**Physical data**

Grain size	:	0.2- 2.0 mm
Density of grains	:	1.59 kg/dm <sup>3</sup>
Bulk density	:	1.22 – 1.29 kg/dm <sup>3</sup>
Porosity of grains	:	72 –77 %
Specific surface	:	250 – 300 m <sup>2</sup> /dm <sup>3</sup>
Bulk porosity	:	22b – 28 %

### Application

As shown in figure 3, the arsenate adsorption density on Granular Ferric Hydroxide is almost similar to that on freshly prepared ferric hydroxide. Granulation does not lead to a considerable decrease in adsorption capacity. The granulated adsorbent can be successfully applied in the pH range between 5.5 to 9. However, the arsenate adsorption decreases slightly with pH, which is typical for anion adsorption.

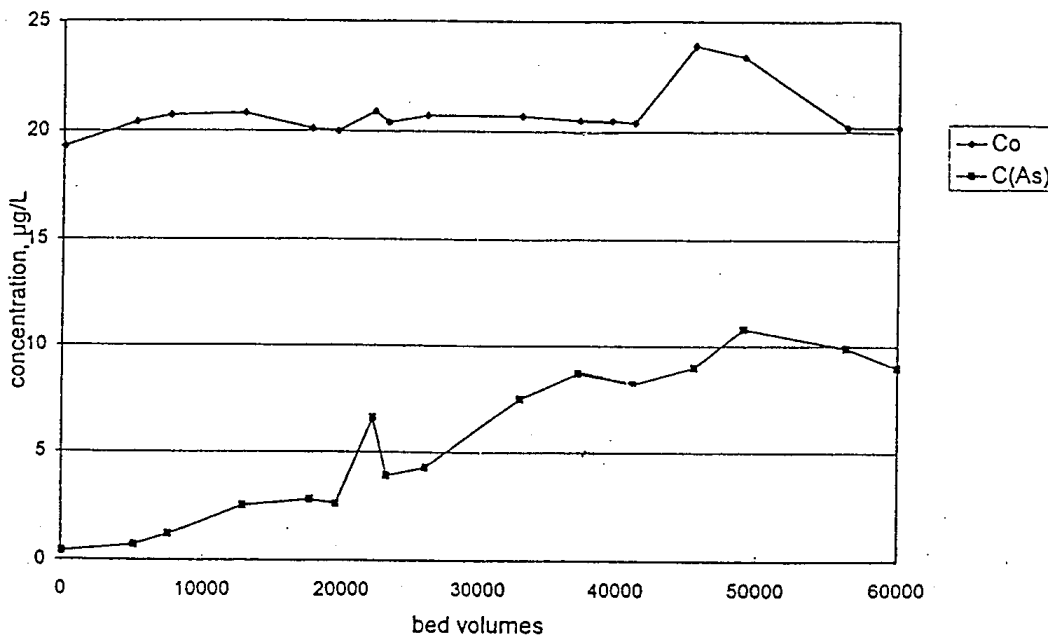


**Figure. 3 : Arsenate adsorption density  $q(\text{As})$  on AdsorpAs® (gran) and on freshly prepared ferric hydroxide (ff) in the pH range 5 – 9.**

Granular Ferric Hydroxide can remove huge amount of arsenic from ground water. Various tests conducted with the adsorbents in operation have shown a high treatment capacity of the adsorbent between 40 000 to 60 000 bed volumes, until the permissible limit for arsenic of  $10 \mu\text{g/L}$  was exceeded. The typical residual mass is in the range of  $5 - 25 \text{ g/m}^3$  of treated water.

Figure 4 shows the result of the studies carried out with natural groundwater by a plant installed in the southern part of Lower Saxony, Germany. The raw water had a pH of 7.8 and an arsenic concentration of  $21 \mu\text{g/L}$ . The maximum contaminant level (MCL) of  $10 \mu\text{g/L}$  of the effluent was reached only after 60000 bed volumes were treated.

Several arsenic elimination plants with Granular Ferric Hydroxide in fixed bed reactors are being successfully operated in Germany and Great Britain to remove the toxicant from groundwater contaminated from geogenic as well from anthropogenic sources.



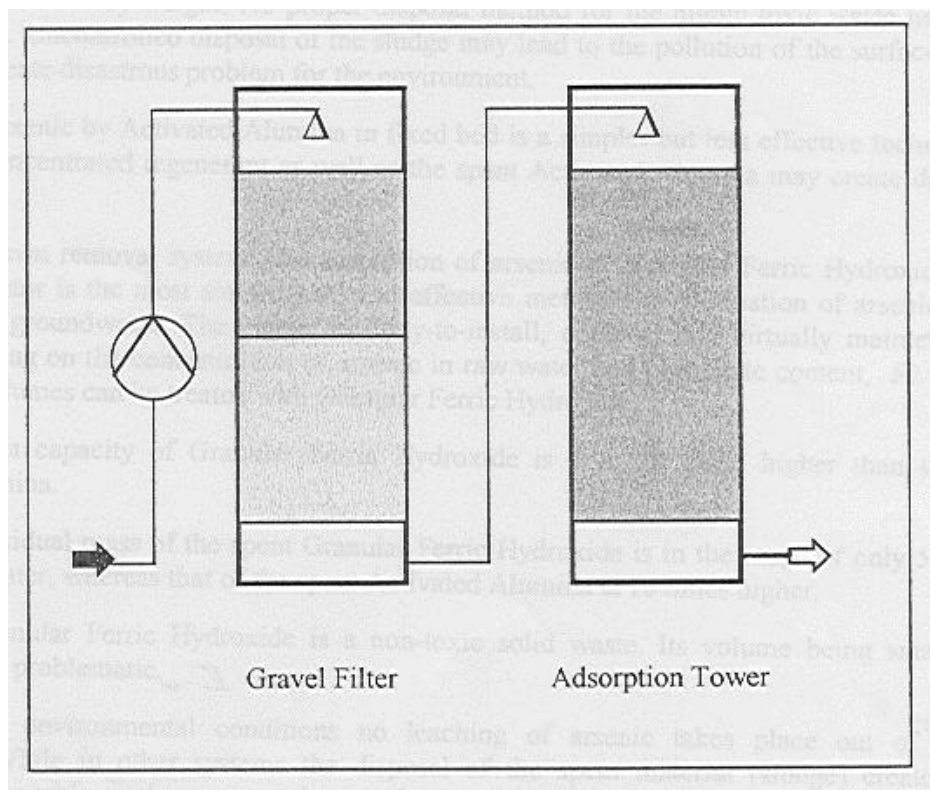
**Figure. 4 : Arsenic concentration in groundwater (pH 7.8) before and after treatment with AdsorpAs® at a water facility in Lower Saxony.**

At the initiative of the Central Ground Water Board (CGWB), Govt. of India [1], Public Health Engineering Department (PHED), Govt. of West Bengal [2], and State Water Investigation Directorate (SWID), Govt. of West Bengal [3] a number of tests had been carried out with a model Granular Ferric Hydroxide reactor at their laboratories and at different arsenic contaminated sites, e.g., Habra, Barasat, Ashoke Nagar, Baruipur etc. in West Bengal. The analysis report of all these tests reveal that input water containing any amount of arsenic (5 mg/lit at CGWB laboratory) could be freed from the toxicant by Granular ferric Hydroxide to a level much below the permissible limit of 0.01 mg/L.

**Process**

Granular Ferric Hydroxide reactors are fixed bed adsorbers operating like conventional filters with a downward water flow. The technique aims at the combination of the high arsenic removal efficiency of the coagulation-filtration process with the simple operation of the fixed bed adsorption. This technology is not only economical but also the most effective system as far as the efficiency in eliminating arsenic from groundwater is concerned. It can be used for small-scale application in rural areas with hand tubewells, as well as for large-scale application in towns with community waterworks.





**Figure. 5 : Arsenic Removal Plant**

The configuration is easy to install, as it consists only of a iron removal-cum- gravel filter followed by an adsorption tower filled with AdsorpAs® . The feed water passes through the first filter to be freed from iron and suspended particles contained in groundwater. It then passes through the adsorption tower, where the arsenic content in water will be brought down by adsorpAs® to a level below  $10 \mu\text{g/L}$ . Contaminated water containing arsenite (III) and arsenate (V) while passes through AdsorpAs® bind on the surface of ferric hydroxide building inner-sphere complexes. This is a specific adsorption process, also known as chemisorption.

There is no need to man the system round the clock, as is the case with the precipitation and flocculation methods. It cuts considerably down on operation and personnel costs. For a trouble-free operation of the plant, it is equipped with a back-washing system for the filter.

As the technology involves fixed-bed adsorption, the adsorbent is better utilized; the amount of solid residue at the end of the adsorption process is small and needs no further dehydration. The spent adsorpAs® is a non-toxic and non-hazardous solid waste. Its volume being small, its disposal is less problematic.

## CONCLUSIONS

The occurrence of geogenic As(III) and As(V) in groundwater is a serious problem in certain regions, particularly in Bangladesh and West Bengal. As stated above, different treatment technologies are available at present, which may offer solutions to this menace. Among them arsenic removal by co-precipitation technique is the best known system, but it is also one of the most unsafe systems for arsenic separation. In arsenic affected areas where the contents of naturally occurring iron and /or manganese in groundwater is high, one may be tempted to remove arsenic together with iron and manganese by using the co-precipitation technique. The precipitation (Iron-Manganese removal) process produces sludge with considerable arsenic content of up to 10% by weight. No proper disposal method for the highly toxic waste has been developed yet. Uncontrolled disposal of the sludge may lead to the pollution of the surface water system and create disastrous problem for the environment.

Removal of arsenic by Activated Alumina in fixed bed is a simpler but less effective technology. The highly concentrated regenerant as well as the spent Activated Alumina may create disposal problem. Of all the known removal systems the adsorption of arsenic by Granular Ferric Hydroxide in a fixed bed reactor is the most simple, safe and effective method for elimination of arsenic from contaminated groundwater. The plants are easy-to-install, compact and virtually maintenance-free. Depending on the concentration of arsenic in raw water and phosphate content, 50 000 to 70 000 bed volumes can be treated with Granular Ferric Hydroxide. The adsorption capacity of Granular Ferric Hydroxide is 5 to 10 times higher than that of activated Alumina. The typical residual mass of the spent Granular Ferric Hydroxide is in the range of only 5 to 25 g/m<sup>3</sup> treated water, whereas that of the spent Activated Alumina is 10 times higher.

The spent Granular Ferric Hydroxide is a non-toxic solid waste. Its volume being small, its disposal is less problematic. Under normal environment conditions no leaching of arsenic takes place out of spent AdsorpAs®. While in other systems the disposal of the spent material (sludge) creates big environment problem, the spent AdsorpAs® can be advantageously utilized as an useful component for manufacturing bricks. AdsorpAs® is the safest and the most effective system for removal of arsenic of arsenic from groundwater.

## REFERENCES

- [1] Jekel, M. and Van Dyck- Jekel, H.: Spezifische Entfernung von anorganischen Spuren-stoffen bei der Trinkwasseraufbereitung. DVGW-schriftenreihe: wasser 62;1989.
- [2] Pontius F. W.: Crafting a new arsenic rule. JAWWA 1995 ; 87(9);6-10,104.
- [3] Rosenblum, M. and Clifford, L. : The equilibrium arsenic capacity of activated alumina. US-Environmental Protection Agency Report EPA, 600/S2-83/ 107, 1984.
- [4] Pierce, M. L. and Moore, C. B. (1982) : Adsorption of Arsenite and arsenate on amorphous iron hydroxide. Water Res. 16 , 1247 – 1253.
- [5] Driehaus, W., Jekel, M. and Hildebrandt, U. : Granular ferric hydroxide – a new adsorbent for the removal of arsenic from natural water. 1998 Blackwell Science Ltd. J. Water SRT- Aqua 47 , 30 –35.

## Approaches for Removal of Arsenic from Tubewell Water for Drinking Purpose

**M. D. Hussain , M. A. Haque, M. M. Islam and M .A. Hossen**  
Deapartment of Farm Power and Machinery,  
Bangladesh Agricultural University  
Mymensingh-2202

### ***Abstract***

*Removal of arsenic from tubewell water is possible by passing it through wood charcoal, by chemical treatment, by sedimentation method or by removing the layer floating on arsenic bearing water. It was found that when arsenic water was treated with calcium oxide, it produced arsenic-free water. In this method more than 90 percent removal of arsenic was achieved by adding 0.10% (by weight) calcium oxide to arsenic-contaminated water. After 10 hrs the water becomes arsenic-free. In another experiment, arsenic-bearing water was passed through wood charcoal at different flow rates and it was found that up to 98% removal was possible. If arsenic water (0.45 mg/L) is kept in a big tank (about 3000-liter capacity) for about 9 days, arsenic concentration level is reduced in the top layers to acceptable level (0.05 mg/L). When arsenic-bearing water comes in contact with free air, a thin layer is formed which is nothing but an arsenic compound and its concentration was about 0.7 mg/L. In this way arsenic level can be reduced to acceptable level by repeated removal of the floating layer. Any of the methods mentioned above can be used to produce arsenic-free water and it can be recommended for use in rural areas of Bangladesh.*

### **INTRODUCTION**

Safe drinking water is still an important issue in Bangladesh. In the past, most drinking water was used to be harnessed from rivers, ponds, dug wells with little

or no arsenic, but with contamination by pathogens which transmitted various diseases, such as cholera, diarrhea, dysentery, hepatitis and typhoid. To control these diseases, program for safe drinking water initiated the use of tubewells to harness groundwater. Although it succeeded in achieving its goal of supplying water free of pathogens, after a couple of decades since inception, an unexpected side effect has been noticed. This was the detection of inorganic arsenic in tubewell water in many regions of the country. Intake of arsenic associated with food is a common phenomenon, but this arsenic is the low-toxicity organic arsenic. But drinking water derived from underground source contains arsenic in inorganic form, which is of higher toxicity and a significant hazard for human health. Prolonged use of arsenic-rich water for drinking purpose is unsafe and the most commonly reported symptoms of chronic arsenic exposure are hyperpigmentation, depigmentation, keratosis, skin cancer and a number of internal cancers. Cardiovascular and neurological diseases have also been found to be linked to arsenic contamination (WHO, 1999 and Saha, 1998). High concentration of arsenic in water when associated with malnutrition and hepatitis B, which are very common in Bangladesh, accelerate the effects of arsenic poisoning.

According to recent statistics, fifty four out of the sixty four administrative districts are affected by arsenic contamination in tubewell water (WHO, 1997). The number of people drinking arsenic contaminated water has increased over last 25 years due to well drilling and population growth in Bangladesh. The number of affected persons may, therefore, increase further (WHO, 1999). The most important remedial measure is prevention of further exposure by providing safe drinking water. Many programs on arsenic detection and creation of awareness have so far been completed and some are being implemented. But very few efforts have been undertaken for the removal of arsenic from tubewell water except to abandon the arsenic affected tube wells. Yet no proven technologies for the removal of arsenic at water collection points, such as wells, are available (BES, 1999). So, simple technologies for removal of arsenic from tubewell water is of urgent need.

From this point of view, several approaches have been tested in this study to remove or reduce arsenic from tubewell water to safe limit at household level.

## **METHODOLOGY**

Field experiment was conducted at Goneshampur village under Mymensingh sadar upazila during November 2000 to March 2001. Four different approaches were tested for removal or reduction of arsenic level from tube well water. Arsenic concentrations were determined by an arsenic kit provided by NIPSOM.

In the first attempt, arsenic contaminated water was allowed to pass through successive layers of sand and wood charcoal at a controlled flow rate. In this setup, three pitchers (11 liters each) were placed one above another vertically in a bamboo-tripod. The top most pitcher, having a small hole at its bottom, contained arsenic contaminated water. The middle one contained layers of wood charcoal and sand. This pitcher also had a small orifice at its bottom covered with a screen to prevent sand from leaking out. Size of pieces of charcoal was in the range of 1-1.5 cm. Weight of the layers of charcoal was varied (606 gm, 754 gm and 457 gm), while weight of the layer of sand was 4480 gm. The bottom pitcher was used to collect filtered water. Contaminated water was allowed to flow at different flow rates.

For chemical treatment, calcium oxide was added at different doses to arsenic contaminated water and allowed to stay for several hours in a container. In sedimentation method, arsenic contaminated water was kept in a tank (capacity 3000-liter). Every 72 hours arsenic level of the water was tested at 5 different layers of water in the tank. Each layer was 20 cm thick and the 6<sup>th</sup> layer at the bottom acted as sedimentation trap. Finally, a thin layer, formed at the surface of arsenic contaminated water, was removed and the level of arsenic in the water was tested.

## RESULTS AND DISCUSSION

Very good arsenic removal was observed when arsenic contaminated water was allowed to pass through wood charcoal. Table 1 shows percentage of arsenic removal from arsenic-bearing water at different flow rates. It was found that removal of arsenic was higher with lower flow rates through the layer of charcoal. With the successive layers containing 4480 gm of sand and 606 gm of coal, about 97% to 99% removal of arsenic was observed with flow rates varying from 54 to 12 ml/min, respectively. Similar results were found when 754 gm and 457 gm of charcoal were used with the 4480 gm of sand, respectively (Table 2 and Table 3).

Arsenic level of arsenic-bearing water was found to be reduced in sedimentation method, as arsenic is heavier than water. Table 4 shows that arsenic content of different layers of water reduced as time passed. After a period of 216 hours, 1/2 portion of water from the top surface attained safe level of arsenic content while 2/3 portion of water showed safe level of arsenic content after 288 hours of sedimentation period.

While treating with calcium oxide, arsenic contaminated water showed positive response. Table 5 reveals that adding 0.1% (by weight) of lime to arsenic contaminated water, reduced arsenic to safe level after a period of 10 hours, while no arsenic was detected after a period of 16 hours.

**Table 1: Arsenic removal from contaminated water by charcoal method at different flow rates (Sand 4480 gm and Coal 606 gm).**

Sl. No.	Flow rate (ml/min)	Initial arsenic Content (mg/L)	After filtration (mg/L)	% removal
1	12	0.46	0.004	99
2	30	0.46	0.007	98
3	40	0.46	0.007	98
4	54	0.46	0.013	97
5	126	0.46	0.015	97
6	137	0.46	0.026	94
7	148	0.46	0.028	94
8	150	0.46	0.034	93
9	192	0.46	0.038	92
10	260	0.46	0.05	89
11	265	0.46	0.054	88
12	336	0.46	0.25	46

**Table 2: Arsenic removal from contaminated water by charcoal method at different flow rates (Sand 4480 gm and Coal 754 gm).**

Sl. No.	Flow rate (ml/min)	Initial arsenic content (mg/L)	After filtration (mg/L)	% removal
1	12	0.46	0.012	97
2	30	0.46	0.014	97
3	40	0.46	0.02	96
4	54	0.46	0.027	94
5	126	0.46	0.047	92
6	137	0.46	0.052	89
7	148	0.46	0.067	85
8	150	0.46	0.066	86
9	192	0.46	0.098	79
10	260	0.46	0.017	63
11	265	0.46	0.22	53
12	336	0.46	0.28	39

During experiment it was found that arsenic contaminated water, when kept in a storage tank, formed a thin layer at the top of its surface after a couple of days. This may occur due to formation of arsenic compound when the water containing arsenic came in contact with free air. Formation of this layer was augmented in the presence of iron in the water. This layer contained excessive level of arsenic (0.7 mg/L). Repeated removal of this thin layer from the top surface reduced the arsenic content to safe level.

**Table 3: Arsenic removal from contaminated water by charcoal method at different flow rates (Sand 4480 gm and Coal 757 gm).**

Sl. No.	Flow rate (ml/min)	Initial arsenic content (mg/L)	After Filtration (mg/L)	% removal
1	12	0.46	0.006	99
2	30	0.46	0.006	99
3	40	0.46	0.006	99
4	54	0.46	0.011	98
5	126	0.46	0.014	97
6	137	0.46	0.019	96
7	148	0.46	0.02	96
8	150	0.46	0.024	95
9	192	0.46	0.032	93
10	260	0.46	0.04	91
11	265	0.46	0.048	90
12	336	0.46	0.16	65

**Table 4 : Reduction of arsenic level from water by sedimentation method**

Duration (hrs)	Amount of arsenic ( mg/L)					
	1 <sup>st</sup> layer	2 <sup>nd</sup> layer	3 <sup>rd</sup> layer	4 <sup>th</sup> layer	5 <sup>th</sup> layer	6 <sup>th</sup> layer
0	0.45	0.45	0.45	0.45	0.45	Sedimentation trap
72	0.05	0.1	0.2	0.3	0.30	
144	0.05	0.1	0.2	0.2	0.30	
216	0.05	0.03	0.04	0.2	0.3	
288	0.05	0.01	0.01 <sup>+</sup>	0.02 <sup>+</sup>	0.2 <sup>+</sup>	



**Table 5: Treatment of arsenic contamination water with Calcium Oxide**

Amount of water (gm)	Amount of CaO (gm)	Initial arsenic content (mg/L)	Arsenic concentration (mg/L)			% removal		
			After 1 hr	After 10 hrs	After 16 hrs	After 1 hr	After 10 hrs	After 16 hrs
5000	0.5	0.45 <sup>+</sup>	0.45 <sup>+</sup>	0.4	0.4	0.0	11	11
5000	1.0	0.45 <sup>+</sup>	0.45 <sup>+</sup>	0.35	0.3	0.0	22	38
5000	2.0	0.45 <sup>+</sup>	0.4 <sup>+</sup>	0.25	0.15	0.0	44	67
5000	2.5	0.45 <sup>+</sup>	0.4 <sup>+</sup>	0.09	0.06	0.0	80	87
5000	3.0	0.45 <sup>+</sup>	0.35 <sup>+</sup>	0.07	0.05	22	84	89
5000	3.5	0.45 <sup>+</sup>	0.3	0.07	0.05	33	84	89
5000	4.0	0.45 <sup>+</sup>	0.3	0.05	0.03	33	88	93
5000	4.5	0.45 <sup>+</sup>	0.3	0.05	0.03	33	88	43
5000	5.0	0.45 <sup>+</sup>	0.25	0.035	Nil	44	92	100
5000	5.5	0.45 <sup>+</sup>	0.25	0.03	Nil	44	93	100
5000	6.0	0.45 <sup>+</sup>	0.25	0.02	Nil	44	96	100
5000	6.5	0.45 <sup>+</sup>	0.2	0.15	Nil	56	97	100
5000	7.0	0.45 <sup>+</sup>	0.2	0.01	Nil	56	98	100
5000	7.5	0.45 <sup>+</sup>	0.15	0.01	Nil	67	98	100
5000	8.0	0.45 <sup>+</sup>	0.10	0.01	Nil	78	98	100
5000	8.5	0.45 <sup>+</sup>	0.10	Nil	Nil	78	100	100

## CONCLUSION

Experiments conducted so far for arsenic removal showed positive results. It was found that removal of arsenic from drinking water is possible by passing the water at controlled flow rate through wood-charcoal, treating the water with calcium oxide, by sedimentation method and by repeated removal of the top surface layer containing high level of arsenic. These methods may be adopted as cheap and simple technologies for removal of arsenic from drinking water.

## **REFERENCES**

- BES (1999) Bangladesh Environmental Society News Letter. Vol.3 No 1-2
- Saha, K.C. (1998) Diagnosis of arsenicosis. Abstracted In: Int. Conf. On Arsenic Pollution of Ground Water in Bangladesh: Causes, Effects and Remedies.Organized by DCH & SOES LGED Auditorium, Dhaka 8-12 February (1998) .94-96 pp.
- WHO (1997) Arsenic contamination of Drinking water in Bangladesh. Report No. SAE/EH /506 19 June 1997. 1-9 pp.
- WHO (1999) Fact Sheet No. 210-Fenriaru

## **Comparative Studies for Selection of Technologies for Arsenic Removal from Drinking Water**

**J. C. Saha**

Development Design Consultants Limited  
DDC Centre, 47 Mohakhali C/A, Dhaka-1212, Bangladesh

**K. Dikshit and M. Bandyopadhyay**

Department of Civil Engineering  
Indian Institute of Technology, Kharagpur-721302, India

### ***Abstract***

*This paper present the possible alternative removal options for the development of safe drinking water supply in the arsenic-affected areas. Each alternative option was studied in the Environmental Engineering Laboratory at Indian Institute of Technology (IIT) Kharagpur, India. In this paper conventional precipitation (Alum and Iron salt) and adsorption (With various types of adsorbent) method were used for arsenic removal. Various parameters such as, coagulant dose, pH, anions concentration and reaction time were studied to establish optimum conditions. Iron salt as a coagulant and Hydrous Granular Ferric Oxide as a fixed bed adsorbent were found to be effective options for arsenic removal.*

### **INTRODUCTION**

The occurrence of geogenic As(III) and As(V) in ground water is a major problem in Bangladesh. A major part of village people are suffering from arsenicosis due to consuming arsenic contaminated water. About 80 million people in 59 districts out of 64 districts poses a serious health threat (BGS, 1999). Numerous recent investigations have indicated that arsenic constitutes a serious health risk at different places and it has been confirmed by the medical studies (Saha, 1999). Ingestion via food or water is

the main pathway of this metalloid in the organism where its absorption takes place in the stomach and intestines, followed by its release into the blood stream. Arsenic is then converted by the liver to a less toxic form, which is eventually largely excreted in the urine (Caroli et al., 1996). Due to the illness of people the nation is loosing million and million of manpower-hour as well as impoverish strength, knowledge, economy, development and finally it begins to kill slowly and painfully.

The removal technology of arsenic and disposal of arsenic bearing waste presents a challenging task to the environmental engineers. Unlike organic waste, inorganic arsenic cannot be degraded biologically to harmless products. The chemistry of arsenic is quite complex and interesting, as it can be stable in four oxidation states, continue changing its states and its removal is dependent on pH of the medium, oxidation state and redox potential.

Recent publications discussing methods of removing arsenic from water are too numerous to mention. A comprehensive search of literature by reference to abstracts and articles, followed by computer search, reveals that aqueous arsenic removal techniques fall into four major categories – chemical precipitation, ion exchange, membrane processes and adsorption.

Since contamination of drinking water due to arsenic compound is a severe problem with regards to health hazards and in this connection a lot of research has been undertaken in this field to remove arsenic from contaminated water using different technique. But most of them were found to be less effective for removing arsenic and many drawbacks when applied in the field. It is very difficult to select a unique method for arsenic removal. Some are effective but economically not feasible, some are economically feasible but are not effective. Some are not user friendly, technologically not sound, energy dependent, post treatment required, skill manpower required, quality of treated water in respect to other parameter in water not maintaining with standard. It is difficult to the meet stringent arsenic standard as well as drinking water quality standard for different parameter and other drawbacks is still a great problem. Even specific information on the major factors affecting arsenic removal is also still incomplete.

### **Complexities of Arsenic Removal**

The following are the various difficulties arise at the removal of arsenic when applied in the field:

- Wide range of initial concentration of arsenic in water, other elements and its variation of concentration in water, optimization of right dose for generalization, filtration of treated water, adjustment of pH in water, analysis of arsenic specially by field test kit method, post treatment difficulties, handling of waste and proper operation and maintenance.
- It is apparent that selection of an arsenic removal method is a really complex decision and the method of choice changes depending on the oxidation state

of arsenic and a number of other factors. There are many technologies, which are successful in the laboratory but in the field condition they do not working properly.

### **Best Available Technology for Removal of Arsenic**

Selection of arsenic removal technology can be done by best available technology (BAT) method, which the administrator finds after examination for efficacy under field conditions and not solely under laboratory conditions is available (taking cost into consideration). BAT can be determined by identifying available technologies, which reduce contaminant concentration levels and by evaluating the costs and commercial availability of the technology. Environmental Protection Agency (EPA) uses required and large metropolitan water systems to serve the basis for making the cost determination for BAT.

In this system, the cost can be measured by the increase in the annual household water bill due to the installation of a technology under consideration.

The arsenic removal performance data for all the treatment technologies could be evaluated to determine the best technologies that should be designated as BAT.

BAT can be designated based upon the following criteria:

- High removal efficiency
- Affordability (using large system as the basis)
- General geographic applicability
- Compatibility with other water treatment processes, and
- Process reliability

## **MATERIALS**

### **Glassware and apparatus**

All glassware used in the present study were manufactured by M/S Bhattacharya Co. Ltd. (Calcutta, India) and marked under brand name 'Borosil'. 150 ml capacity special types of arsine generator apparatus were used throughout the experiment for determination of total arsenic. All glassware except arsine generator apparatus were cleaned by soaking in 10% HCl for 24 hours followed by washing with dilute soap solution (Rankleen, Ranbaxy Laboratories Ltd., Punjab, India), tap water and then distilled water. Arsine generation apparatus were cleaned by soaking 24 hours in 8M nitric acid followed by other method as mentioned.

## **Water**

Distilled water was obtained by distilling tap water in glass distillation apparatus. All the working arsenic solutions were prepared in freshly prepared double distilled water unless otherwise mentioned. The pH of the distilled water was around 6.9.

## **Chemicals**

All chemicals were of analytical reagent grade and were used without further purification. All solutions were prepared using double distilled water (Standard method, 1989). The arsenite As(III) stock solution was prepared by  $\text{NaAsO}_2$  (E Merck, Germany) in double distilled water from 1000 mg/l to 100 mg/l. The arsenate As(V) stock solution was prepared from sodium salt heptahydrate,  $\text{Na}_2\text{HAsO}_4 \cdot 7 \text{H}_2\text{O}$  E-Merck, (Germany) dissolved in double distilled water. Prior to each analysis, intermediate standard As(III) and As(V) solutions were diluted with double distilled water to 10 mg/l from the arsenic stock solutions. Secondary standard solutions 1 mg/l were also freshly prepared for each experiment from the 10 mg/l intermediate stock solutions to 1 mg/l. Stock solutions of different element were prepared from metal nitrate salts. These solutions were diluted to prepared working solutions.

## **Analysis of water samples**

Total arsenic content in water sample was measured spectrophotometrically using Silverdiethyldithiocarbamate (SDDC) method. (Model Shimadzu Spectrophotometer UV-160A). Graphite furnace AAS method was used for cross-check at lower concentration of arsenic and other metal.

## **EXPERIMENTAL METHOD**

### **Precipitation Method**

Among them arsenic removal by chemical precipitation with aluminium or iron hydroxides is the best-known and most frequently applied technique. At present many countries successfully using the conventional method of arsenic removal. The treatment process is consists of coagulation followed by flocculation, sedimentation and filtration.

Removal of arsenic by alum (aluminium sulphate) and iron salt (ferric sulphate) from drinking water were studied separately in the laboratory as well as in the field. To avoid chlorine natural sunlight was used as an oxidizing agent to convert arsenite to arsenate. Alum and iron salt were added in the arsenic contaminated water in the range of 30-75mg/l and 20-50 mg/l respectively. Concentration of arsenic in water was maintained in the range 0.1 to 1.0 mg/l.

The findings of different studies are briefly presented below:

- Oxidation of arsenite to arsenate by sunlight is a very slow process. An investigation of precipitation methods indicates that the removal of arsenic by coagulation is a function of the oxidation state of the arsenic, the type and dose of coagulant, the pH of the water and the initial arsenic concentration.
- Iron salt is more preferable than alum. Because iron is more soluble than aluminum in water. When ferric coagulant are added, all the iron forms particulate  $\text{Fe}(\text{OH})_3$ . However, not all aluminum added as alum coagulant precipitates as  $\text{Al}(\text{OH})_3$ . Because only particulate metal hydroxides can mediate arsenic removal, alum plants must carefully considered all solubility when improved arsenic removal is desired. 92% removal was achieved using 20 mg/l of alum in 0.1 mg/l of arsenic in water at pH 6.6 and 96% removal was achieved using 10 mg/l ferric sulphate in 0.1 mg/l of arsenic in water at neutral pH range with 6 hour retention time. Doses of coagulant increase with increasing concentration of arsenic in water.

## **Adsorption Method**

### ***Screening of Existing Adsorbents***

Arsenic can be removed by adsorption onto many adsorbent materials. Some of adsorbent materials are very costly and some are less effective. The criteria for selection of suitable adsorbent include: the cost of the medium, the ease of operation or handling, the cost of operation, the useful service life per cycle / the adsorption capacity of the adsorbent, the potential of reuse, the number of useful cycles and the possibilities of regeneration of adsorbent.

For selecting an appropriate adsorbent for removal of arsenic, a number of available adsorbents such as Kimberlite tailing, wood charcoal, banana pith, coal fly ash, spent tea leaf, mushroom, saw dust, rice husk, sand, water hyacinth, activated carbon, bauxite, hematite, laterite, iron-oxide coated sand, activated alumina, CalSiCo and Hydrous Granular Ferric Oxide were evaluated for arsenic removal. The adsorbents were compared on the basis of percentage removal of As(III) and As(V) with activated alumina being the reference. Preliminary screening of the adsorbents was made through the batch sorption screening test with 6 hr contact time. The results are presented in Table 1.

**Table 1: Arsenic removal efficiency of different adsorbent materials.**

Adsorbent	Dose (g/l)	% Removal	
		As(III)	As(V)
1. Kimberlite tailing	10	25	40
2. Water hyacinth	10	45	70
3. Wood charcoal	10	19	37
4. Banana pith	10	12	18
5. Coal fly ash	10	20	28
6. Spent tea leaf	10	25	42
7. Mushroom	10	22	35
8. Saw dust	10	28	36
9. Rice husk ash	10	5	12
10. Sand	10	15	22
11. Activated carbon	10	50	65
12. Bauxite	10	58	80
13. Hematite	10	40	60
14. Laterite	10	45	70
15. Iron-oxide coated sand	10	72	90
16. Activated alumina	10	90	96
17. CalSiCo	5	90	98
18. Hydrous granular ferric oxide	2	92	99

Most of the adsorbent were found poor arsenic removal but iron-oxide coated sand, activated alumina, CalSiCo and Hydrous Granular Ferric Oxide showed a considerable amount of arsenic removal.

Three adsorbent named iron oxide coated, CalSiCo and Hydrous granular ferric oxide were prepared in the laboratory and activated alumina was collected from the market. All the four adsorbent were evaluated its capacity to adsorb arsenic under different conditions using synthetic As(III) and As(V) solutions. The experiments were conducted in three phases: (i) batch studies, (ii) column studies, (iii) desorption and regeneration studies.

In batch (static) studies, apart from kinetic and isotherm studies, the effects of different parameters such as pH, adsorbent dose, adsorbent size, presence of chloride, sulphate, nitrate, chromate, calcium, magnesium, and iron were studied. All the above parameters were varied one at a time to study their effect on the adsorption process. Interruption test was conducted to determine the rate-limiting step by kinetic data; by



the effect of initial adsorbate concentration and adsorbent size on removal rate; and by multiple interruption test. Effect of anionic ligands such as EDTA, fluoride and phosphate on the removal of As(III) and As(V) was also studied. All the above parameters taken together were varied to study their combined effect on removal efficiencies.

Column (dynamic) studies were conducted to ascertain the engineering aspect of arsenic removal by CalSiCo. The experiments were carried out with distilled and tap water spiked with 1 mg/l of arsenite and 1 mg/l of arsenate separately. A glass column of 15 mm diameter having 220 mm bed depth of all the adsorbent about 0.2 mm geometric mean size was used. The flow of influent was maintained at 10 ml/min for all the adsorbents.

Desorption and regeneration studies were conducted to investigate the possibility of reuse of spent adsorbent. Various eluents such as distilled water, NaOH, NaHCO<sub>3</sub>, Na<sub>2</sub>CO<sub>3</sub>, and H<sub>2</sub>O<sub>2</sub> in HNO<sub>3</sub> were used in batch experiment. The regeneration study was conducted for 3 cycles. H<sub>2</sub>O<sub>2</sub> in HNO<sub>3</sub> for CalSiCo and NaOH for rest three were used as an eluent in the dynamic desorption studies carried out for three cycles.

## EXPERIMENTAL RESULTS AND DISCUSSION

It was found that all the four iron-oxide coated sand, activated alumina, CalSiCo and Hydrous Granular Ferric Oxide adsorbent could be effectively used as media for the removal of arsenic from ground water. Removal was found to be 90, 96, 98 and 99% respectively for As(V) with initial concentration of 1 mg/l and around 85% for As(III) with initial concentration of 1 mg/l in neutral pH range. Activated alumina, CalSiCo and Hydrous Granular Ferric Oxide could be used for the selective removal of arsenic from water environment upto certain extent over other ions, such as Cl<sup>-</sup>, SO<sub>4</sub><sup>2-</sup>, PO<sub>4</sub><sup>3-</sup>, NO<sub>3</sub><sup>-</sup>, F<sup>-</sup>, CrO<sub>4</sub><sup>2-</sup>, Ca<sup>2+</sup>, Mg<sup>2+</sup> and Fe<sup>2+</sup>. The overall reaction kinetics could be represented by first order reaction equation. Film diffusion was the rate-limiting step for arsenic removal as indicated by kinetic data; by the effect of initial adsorbate concentration and adsorbent size on removal rate; and by multiple interruption test. The equilibrium adsorption data fitted to Langmuir and Freundlich isotherm models. However, the Langmuir equation gave better fit. Arsenic removal by these adsorbent was found pH dependent. In drinking water neutral pH range, it exhibited excellent arsenic removal. The best arsenic removal was achieved at pH 7.2 for As(V) and above 9 for As(III) for CalSiCo and 7.1-7.5 for others. Removal achieved was typically from 1 mg/l to 0.01-0.05 mg/l. The removal of As(V) was easier than that of As(III), so As(III) could be converted to As(V) by adding oxidising agent for better removal. Removal efficiency decreased with the presence of phosphate (more than 10 mg/l), fluoride (more than 2 mg/l) and EDTA (more than 0.01 moles/l) but the presence of nitrate, sulphate, chloride, chromate, calcium, magnesium and iron did not affect removal significantly. Spent adsorbent could be regenerated with 15% H<sub>2</sub>O<sub>2</sub> in

0.2 M HNO<sub>3</sub> for CalSiCo and 1N NaOH for iron-oxide coated sand, activated alumina and Hydrous Granular Ferric Oxide.

The adsorbent coefficients determined by Logit method could be used successfully to predict the breakthrough of another column.

**Table 2 : Results of mini-column study in the field at the 20<sup>th</sup> day.**

Parameter	Influent Concentration, (mg/l)	Effluent concentration for CalSiCo, (mg/l)	Effluent concentration for Hydrous Granular Ferric Oxide , (mg/l)
Hardness	145	135	140
Cl <sup>-</sup>	8	8	8
SO <sub>4</sub> <sup>2-</sup>	5	4	3
NO <sub>3</sub> <sup>-</sup>	0	0	0
F <sup>-</sup>	0	0	0
PO <sub>4</sub> <sup>3-</sup>	0	0	0
Ca	26	25	24
Mg	5	4	4
Na	10	10	8
Fe	4.61	0.3	0.2
As	0.32	0.015	0.01

Table 2 shows the performance of CalSiCo and Hydrous Granular ferric Oxide were evaluated for its efficiency in removing arsenic in the actual field situation by means of a pilot plant study. Two 30 cm long mini-column of 40 mm diameter each containing 250 gm of CalSiCo and Hydrous Granular ferric Oxide (15 and 18 cm bed depth respectively) was installed at Deganga (North 24-Parganas District) and was run continuously for 20 days at a flow rate of 20 ml/min containing 0.32 mg/l of arsenic. It was found that the columns were able to supply 28 l/day for CalSiCo and 45 l/day for Hydrous Granular ferric Oxide of treated water containing arsenic less than 0.015 mg/l for CalSiCo and less than 0.01 Hydrous Granular ferric Oxide for 20 days. It clearly demonstrates that these adsorbents can be used as a filter media for removing arsenic from ground water in arsenic-affected areas of Bangladesh and West Bengal, India. A 20-liter capacity home water purifier for arsenic was developed for community as well as individual family, which should be subjected to a field trial to assess the long-term performance of the medium.

## CONCLUSIONS

Bangladesh and West Bengal (India) are now facing tremendous difficulties in

removing arsenic from the ground water. It is apparent that selection of an arsenic removal method is a really complex which continuously changes its form of oxidation states of arsenic and it is dependent on many factors. Conventional coagulation method of arsenic removal using iron salt is a prefer option in many respect. Hydrous Granular ferric Oxide was found best for arsenic removal from contaminated drinking water as a fixed bed adsorbent. Iron salt and Hydrous Granular ferric Oxide will be able to meet national drinking water standards.

## REFERENCES

- AIHH &PH, (1997). National workshop on removal of arsenic from drinking water. 19-20<sup>th</sup> December, 1997, conducted by All India Institute of Hygiene and Public Health, Calcutta, and PHED, Govt. of West Bengal, India.
- British Geological Survey, (1999). Groundwater studies for arsenic contamination in Bangladesh.
- Phase 1: Rapid Investigation Phase Main Report, British Geological Survey Mott MacDonald Ltd. (UK).
- Caroli, F. LA Torre, Petrucci, F. and Violante, N. (1996). Element speciation in Bioinorganic chemistry, edited by Sergio Caroli, *Chemical Analysis Series*, Vol. 135, pp 445-463.
- Saha, J. C. (1999). *PhD. Thesis*. Removal of Arsenic from Water Environment by New Adsorbent.

## **Design of A Low-cost Purification System for the Removal of Arsenic from Tubewell water in Bangladesh and India**

**Phillip Thomas Crisp and Ahmedul Hye Chowdhury**  
School of Chemical Engineering and Industrial Chemistry  
University of New South Wales, Sydney 2052, Australia

### ***Abstract***

*A low-cost purification system has been designed which incorporates air/light oxidation, a sediment trap and a bed of adsorbent chemicals in a brick-tank which can be placed next to a tube well. The brick-tank (5.5 m long, 2.0 m wide and 1.5-2.0 m high) comprises a reservoir for arsenic-contaminated water, a tap for flow control, spreader troughs from which water drips (in order to expose a large water surface to air), a series of baffles which forces water repeatedly to the surface (in order to expose it to air and light), a series of sediment traps (to remove arsenic-contaminated iron hydroxide, calcium carbonate and other sparingly soluble salts), an adsorbent bed to remove remaining arsenic species, a water lock so that the system can not run dry, and a reservoir for purified water. Baffles are low brick walls with every second half-brick removed in the base row of every second wall. Sediment traps are layers of crushed brick with particles of increasing size (2 to 10 mm), placed at the bottom of the baffles. Layers of crushed brick of decreasing particle size are placed above and below the adsorbent bed in order to prevent mechanical disturbance during the percolation of water. The adsorbent bed comprises a mixture of charcoal and ash to which is added spent brine, followed by a suspension of fine rust particles. Charcoal is obtained by heating rice husks or coconut husks in the absence of air in a modified brick kiln. Ash is obtained from the fuel used in the brick kiln. Spent brine, rich in magnesium salts, is the liquid remaining from the crystallization of salt from seawater. Rust particles are obtained by placing scrap iron in water. In the adsorbent bed, potassium carbonate from the ash reacts with magnesium salts from the brine to form magnesium hydroxy-carbonate as a gelatinous precipitate which coats the charcoal and ash particles and serves to retain the*

*fine particles of rust. Considerable oxidation of arsenite to arsenate ions occurs in the baffles due to the action of light and oxygen, perhaps assisted by microbial activity. Most arsenic(V) and some arsenic(III) species precipitate with iron(III) hydroxide and are retained in the crushed brick of the sediment trap. Remaining arsenic is retained as magnesium arsenate, iron(III) arsenite and iron(III) arsenate in the adsorbent bed. The adsorbent bed does not clog with particles, since iron and calcium salts have already been removed. The design allows treatment of 750 L of water each day, with long residence time (~10 days) and low linear flow rates, in order to maximize air/light oxidation, sedimentation and adsorption processes.*

## INTRODUCTION

Arsenic in water from tube wells in Bangladesh<sup>1,2,3</sup> and West Bengal<sup>4,5,6</sup> is currently poisoning around 20 million people<sup>7,8,9,10,11,12,13</sup>. Symptoms of arsenic poisoning have already reached epidemic proportions and cataclysmic effects are predicted if the majority of people in affected areas are not soon provided with safe drinking water<sup>14</sup>.

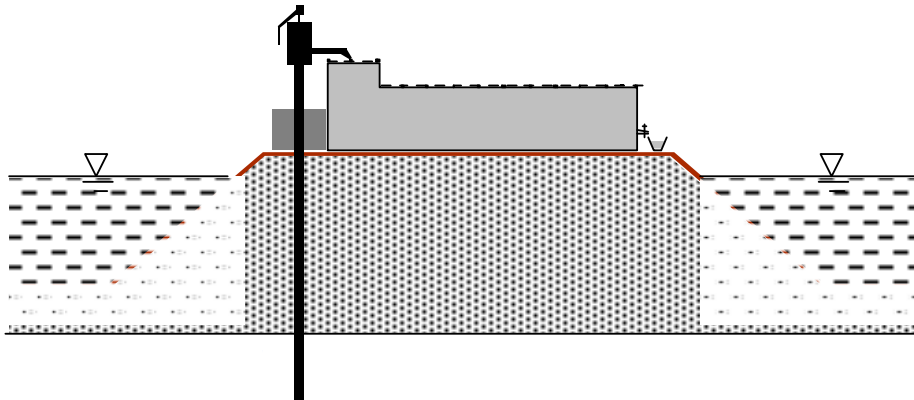
Water purification techniques using membrane systems, coagulation-flocculation<sup>15,16</sup> and other advanced systems<sup>17</sup> may find use in large-scale water treatment for towns and cities but are not appropriate to the treatment needs of the majority of the population, who live in small villages or on farms. Small-scale systems for purifying the water for a single household have been demonstrated<sup>18,19</sup>, but these systems have two disadvantages. They are time-consuming, reducing time available for family care and education, especially for women. Secondly, they are expensive by the standards of the region, especially for initial purchase of equipment. Due to the widespread poverty amongst the affected people, arsenic removal from groundwater must be accomplished at very low cost, using materials that are either widely available or capable of being produced with only minor modifications to existing production techniques. Materials that can be made using few resources other than human labor are favored. A second consideration is that water treatment should be accomplished on a scale that allows sharing of duties by several families and hence minimum time-wasting activities. The purification system described in this paper is designed to meet these objectives.

The design has two components: the physical design of a water treatment tank that can be constructed next to a tube well, and the chemical design of an adsorbent bed of harmless low-cost chemicals which can trap and remove arsenic species from the water. The design allows 750 L volumes of water to be treated each day, sufficient for several families, who could share costs of construction and maintenance.

## COMPONENTS OF THE PURIFICATION SYSTEM

### Water Treatment Tank

The water treatment tank (Figures 1 and 2) is constructed in stages as follows:



Figures 1 : Water treatment system.

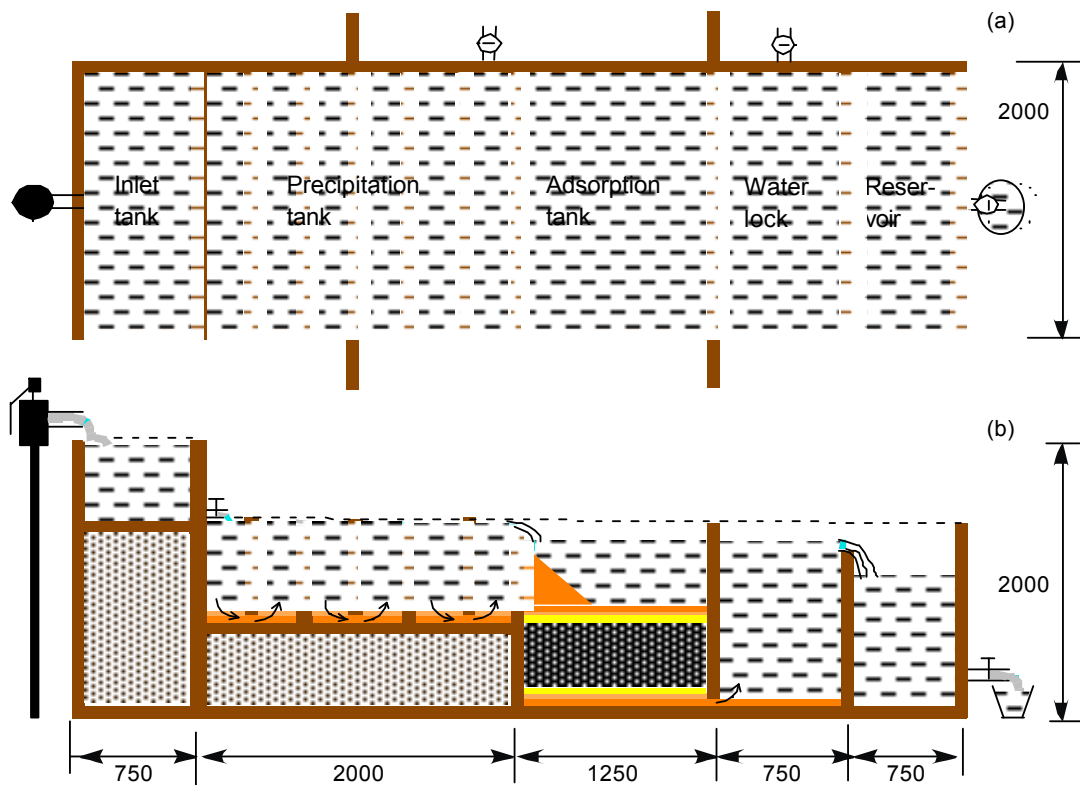


Figure 2 : Water treatment system in plan view (a) and cross-sectional view (b)  
All Dimensions are in mm.

## **Mound**

Since Bangladesh and West Bengal are subject to regular flooding and clean water supplies are critical during times of inundation, the water treatment tank should be built on a mound of earth, the top of which is comfortably above the maximum flood level recorded in the area. It is likely that global climate change is occurring and that flooding will become more severe in the future. Since the mound will be subject to frequent human traffic and will be prone to erosion in times of flood, the mound should preferably be paved with brick. The top of the mound should be flat, to accommodate the treatment tank (5.5 m x 2.0 m) and should allow a sufficient walkway (minimum 2 m) around the tank for traffic and maintenance. The soil in the mound should be allowed to compact fully before further construction (Figure 1).

## **Tube Well**

A tube well should be sunk at one end of the mound, so that there is space for the treatment tank next to it (Figure 1). The tube well should terminate with its outlet 2.2 m above the top of the mound. Since it is necessary to manually operate the pump in the top of the tube well, a brick platform and a set of steps should be constructed to allow easy access for pumping. Even during times of flood, no surface water should enter the tube well due to the compacted earth around it.

## **Outer Structure**

The tank should be constructed from double brick, in order to provide strength. Bricks with low porosity and grout containing a large proportion of cement should be used in order to reduce water permeability. Sealing of the structure need not be perfect, but low permeability will make the system more efficient and longer lasting.

The tank is rectangular in shape, 2.0 m x 5.5 m, with walls 1.5 m high, rising to 2.0 m at the inlet tank (Figures 1 and 2). Construction begins by cementing together a base layer of bricks (or using an area of the paving bricks), and then adding another layer of bricks with grout between them. It may be desirable to incorporate a sheet of plastic into the base of the structure as a sealant, since leaks would be difficult to detect at the bottom of the tank. The walls are then constructed on the base, taking care to seal the joints. It is desirable to buttress the outer walls with tapering brick supports at right angles to the walls, especially in the center of the larger tanks.

### **Internal Structure**

The internal walls are constructed at the same time as the outer walls, so that the fresh cement will bind all components together. The only exceptions are the internal baffles of the precipitation tank. Four internal walls are required to provide the inlet reservoir, the precipitation tank, the absorption tank, the water lock and the reservoir for purified water (Figure 2). The minimum width for an internal structure of full height is 0.75 m, to allow access for maintenance.

The inlet reservoir is filled with dirt until only 0.5 m depth remains, the dirt is compacted and a brick floor cemented into place. The precipitation tank is filled to half its depth with compacted dirt and a brick floor similarly constructed, followed by a series of five vertical baffles. Gaps are left at the bases of odd-numbered baffles by omitting each second half-brick in the bottom brick layer. This allows water to alternately pass through the base and over the top of successive baffles.

### **Drip Troughs**

The spout from the tube well delivers water to a trough, which extends across the 2-m width of the inlet tank and is shaped so that water dips evenly off its entire width. This ensures maximum absorption of oxygen from the atmosphere. Similar drip troughs are constructed beneath the tap from the inlet tank and at the end of the precipitation tank.

### **Sediment Trap**

The precipitation tank is filled to a depth of 0.25 m with layers of crushed brick, the bottom layer being 10-mm diameter and the top 2 mm diameter. This allows free migration of liquid in the lowest layer, while maintaining adequate particle trapping in the top layer.

### **Taps**

A brass tap with a washer, seat and handle is used to set the flow rate of water through the system at the bottom of the inlet tank. A tap, in the simplest form, comprising a short length of plastic tubing with a stopper, is required in the wall of the purified water reservoir, and two others should be inserted near mound level in the precipitation tank and the water lock, to allow draining of the system for maintenance.

### **Covering**

In order to prevent insects and other animals entering the tank, timber structures supporting mosquito netting should be kept on top of the tanks at all times. A durable covering (Figures 1 and 2) would be provided by five timber frames,



each 2 m wide and the length of each tank, with cross supports at approximately 0.5 m intervals. To each is fixed a layer of mosquito netting between two layers of wire gauze (e.g. chicken wire). Metal hooks could be inserted in the brickwork of the tank during construction to provide anchor points for ropes which hold the covering in place during high winds. The covering should be carefully maintained in order to prevent spread of water-borne diseases or use of the tank by disease vectors such as mosquitoes. Birds and other animals will be attracted to the treatment tank and may defecate on the mesh screen. The cover for the last section, containing purified water, must be continuous and totally animal-proof. Tube wells are typically housed in a roofed structures, but this would greatly reduce ultraviolet radiation intensity and should be avoided.

### **Adsorbent bed for Arsenic Removal**

The adsorbent bed (Figure 2b) is inserted into the treatment tank after the cement of the latter has thoroughly set and all other components are in place. There must be as little disturbance as possible to the adsorbent bed after it has been installed. The following sections describe the design for a low-cost adsorption bed based on available materials. Other adsorbents, such as iron filings, finely-chopped tin cans, aluminum oxide and treated clays, could be substituted, if available. The bed should not clog with particles (largely iron(III) hydroxide and calcium carbonate) as has occurred with other adsorption systems tested in the region, since reactions with the atmosphere should have proceeded almost to completion in the precipitation tank. A large proportion of the arsenic species in the water should also have been removed with the sediment forming in the precipitation tank, reducing the load on the adsorption bed.

### **AQUEOUS CHEMISTRY OF ARSENIC**

Arsenic occurs in groundwater in two forms: arsenite ( $\text{AsO}_3^{3-}$ ) and arsenate ( $\text{AsO}_4^{3-}$ ) ions, often referred to as arsenic(III) and arsenic(V) species due to the oxidation number of the central arsenic atom<sup>20</sup>. The chemistry is complicated<sup>21</sup> by the fact that each ion can acquire from water one or more protons, depending on the acidity, to yield a series of chemical species:

Arsenic(III) series	$\text{AsO}_3^{3-}$	$\text{HAsO}_3^{2-}$	$\text{H}_2\text{AsO}_3^-$	$\text{H}_3\text{AsO}_3$
Arsenic(V) series	$\text{AsO}_4^{3-}$	$\text{HAsO}_4^{2-}$	$\text{H}_2\text{AsO}_4^-$	$\text{H}_3\text{AsO}_4$

At the acidity of drinking water, the dominant arsenic(III) species is the neutral compound  $\text{H}_3\text{AsO}_3$  and the dominant arsenic(V) species are the ions  $\text{HAsO}_4^{2-}$  and  $\text{H}_2\text{AsO}_4^-$ . However, all arsenic(III) species coexist and rapidly interconvert, as is the case for arsenic(V) species. The arsenic(III) and arsenic(V) series can also interconvert. This is more difficult since oxidation or reduction processes are

required, but conversion occurs slowly in rocks, groundwaters and surface waters due to the influence of minerals<sup>22</sup>, microorganisms and atmospheric oxygen<sup>23</sup>. Arsenic(III) compounds are more toxic than arsenic(V) compounds<sup>24</sup>, by a factor of about ten. The proportion of arsenic(III) in well water typically ranges between 50 and 90%.

The idea of using harmless metal ions, such as iron<sup>4,25,26,27,28,29</sup>, copper<sup>24</sup>, manganese<sup>30,31,32</sup> or aluminum<sup>33</sup>, to trap and remove arsenic species from drinking water as their insoluble salts is attractive since the chemicals required are inexpensive. Other metals with somewhat more soluble arsenic salts, such as magnesium and calcium, are also worthy of examination. Metal salts have been used for large-scale treatment of wastewaters for arsenic removal, for example, in the mining industry. The problem is that the metal salts of arsenic(III) and arsenic(V) have widely different solubilities<sup>34, 35</sup> and it is necessary to choose metals carefully. Arsenic(V) salts (metal arsenates) are generally less soluble than arsenic(III) salts (metal arsenites)<sup>36</sup>. It is vital, however, that arsenic(III) compounds be removed since they are the more dangerous.

Sparingly soluble metal arsenites and arsenates in equilibrium with water near neutral pH, generally yield concentrations of dissolved arsenic species greater than those acceptable in drinking water (currently 50 µg/L; proposed 20, 10 and 5 µg/L). On the other hand, binding of arsenic species to solid surfaces by adsorption may be extremely strong, since adsorption processes are not limited by the thermodynamics of solubility products, and adsorption is frequently better for reducing the concentration of dissolved arsenic species than precipitation.

Many ions in natural waters, particularly phosphate, may interfere with adsorption processes involving arsenic species. Even chloride and sulfate may influence adsorption. Sufficient excess adsorption capacity must be available or selective adsorbents used. Growth of algae in sections of the treatment system may be beneficial for removing phosphate ions.

Calcium ions and hydrogen-carbonate ions are abundant in well waters. When a well water is exposed to the air, carbon dioxide is lost and calcium carbonate precipitates. Iron(II) ions, also abundant in well waters, are slowly oxidized by oxygen in the air, especially in the presence of light, forming iron(III) hydroxide which precipitates with the calcium carbonate. Large amounts of aqueous arsenic species are adsorbed by iron(III) hydroxide/calcium carbonate mixtures as they precipitate. Typically, half the arsenic(III) and nearly all the arsenic(V) species are removed.

## DESIGN AND CONSTRUCTION OF ADSORBANT BED

### Chemicals for the Adsorbent Bed

In most areas of Bangladesh and India, no money is available for the purchase of imported chemicals or treatment devices. It is essential to use chemicals that can be made locally, from materials that are free or widely available at little cost, e.g. agricultural wastes. The chemicals chosen for construction of the adsorbant bed are:

- *Charcoal*, from heating coconut or rice husks in an oven the absence of air,
- *Ash*, from combustion of coconut or rice husks in air,
- *Magnesium salts*, from the brine left after the recovery of salt from sea water, and
- *Rust*, from clean scrap iron placed in water and exposed to the air.

Charcoal is a well-known adsorbent for organic compounds and may weakly adsorb arsenic species. Its main value is as a porous material to provide a large surface area on which to deposit other chemicals. Ash contains several percent by weight of potassium carbonate, a chemical critical for construction of the proposed adsorbent bed. Mineral particles, such as silica, will help to provide bulk and surface area for the adsorption bed. A brick kiln could be modified to produce charcoal and ash, using available agricultural wastes. Rice husks, for instance, could be burnt beneath the kiln to produce ash and heat for pyrolysis of other rice husks in the kiln chamber to produce charcoal.

Magnesium ions occur in seawater at a concentration of 1.27 g per litre<sup>36</sup>. After salt has been crystallized from seawater, the remaining liquid is greatly enriched in magnesium salts, principally magnesium chloride. The liquid is usually discarded to the sea, but could be inexpensively dried in the sun to yield a damp solid (magnesium chloride, the principal salt absorbs moisture from the air) and transported throughout the region. Production of magnesium chloride would provide additional income for impoverished salt workers.

Rust can be prepared by heating scrap iron in a fire (perhaps with rice husks in a modified brick kiln) to burn off paint, oil or metal plating, and then the clean iron can be placed in water in a shallow container to allow easy access by atmospheric oxygen. Addition of small amounts of acidic materials such as lemon juice may promote more rapid rusting. The slurry of rust particles settling to the bottom is collected and used. Lumps of clean scrap iron could be reused until they had corroded completely.

### **Construction of the Adsorbent Bed**

The adsorbent bed (Figure 2b) is constructed by mixing together charcoal and ash, then moistening the mixture with water to dissolve the potassium carbonate in the ash and allow it to soak into the pore spaces in the charcoal particles. A concentrated solution of magnesium ions, prepared by mixing impure magnesium chloride with a little water, is then added to the wet charcoal/ash and the combined materials further mixed. At this stage, magnesium ions and carbonate ions will react to form magnesium hydroxy-carbonate<sup>37</sup>, which will deposit on and within the charcoal particles. The reaction conditions must be optimized to obtain the maximum surface area of magnesium hydroxy-carbonate, a white gelatinous solid.

The base of the adsorption tank must now be prepared to receive the adsorbent bed. The problem is that the adsorbent is in the form of fine particles and will wash away unless the particles are anchored in some manner. Rock, gravel and sand are not available in most areas due to the abundance of deltaic silt deposits; however, bricks are made from clay silts and are a common building material. Bricks can be crushed and sieved to yield fractions with different particle-size ranges. Anchoring the bed can be achieved by means of layers of crushed brick. A layer of coarsely crushed brick (~10 mm particle diameter; 50 mm thickness) is placed in the bottom of the treatment tank, extending through the holes at the bottom of the wall separating the water lock. On top of this is placed a layer of medium crushed brick (~3 mm particle diameter; 50 mm thickness) and a third layer of fine crushed brick (~1 mm particle diameter; 50 mm thickness). It is important that the layers be level, uniform in thickness and continuous. If there are any gaps or other defects, water and particles of adsorbent will channel through them, reducing the efficiency of the bed.

The magnesium-treated mixture of charcoal and ash is now poured on top of the fine layer of crushed brick in the treatment tank. Water is carefully added so that the surface of the bed is not disturbed and the tank is filled with water to the top of the charcoal/ash bed.

The next stage is to incorporate particles of rust (hydrated iron oxide) into the bed. A slurry of rust particles in water is now added carefully to the bed. The rust particles will percolate part of the way through the bed and be retained by the charcoal and magnesium hydroxy-carbonate. The bed should be allowed to stand for several days to compact.

Fine, medium and coarse particles of brick, in that order, are now added to the bed as successive layers, to form a mirror image of the layers below (Figure 2b). The purpose is to stabilize the top of the bed and prevent erosion and channeling, both of which would reduce efficiency. Finally a heap of coarse brick is placed next to the wall from which water enters the tank, in order to spread the inflow of water and prevent damage to the adsorbent bed.

### **Chemistry of the Adsorbent Bed**

The chemistry will involve principally the magnesium hydroxy-carbonate and the hydrated iron oxide. Arsenic(V) ions are expected to exchange with carbonate and hydroxide ions at the particle surfaces, becoming trapped as highly-insoluble magnesium arsenate, and releasing harmless ions in their place. However, magnesium arsenite is slightly soluble and it is likely that only a small amount of arsenic(III) will be retained as magnesium salts. It is the task of the rust particles to retain most of the arsenic(III) species, principally by adsorption<sup>38</sup>. Iron(III) arsenite is highly insoluble in water and surfaces containing iron(III) species should be readily available in the rust particles embedded in a matrix of magnesium hydroxy-carbonate. In areas where well waters are already rich in iron, there may be no need to add particles of rust.

Oxidation of arsenic(III) to arsenic(V) species will occur between the baffles in the precipitation tank due to the direct action of sunlight and oxygen from the air, or as a result of trace quantities of hydrogen peroxide and other oxidized species generated. Oxidation reactions are catalyzed by particle surfaces containing iron(III) species.

Algae and bacteria are expected to grow in all chambers of the treatment tank, forming a layer on top of the crushed bricks and the tank walls. Provided air is available, biological activity is likely to stimulate oxidation processes and may contribute to the conversion of arsenic(III) to less-toxic arsenic(V) compounds which can be more easily removed. Removal of excess algae may be a major maintenance task.

### **OPERATION OF THE SYSTEM**

The inlet tank (750 L) is filled with water from the tube well. The flow of water from the tank is set by the tap at the base to approximately 1.5 L/min, so that the entire volume flows into the system during the most brightly-lit hours of the day, say from 8 a.m. until 4 p.m.. Purified water is available soon after the day's treatment begins.

The water volumes in the sections of the treatment system are: inlet tank (0.75 m<sup>3</sup>), precipitation tank (~2.25 m<sup>3</sup>), adsorption tank (~2.75 m<sup>3</sup>), water lock (1.5 m<sup>3</sup>) and reservoir (0.75 m<sup>3</sup>), making a total volume of approximately 8 m<sup>3</sup>. If 0.75 m<sup>3</sup> of water are passed into and out of the system each day, the residence time is approximately 10 days. If smaller volumes of water are required, the flow rate can be reduced, so that greater residence time is available in the system, leading to more efficient operation.

It is expected that most of the arsenic(V) and around half of the arsenic(III) in the well water will precipitate with the iron hydroxide in the precipitation tank.

The greater the extent of oxidation of arsenic(III), the greater the removal efficiency. The role of the adsorption tank is to eliminate virtually all of the remaining arsenic(III) and any traces of arsenic(V) species.

If the tap for purified water is left open accidentally, the water level will drop to the level of the tap but will not cause the treatment tank to dry out. If the adsorbent bed in the treatment tank should dry out, it would probably channel and lose efficiency. Provided the tank is in daily use and checked regularly, the adsorption bed should never dry out.

It is important that the purified water be free from suspended particles of iron hydroxide or other minerals, since arsenic species may be adsorbed on mineral surfaces and may dissolve in the hydrochloric acid in the human stomach following ingestion. Arsenic species which have been removed from solution as insoluble material could be remobilized in the human body.

## **CONCLUSION**

The design described in this paper attempts to extract maximum benefits from air, ultraviolet radiation, natural iron(II) ions and time, allowing spontaneous reactions to go virtually to completion, then eliminating remaining traces of arsenic by means of simple adsorbents.

Construction of a treatment tank will be time consuming and will require a high level of practical skills in bricklaying and manipulating powdered materials. However, skilled human labour should be available and necessary crafts could be learned. The cost of materials for a treatment tank is modest, especially if shared between a community of users. Most materials should be available locally or able to be manufactured locally. Once skilled workers develop the necessary techniques, rapid construction of treatment tanks should be possible. Only a fraction of the tube wells in affected areas require treatment tanks to be fitted: those for providing drinking water. Contaminated wells can be used for washing and other purposes.

A scale model of the treatment system described in this paper is currently being constructed and will be tested with simulated well waters. The adsorbent properties of magnesium hydroxy-carbonate and rust particles are also being evaluated. The treatment tank should be able to accommodate any type of adsorbent bed, and its development is independent of the final composition of the adsorbent. The retention times required in the precipitation tank for waters with different iron(II), calcium and hydrogen-carbonate ion concentrations are not known. The efficiency and long-term performance of the adsorbent bed also must be assessed. Extensive practical testing of the design will be needed to identify optimum components and the best manner for combining them.

## ACKNOWLEDGEMENTS

The authors would like to thank Prof. M. Feroze Ahmed (BUET, Dhaka), Prof. Bob Robbins and Prof. Tam Tran (UNSW, Sydney) and Prof. Pritam Singh (Murdoch University, Perth) for their helpful comments.

---

## REFERENCES

1. M. M. Karim, "Arsenic in groundwater and health problems in Bangladesh", *Water Res.* 34(1) 304-310, 2000.
2. T.E. Bridge and M.T. Husain, "Groundwater arsenic poisoning and a solution to the arsenic disaster in Bangladesh", <http://www.dainichi-consul.co.jp>, 2000.
3. A.Z.M. Iftikhar Hussain, "Arsenic contamination of ground water in Bangladesh", <http://www.dainichi-consul.co.jp>, 2000.
4. S.P. Panda, L.S. Deshpande, P.M. Patni and S.L. Lutade, "Arsenic removal studies in some ground waters of West Bengal, India", *J Environ. Sci. Health* A32(7) 1981-1987, 1997.
5. P. Bhattacharya, D. Chatterjee and G. Jacks, "Occurrence of arsenic-contaminated groundwater in alluvial aquifers from Delta Plains, Eastern India: options for safe drinking water supply", *Water Resources Develop.* 13(1) 79-92, 1997.
6. D. Das, A. Chatterjee, B.K. Mandal, G. Samanta, D. Chakraborti and B. Chanda, "Arsenic in ground water in six districts of West Bengal, India: the biggest arsenic calamity in the world. Part 2. Arsenic concentrations in drinking water, hair, nails, urine, skin scale and liver tissue (biopsy) of the affected people", *Analyst* 120(3) 917-924, 1995.
7. F. Pearce, "Death and the devil's water" *New Scientist* 16 Sep, 1995, 14.
8. F. Pearce, "Wells that bring nothing but ills" *Guardian Weekly* 2 Aug 1998, 22.
9. S. Goldenberg, "Death by a thousand drops", *Guardian Weekly* 27 Jul 1997.
10. S. Beard, "Safe to drink", *New Scientist* 28 Mar 1998, 10.
11. W. Lepkowski, "World Bank takes on arsenic poisoning", *Chem. Eng. News* 9 Nov 1998, 12.
12. F. Pearce, "Danger in every drop", *New Scientist* 12 Feb 2000, 16-17.
13. W. Lepkowski, "Arsenic crisis in Bangladesh" *Chem. Eng. News* 16 Nov 1998, 27.
14. S.M. Rahman, "Arsenic in Bangladesh ground water: the world's biggest arsenic calamity", <http://www.dainichi-consul.co.jp>, 1999.

15. A.M. Sancha, "Removal of arsenic from drinking water supplies: Chilean experience", *Int. Water Assoc.* 18(1) 621-624, 2000.
16. S. Karcher, L. Caceres, M. Jekel and R. Contreras, "Arsenic removal from water supplies in Northern Chile using ferric chloride coagulation", *Water Environ. Management* 13(3) 164-169, 1999.
17. M. Jekel and R. Seith, "Comparison of conventional and new techniques for the removal of arsenic in a full-scale water treatment plant", *Int. Water Assoc.* 18(1) 628-632, 2000.
18. G.H. Khoe, M.T. Emmett, M. Zaw and P. Prasad, "Arsenic removal from tubewell water in Bangladesh", AusAID Report, Australian Nuclear Science and Technology Organisation and CRC for Waste Management, August 1999.
19. BAMWSP/DFID/WaterAid, "Rapid assessment of household level arsenic removal technologies", Phase 1 – Final Draft Report, WS Atkins International Ltd, January 2001.
20. D.B. Vance, "Arsenic – chemical behavior and treatment", <http://www.2the4.net/arsenicart.htm>, 2000
21. N.N. Greenwood and A. Earnshaw, "Chemistry of the Elements", Pergamon Press, Oxford, ch. 13, 1984.
22. US Geological Survey, "Arsenic in ground water of the Willamette Basin, Oregon: Geochemistry of arsenic", <http://oregon.usgs.gov/pubs>, 2000.
23. H. Madiec, E. Ceperto and D Mozziconacci, "Treatment of arsenic by filter coagulation: a South American advanced technology", *Water Supply* 18(1-2), 2000.
24. G.N. Manju, C. Raji and T.S. Anirudhan, "Evaluation of coconut husk carbon for the removal of arsenic from water", *Water Res* 32(10) 3062-3070, 1998.
25. J.G. Hering, P.Y. Chen, J.A. Wilkie, M. Elimelech and S. Liang, "Arsenic removal by ferric chloride", *Am. Waste Water Assoc.* April, 155-167, 1996.
26. U. Rott and M. Friende, "Eco-friendly and cost-efficient removal of arsenic, iron and manganese by means of subterranean ground-water treatment", *Int Water Assoc.* 18(1) 632-635, 2000.
27. A. Joshi and M. Chaudhuri, "Removal of arsenic from ground water by iron oxide-coated sand", *J. Environ. Eng.* 122(8) 769, 1996.
28. V.P. Simeonova, "Pilot study for arsenic removal", *Int. Water Assoc.* 18(1) 36-640, 2000.
29. C. Stamer and K.A. Nielsen, "Arsenic removal without sludge generation", *Int. Water Assoc.* 18(1) 625-627, 2000.
30. K.S. Subramanian, T. Viraraghavan, T. Thommavong and S. Tanjore, "Manganese Greensand for removal of arsenic in drinking water", *Water Qual. Res. Canada* 32(3) 551-561, 1997.



31. S. Bajpai and M. Chaudhuri, "Removal of arsenic from ground water by manganese dioxide-coated sand", *J. Environ. Eng.* 125(8) 782-784, 1999.
32. K.S. Subramanian, T. Viraraghavan, T. Phommavaong and S. Tanjore, "Manganese Greensand removal of arsenic in drinking water", *Water Qual. Res. J. Canada* 32(3) 551-561, 1997.
33. B.A. Manning, "Adsorption and stability of arsenic(III) at the clay mineral-water interface", *Environ. Sci. Technol.* 31(7) 2005-2011, 1997.
34. T. Nishimura and K. Tozawa, "On the solubility products of ferric, calcium and magnesium arsenates", *Tohoku Daigaku Senko Seiren Kenkyujo Iho* 34(1) 19-26, 1978.
35. G.B. Harris and S. Monette, "The stability of arsenic-bearing residues", In: "Arsenic Metallurgy Fundamentals and Applications", R.G. Reddy, P.B. Queneau and J.L. Hendrix (eds), Committee Metallurgical Society US Mackay Mineral Research Institute, Metallurgical Society, 1987.
36. R.C. Weast, "CRC Handbook of Chemistry and Physics", CRC Press, 55<sup>th</sup> ed., 1974.
37. S. Taylor, "Inorganic and Theoretical Chemistry", 3<sup>rd</sup> ed., Heinemann, London, 1960, p.331.
38. J.L. Jambor and J.E. Dutrizac, "Occurrence and composition of natural and synthetic ferrihydrate, a widespread iron oxyhydroxide", *Chem. Rev.* 98 2549-2585, 1998.

## Development of Low-cost Technologies for Removal of Arsenic from Groundwater

M. Ashraf Ali, A.B.M. Badruzzaman, M.A. Jalil, M. Delwar Hossain,  
M. M. Hussainuzzaman, M. Badruzzaman, O.I. Mohammad, N. Akter

Department of Civil Engineering,

Bangladesh University of Engineering and Technology, Dhaka 1000, Bangladesh

### *Abstract*

*Performance of three alternate arsenic removal technologies was evaluated in the laboratory. These were: (i) removal system based on alum and iron coagulation; (ii) removal system based on sorptive filtration using iron coated sand filter, and (iii) removal system based on sorptive filtration using gravel bed containing iron sludge. Based on laboratory performance, two technologies, ferric chloride coagulation, and sorptive filtration through iron-coated sand, were selected for the development of household arsenic removal units. The ferric chloride based unit is similar in design to the bucket treatment unit developed by DPHE-Danida. It involves precipitation of arsenic by adding a packet of coagulants to 25 liters of tubewell water and subsequent filtration of the water through a sand filter. The unit based on iron-coated sand has a pre-treatment system for removal of excess iron. This consists of a bucket where water is poured and stirred for sometime to accelerate precipitation of iron. The water then flows through a sand filter where the excess iron is filtered out. Finally the water is passed through the iron-coated sand filter. Field testing of 15 ferric chloride based units at Adda village in Barura thana of Comilla district showed very good arsenic removal efficiency. Arsenic concentrations in the treated water were found to be mostly below 20 ppb; while maximum arsenic concentration in the tubewell water was about 400 ppb. For some of these units, presence of fecal coliform was detected in the treated water. However, continued use of bleaching powder, along with the coagulant, for a period of about 15 days eliminated fecal coliform. This type of unit appeared to be widely accepted and in great demand at the village. The cost of chemical for treatment by this unit is about Tk. 0.10 per liter of water. Field testing also showed good arsenic removal*

*with the iron-coated sand unit. Although clogging of the sand filter was a major concern for this unit, this did not happen and a reasonable flow rate could be maintained with regular washing (about once in a month) of the upper sand bed in the unit. However, until an easier methodology becomes available for mass production of iron-coated sand, it would be difficult to produce such units for mass use.*

## **INTRODUCTION**

Presence of elevated levels of arsenic in groundwater has become a major concern in Bangladesh. Although arsenic contamination of water sources has been reported for a number of countries, the contamination scenario in Bangladesh and in the West Bengal State of India appears to be the worst detected so far world-wide, both in terms of area and population affected. Arsenic pollution of groundwater is particularly challenging in Bangladesh since tubewell water extracted from shallow aquifers is the major source of drinking water for most of its population. Estimates of population exposed to arsenic concentration above the Bangladesh drinking water standard of 0.05 mg/L vary from about 20 million to over 36 million (DPHE/BGS/MML, 1999; EES/DCH, 2000). In a recent survey conducted in 270 villages of Bangladesh, more than 7000 arsenicosis patients have so far been identified (Rahman et. al., 2000). Arsenic toxicity has no known effective treatment, but drinking of arsenic free water can help arsenic affected people at early stage of ailment to get rid of the symptoms of arsenic toxicity. Therefore, the most important measure needed is to prevent further exposure of population by providing them with arsenic-free safe drinking water.

People in Bangladesh, particularly in the rural areas, are accustomed to using groundwater from hand tubewells for long and, unlike surface water, it is considered safe from bacteriological pollution. In view of the overwhelming dependence of the population on groundwater, development of suitable treatment systems for arsenic removal from groundwater appears to a promising option for providing safe water to the rural population. Socio-economic conditions of Bangladesh demands low-cost as well as small-scale treatment systems that could be implemented in the rural areas at household or community levels. Various technologies have been used for removing arsenic from groundwater. The most commonly used technologies include co-precipitation with alum or iron, adsorptive filtration (e.g., using activated alumina), ion exchange, and membrane processes such as reverse osmosis. Bases on available information and experience on arsenic removal in Bangladesh, it appears that removal

systems based on coagulation-adsorption-coprecipitation and sorptive filtration are probably most promising for use in Bangladesh.

In the backdrop of the widespread arsenic contamination of groundwater in the Bengal Basin, United Nations University (UNU), Tokyo, Japan and Bangladesh University of Engineering and Technology (BUET) undertook a joint research initiative aimed at developing low-cost household arsenic removal units. The major objectives of the UNU-BUET joint research project was: (a) to evaluate the performance of alternate arsenic removal technologies/systems; (b) to design household arsenic removal units based on the selected technology(ies); and (c) to perform field-testing of the household arsenic removal units.

## **EXPERIMENTAL METHODS**

### **Evaluation of Performance of Alternate Removal Technologies/Systems**

Performance of three alternate arsenic removal technologies/systems was evaluated in the laboratory. These were (i) Removal system based on alum and iron coagulation; (ii) Removal system based on sorptive filtration using iron coated sand filter, and (iii) Removal system based on sorptive filtration using gravel bed containing iron sludge.

#### ***Removal System Based on Alum and Iron Coagulation***

Alum and ferric chloride available in the local market were used in this study. All coagulation experiments were carried out in 25-L plastic buckets with natural groundwater (without any pH adjustments) spiked with arsenite and arsenate at three different concentrations. Removal of both arsenite and arsenate present at different initial concentrations were evaluated for different doses of alum and ferric chloride. After addition of a particular dose of a coagulant (alum or ferric chloride), the water in the bucket was mixed with a wooden stick, first vigorously for about 30 to 60 seconds and then slowly (approximately one turn of the wooden stick per second) for about 90 seconds. Wooden stick, instead of a mechanical device, was used in order to mimic field condition in rural Bangladesh. The effect of mixing on floc formation and presence of residual alum/iron was evaluated (Ali et al., 2001) by varying the duration of slow mixing, and the mixing procedure adopted was found to provide good results in terms of floc formation. After mixing, the flocs were allowed to settle for periods ranging from 30 minutes to 24 hours. Water samples were then collected with a pipette from a depth approximately 10 cm from the bottom of the bucket. The water samples were then tested for total arsenic. Arsenic concentrations were measured by a Graphite Furnace Atomic Absorption Spectrophotometer (Shimadzu 6800) donated by the United Nations University, as part of the joint

research project. In addition a number of other parameters e.g., iron (for iron coagulation experiments), aluminum (for alum coagulation experiments) were also tested. Similar experiments were carried out to evaluate the effect of pre-oxidation (by different doses of potassium permanganate) on arsenite removal by alum and ferric chloride. Color produced by potassium permanganate is a concern and hence for these experiments, the effect of permanganate dose on color of the treated water was also evaluated.

#### ***Removal System Based on Sorptive Filtration Using Iron Coated Sand Filter***

In this study, arsenic removal efficiency of iron coated sand filters have been evaluated. Iron coated sand has been prepared following a procedure similar to that used by Joshi and Chaudhuri (1996). The procedure basically consists of pre-washing sand by immersing in an acid (20% commercial grade hydrochloric acid ) solution for 24 hours. After drying, the sand is mixed with 2M ferric nitrate and 10 N sodium hydroxide solution (80 mL of ferric nitrate solution and 4 mL of sodium hydroxide solution is required for each 200 cm<sup>3</sup> of sand). The mixture is then heated in an oven at 110 °C for 14 hours. It is then washed with distilled water a number of times and then dried. In this study, locally available sand passing #30 sieve and retaining on #40 sieve (as suggested by Joshi and Chaudhuri, 1996) was used. Smaller size sand passing through #40 sieve and retained on #50 sieve was also used in preparing iron-coated sand. But flow rate of water through this fine sand was found to be very low and not suitable for filtration. Different types of acid solutions were used for pre-washing the sand in order to assess its effect on formation of iron coating (Ali et al., 2001); and 20% commercial grade hydrochloric acid was found to be most cost-effective. The total iron content of the sand prepared in this way was found to be around 25 mg/g of sand. Efficiency of iron-coated sand in removing arsenate and arsenite was evaluated in glass burettes with a cross sectional area of 1 sq. cm. Based on experiences from similar works (e.g., Benjamin et al., 1996; Lo et al., 1997; Joshi and Chaudhuri, 1996; Stemkemp and Benjamin, 1996), sand bed depth was varied from 20 cm to 40 cm.

#### ***Removal System Based on Sorptive Filtration Using Gravel Bed Containing Iron-sludge***

In this study, removal efficiency of As(III) and As(V) by a gravel media containing iron-sludge (freshly precipitated iron hydroxide) was evaluated. Iron-sludge was prepared using ferric sulfate, ferrous sulfate and ferric chloride. Iron-sludge was prepared by raising the pH of the respective iron salt solutions by the addition of sodium hydroxide (or sodium carbonate) solution.

Two types of gravel filter columns (containing the iron sludge) were prepared. In the first type, the columns were prepared by placing locally

available gravel (gravel size passing 3/4" sieve and retaining on 3/8" sieve) in a straight transparent plastic tube of 1.5" diameter and then adding to it the prepared iron-sludge. The iron-sludge (ferric hydroxide-water slurry) was either poured down the gravel media or introduced in the gravel media in an up-flow mode. The length of gravel bed was 40 cm for this type of filter column. The second type of column was prepared by placing similar gravel media in 1.5" diameter plastic U-tubes and then adding to it the prepared iron-sludge in a similar manner. The length of the gravel filter media was 80 cm in this case, 40 cm on each side of the U-tube. Removal of arsenic (both arsenate and arsenite) by these filter columns was evaluated by passing through them groundwater spiked with arsenic at different concentrations in an up-flow mode. The different fixed flow rates through the filter media were maintained by using a float in the feed reservoir. Filtered water samples were collected from an outlet 20 cm above the gravel bed.

All laboratory tests were conducted using natural groundwater, collected from the deep tubewell pump station at BUET, with arsenic concentration below detection level (less than 1 ppb) and iron concentration of 0.1 mg/L. For laboratory experiments, this groundwater was spiked with arsenic (either arsenite or arsenate), as required. Table 1 provides a detailed characterization of groundwater used in laboratory experiments.

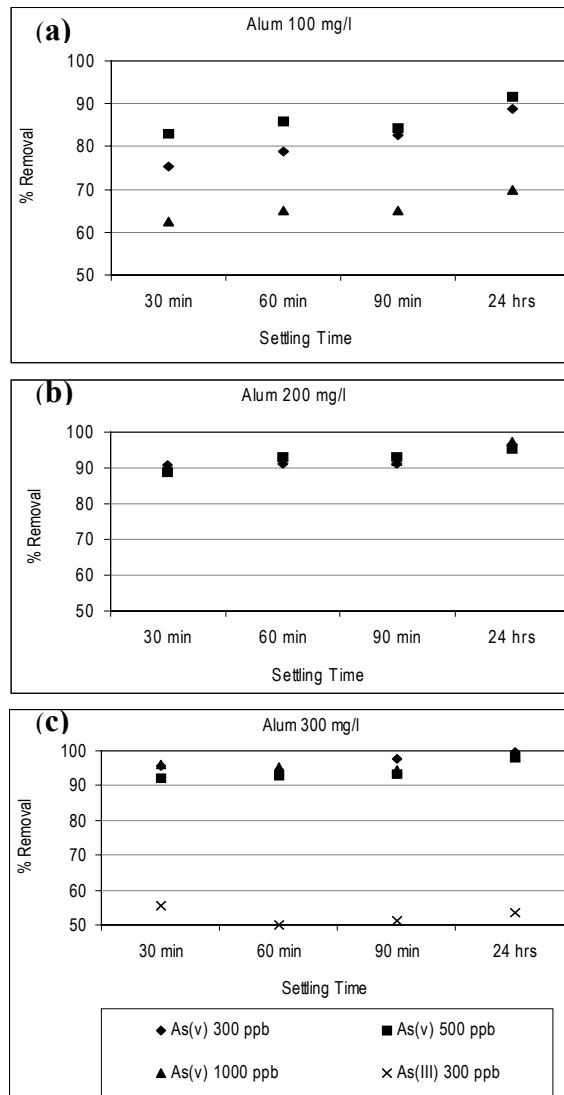
**Table 1: Detailed Characterization of Groundwater used in Laboratory Experiments**

Parameter	Unit	Concentration	Parameter	Unit	Concentration
pH	--	6.0	Iron	mg/L	0.07
Color	Pt.-Co.	15	Manganese	mg/L	0.010
Turbidity	NTU	0.90	Potassium	mg/L	25.4
Alkalinity as CaCO <sub>3</sub>	mg/L	242.0	Sodium	mg/L	131.9
Carbon-dioxide	mg/L	203.0	Arsenic	µg/L	< 1.0
DO	mg/L	2.97 at 26°C 2.03 at 26.1°C	Lead	mg/L	0.0214
Conductivity	µs/cm	1054	Cadmium	mg/L	0.0018
Chloride	mg/L	165.0	Zinc	mg/L	0.0372
Hardness as CaCO <sub>3</sub>	mg/L	338.0	Copper	mg/L	0.0467
Sulfate	mg/L	35.1	Nickel	mg/L	0.0074
Nitrate	mg/L	0.4	Mercury	mg/L	Nil
Phosphate	mg/L	0.14	Chromium	mg/L	0.0049
Fluoride	mg/L	0.35	Silica	mg/L	32.0

## RESULTS OF LABORATORY EXPERIMENTS

## Arsenic Removal by Alum Coagulation

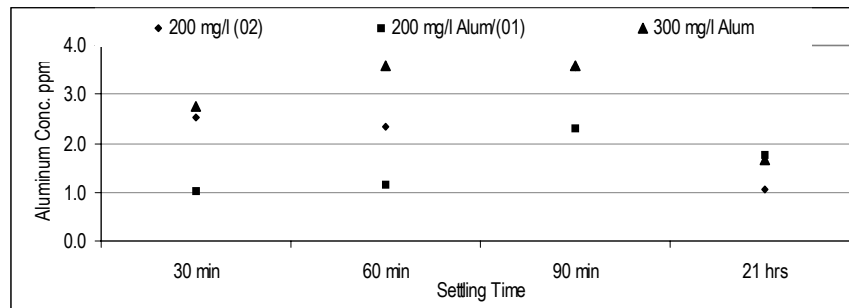
Figure 1 shows removal of As(III) and As(V), present at different initial



**Fig. 1: Removal of As(III) and As(V) by different doses of Alum**

concentrations, by different doses of alum. It shows that for any particular arsenic concentration, removal efficiency increases with increasing alum dose. Removal efficiency also appears to increase with increasing settling time. As shown in Fig. 1(c), removal efficiency of As(III) is significantly lower than that of As(V). Even for As(V), very high doses of alum are required to bring the concentration of arsenic in the treated water below the Bangladesh standard of 50 ppb. In fact, this limit could not be achieved for a water sample with initial arsenate concentration of 1000 ppb treated with an alum dose as high as 300 mg/L. Removal of arsenite [As(III)], pre-oxidized with potassium permanganate, by different doses of alum was found to be similar to those achieved with As(V) (Ali et al., 2001). In these experiments, a permanganate dose twice that required from stoichiometric consideration was used.

A major concern in arsenic removal with alum coagulation is presence of high residual aluminum in the treated water. Figure 2 shows residual aluminum concentration in water treated with different doses of alum. It shows high residual aluminum concentration in the treated water ranging from around 1.0 mg/L to over 3 mg/L, against a drinking water standard of 0.20 mg/L (GoB, 1997). So the aluminum concentration of water treated by alum appears to exceed the drinking water standard by a wide margin.



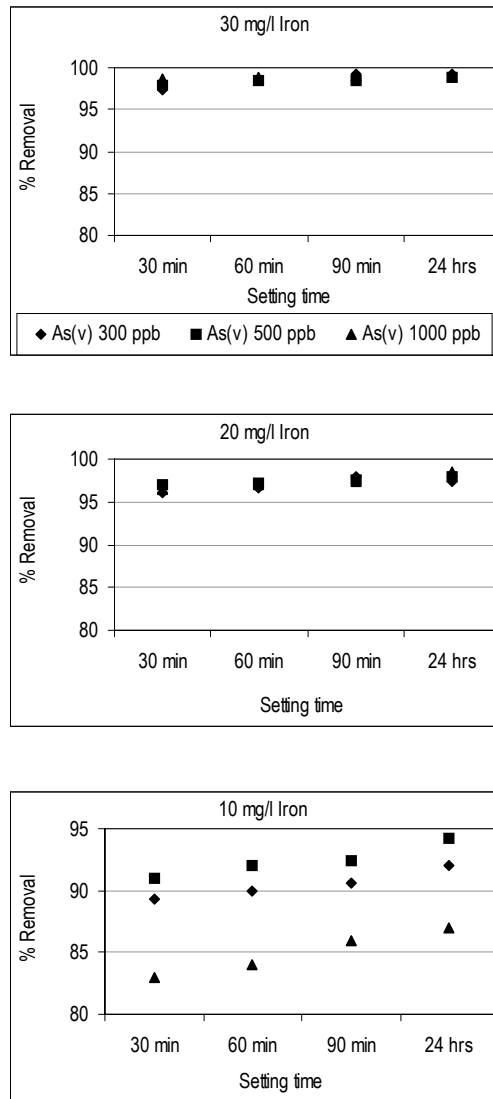
**Fig. 2: Residual aluminum concentration in water treated with Alum (Initial As(V) Concentration = 500ppb)**

#### Arsenic Removal by Ferric Chloride Coagulation

Figure 3 shows removal of As(III) and As(V), present at three different initial concentrations, by different doses of ferric chloride. It shows very good removal of arsenate with ferric chloride. In general, removal efficiency was found to improve with increasing ferric chloride dose and longer settling times. An iron (added as ferric chloride) dose of 20 mg/L could bring down arsenate concentration below 30 ppb from an initial concentration of 1000 ppb. As shown in Fig. 3, compared to As(V), As(III) removal was found to be significantly poor, confirming the results of previous studies and suggesting the need for pre-oxidation of As(III) to improve removal efficiency. As in the case of alum, removal of arsenite [As(III)] following pre-oxidation with potassium permanganate, by different doses of alum was found to be similar to those achieved with As(V) (Ali et al., 2001). A permanganate dose twice that required from stoichiometric consideration was used in these experiments.

As was the case during alum coagulation, pre-oxidation with potassium permanganate was found to produce a strong pink color, reaching as high as 80 Pt.-Co. unit, against a Bangladesh standard of 15 Pt.-Co. unit. Additional experiments were conducted to evaluate the effect of permanganate dose (as well as settling time) on color of treated water by varying permanganate dose at





**Fig. 3: Removal of As(III) and As(V) by different doses of Ferric Chloride**

of 50 ppb. For the 40-cm bed with a contact time of about 3 to 3.5 minutes, the initial flow rate varied from 10 to 15 ml/min. In this case, 350 to 400 bed volumes of water could be treated before breakpoint occurs at the Bangladesh standard of 50 ppb. Thus the efficiency of the iron coated sand bed increased

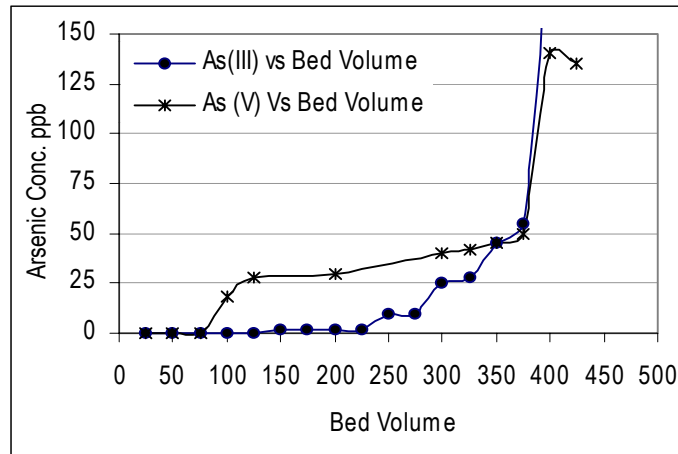
different doses of arsenite (Ali et al., 2001). In all cases, high color concentrations ranging from 30 to 80 Pt.-Co. units were recorded.

In order to remove this color, the treated water was passed through sand filters (prepared with sands passing sieve #30 and retained on #40 as well as un-sieved sands) of varying depths ranging from 10 cm to 30 cm. Very good color removal was achieved with both types of sand filters with depths of 20 cm and higher (Ali et al., 2001).

### Removal System Based on Sorptive Filtration Using Iron Coated Sand Filter

Efficiency of iron-coated sand in removing arsenate and arsenite was evaluated in glass burettes with a cross sectional area of 1 sq cm and with sand bed depth of 20 cm and 40 cm. For the 20-cm bed, groundwater spiked with both As(III) and As(V) at a concentration of 300 ppb was passed through the bed and arsenic content of effluent water was determined after passage of each liter of water. In this case calculated contact time (between arsenic-bearing water and iron coated sand) was about one minute. It was found that 200 to 225 bed volumes of water could be treated before breakpoint occurs at the Bangladesh drinking water standard

significantly with increase of contact time. The groundwater passing through the sand had an iron concentration of 0.10 mg/L, which appeared to have little effect on the flow rate; the final flow rate varied from 8 to 12 ml/min. Contrary to the results obtained with coagulation experiments, removal efficiency of both arsenate and arsenite was found to be similar for the iron coated sand. Figure 4 shows arsenic concentration as a function of bed volume of water (with initial arsenic concentration of 300 ppb) passed through the 40-cm iron coated sand bed.

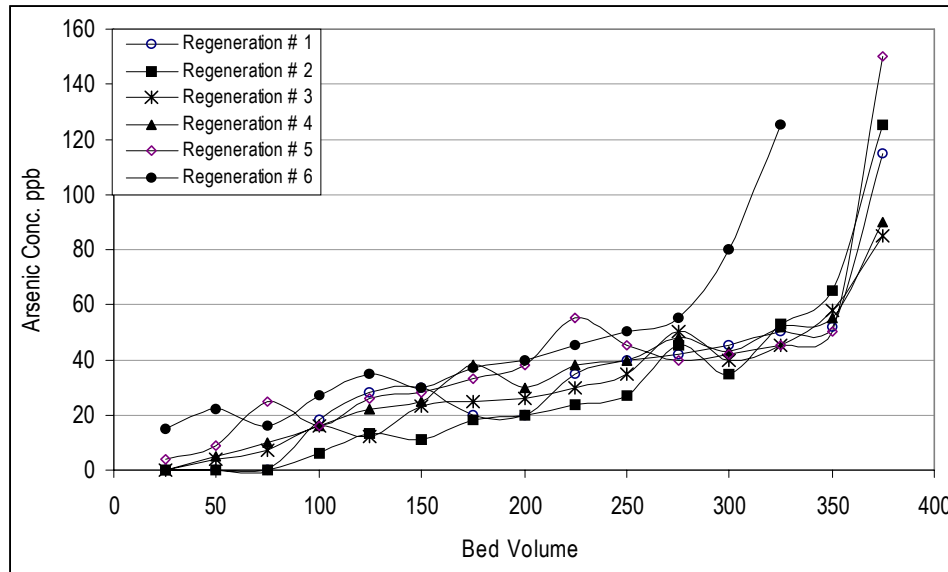


**Fig. 4:** Arsenic concentration as a function of bed volume of water passed through a 40-cm iron coated sand bed

After a breakpoint of 50 ppb arsenic in the treated water, the iron coated sand was regenerated following three different procedures. These were: (1) by taking the iron coated sand from the burette and soaking it in 0.2N NaOH for several hours, followed by washing with three liters of distilled water; (2) by passing 1.5 liters of 0.2 N NaOH through the column, followed by washing with three litres of distilled water; and (3) by soaking the sand (inside the burette) in 50ml of 0.2 N NaOH for two days, followed by washing with 3 liters of distilled water.

When the sand, regenerated following the first method, was poured back into the burette, the bed depth was found to be reduced by 2 to 3 cm. Arsenic removal efficiency of this regenerated bed was found to be very poor, probably due to a reduction in bed depth. On the other hand, arsenic removal efficiency of the sand regenerated following the second and third methods was found to be almost similar to those obtained with the original iron-coated sand. On an average 300 to 325 bed volumes could be treated (satisfying Bangladesh

standard) with the regenerated sand and this level of performance continued for upto five regeneration cycles. After the sixth regeneration cycle, the treated bed volume came down to about 275 to 300. Figure 5 shows arsenic removal efficiency of the regenerated (following the second method) sand for a 40-cm iron coated sand bed.



**Fig. 5:** Arsenic concentration as a function of bed volume of water passed through regenerated iron coated sand bed (40-cm)

### Removal System Based on Sorptive Filtration Using Gravel Bed Containing Iron-sludge

Removal of arsenic (both arsenate and arsenite) by these filter columns was evaluated by passing through them groundwater spiked with arsenic at different concentrations in an up-flow mode. Two different initial arsenic concentrations - 300 ppb and 500 ppb were used and flow rates were varied from less than 10 ml/min to over 50 ml/min. For this system it was found that the prepared iron-sludge does not adhere strongly to the gravel bed. Most of the iron sludge accumulates on top of the gravel bed. The iron sludge accumulated on top of the gravel bed was found to be very sensitive to the flow rate of water passing

through the gravel bed. Higher flow rates or abrupt increase of flow rate destabilized the accumulated iron sludge (Ali et al., 2001).

Arsenic removal efficiency of the gravel beds was found to be relatively low. The maximum removal achieved, with an initial arsenate concentration of 300 ppb, was in the vicinity of 50%. The primary reason for the lower arsenic removal efficiency appears to be the formation of “flow channels” through the iron sludge accumulated on top of the gravel bed. These “flow channels” formed along the sides of the plastic tubes reduced contact time between the water and the iron-sludge resulting in lower arsenic removal (Ali et al., 2001).

## **CONSTRUCTION OF ARSENIC REMOVAL UNITS**

Experimental results of the three arsenic removal systems described above were analyzed in order to select suitable methods for development of household arsenic removal units. Removal system based on alum coagulation was discarded due to its lower removal efficiency (compared to ferric chloride coagulation) and due to the presence of high levels of residual aluminum in the treated water. The removal system based on sorptive filtration through gravel bed containing iron-sludge was also discarded due to poor removal efficiency and unstable nature of the system (e.g., destabilization of iron-sludge in response of changes in flow rates).

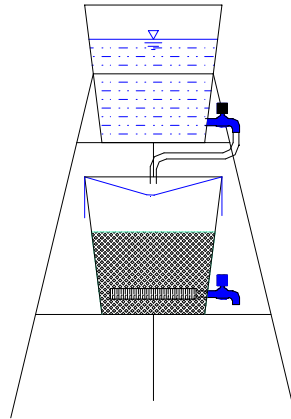
The arsenic removal technique based on ferric chloride coagulation appeared to be suitable for development of household arsenic removal units. The technique based on sorptive filtration through iron-coated sand also appeared to be an effective means of arsenic removal from groundwater. Although initial cost analysis favored the system based on ferric chloride coagulation, it was decided that household arsenic removal systems would be developed based on both these technologies. A major factor behind this decision was the somewhat opposite characteristics of these two techniques. The system based on ferric chloride coagulation would be benefited by the presence of naturally occurring iron in groundwater; while for the system based on iron-coated sand, this is a major problem requiring pre-treatment for excess iron removal. The operation and maintenance of the two systems are also different in nature, which may have implications on user acceptance. The system based on ferric chloride coagulation would require daily addition of the chemical (coagulant-oxidant) to water by the user and regular supply of the chemical. The system based on iron-coated sand on the other hand does not need daily supply of chemicals, but it may require monitoring to detect arsenic breakpoint and regular regeneration of the filter media. Thus two technologies/systems were selected for the

development household arsenic-removal-units: (1) ferric chloride coagulation, and (2) sorptive filtration through iron-coated sand.

### **Arsenic Removal Unit Based on Ferric Chloride Coagulation**

In the design of the household arsenic removal unit, it was assumed that the maximum arsenic concentration in the treated water would be limited to 50 ppb. Analysis of recent data on arsenic concentration in tubewell water all over Bangladesh (BGS, 2000) revealed that about 99.6% tubewells have arsenic concentration below 1000 ppb, 98.7% tubewells have arsenic concentration below 700 ppb, and 92.6% tubewells have arsenic concentration below 500 ppb. Based on these data, a design iron (added as ferric chloride) concentration of 20 mg/L was set for the household arsenic removal unit, which can bring down arsenic concentration in groundwater to less than 50 ppb from an initial concentration of upto 1000 ppb.

The designed household arsenic removal unit is similar to that developed by DPHE-Danida in structure. As shown in Fig. 6, the removal unit consists of two 35-L plastic buckets, placed one over the other (preferably in a stand). The top bucket has a tap attached 4 cm from its bottom. About 25 liters of raw water is poured in the top bucket (upto a mark). Required quantity of ferric chloride and



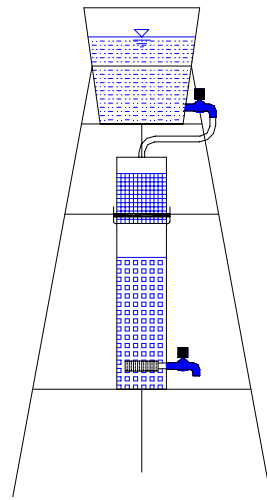
**Fig. 6: Household arsenic removal unit based on ferric chloride coagulation**

potassium permanganate is then added to the bucket from a sealed plastic packet. The water in the bucket is then mixed thoroughly with a wooden stick for about

a minute, followed by slow mixing (about one turn per second) for about one and a half minutes. The water is then allowed to settle for about one and a half hours. The tap at the bottom of the bucket is then opened. A plastic pipe attached to the tap carries the water to the lower bucket through an opening in its lid/cover, which then passes through a white cloth-strainer. This strainer removes iron flocs that may come along with water from the top bucket. The water then passes through a 20-cm deep sand layer placed in the lower bucket. At the bottom of the sand layer, there is a 1.5 inch diameter strainer, which is connected to a tap (also located 4 cm from the bottom of the bucket) by a plastic pipe. Water enters this strainer and eventually flows to the tap from which it can be collected. Laboratory testing of these arsenic removal units with synthetic water containing 500 ppb of As(III) yielded excellent arsenic removal (Ali et al., 2001).

### **Arsenic Removal Unit Based on Sorptive Filtration Through Iron-coated Sand**

As shown in Fig. 7, this household arsenic removal unit basically consists of a pre-treatment system for removal of excess iron. The pre-treatment system consists of a bucket where water is poured and stirred for sometime to accelerate



**Fig. 7 :** Household arsenic removal unit based on iron-coated sand

precipitation of iron. The water then flows through a sand filter where the excess iron is filtered out. This sand filter, about 10 cm in depth, is placed in a 15-cm diameter PVC chamber having perforations at its base. A 1~2 cm thick gravel bed placed at its bottom for preventing sand from passing through the bottom. The water then passes through a 40-cm deep iron-coated sand filter (also placed in a 15-cm diameter PVC chamber) where arsenic is removed. At the bottom of the iron coated sand layer, there is a 1.5 inch dia strainer, which is connected to a tap (also located 4 cm from the bottom of the chamber) by a plastic pipe. Water enters this strainer and eventually flows to the tap from which it can be collected. With about 7100 cm<sup>3</sup> of iron-coated sand, this unit should be able to treat at least 2500 liters of water (assuming treatment of 350 bed volumes) with an initial arsenic content of about 300 ppb before regeneration of the sand is required.

### **FIELD TESTING OF ARSENIC REMOVAL UNITS**

Field-testing of both types of household arsenic removal units is now being conducted in the village of Adda in the Barura thana of Comilla district. According to the villagers, no government or non-government initiatives have been taken for detecting arsenic in the tubewells of this village, although the villagers suspected presence of arsenic in their tubewell water for long. Random sampling of tubewell water from this village revealed presence of high level of arsenic in many tubewells.

#### **Removal Unit Based on Ferric Chloride Coagulation**

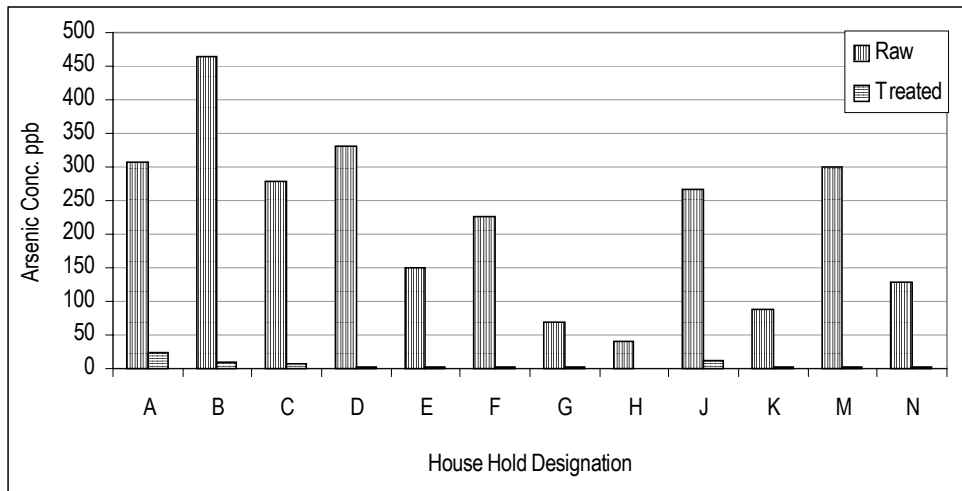
The field-testing started on 21<sup>st</sup> July 2000 with installation of three such units in three different households in the village. The arsenic concentration in the tubewells located at these households are 450 ppb, 640 ppb, and 375 ppb. On 11<sup>th</sup> August 2000, two more arsenic removal units were installed at two other households of the same village. Ten more units, built by the villagers themselves, became operational on 25<sup>th</sup> September 2000.

The operation of the arsenic removal unit was explained to the people of these households and they were provided with a simple instruction sheet detailing proper operation and maintenance of the unit. People in these households collect treated water (in a bottle), initially one everyday and now after more than seven months of operation, once every two weeks. The research team members collect these bottles during their field visits. Questionnaire surveys were also conducted during some of the field visits. Results of field testing of this type of arsenic removal unit are summarized below. Detailed results are provided in Ali et al. (2001). Four more ferric chloride based units

have recently been installed at village Bejgaon in Srinagar, Munshigong. Results of field testing at this site are still being evaluated and have not been presented in this paper.

**Arsenic Removal Efficiency**

Very good arsenic removal was achieved in all the 15 arsenic removal units installed in the village. Analysis of arsenic concentration in the treated water samples from the 15 households have been found to be mostly below 20 ppb level, much below the Bangladesh standard of 50 ppb. The maximum concentration in the treated water recorded so far is 37 ppb. Figure 8 shows arsenic concentration in the well water and average arsenic concentration in the treated water for the 12 out of 15 households. Detailed results of arsenic concentration in the treated water are provided in Ali et al. (2001).



**Fig. 8 : Comparison of arsenic concentration in the tubewell water and the average arsenic concentration in the treated water**

**Other Water Quality Parameters**

Besides arsenic, a number of water quality parameters (e.g., pH, Fe, Mn, Phosphate, Silica, Nitrate and redox potential) of the raw (tubewell) and treated water were measured at selected households in the field (using *Chemets* Field Kits) as well as in the laboratory. Table 2 shows results of field measurements



of a number of parameters at selected households. These results show significant reduction of iron and phosphate concentrations in the treated water. There was also some reduction in silica concentration. Compared to raw tubewell water, nitrate concentration of the treated water was raised and pH was slightly depressed. Redox potential data clearly show a complete shift from the reducing condition of the raw water to the oxidizing condition of the treated water. Average manganese concentrations in the treated water was about 0.05 mg/L, far below the drinking water standard of 0.10 mg/L. Only one sample of treated water with Manganese concentration of 0.11 mg/L marginally exceeded the drinking water standard. It should be noted manganese concentration resulting from addition of permanganate was about 0.43 mg/L. Thus, it appears that along with arsenic, manganese was also very effectively removed from water by ferric chloride coagulation.

**Table 2: Field Measurements of Water Quality at Selected Households**

Parameter	Unit	Household A		Household C		Household D	
		Raw	Treated	Raw	Treated	Raw	Treated
pH	--	6.5	6.3	6.3	6.2	6.0	6.0
Redox Potential	mV	- 98	102	- 103	103	- 112	21
Flow Rate	ml/min	--	900	--	1740	--	1160
Ferrous Iron (Fe <sup>2+</sup> )	mg/L	2.5~5.0	0.0~0.1	2.5~5.0	0.0~0.1	6~7	0.3~0.4
Total Iron (Fe)	mg/L	2.5~5.0	0.0~0.1	3.5	0.1~0.2	8~10	0.4~0.6
Nitrate (NO <sub>3</sub> <sup>-</sup> )	mg/L	0.0~0.1	1.0~1.5	0.0~0.1	1.0~1.5	0.0~0.1	0.6~0.8
Silica (SiO <sub>2</sub> )	mg/L	50~60	40~50	60	60~70	40~50	25~30
Phosphate (PO <sub>4</sub> <sup>3-</sup> )	mg/L	8~10	1~2	7~8	0.1~0.2	7~8	0.2~0.3

### ***Bacteriological Quality of Water***

For some of the ferric-chloride-based units, presence of fecal coliform was detected in the treated water (see Table 3). This appears to be, primarily, due to contamination of water during transportation from the tubewell to the upper bucket in the arsenic removal unit. However, it should be mentioned that raw tubewell water samples from some households also showed presence of fecal coliform (Ali et al., 2001). The sand filter media appear to sustain growth of fecal coliform as was evidenced from continued presence of these organisms in some of the units. This problem was however eliminated by introducing

bleaching powder in the chemical packet. Continued use of chemical packets with bleaching powder for a period of about 15 days eliminated faecal coliform.

### *User Acceptance*

As mentioned earlier, villagers of Adda complained about lack of government or non-government initiatives for detecting arsenic in the tubewells of this village, although they suspected presence of arsenic in their tubewell water for long. When this research team confirmed the presence of high level of arsenic in many of the tubewells in the village and proposed to provide some households with arsenic removal units on a test basis, people became very enthusiastic. Initially only five units were supplied. But, requests for more units were made by many in the village. With an objective of transfer of technology, the villagers were trained in constructing the removal units. Following the brief training, the villagers themselves built ten more arsenic removal units locally (at the village).

**Table 3: Bacteriological Quality of Raw (Tubewell) and Treated Water from Some Households in Adda village.**

Household Designation	Fecal Coliform ( # per 100 ml)		
	Tubewell Water	Treated Water	
		Before Addition of Bleaching Powder	After Addition of Bleaching Powder
A	nil	*TNTC	Nil
B	nil	Nil	Nil
C	nil	1	Nil
D	nil	7	Nil
F	5	5	Nil
H	*TNTC	*TNTC	Nil

\* TNTC : Too numerous to count.

After more than seven months of operation, the ferric chloride based units appeared to have become very popular with the people in the village Adda. Although there are differences in the level of enthusiasm regarding these units, people in general were very eager to use these units. This was particularly true among the people who were more aware about the adverse effects of arsenic. This was evidenced by requests for many more units by the people. Many people showed their willingness to pay for the chemical packets (which are now supplied free of cost by the project). The good name of BUET appeared to have helped in generating peoples' confidence in these units. The easy operation and maintenance (discussed later) is one aspect that appeared to have made these

units popular. As mentioned earlier, with little assistance, people themselves could build such units at the village.

Apart from the arsenic removal efficiency of these units, the aspect that impressed people most was the clarity of water produced by these units. Many households identified this aspect as the primary reason for using the unit. With relatively high iron content (upto about 10 mg/L), raw water from many tubewells in the village showed high turbidity (resulting from precipitated iron flocs). The units were very effective in removing the iron content of water (along with arsenic) and the clear water produced was very attractive aesthetically. There was another interesting aspect regarding use of these units. Some of the households informed that they did not use the treated water for drinking during winter because the water was very cold; instead they used tubewell water directly, which was much warmer.

### ***Operation and Maintenance***

Survey of the 15 households revealed that on an average most of them treated two buckets of water daily. This water was used primarily for drinking and cooking. However, one household reported to have treated about four to five buckets daily. This was due to the fact that the household was supplying water to a number of surrounding households.

Some households informed that it was difficult for women in the households to stir the water in the upper bucket. They suggested that if the upper bucket is placed at a lower height, it would be easier for them to stir. People informed that they have to regularly wash the white cloth placed in the upper bucket for straining some of the iron flocs coming from the upper bucket. The users also informed that they have to periodically wash the sand in the lower bucket to maintain a reasonable flow rate of treated water (which varied from about 1 to 2 L/min). The frequency of washing varied from twice a week to about once in every two weeks, depending on the volume of water treated, the iron content of tubewell water and operation of the unit.

During field visits, it was observed that the instructions for operation of the unit, though simple, were not strictly followed by all the users. For example the mixing (one minute of rapid mixing and one and a half minutes of slow mixing) instructions were not always followed because many felt it was too much work. The required time for settling of iron flocs (one and a half hours) was also not maintained. But it should be mentioned that the arsenic removal efficiency did not appear to have been affected much by these irregularities.

### **Cost**

The total cost of constructing the ferric chloride based unit was about Tk 550/- (detailed breakdown provided in Ali et al., 2001). The cost of each packet of chemical cost around Tk. 2.25/-, which can produce about 23 liters of treated water. In other words, the cost of chemical is about Tk. 0.10 per liter. The mild steel frame for holding the two buckets, which is not a necessary part of the arsenic removal unit, costs around Tk. 300/-.

### **Household unit based on Sorptive Filtration through Iron Coated Sand**

On 11<sup>th</sup> August 2000, one such arsenic removal unit was installed at a household of the same village (Adda). Since preparation of iron coated sand is time consuming and rather expensive, only one such unit was made and installed at a household. The operation of the arsenic removal unit was explained to the people of the household and they were provided with a simple instruction sheet detailing proper operation and maintenance of the unit. People in this household collected one bottle of treated water, initially one everyday, and now after more than seven months of operation, once every week. The research team members collect these bottles during their field visits. Questionnaire surveys were also conducted during some of the field visits. Results of field testing of this type of arsenic removal unit are summarized below, although with only one unit in operation, detailed evaluation of this unit could not be made. Detailed results are provided in Ali et al. (2001). One iron-coated sand unit has recently been installed at village Bejgaon in Srinagar, Munshigong. Results of field testing at this site are still being evaluated and have not been presented in this paper.

Good arsenic removal was achieved with this filtration unit. Arsenic concentration came down to below 15 ppb in most cases from an initial concentration of 226 ppb. The user of this unit was very happy with the performance of the unit. The major advantage of this unit was that it did not require any chemicals and that the only maintenance required for this unit was periodic washing of the sand filter in order to maintain reasonable flow rate through the system. The major concern for this unit was quick clogging of the sand filter bed. But for this household with a iron content of 6~7 mg/L in its tubewell, this did not happen and a reasonable flow rate (from 1 to 2 liter/min) could be maintained with regular washing of the upper sand bed in the unit about once a month.

During field visits, it was observed that the instructions for operation of the unit were not strictly followed. For example, it was advised that the water be poured in the upper bucket and stirred for sometime in order to facilitate precipitation of naturally occurring iron (in order to avoid quick clogging of the filter bed). But most often this was not followed.

It should be mentioned that this type of filtration unit requires regular monitoring to determine the breakpoint of arsenic in the treated water. Monitoring of this unit suggests that more than eight months of operation it has not yet reached the breakpoint of 50 ppb arsenic.

## CONCLUSIONS

Performance of three alternate arsenic removal technologies/systems was evaluated in the laboratory in order to determine their suitability for development of a low-cost arsenic removal unit. These were (i) Removal system based on alum and iron coagulation; (ii) Removal system based on sorptive filtration using iron coated sand filter, and (iii) Removal system based on sorptive filtration using gravel bed containing iron sludge. Removal system based on alum coagulation was not found to be suitable due to its lower removal efficiency (compared to ferric chloride coagulation) and due to the presence of high levels of residual aluminum in the treated water. The removal system based on sorptive filtration through gravel bed containing iron-sludge was also found to be unsuitable due to poor removal efficiency and unstable nature of the system (e.g., destabilization of iron-sludge in response of changes in flow rates). Two household arsenic removal units were developed, one based on ferric chloride coagulation and the other based on sorptive filtration through iron coated sand. Field testing of 15 ferric chloride based units and one iron coated sand unit is being conducted in the village of Adda in the Barura thana of Comilla district for over seven months.

Field testing at Adda village showed very good arsenic removal efficiency for the ferric chloride based units. Arsenic concentrations in the treated water were found to be mostly below 20 ppb level, much below the Bangladesh standard; while maximum arsenic concentration in the raw was about 400 ppb. For some of the ferric chloride based units, presence of fecal coliform was detected in the treated water. Continued use of chemical packets with bleaching powder for a period of about 15 days eliminated fecal coliform. So there appears to be a need for a disinfectant (in addition to the coagulant and the oxidant) in the chemical packet for ensuring good bacteriological quality of water. In general, this type of unit appeared to be widely accepted and in great demand at the village where field-testing was conducted. The clarity of treated water and easy operation and maintenance appear to be major factors behind ready acceptance of this type of unit. The good name of BUET appeared to have helped in generating peoples' confidence about the effectiveness of these units. With little assistance from the study team, villagers could produce such units locally (at the village) and there are still demands for many more. The cost of

chemical for treatment is about Tk. 0.10 per liter. Although the chemicals were supplied free of cost, some villagers showed their willingness to pay for the chemicals, if needed.

With only one unit in operation, detailed evaluation of the iron-coated sand unit could not be made in this study. Good removal of arsenic was achieved with this unit as well and to date this unit has not yet reached the breakpoint of 50 ppb of arsenic after over seven months of operation. With minimum maintenance required, the user was also very happy with the performance of this unit. Although clogging of the sand filter was a major concern for this unit, this did not happen and a reasonable flow rate (from 1 to 2 liter/min) could be maintained with regular washing (about once in a month) of the upper sand bed in the unit.

It should be pointed out that unlike the ferric chloride based unit, this unit could not be readily reproduced at the village level because the preparation of iron-coated sand is rather costly, time consuming and cumbersome requiring an oven with temperature control. Until an easier methodology becomes available for mass production of iron-coated sand (e.g., using brick klin burners), it would be difficult to produce such units for mass use.

#### **ACKNOWLEDGEMENT**

The United Nations University, Tokyo, Japan, provided funding for this UNU-BUET project. The authors acknowledge Dr. Zafar Adeel and Dr. M. Feroze Ahmed for their valuable suggestions during the course of this research work.

#### **REFERENCES**

- Ali, M. A., Badruzzaman, A. B. M., Jalil, M. A., and Hossain, M. D. (2001), Development of low-cost technologies for removal of arsenic from tubewell water, Draft final report presented to the United Nations University, Tokyo, Japan.
- Benjamin, M. M., Sletten, R. S., Bailey, R. P., and Bennett, T. (1996), "Sorption and Filtration of Metals using Iron-oxide-coated Sand", *Water Research*, 30(11), 2609-2620.
- DPHE, BGS, and MML (1999), *Groundwater Studies for Arsenic Contamination in Bangladesh*, Final Report (Phase-1), January.

- EES and DCH (2000), *Groundwater Arsenic Contamination in Bangladesh*, A. Summary of Field Survey from August 1995 to February, 2000: B. Twenty Seven Days Detailed Field Survey Information from April 1999 to February 2000, April
- GoB (1997), Environment Conservation Regulation 1997, Government of Peoples' Republic of Bangladesh, 1997.
- Joshi, A. and Chaudhuri, M. (1996), "Removal of Arsenic from Ground Water by Iron Oxide-Coated Sand", *ASCE Journal of Environmental Engineering*, 122(8), p. 769-771.
- Lo, S., Jeng, H., and Lai, C. (1997), "Characteristics and Adsorption Properties of Iron-coated Sand", *Water Sci. Tech.*, 35(7), 63-70.
- Rahman, M., Quamruzzaman, Q., and Others, (2000), *Arsenicosis- Yet to be Cared*, Paper presented at the International Conference on Bangladesh Environment, 14-15 January 2000.
- Stenkamp, V. S. and Benjamin, M. M. (1994), "Effect of Iron-oxide Coating on Sand Filtration", *J. AWWA*

# 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  $\text{SO}_4^{2-}$ ,  $\text{SeO}_3^{2-}$ ,  $\text{PO}_4^{3-}$ , and  $\text{CrO}_4^{2-}$  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 ( $\text{mg/L}$ )	P ( $\text{mg/L}$ )	Si ( $\text{mg/L}$ )	Na ( $\text{mg/L}$ )	Ca ( $\text{mg/L}$ )	Mg ( $\text{mg/L}$ )
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  $\text{mg/L}$  was maintained by the addition of the hypochlorite solution during approximately 5 minutes of mixing. Different amounts of ferric solution ( $\text{Fe(III)}=0, 5, 10, 20 \text{ mg/L}$ ) 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- $\mu\text{m}$  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  $\mu\text{g/L}$  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.

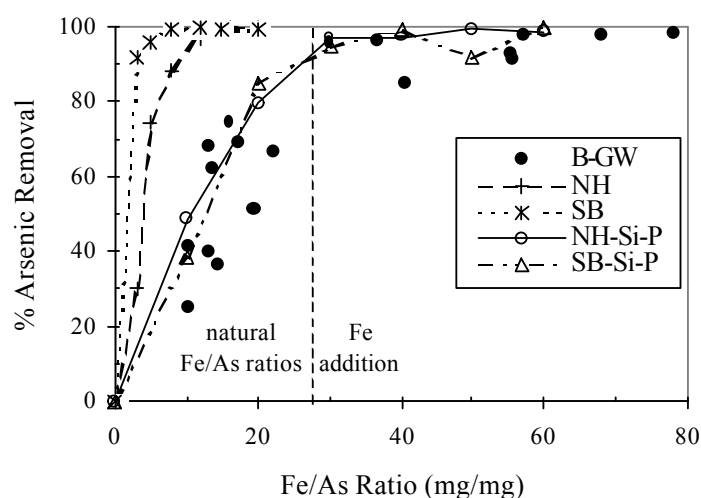
## **RESULTS AND DISCUSSION**

### **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  $\text{NaClO}$  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  $\mu\text{g/L}$ . 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.



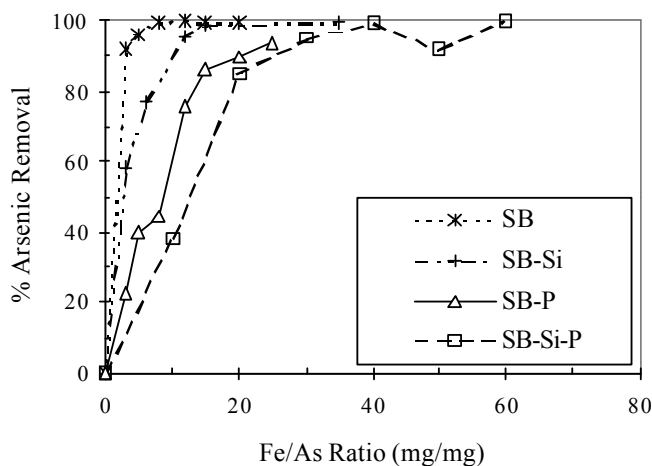
**Figure 1: Removal of As by co-precipitation as a function of Fe/As ratio. Water samples are provided in Table 1. Samples “NH-Si-P” and “SB-Si-P” contained 18 mg-Si/L and 1.9 mg-P/L.**

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).



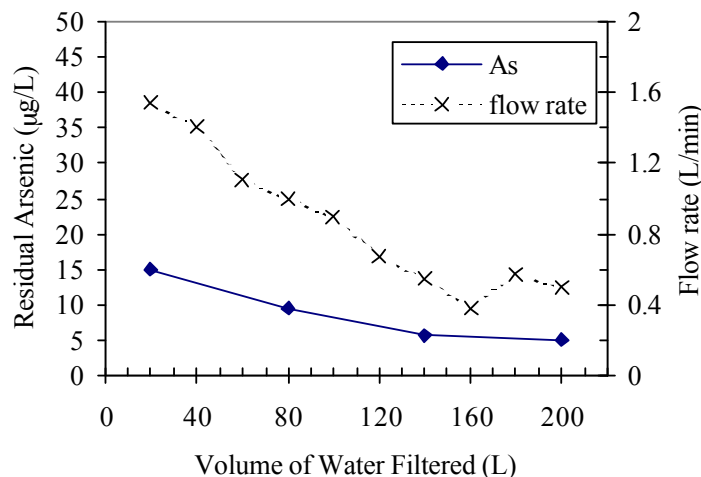
**Figure 2 : Effects of phosphate and silicate on As removal by co-precipitation. The “SB-Si”, “SB-P”, and “SB-Si-P” samples were amended with 18 mg-Si/L or/and 1.9 mg-P/L.**

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  $\mu\text{M}$ . 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  $\mu\text{M}$ . 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.

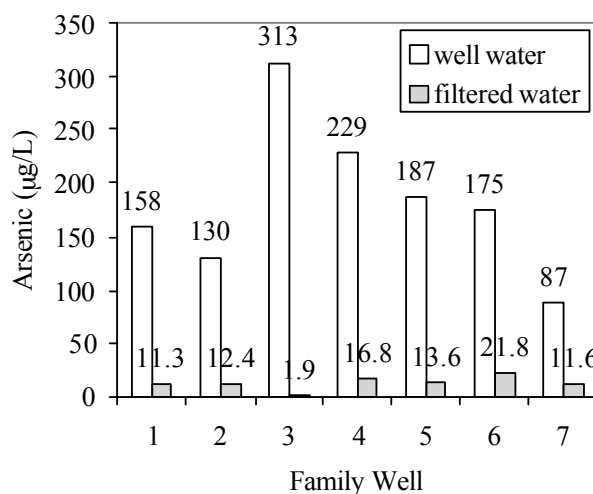


**Figure 3: Performance of the bucket filter for treatment of water in a well in Munshiganj district.**

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 Bangal, 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)<sub>3</sub>/SiO<sub>2</sub> 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.

## Development of An Activated Alumina Based Household Arsenic Removal Unit

**M. A. Jalil and Farooque Ahmed**

Department of Civil Engineering

Bangladesh University of Engineering & Technology (BUET), Dhaka-1000,  
Bangladesh

### ***Abstract***

*The people of Bangladesh have been facing arsenic contamination of drinking water supplied by hand pump tubewells. At present, the most feasible short-term solution of this problem appears to be treatment of tubewell waters through suitable and low cost technologies. The groundwaters of Bangladesh contain both As(III) and As(V) and in addition high concentration of iron is also present in most of the groundwaters. Activated alumina adsorption process is very efficient in removing As(V) from water; while As(III) is poorly removed. The naturally occurring iron degrades the performance of an alumina bed by fouling and clogging the bed. However, the iron can be beneficially used to remove part of the arsenic in the water through co-precipitation and adsorption. A system has been developed to improve the performance of alumina columns through efficient pretreatment of natural groundwater. The pretreatment steps include oxidation of As(III) and removal of iron. Through the pretreatment steps the problems of iron have been eliminated; while its beneficial use has been ensured. The developed system is suitable for any adsorbent or ion exchange resin. A detail assessment of the performance of the technology at household level has been carried out recently. The findings reveal that the arsenic removal efficiency of the technology is excellent. It removes iron very efficiently and an appreciable amount of manganese is also removed. The removal/addition of other water quality parameters is insignificant. However, unhygienic practices of the users may result in bacterial contamination of the treated water. The problems identified regarding users' acceptability of the technology can be minimized significantly with minor modification of the present design.*

## INTRODUCTION

A wide spread contamination of shallow groundwaters of Bangladesh has been reported and over 25% of the hand pump tubewells is producing arsenic contaminated water (DPHE/DFID/BGS, 2000). This is a serious public health concern as hand pump tubewell water is the major source of drinking water for almost all of her population. Thousands of people are reported to have already been suffered from arsenicosis by drinking arsenic contaminated water and millions are at risk of arsenic toxicity due to exposure to arsenic contaminated tubewell water (EES/DCH, 2000; Rahman et al., 2000; DPHE/DFID/BGS, 2000). The most important measure needed to combat the arsenic problem is to provide arsenic safe drinking water to the exposed people. Unless suitable alternative drinking water sources are made available, arsenic removal from the shallow tubewell water through simple and low cost technologies appears to be an immediate and short term solution of this problem. In this perspective, a household arsenic removal unit (ARU) based on activated alumina has been developed. A household system has been preferred over a community system because of the fact that the community-managed systems have not yet been proved successful in Bangladesh. This paper presents the development steps and an evaluation of the performance of the arsenic removal unit.

## DEVELOPMENT CONSIDERATIONS

Apart from arsenic, the majority of groundwaters of Bangladesh show the presence of high iron and manganese concentrations (DPHE/DFID/BGS, 2000). It has been found that handpump tubewell water in 65% of the area in Bangladesh contains iron in excess of 2 mg/L and in many acute iron problems areas, the concentration of dissolved iron is higher than 10 mg/L. Many groundwaters also show high phosphorous concentration. However, nitrate and sulfate concentrations are normally low. In groundwaters, arsenic occurs both in reduced [As(III)] and oxidized [As(V)] forms and the ratio of As(III) to As(V) varies significantly ranging from less than 0.1 to greater than 0.9.

Activated alumina adsorption is an efficient process for removing As(V) from water, but the removal capacity is very low for As(III). A laboratory study was carried out at BUET on the effectiveness of activated alumina in removing arsenic from both synthetic and natural groundwaters under a number of experimental conditions (Ahmed and Jalil, 1999). The study revealed that As(V) is much more effectively removed than As(III) and the smaller alumina particles are more effective than the coarser particles. Presence of chloride in water has no effect on the removal efficiency while sulfate and phosphate have significant effect only at very high concentrations. However, the presence of iron in water

has a very significant effect on the performance of alumina columns. Due to exposure of groundwater to air, the supersaturated free carbon dioxide is removed from the water and oxygen content of the water increases. As a result the pH value of water is raised and the dissolved iron [Fe(II)] is oxidized to [Fe(III)] producing insoluble iron precipitates [Fe(OH)<sub>3</sub>] through hydrolysis. The water becomes turbid due to the presence of the iron precipitates/flocs. When this water is passed through an alumina column, the iron precipitates foul the bed by attaching to the surfaces of alumina particles and clogging the pores of the column - leading to a progressive deterioration of the column performance. As water flows, the active sites of alumina becomes occupied increasingly by iron precipitates. The precipitates block the adsorption of arsenic species resulting in reduction of the arsenic removal efficiency of the column. At the same time, the flow rate through the bed is progressively reduced due to clogging of the pores by iron flocs and the column may become non operable within a short time depending on the size and amount of iron flocs in the flowing water. However, during iron precipitation, arsenic is co-precipitated and adsorbed. Moreover, iron flocs accumulated in an alumina column provide an adsorption mass for arsenic in the flowing water (Ahmed and Jalil, 1999). The disadvantages of presence of naturally occurring iron can be eliminated and its beneficial use in removing a part of the arsenic can be derived if iron is removed from groundwater prior to passing through an alumina column. Hence in developing an efficient arsenic removal unit based on activated alumina, the following pre-treatments must be considered : (i) oxidation of As(III) to As(V), and (ii) removal of iron.

### **Oxidation of As(III) to As(V)**

At household level, oxidation of As(III) can be achieved by both bleaching powder and potassium permanganate. Bleaching powder usually causes an unpleasant taste in the treated water and there is also the risk of formation of trihalomethanes. Moreover, it is a very unstable chemical and the quality of bleaching powder available in the open market of Bangladesh varies widely, it is very difficult to ensure the proper dosing of bleaching powder. On the other hand, potassium permanganate is a stable chemical and easily available locally. However, it produces a color in the treated water making it less attractive for drinking. If the problem of color can be solved, potassium permanganate is preferable as an oxidizing agent. Therefore in developing the ARU, potassium permanganate has been chosen as the oxidant and a sand filter has been developed to remove the residual color. Tests were conducted to determine the optimum dose of potassium permanganate for oxidation of arsenic. It was found that a permanganate dose of around 1.0 mg/L is enough to oxidize as high as 500 ppb As(III) (Ali et al, 2001).

### **Pretreatment for Iron Removal**

Experiments were conducted to remove naturally occurring iron in groundwater by adopting simple aeration followed by flocculation and sedimentation. Macro iron flocs settled easily but micro iron flocs could not be removed from the supernatant water in this way, which subsequently deteriorated the performance of alumina columns (Ahmed and Jalil, 1999). Sand filtration of the supernatant water was perceived as a solution of this problem.

### **Sand Filter**

A sand filter was designed to remove both the color and micro iron flocs (Ali et al., 2001). Initially, a number of filters were prepared with sand passing # 30 sieve and retaining on # 40 sieve and using variable depth of bed ranging from 10 cm to 30 cm. After pre-oxidation and settling of macro flocs in settling tank the supernatant water was allowed to flow through the sand filters. An efficient color and iron removal was achieved with sand bed of minimum 20 cm depth.

## **DESIGN OF ARSENIC REMOVAL UNIT**

In designing the household arsenic removal unit, it was assumed that 40 to 50 liters of water per family per day would be required for drinking and cooking purposes. It was also assumed that the maximum arsenic concentration in the treated water would be within the current Bangladesh Drinking Water Standard of 50 ppb. The unit operations and processes involved in the arsenic removal system are mixing of oxidant and aeration, precipitation, flocculation, co-precipitation and adsorption, sedimentation, screening and filtration and activated alumina adsorption. The ARU consists of three sub-units namely oxidation-sedimentation unit, filtration unit and adsorption unit. A brief description of the units and their operation is given below.

### **Oxidation–Sedimentation Unit**

It consists of a 25L plastic bowl fitted with a plastic tap near the base for controlling the outflow. Raw water is fed into the bowl where a number of operations and processes take place. Potassium permanganate solution is added to arsenic contaminated raw water using a dropper. After the dosing, the water is vigorously agitated with a wooden stick for complete mixing and aeration. As a result, the As(III) present in the water is oxidized to As(V) and the dissolved iron precipitates. The precipitates are then flocculated through slow mixing with the wooden stick. The water is allowed to stand under quiescent condition for about one hour for settling of the iron flocs. Co-precipitation and adsorption of arsenic occur during these operations. The supernatant water is then allowed to flow to

the filtration unit through a rubber tube. The bowl has a lid to prevent the contamination of feed water from external sources.

### **Filtration Unit**

The down flow filtration unit consists of a 20 cm deep sand layer in a 22 L plastic bucket. At the bottom part of the sand layer, there is a plastic strainer of 1.5 inches diameter and it is connected to a tap. The sand filter removes the iron flocs coming along with water from the oxidation-sedimentation unit. It also removes the residual color of potassium permanganate. A cloth screen is placed on the sand filter to remove a part of the micro flocs with the purpose of increasing the filter run. Further removal of arsenic was achieved through adsorption on the iron flocs retained on the screen and in the interstices of the sand bed. The filtration unit is covered with a lid so that external contamination can be prevented. The filtrate comes out through the under-drain system and enters into the activated alumina adsorption unit.

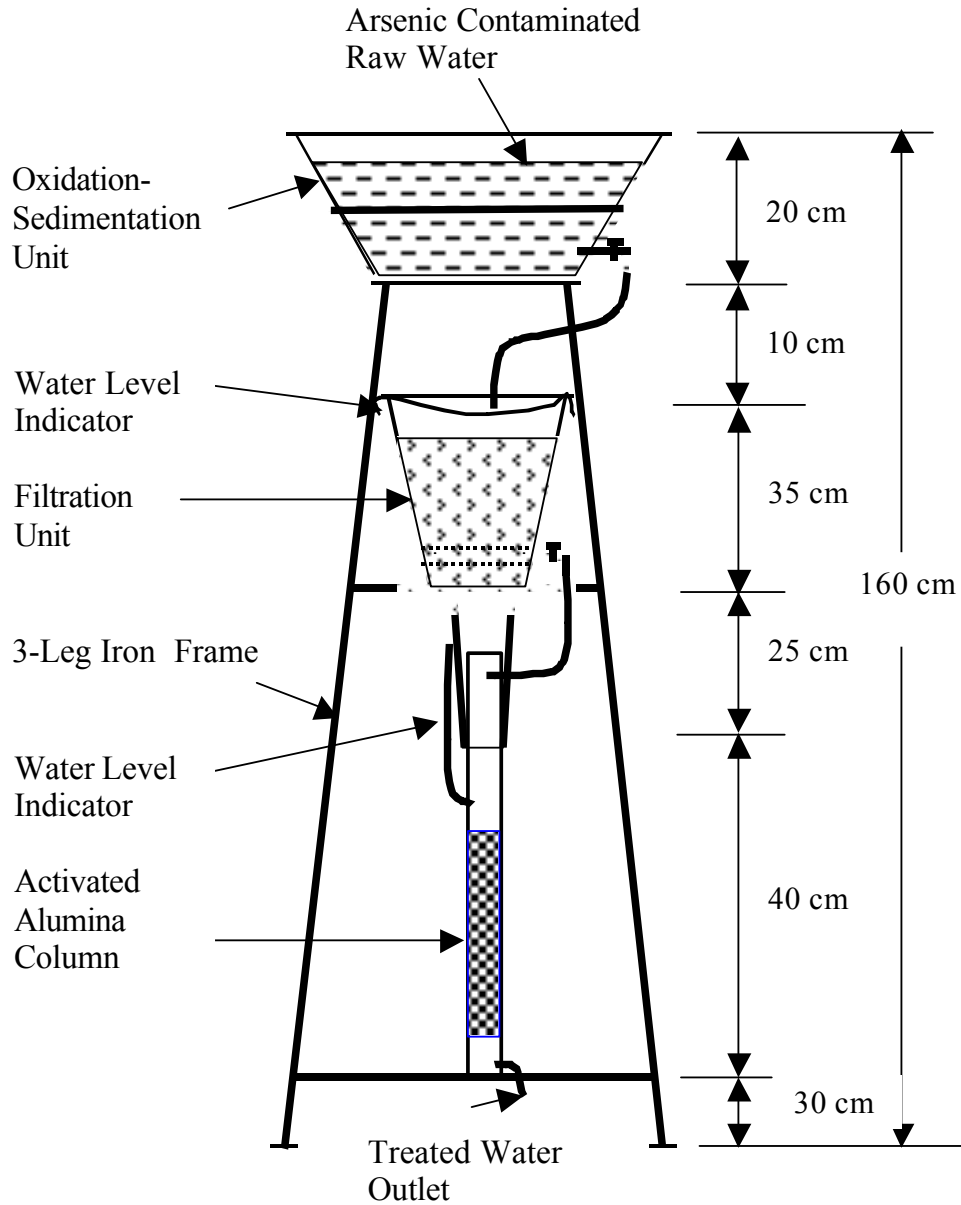
### **Activated Alumina Adsorption Unit**

The unit consists of a down flow adsorption column made of 37 mm diameter plastic pipe containing 22 cm deep activated alumina granular particles (mesh size- 28x48). A level indicator is fitted with the adsorption unit with a mark on it and the water level should be kept below the mark to prevent overflow. This can be done easily by controlling the tap of the filtration unit. The water coming from the filtration unit flows through the alumina column and the treated water is collected from an outlet fitted at the bottom of the adsorption unit.

The three sub-units of the arsenic removal system are assembled in a suitable iron frame. It should be noted that although the arsenic removal system has been developed based on activated alumina, the system is applicable for any other suitable adsorptive material or ion exchange resin. Figure 1 shows the details of the arsenic removal unit.

## **EVALUATION OF PERFORMANCE OF THE ARU**

WS/Atkins of United Kingdom carried out an independent, comparative assessment of the performance and acceptability of nine arsenic removal technologies at household level through a two phase project under BAMWSP (Bangladesh Arsenic Mitigation Water Supply Project) (WS/Atkins, 2000; BAMWSP/DFID/WAB, 2001). The arsenic removal unit developed at BUET was included in the project. The major findings related to the BUET ARU is briefly discussed here.

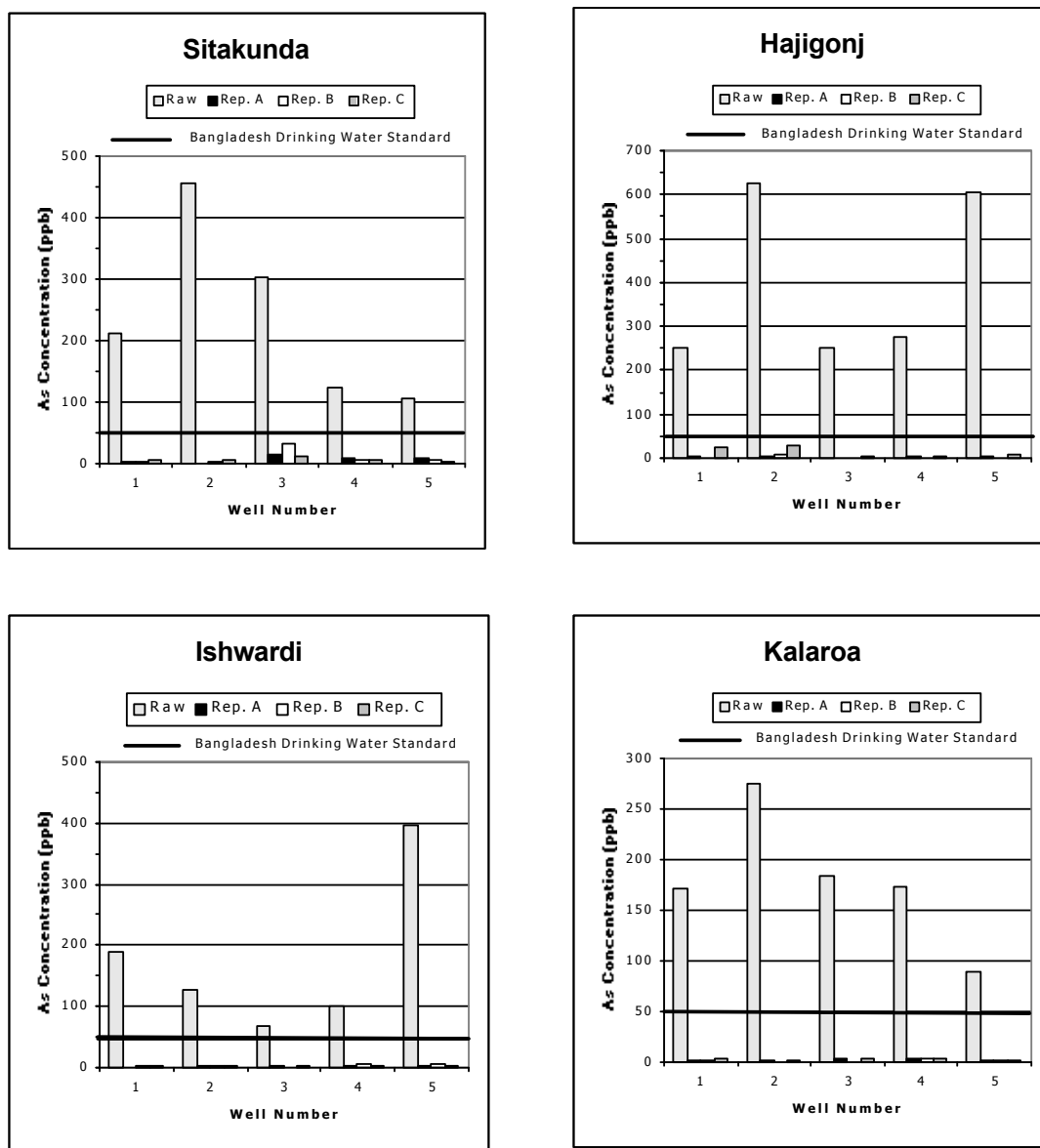


**Figure 1 : Activated Alumina based Household Arsenic Removal Unit.**

**Phase I**

The field based performance study of the BUET ARU was carried out in four areas of Bangladesh (Sitakunda of Chittagong, Ishwardi at Pabna, Hajigonj at

Chandpur and Kalaroa at Satkhira). At each area, five tubewells were selected and three replicates of the ARU were run at every well and the units were operated by the project team. Four paired samples (feed and treated waters) for every replicate were tested for a number of water quality parameters. Data from the feedwaters demonstrated broad differences in groundwater chemistry among the four test areas. Performance of the BUET ARU on an area by area basis is illustrated in Figure 2.



**Figure 2: Arsenic Removal by BUET Arsenic Removal Unit from Groundwaters in Four Areas of Bangladesh**



Figure 2 shows that BUET ARU removes arsenic very efficiently reducing the concentration much below 50 ppb level although there are much variation on the water chemistry among the four areas. The average of feed mean arsenic concentrations in the four areas were 240 ppb, 402 ppb, 176 ppb and 179 ppb and after treatment the average effluent arsenic concentrations reduced down to 7.5 ppb, 5.5 ppb, 3.1 ppb and 2.2 ppb respectively, indicating excellent arsenic removal efficiency of the technology. However, in a few cases, there were some differences in the arsenic removal performance among the three replicates which may be due to occasional instrumental error in the arsenic measurement.

## **Phase II**

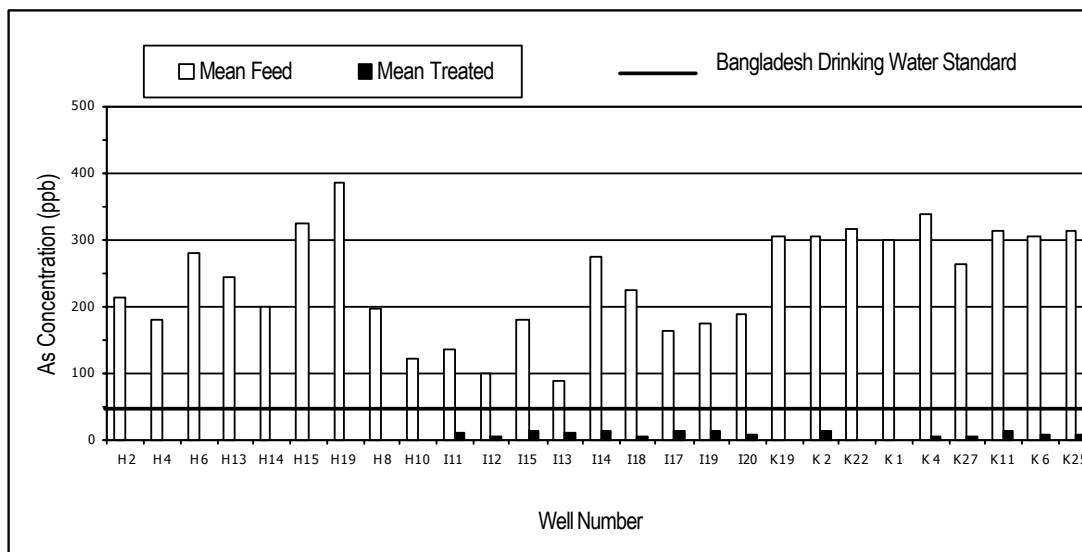
The survey areas for field based performance and acceptability assessment in Phase II were those as in Phase I except Sitakunda. At each area, nine tubewells were selected and three replicates of the BUET technology were supplied. One replicate was run per well and eight paired samples (feed and treated waters) for every unit were tested for a number of water quality parameters. The units were operated by owners of the wells.

## **Technical Performance**

### ***Arsenic Removal***

Data from the feed-waters demonstrated broad differences in groundwater chemistry among the three test areas. At Hajigonj, silicon, boron and potassium concentrations were high and alkalinity, calcium, barium and strontium levels were low compared to the other areas. At Ishwardi, phosphorous and iron concentrations were low while, alkalinity, manganese and sulphur were high compared to Hajigonj and Kalaroa waters. Performance of the BUET ARU on an area by area basis is illustrated in Figure 3.

Despite the broad differences in the water chemistry, Fig. 3 shows that the BUET ARU removes arsenic very efficiently reducing the concentration much below 50 ppb. The average arsenic concentration in the feed water for all the areas was 238 ppb while the average treated water arsenic concentration was 5.5 indicating over 97% arsenic removal. However, there were some variations from area to area which may be due to the variation in the iron content of the feed waters. Generally, presence of iron in higher concentrations enhanced the removal of arsenic through co-precipitation and adsorption.



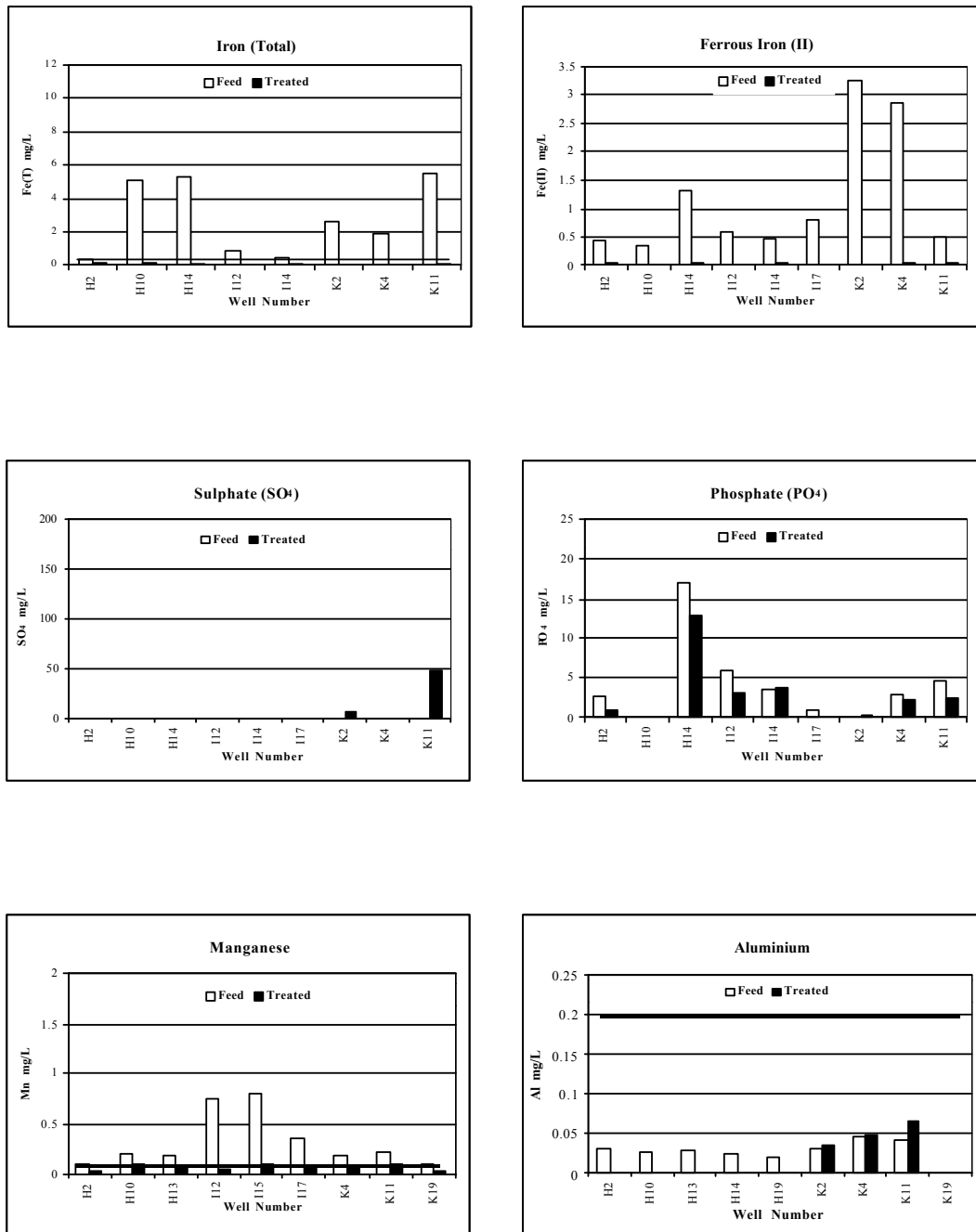
**Figure 3: Arsenic Removal by BUET Arsenic Removal Unit from Groundwaters in Three Areas of Bangladesh ('H' stands for Hajigonj, 'I' for Ishwardi, and 'K' for Kalaroa).**

***Removal/Addition of other Key Parameters***

Iron, redox potential, manganese, aluminum, chloride, phosphate, Sulphate, alkalinity, pH, conductivity and some other parameters in the feed waters and treated waters were measured to assess the change in water quality by the BUET ARU. The removal/addition of more important parameters from the view point of drinking water quality is depicted in Figure 4. From the figure it is observed that both total and ferrous iron are removed from the water during the treatment. Manganese is removed but not as efficiently as Fe(II) because oxidation of Mn(II) is a slower process. BUET ARU removes aluminum at Hajigonj and Ishwardi but appears to add it at Kalaroa in some cases. The reason for this is not clear. Phosphate is reduced in small amount while sulphate is added to Kalaroa waters which can not be explained.

***Bacteriological Performance***

Bacteriological quality of the feed waters and treated waters were determined at all the three areas. Test results revealed that fecal coliforms were rarely detected in most of the feed waters samples. For treated water samples, the fecal coliform counts per 100 mL were low ( less than 10 ) in most cases in Hajigonj and



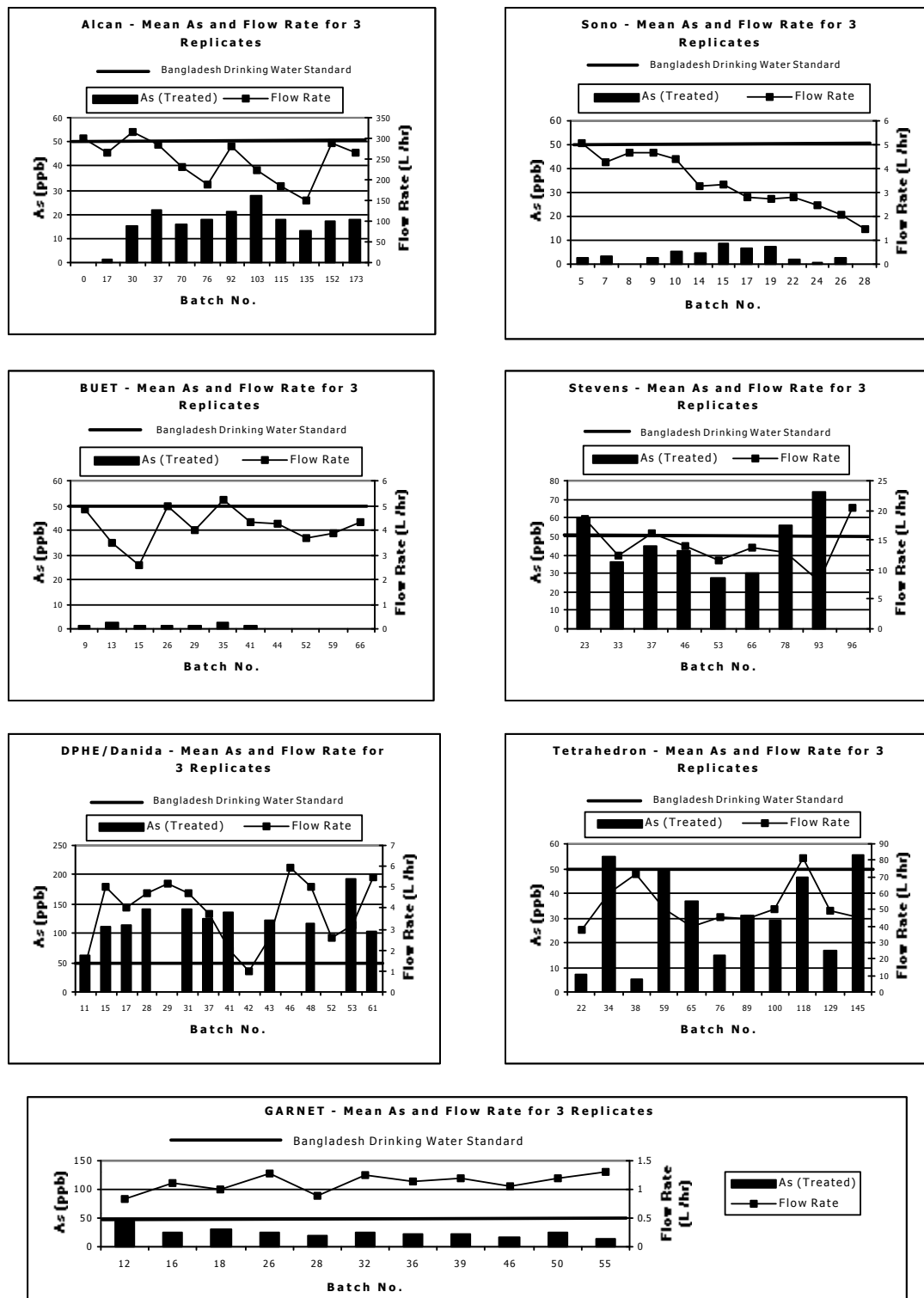
**Figure 4: Iron (Fe), Manganese (Mn), Aluminium (Al), Phosphate (PO<sub>4</sub>) and Sulphate (SO<sub>4</sub>) Concentrations in Feed and Treated Waters.**

Ishwardi, and only two cases showed the count around 20. But in Kalaroa, high fecal coliform counts greater than 100 no. per 100 mL) were detected. It was also revealed that once contaminated, the sand filters harboured bacteria and were not readily flushed by further clean batches of water. Surely, the bacterial contamination source was external and unhygienic practices of the users were the most probable reason. Hence personal hygiene of the users should be improved to get rid of the problem. However, as an additional safety measure, weakly bleaching or hot water treatment of the ARU should be practiced.

### ***Comparison with Other Technologies***

A comparative study of seven technologies in terms of arsenic removal was carried out at Sonargaon, Narayanganj. The technologies were (i) Alcan enhanced activated alumina (Alcan), (ii) BUET arsenic removal unit (BUET), (iii) DPHE/Danida two bucket system (DPHE/Danida), (iv) GARNET home-made filter (GARNET), (v) Sono 3-kolshi method, (vi) Steven's Institute Technology (Stevens), and (vii) Tetrahedron Ion Exchange Resin Filter (Tetrahedron). Three replicates of each technologies were set up at a well and the volumes of water passing through the technologies were recorded in terms of 20 litre batches. The feed water arsenic concentration was 0.332 mg/L and the water was turbid. The variations in effluent arsenic content and flow rate with cumulative volume of water passed for all the technologies are illustrated in Figure 5. From the Figure it appears that for the particular water at Sonargaon, the Alcan, BUET, Sono and GARNET technologies performed consistently well reducing arsenic concentrations below 50 ppb in the treated water samples. But in terms of low arsenic concentrations in the effluent, BUET ranked 1 followed by Sono, Alcan and GARNET. The GARNET did well in this particular case, the probable reason might be the high iron content of the feed water. DPHE/Danida performance was the worst producing effluent having arsenic concentrations more than 50 ppb for all the treated water samples, the reason for this is not clear. The Stevens performance was not consistent, sometimes the effluent arsenic concentration exceeded 50 ppb level, the quality of chemicals and improper operation might be the reasons for this. The performance of the Tetrahedron was the least consistent, sometimes producing effluent with very low arsenic content and sometimes the effluent concentrations exceeding 50 ppb level. Improper chlorination might be the possible cause.

For each technology, the flow rate is progressively reduced due to accumulation of iron flocs in the system. Upon maintenance following the specified procedure, the flow rate increases significantly. So, the flow rate do vary considerably depending on the frequency of maintenance. The impact and importance of maintenance is illustrated by the increase in flow rates following



**Figure 5: Comparison Among Different Arsenic Removal Technologies Regarding Arsenic Removal and Flow Rate**

maintenance (Fig. 5). The Sono developed a 'crust' in top kolshi resulting in a progressively lower output. A comparison of flow rates among the technologies reveals that for the particular water at Sonargaon, Stevens and Tetrahedron would comfortably provide sufficient drinking water for a household. The BUET, DPHE/Danida and Sono are close to provide enough water for a household with one unit, whilst the GARNET would fail to do this.

### **Social Assessment**

Acceptability to users of the BUET ARU was assessed through questionnaire survey in each of the three areas. Fifteen different criteria including flow rate, taste, smell, ease of operation, cost, ease of movement, ease of maintenance, waiting time, physical structure and cleaning frequency were set in the questionnaire. The householders indicated their willingness to pay upto Tk. 1000 for a BUET ARU (the present cost being Tk. 1500 but mass production would lower the unit cost) and to spend Tk. 30-50 a month for operation and maintenance. The majority, however, were willing to pay between Tk. 300 and Tk. 500. Most of them preferred to use an ARU on an individual basis, since collective management would create problems.

A number of practical problems were identified through the questionnaire survey. They were (i) frame is flimsy and liable to fall over, (ii) tubes and column are not well sealed and prone to leakage, (iii) too tall for average villager to reach the top bowl, (iv) pipette and bottle of reagent are hard to dispense accurate dosage without getting reagent on hand, (v) adjusting flow rate to designated mark on the level indicator tube, usually find water flowing from the tube, (vi) connection tubes are hard to wash and easily contaminated, (vi) sand bucket and cloth become dirty, and (vii) waiting time is long. Hence the users' acceptability of the technology was not so good.

From the response of the users, it appears that they were not properly and adequately trained to run the units. It was the main reason for some of the identified problems. Some other problems can be eliminated by taking due care during fabrication of the unit. From the users' point of view, the significant limitations seem to be the height, flow control devices and flow rate. Hence, the design of BUET ARU should be modified in terms of height reduction, improvement of the flow control devices and increasing the flow rate. This improvement can be achieved with minor modification of the present design. The redesign is underway to make the unit more user friendly and socially acceptable.

## **Summary and Conclusions**

The development process of a household BUET technology based on activated alumina adsorption process for arsenic removal has been described here. An assessment of the performance of the BUET ARU at household levels has also been discussed. The following conclusions can be made on the BUET ARU:

- Groundwater chemistry has been adequately considered in developing the unit. The beneficial use of naturally occurring iron in groundwater has been ensured in removing arsenic in the technology.
- A few unit operations and processes have been added as pretreatment to increase the capacity of the alumina adsorption unit.
- Arsenic removal efficiency of the technology is excellent irrespective of feed water quality. It removes iron very efficiently and appreciable amount of manganese is also removed. The removal/addition of other water quality parameters is insignificant.
- Lack of personal hygiene of users may result in bacterial contamination of the treated water. Weekly chlorination or hot water treatment of the ARU should be practiced.
- Users' acceptability of the technology was not so good mainly due to height of the unit, difficulty in flow control and inadequate flow rate. These limitations should be corrected to increase its acceptability.

## **ACKNOWLEDGEMENT**

The authors express their gratitude to BAMWSP for including the BUET ARU in the project "Rapid Assessment of Household Level Arsenic Removal Technologies". They also acknowledge the support of UNICEF, Bangladesh and DPHE to carry out the study "The Effectiveness of Activated Alumina in Removing Arsenic from Groundwater".

## REFERENCES

- Ahmed, F. & Jalil, M. A. (1999): *The Effectiveness of Activated Alumina in Removing Arsenic from Groundwater*, Final Report of UNICEF-DPHE-BUET Research Project, 50 pages.
- Ali, M. A., Badruzzaman, A. B. M., Jalil, M. A., & Hossain, M. D. (2001): *Development of Low Cost Technologies for Removal of Arsenic from Groundwater*, Final Report (in preparation) to submitted to UNU, Tokyo, Japan.
- BAMWSP/DFID/WAB/WS/Atkins (2001) : *Rapid Assessment of Household Level Arsenic Removal Technologies, Phase II Report*, submitted to BAMWSP.
- DPHE/DFID/BGS (2000): *Groundwater Studies for Arsenic Contamination in Bangladesh*, Final Report.
- EES & DCH (2000): *Groundwater Arsenic Contamination in Bangladesh, A Summary of Field survey from August 1995 to February 2000: Twenty Seven Days Detailed Field Survey Information from April 1999 to February 2000*.
- Rahman, M., Quamruzzaman, Q & others (2000), "Arsenicosis - Yet to be Cared", *Bangladesh Environment 2000 - A compilation of Papers of the ICBEN-2000*, Dhaka, Bangladesh, pp. 135-150.
- WS/Atkins (2000), *Rapid Assessment of Household Level Arsenic Removal Technologies, Phase I - Draft Report*, submitted to BAMWSP.



## **Apyron Arsenic Treatment Unit – Reliable Technology for Arsenic Safe Water**

**Kiron Senapati**

4030-F Pleasantdale Road  
Atlanta, Georgia 30340, USA

**Iftekhar Alam**

ATAZ Bangladesh  
67 Naya Paltan, Dhaka-1000, Bangladesh

### ***Abstract***

*Apyron Technologies Inc. has developed Arsenic Treatment Unit (ATU) in which Aqua-Bind™ media is used for ground water arsenic reduction. These prototype units are field tested both in Bangladesh and in India. The results of laboratory testing of the treated water have proven the effectiveness of the arsenic removal technology. The test results of the treated water have been consistently below 10 ppb of arsenic. This highly effective arsenic treatment system is user friendly and is easily adaptable in the rural settings of Bangladesh. The spent media is non-hazardous to the environment and does not pose any risk to the users.*

### **INTRODUCTION**

Arsenic is a naturally occurring element in rocks, soils and the waters that contact them. Other major sources of arsenic include agricultural run-off and industrial effluents from metallurgy, glassware/ceramics, dyes, herbicides/pesticides, petroleum refining, wood/hide preservatives, fertilizers, and phosphate detergents. Recognized as a toxic element for centuries, arsenic today is a recognized major human health concern because it can contribute to long term morbidity and mortality.

Bangladesh is the largest alluvial delta of the world and the country is crisscrossed by hundreds of rivers. This huge supply of water is contaminated by human, animal and industrial pollutants resulting in high incidence of diarrheal diseases. So, the need of supplying people with safe drinking water was given the priority in the seventies and ground water lifted by hand pump was thought to be a better option than drinking surface water. The Bangladesh Government and UNICEF embarked on a program to install thousands of tube wells throughout the country. These tube wells were introduced into the ground water in good faith and saved countless lives from waterborne diseases. At that time ground water was not tested systematically for arsenic and for the last 20-30 years water from shallow aquifers was extensively used for drinking water in rural areas. By 1993 it was found that, the ground water is contaminated by highly soluble arsenic and the problem of chronic arsenic poisoning surfaced.

More than 97% of the Bangladesh population of 130 million drinks water supplied from groundwater and estimates are that as many as 77 million people are consuming water high in arsenic. In terms of population exposed it is the most serious ground water arsenic problem in the world. Similarly, more than 90% of the rural population of India is dependent upon groundwater for drinking (i.e., well water). Some estimates have indicated that 1 in 10 people in some areas of India are exposed to high concentrations of arsenic in well water. However total population exposed in India is less than Bangladesh. In addition, the World Health Organization, whose guidelines are 10  $\mu\text{g/L}$ , has compiled reported cases of arsenic in drinking water in countries such as Argentina, China, Chile, Ghana, Hungary, Mexico, Thailand and the United States.

## Background

To protect people from this serious health hazards the Government of Bangladesh, through its various agencies, has been working hand in hand with WHO, World Bank, UNICEF, DFID and other organizations. Many foreign companies and local entrepreneurs have come forward with systems to mitigate the problem of arsenic poisoning. Apyron Technologies Inc. (ATI) USA has developed a unique unit, which on available evidence can assure arsenic safe ground water.

The Apyron solution to this crisis is a specialty media designed for arsenic reduction. Historically, common adsorbents such as activated alumina, zeolites, and even granular activated carbon (GAC), have been used commercially to remove arsenic. However, Apyron Technologies, Inc. (ATI) has developed an inorganic granular metal oxide-based media that can *selectively* remove As(III) and As(V) from water, which makes the media more effective than commonly used adsorbents. The *selective* adsorbent is manufactured using a unique binder technology, which greatly enhances its surface properties and creates a composite particle with a unique surface, pore properties, and chemical characteristics that

enable arsenic adsorption capacities many times greater than conventional materials.

### **Test Description Summaries**

To date, ATI has performed arsenic removal field-testing in Bangladesh for four separate villages using groundwater via tube-wells for drinking water. Another similar field test is on going in four villages in India. The technologies employed in each test are the same, with the variances occurring in the water quality and the arsenic concentrations being treated. The testing, performance and costs are described later in this paper. The field-testing performed in Bangladesh and India for the tube-well drinking water is the most comprehensive testing performed and represents the most challenging application of the technology.

The benefits of ATI's Aqua-Bind™ media are:

- Removal of Both Arsenic (III) and Arsenic (V)
- Treats Arsenic levels from 25 to >4,000 ppb in the presence of Iron up to 15 ppm
- Reduced Contact Times (Rapid kinetics ideal for POU/POE systems)
- Operational over Wide pH Ranges (6-8) & Temperatures (0 to > 100°C)
- Non-Leachable, allows Non-hazardous Disposal of Spent Media (per EPA TLCP)
- NSF 61 Certified for use in drinking water applications
- Resistant to microbial growth
- Highly Selective for As, Even With Competing Ions (Sulfates, Silica, Ca, etc.)

## **TECHNOLOGY DESCRIPTION**

### **Overall Definition**

The technology is based upon the Aqua-Bind™ Arsenic media, which consists of highly activated hybrid aluminas and alumina composites, which are produced using proprietary technology. These materials are employed to produce particles with enhanced pore and surface properties for cost-effective removal of contaminants. By controlling the pore size, the particles become selective for specific ions, which for this demonstration were arsenic ions.

For point of entry (POE) / point of use (POU) systems, the capabilities of the Aqua-Bind™ Arsenic media are especially useful in meeting the following concerns:

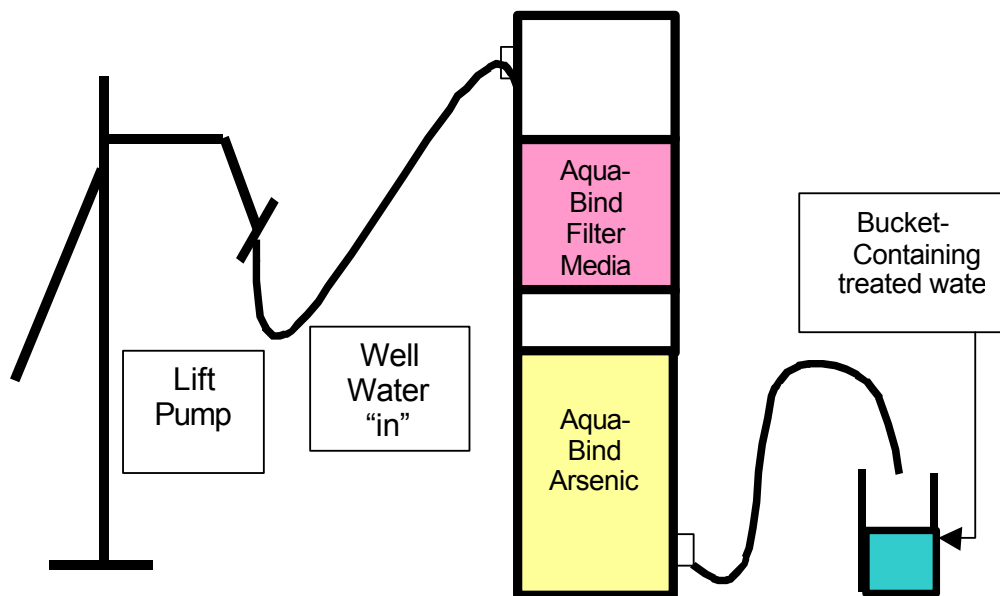
- Arsenic species**                      The primary arsenate species in the pH range of 6-9 is monovalent  $\text{H}_2\text{AsO}_4^-$  and divalent  $\text{HAsO}_4^{2-}$ . Uncharged arsenious acid ( $\text{H}_3\text{AsO}_3$ ) is the predominant species of trivalent arsenic found in groundwater. The oxidized form of arsenic is much more readily removed with conventional technologies, usually requiring an oxidation/pre-treatment step to enhance removal of As (III). Because arsenic can be found in either form and selected Aqua-Bind™ media can remove both types, it is ideally suited for POE/POU systems.
- Kinetics**                                      Given the relatively compact size of treatment systems for rural areas or household, effective adsorbents must be very rapid, allowing efficient removal of arsenic to low levels. Unlike fixed-bed adsorption processes, such as in centralized larger systems where contact times of five minutes or more are not unusual, the contact time in a POU device is often less than 15 seconds. This presents a much greater challenge for a 90+ percent removal of arsenic from 50 mg/l to less than 5 mg/l. However, as shown in the test results presented later in this document, ATI's Aqua-Bind™ Arsenic media is able to meet the adsorption kinetic requirements while still retaining its removal efficiency.
- Influent water quality**                      Like any technology, the water quality profile plays an important role in proper selection and overall performance. Primary adsorption performance parameters include arsenic concentration and species, pH and contact time. Secondary performance factors include the presence and influence of other species that can compete with arsenic adsorption, occupy adsorption sites or foul the media. Adsorption capacities can vary widely depending on influent concentrations of these parameters. Test results show that the Aqua-Bind™ Arsenic media are highly selective and retain their adsorption capacities even in the presence of high concentrations of other negatively charged species.

### Groundwater from Tube-Wells

The overall objective of the demonstration project for Bangladesh and India was evaluation of the capability of the adsorbent to remove arsenic from tube-well water supplies and the ability of the associated design to meet its specifications. The treatment units have been operated successfully for the past two years and do provide a practical and low cost system for treating tube-well water in rural areas affected by groundwater contaminated with arsenic.

The demonstration units used for the field-testing in Bangladesh and India were designed and constructed by Apyron as prototype units. The units were installed in various villagers under the supervision and observation of Apyron personnel, and site monitoring provided by BAMWSP in Bangladesh and the Public Health & Engineering Directorate of the Government of West Bengal in India.

The arsenic treatment unit (ATU) consists of a cylindrical adsorber vessel with two proprietary ATI media. The composition of the Aqua-Bind™ Arsenic media is aluminum oxide ( $\text{Al}_2\text{O}_3$ ) and Manganese Oxide ( $\text{Mn}_2\text{O}_3$ ) and is non-hazardous. The column receives water under slight pressure from the lift pump. Water flows in the down-flow direction through the two chamber housing to capture particulate iron and adsorb arsenic. The water exits through a discharge hose into the designated container, at approximately 15 liters per minute. Figure 1 is a schematic of the process flow diagram.



**Figure 1: Schematic diagram of arsenic treatment unit**

Periodically (approximately once every two weeks) the ATU is “backwashed” to remove the suspended solids and filtered iron. The suspended solids and iron are captured in a filter bag for disposal. The Aqua-Bind™ Arsenic media is designed for 6 months service (dependent on the arsenic concentration) before change-out. Fresh media is installed and the ATU is returned to service.

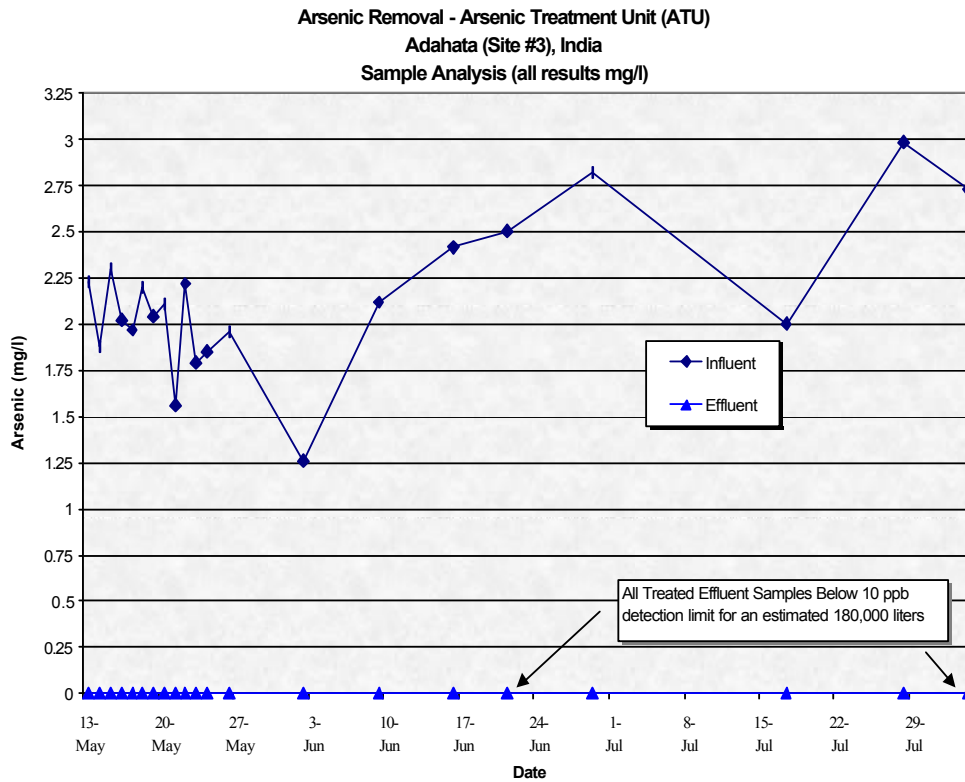
There are currently twelve (12) ATU operating units in West Bengal, India, three (3) in 24 N Parganas, and nine (9) in the Malda District. Similarly, there are four (4) ATU operating units in Bangladesh, one each at Nilkanda in Sonargaon, Gobra at Gopalganj, Bhaberchar at Munshigonj and Gulbahar at Chandpur. The experience from operating these units (and others) have helped Apyron to gain specific understanding of the water quality issues and variability of the water quality that may be specific to each site. This understanding is critical to the successful deployment of an arsenic removal system, not only for tube-wells but for other applications as well. Selected examples of testing for the Aqua-Bind™ Arsenic media for other applications are described below:

## PERFORMANCE

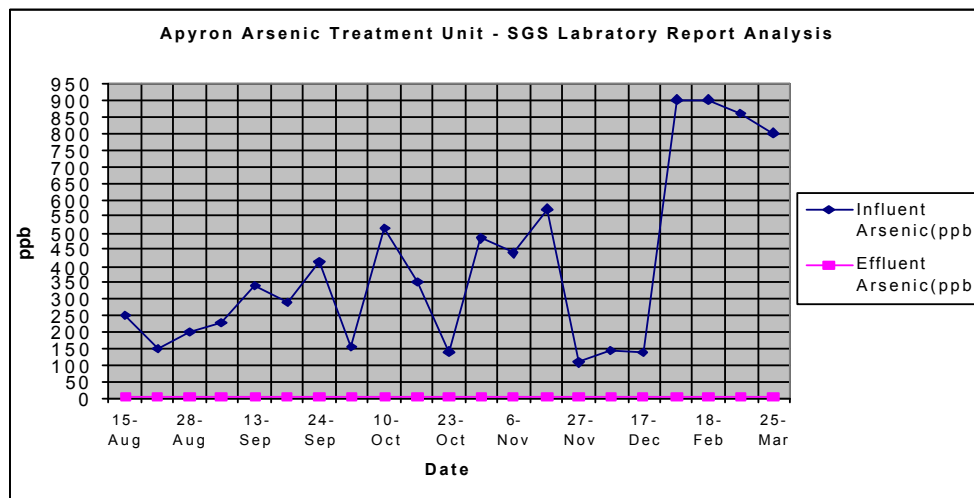
### Groundwater from Tube-wells

The Indian demonstration units have operated successfully for over 2 years, in some cases treating in excess of 200,000 liters of water for every six months. During the period of operation for this system, arsenic concentrations in the pre-treated water ranged from 1000 microg/liter to 3500 microg/liter, with an average of 2500 microg/liter. The treated water effluent contained arsenic concentrations below detection limits (i.e., below 10 microg/L). This was achieved with water containing competing ions such as  $\text{Ca}^{+2}$  and  $\text{Mg}^{+2}$ , and up to 10 mg/L of  $\text{Fe}^{+2}$ . While testing, field personnel discovered wide variations in groundwater chemistry in the region and the need to address tube-well water containing high concentrations of both dissolved iron and arsenic. Iron concentrations were observed at over 25,000 ppb (25 mg/L) in some wells. Figure 2 illustrates arsenic concentration versus time from a treatment unit located in Adahata, West Bengal.

In Bangladesh the ATU at Nilkanda, Sonargaon is in use for the last seven months treating more than 150,000 liters of water. During the period of operation for this system, arsenic concentrations in the pre-treated water ranged from 152 ppb to 900 ppb, with an average of 399 ppb. The treated water effluent contained arsenic concentrations below detection limits (i.e., below 5 ppb). This was achieved with water containing competing ions such as  $\text{Ca}^{+2}$  and  $\text{Mg}^{+2}$ , and up to 4 mg/L of  $\text{Fe}^{+2}$ .



**Figure 2: Tube-well results from site No.3 in Adahata, India**



**Figure 3: Tube well results from Site No. 1 at Nilkanda, Sonargaon, Bangladesh**

The leachate from the media was tested in accordance with U.S. Environmental Protection Agency (EPA) Toxic Characteristic Leaching Procedure (TCLP) methods and found to contain arsenic well below the acceptance criteria. As an example, two samples from the demonstrations leached 0.03 and <0.5 mg/liter arsenic, well below the EPA criteria of <5.0 mg/liter.

**Table 1 : Results of TCLP Tests**

<b>Spent Media TCLP Results – solid residuals (Backwash and Spent Media)</b>		
<b>Parameter</b>	<b>Results (mg/L)</b>	<b>TCLP Limit (mg/L)</b>
Backwash Solids	0.0185	5.0
Backwash Solids	0.0537	5.0
Spent Media	0.032	5.0

## **COST**

### **Methodology**

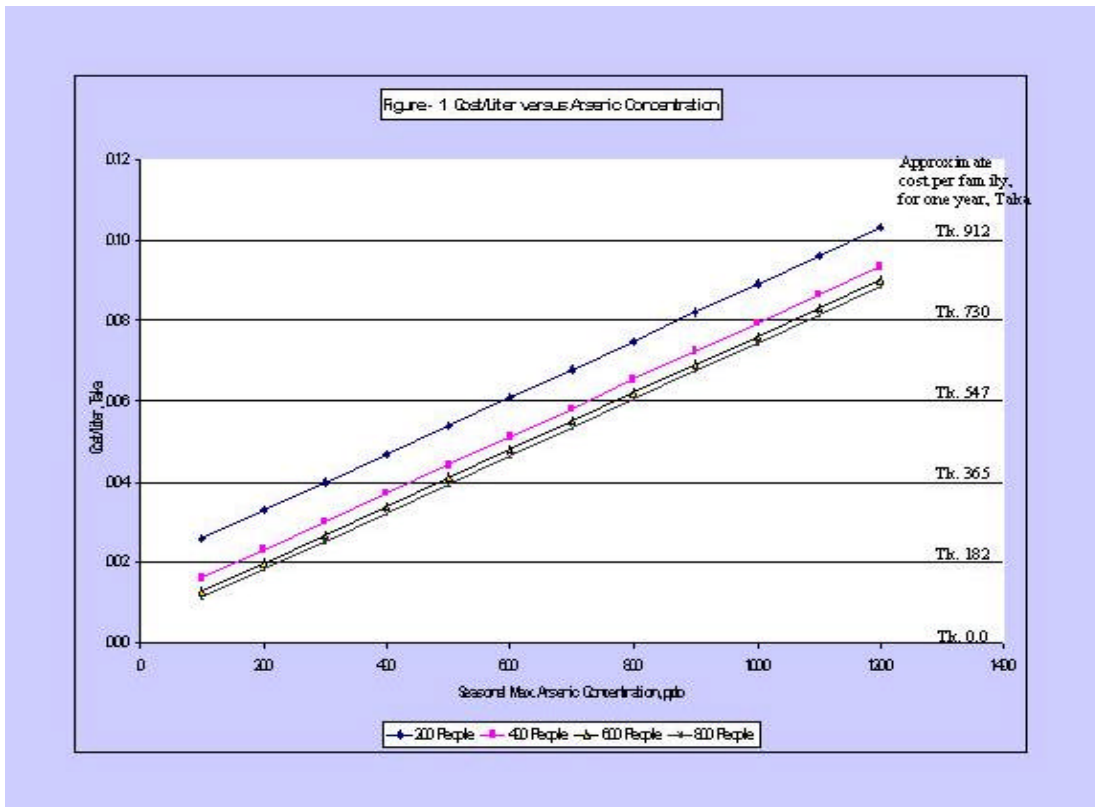
The objective of the cost analysis is to provide guidelines for estimating cost of operation using Aqua-Bind™ Arsenic removal media for Tube-well groundwater treatment. Key assumptions for the applications are described below:

1. Costs are based on treating 2000 liters per day in an existing tube-well system that employs a hand pump to pump the groundwater to the surface for use.
2. Influent arsenic concentration is assumed to be 0.5 mg/L and effluent is assumed to be treated to below 10 ppb (mg/L).
3. The unit is operated and maintained by the users (i.e., villagers) themselves after receiving training on the system.
4. The Aqua-Bind™ Arsenic removal media is replaced every six months and is the only operating cost used in the analysis.
5. Costs are based on using the Aqua-Bind™ XP Arsenic media, which is used for As (III) and As (V).
6. Sampling and laboratory costs are not included.
7. Based on previous test results, the spent media is NOT considered as hazardous waste and no additional costs for waste disposal are added.
8. Capital costs are annualized at 15% interest rate.

The costs for the tube-well drinking water for arsenic treatment using the Aqua-Bind™ media are less than TK. 0.05 per liter of water treated at an average arsenic concentration of 500 ppb. Figure 4 illustrates the cost per liter of water in



Bangladesh Taka for various concentration of arsenic. The Figure also provides annual cost of treated water per family assuming there are 5 members per family using at least 5 liters/day/person. The cost per liter for a 600 ppb arsenic contaminated tube well serving four hundred persons is TK0.05/liter. For a family of five using 5liters of drinking water each then the total cost is TK.450 / yearly or about TK1.25/day/family. Field observation indicates water use is lower about 3 liters/person implying the water cost to TK. 0.75/day/family.



**Figure 4: Cost per liter versus Arsenic Concentration**

### Technology Applicability

The results of the tube-well testing in Bangladesh and India have established the ability of the Aqua-Bind™ Arsenic media to successfully remove arsenic in the groundwater used for drinking water. The treatment system is easy to use and maintain, and does not impede the normal flow from the tube-well. The users have provided the routine bi-weekly maintenance involving backwashing of the media, which takes less than 15-20 minutes of their time. Given the success of this and other testing, a whole family of Aqua-Bind™ Arsenic media have been developed and tested for applications such as potable water, industrial water, remediation, and specialty uses.

Aqua-Bind™ Arsenic XP is a high performance composite material specifically designed for a wide range of arsenic removal applications. It is ideally suited for the most demanding applications involving high arsenic concentrations and high hardness where short contact times are essential. Exhibiting unique properties resulting in efficient removal of both arsenic (III) and arsenic (V), the material does not require either pre- or post-treatment, and it is NSF 61 Certified for use in drinking water applications.

Aqua-Bind™ Arsenic HP is a high-capacity media for removal of arsenic (V) for POE systems where regeneration is not required. It is designed as a high capacity, discardable media that exhibits outstanding performance for arsenic (V), again without requiring any pre- or post-treatment. The material's ability is sustained even in the presence of competing ions such as sulfates, silica, calcium, and magnesium. It also displays excellent kinetic properties for arsenic uptake with very short contact times, from seconds to minutes over a wide operating range of water quality.

Aqua-Bind™ Arsenic EP is an economical media designed for small and large municipal water systems with the option for regeneration. This enhanced composite material is ideal as a low cost, better performing alternative to conventional activated alumina. The material is regenerable using conventional acid/base regeneration techniques prolonging the operating life and extending the frequency of change out. The material can be retrofitted easily into existing adsorption systems and is NSF 61 certified for drinking water applications.

Aqua-Bind™ Arsenic AL is a low cost activated alumina for standard applications in fixed bed adsorbers for arsenic removal. This material is optimal for low-level arsenic concentrations (< 25 ppb) within an operating pH range of 5.5 – 7.0 with 5-minute contact times. This material is amenable to regeneration as well.

Apyron materials can be manufactured to specific particle sizes that are adaptable to conventional filter housings, precoat cartridges, pleated nonwoven fabrics and conventional fiberglass POE cylindrical tanks. The Aqua-Bind™ Arsenic removal adsorbent media are easily adaptable and transferable to an assortment of water applications with arsenic concerns including municipal treatment plants, commercial or centralized water treatment systems, and home water filters for Point of Entry/Point of Use (POE/POU). These media may be employed in a variety of POE and POU systems and devices to meet the needs of end users for arsenic removal. The technology can be incorporated into existing treatment trains as an add-on component, such as a post-softening step for arsenic removal, or as a stand-alone technology.

For POU applications, the media can be formulated as a sole component or active ingredient to carbon blocks, carafes and other devices for achieving multiple functionality where arsenic reduction can be achieved along with other

health or aesthetic-related benefits. Some specific POE and POU configurations for arsenic adsorption media include:

- Household POE treatment vessels incorporating granular media for arsenic removal
- POU granular cartridges and carbon blocks (countertop and under-the-counter for general purpose, ice maker, etc.)
- Pre- and post- reverse osmosis cartridges
- Faucet-mount cartridges and blocks
- Water bottles, coolers, recreational filters and other specialty applications

### **Patents/Certifications/Associations**

The Aqua-Bind™ products are manufactured and marketed for sale by Apyron Technologies, Inc. Numerous POE/POU units are being tested at locations across the US and across the world. The products are based on a technology that is patented in the U.S. and worldwide patents are pending.

Both Arsenic XP and EP are NSF 61 certified for drinking water application and Apyron is pursuing certification for other media. Apyron Technologies, Inc. is a member of the Water Quality Association and the American Water Works Association.

## **REGULATORY AND POLICY ISSUES**

### **Worker Safety**

The Aqua-Bind™ Arsenic media poses no chemical, physical or other health risks to personnel handling the media during installation, operation or removal. There is no special training that must be administered for users of the Aqua-Bind™ Arsenic media. Any necessary training is contingent upon the specific application for the media, and is NOT due to the media itself. Typical training includes replacement of the media and as stated above, no special precautions or safety practices are prescribed for this activity.

### **Environmental Safety/Waste Disposal**

Based on previous testing of applications using the Aqua-Bind™ Arsenic media, the material forms a very strong chemical bond between the adsorbent and the arsenic that is highly resistant to leaching. Spent media have been tested several times by independent U. S. laboratories in accordance with standard Toxicity Characteristic Leaching Procedure (TCLP). Such tests have identified the spent media as non-hazardous (as classified by the EPA), allowing the media to be disposed along with sanitary waste in a controlled public landfill within the U.S.

## **CONCLUSIONS**

Apyron ATU has been demonstrated both in laboratory and field to provide safe water with arsenic contamination below 10ppb. The laboratory results indicate the water is safe to drink and the spent media is non-hazardous to the environment.

Field-testing indicates ready acceptance of the filter, which is proved to produce good quality water, about 800 people now consumes ATU treated water in Bangladesh. However field tests to date have not required users to pay for the water. The backwashing is done by the villagers without difficulty. Maintenance problems in Bangladesh occur at the rate of 0.036/ week. Costs are very low, as the usage rate is high.

## **Evaluation of An Arsenic Removal Household Device: Bucket Treatment Unit (BTU)**

**Saraban Tahura, S M Shahidullah, Tofizur Rahman and Abul Hasnat Milton**

NGO Forum for Drinking Water Supply and Sanitation

4/6, Block-E, Lalmatia, Dhaka-1207, Bangladesh

and

**Rejuan Hossain Bhuiyan**

Department of Geography and Environment, Dhaka University

### **INTRODUCTION**

The widespread contamination of drinking water by arsenic is a major concern in Bangladesh. Arsenic contamination has been detected in the groundwater of at least 47 districts out of 64 districts in Bangladesh (SOES/DCH, 1998). Arsenic is a known carcinogen and causes cancer. It is also responsible for various lethal physiological problems if taken into the body over the maximum acceptable limit of 0.05 mg/L (set as Bangladesh Standard) for a longer duration. It also creates severe skin related problem creating panic among the common people who regularly consume arsenic laden drinking water. There are around five millions of tube-wells all over the country and more than 95% of the rural population have access to tube-well water. Thus the results of a widespread contamination is likely to be catastrophic. Millions of people are at risk of arsenic contamination, but a significant portion is totally unaware of the danger. Again it is very dangerous because it is impossible to detect the presence of arsenic without special chemical tests. In water arsenic is tasteless, colorless and odorless even at high concentrations. The magnitude of all these complexities of the arsenic problem in Bangladesh makes this an extremely difficult problem to control. Added to all these problems are socioeconomic background of Bangladesh and overwhelming dependence of the people on groundwater.

In Bangladesh, only the major cities of the country are covered by water distribution systems. In the rest areas, mostly in the rural and some small town areas, people use groundwater extracted from their tube-wells located near their households or communities. In view of the overwhelming dependence of the people on groundwater, there is an urgent need to develop a suitable treatment system for removal of arsenic from groundwater. Socio-economic conditions of Bangladesh demands low-cost as well as small treatment units that could be implemented in the rural areas at households or community levels. Again people find it convenient to use household units to treat their arsenic polluted tube-well water, as long as the methods are easy to use and convenient.

Various technologies are available for removing arsenic from groundwater. The most common technologies include: (1) co-precipitation using alum or iron (2) adsorptive filtration (3) ion exchange, and (4) membrane processes like reverse osmosis.

To combat the arsenic crisis, only limited initiatives have been taken for evaluation of existing technologies for removing arsenic from groundwater with small sample size that indicated the need for a systematic and extensive field trial. 'Arsenic Cell' of NGO Forum for Drinking Water Supply and Sanitation evaluated 'Two Bucket' household Unit developed by DPHE-Danida to determine its social acceptability, arsenic removal capacity and assess other water quality parameters of treated water.

Through this research an attempt has been made by the NGO forum to evaluate the Bucket Treatment technology by running 60 units in a village in Manikgonj district, collecting users opinion about the unit and testing arsenic and other water quality parameters in the laboratory.

## **OBJECTIVES OF THE STUDY**

The general objective of the study is to evaluate an arsenic removal household device - 'BTU' (Bucket Treatment Unit), developed by DPHE-Danida. The specific objectives are: (1) To determine arsenic removal capacity of the unit, (2) To determine the iron removal capacity of the unit, (3) To analysis other water quality parameters of treated water such as pH, iron content and bacterial contamination, residual aluminum and residual manganese, (4) To determine the affordability of the unit, (5) To determine the social acceptability of the unit, and (6) To identify the weaknesses of the device and propose solutions.

## JUSTIFICATION OF THE STUDY

In this two bucket system, raw water in a 20 liter bucket is coagulated with chemicals containing 4 gm of powdered alum [ $K_2(SO_4)Al_2(SO_4)_3 \cdot 24H_2O$ ] and 0.04 gm of powdered potassium permanganate ( $KMnO_4$ ). So according to specification added dose of aluminum is 11.38 mg/L and that of manganese is 0.693 mg/L. According to the WHO, recommended guideline value for drinking water is 0.2 mg/L for aluminum and 0.1 mg/L for manganese. Therefore residual concentrations of aluminum and manganese are of concern. Aluminum is suspected as a neuro-toxic element and many studies show that there is significant relation between excess aluminum in drinking water and Alzheimer diseases. Manganese may have synergistic effect on aluminum toxicity. Besides excess manganese ion imparts undesirable taste to beverages. But alum and potassium permanganate are cheap, stable and easily available in the market.

Again there is a sand filter in this system that needs regular washing, along with other different parts of the unit. So carelessness may promote bacterial contamination of the unit which may pose another health risk to the users. This is an important aspect and needs evaluation.

The evaluation program analyzes arsenic removal efficiency, affordability, social acceptability and robustness of the unit of the unit and assesses other water quality parameters of treated water. This would help develop/modify design criteria for the unit and would also suggest possible alternative effective option.

## DESCRIPTION OF BTU

This BTU consists of two 20-liter plastic buckets. The upper bucket is red in color and the lower bucket is green in color. The upper bucket is filled with raw water. Chemical containing 4gm of powdered alum and 0.04 gm of powdered potassium permanganate (according with DPHE-Danida) is added and the water and the water is stirred fast for approximately 25 seconds with a wooden spoon provided with the unit. The water in the red bucket is then covered with a lid and allowed to rest for three hours. The supernatant water is then collected through tap attached to the lower end of the red bucket via a plastic pipe. Micro-flocs, if present in water, can be removed by sand filtration. For this purpose, water collected from upper bucket is passed through a sand filter in the lower green bucket.

The two-bucket system combines different water treatment processes. The first stage of chemical process is pre-oxidation of trivalent arsenic to pentavalent arsenic by the applied oxidant (potassium permanganate), followed by co-precipitation, coagulation and flocculation by applied flocculant (alum); adsorption on flocs; sedimentation; and filtration. The dose of potassium

permanganate is 2 mg/L and the dose of alum is 200 mg/L. Coagulation flocculation can also be obtained by ferric chloride/ferric sulfate.

## **METHODOLOGY**

### **Study Area**

Arsenic contamination of groundwater has already been detected in different parts of Ghior, Singair, Harirumpur and Manikganj Thanas of Manikganj district. The study was conducted in the village of Putiajani, Baliakhora Union, Ghior Thana of Manikganj district about 80 kilometers away from Dhaka. Putiajani village is one of the intervention areas of NGO Forum and its efforts were assisted by local and partner NGO, Socio Economic Development Agency, SEDA. Putiajani is a small village with a population of 1245 with a total household of 250. Total number of tube-well in this village is 76, out of which 65 were found to be functioning at the beginning of the study.

The soil type of Manikganj district is non calcareous gray flood plain soils, calcareous dark gray flood plan soils and calcareous brown flood plain soils, which are prone to have arsenic contamination (BBS, 1997).

### **Duration of the Study**

The evaluation program is planned to be conducted in two phases. The first phase has been completed. The duration of the first phase was from July to December 2000.

### **Sample Size and Calculation**

It has been assumed that the Expected mean arsenic concentration before treatment = 60 ppb; Expected mean arsenic concentration after treatment = 50 ppb; Expected standard deviation = 20; Level of confidence (%) = 95; Power (%) = 80.

So, required sample size is = 52. Considering non-compliance and dropouts, 60 samples were taken. So the sample size was 60. Sample size was calculated using WinEpi software.

### **Selection of Samples**

Initially water samples from 60 tubewells of the study village 'Putiajani' were collected in the prescribed plastic containers and were analyzed for arsenic in the Water Quality Testing Laboratory of NGO Forum using Ag -DDC method. Though Putiajani village has more than 60 tubewells, we couldn't collect samples from all of them as many were in submerged condition due to flood during August 2000.



Out of 60 tubewells, 55 were found to be containing arsenic more than the recommended level of arsenic i.e., 50 ppb. Then the tubewells were divided into 3 divisions according to the arsenic concentration of the tubewells. It was grouped as follows: 50ppb-100ppb, 101-200 ppb and > 201 ppb. Out of 57 tubewells 11 contained arsenic above 201 ppb, 12 contained arsenic between 101ppb and 200ppb and 34 contained arsenic between 50 ppb and 100 ppb.

Out of 11 tubewells containing arsenic above 200 ppb, households using 6 tubewells were excluded as they were using other alternative water options, 10 households using the rest 5 tubewells were included in the study. Out of 12 tubewells containing arsenic ranging from 101 ppb to 200 ppb, 22 families using all these 12 tubewells were included in the study. Out of 34 tubewells containing arsenic ranging from 50 ppb to 100 ppb, 13 tubewells were selected randomly, 28 families were randomly selected from those using these 13 tubewells. Thus a total of 60 households were selected for the study.

### **Data Collection Procedure**

At first water samples of 60 tubewells were collected by the field workers and analyzed in the Water Quality Testing Laboratory (WQTL) of NGO Forum for DWSS. Then 60 households using 30 tubewells were selected for the study. Arsenic concentration of the tubewells ranges from 50 ppb to 580 ppb. After 30, 55, and 78 days of BTU installation, water samples from treated water of all of the 60 households were collected and analyzed for Arsenic, Iron and pH at NGO Forum's Laboratory. After 100 days of BTU installation, samples were collected from all the 60 households for analysis of aluminum, manganese and bacterial population.

### **Water Sample Collection procedure**

Water samples for As, pH, Bacteria (TC-FC) were collected with proper methodology. Sample collection and preservation were also done following required procedure (Tahura, 2001).

### **Monitoring of BTU**

For proper running of the program, monitoring was done through a pre-tested partially open-ended monitoring form.

### **Social Acceptability**

It was examined through focus group discussion (FGD) and in-depth interview.

## RESULTS AND DISCUSSION

The presence of arsenic has been detected in groundwater of Bangladesh for at least over the last 8 years. After 8 years of screening tubewells for arsenic, it is clear that this is not the best direction for arsenic mitigation activities. In the absence of any systematic measurement, it is assumed that around 30 million people are at risk of developing arsenic related health hazards through drinking arsenic contaminated water. To save this large endangered population provision of arsenic free safe water is a priority.

Bucket treatment Unit (BTU) is an arsenic removal device developed for household level use. Already many organizations are promoting it. Few small-scale evaluations was made earlier which indicated the need of a systematic field trial of the device to determine arsenic removal efficiency, quality of the treated water, social acceptability and cost-effectiveness of the BTU. Through this study, an attempt has been made to conduct a systematic, extensive field trail of the BTU to evaluate its performance and social acceptability.

The strength of this study is its large sample size, involvement of the community as it is one of the NGO Forum's intervention village, training of BTU caretakers and strong monitoring component of the research.

### **Household Information**

Mean size of the selected 60 household is 5 and sex ratio (M/F) is 0.99. Out of 308 people, 47.4 percent are married. Agriculture, business, and service are the main occupation in the study area. Families having income exceeding the expenditure is 25 percent and mean income of a family is Tk. 3585. About 27 percent families have agricultural land. Only about 12 percent of the families have the pucca and /or semi-pucca houses. 100 percent of the families are using shallow tubewell water. Details of the water use pattern are presented in Table 1.

### **Information Regarding Tube-well Water**

Regarding the location of the tubewells, 65 percent said that they have tubewells in the house premises; the rest of the households were collecting tubewell water from their neighborhood. Out of 34 tubewells only 11.76 percent are government-owned, the rest 88.24 percent are private or owned by NGOs and other private initiatives. The mean age of the tubewells is 9.47 years with wide standard deviation (8.46). Mean depth of the tubewells is 83.82 feet. Minimum depth of the tubewells is 65 feet and maximum is 125 feet. Out of 34 tubewells, 70.6 percent found within the mean depth (85 feet). Fifty percent tubewells had arsenic level between 5-100 ppb and only one tube-well had As level above 500 ppb.

**Table 1 : Water use pattern of the household**

Sources of water	Purposes of using water									
	Drinking		Cooking		Domestic		Bathing		Agriculture	
	Family	%	Family	%	Family	%	Family	%	Family	%
Shallow TW	60	100	52	86.7	13	21.7	20	20	17	28.33
Pond			4	6.7	2	3.3	20	20		
Canal			1	1.7						
Shallow TW and Pond			3	5	44	73.3	56.7	56.7		
Deep-Well									3	5
Deep well and Dug Well					1	1.7				
Pond and River							1.7	1.7		
Deep well and pond							1.7	1.7		
Total	60	100	60	100	60	100	60	100		33.33

### **Arsenic in Raw and Treated Water**

Table 2 shows arsenic concentration in raw water. Among the 60 samples (from 60 families using 34 tubewells), 29 (i.e., 48.3%) samples contain arsenic between 50 and 100 ppb (SD=14), 21 (i.e., 35%) samples have arsenic between 101 and 200 ppb (SD=32.3), and 10 (i.e., 16.7%) samples contain arsenic above 200 ppb (SD=120.9).

It appears from Table 3 that 55 (i.e., 91.7%) households, 60 (i.e., 100%) households, and 56 (i.e., 93.3%) households have less than 50 ppb after 30 days, 55 days and 78 days, respectively.

### **Iron Concentration in Raw and Treated Water**

Iron concentration has been examined at household level. One third of the households were using tubewell water with iron concentration above 10 ppm, and nearly 50 percent households were using water containing iron between 7 and 10 ppm.

**Table 2: Arsenic in Raw Water**

As (ppb)	Selected TWs (No)	No. of families selected	Minimum As (ppb) in raw water	Maximum As (ppb) in raw water	Mean As in raw water (ppb)	Std. Deviation
50-100	18	29	50	98	74.167	14
101-200	9	21	109	192	148.89	32.26
>200	7	10	250	580	352.86	122.92
Total	34	60				

**Table 3 : Arsenic in treated water**

As (ppb)	Treated Water		
	No. of Tubewell after installation		
	30 days	55 days	78 days
<= 50	55(91.67%)	60(100%)	58(96.67)
>50	5(8.33%)	0(0.0)	2(3.33%)
Total	60(100%)	60(100%)	60(100%)

Table 4 shows the basic statistics of iron in raw and treated water. Mean iron concentration in raw water (tube-well water) is 9394 ppb (SD=2931.85, 95% CL=8636.64-10151.39). After 30 days of installation, mean iron conc. of the treated water is 1105.78 ppb (SD= 1466.88, CL=726.93 to 1484.8). After 55 days of installation mean iron concentration of the treated water is 766 ppb (SD=77.59, 95%CL=554.22-977.78). After 78 days of installation, mean iron concentration of the treated water is 1011 ppb (SD=1154.23, 95% CL=712.83-1309.17). Iron concentrations in tube-well water in the DFID study were mostly low (<5 mg/l) and this major difference would appear to account for the more successful behavior of the BTU system in the Ghior Upazila Study.

### Aluminum and Manganese Concentration in Treated Water

Dissolves Aluminum concentration in treated water was found to be very satisfactory. Out of the 60 samples 58 (i.e., 96.67%) samples contained dissolved Aluminum less than 200 ppm, the acceptable limit set by Bangladesh Standard (see Table 5). Minimum Aluminum concentration in treated water is 0 and maximum concentration of Aluminum is 680 ppb. The mean concentration of dissolved Aluminum in treated water is 47 ppb (SD=108.91, Median=20, Mode = 20).

**Table 4 : Basic statistics of iron concentration in raw and treated water**

Description	Range (ppb)		Mean (ppb)	95% Confidence Interval of the Difference		SD	Mean Reduction (%)	Level of significance
	Min.	Max.		Lower	Upper			
Iron in raw water in ppb	1504	15150	9394	8636.6	10151.4	2932		
Iron in treated water in ppb after 30 days of installation	<30	7459	7459	726.93	1484.80	1467	88	.00
Iron in treated water in ppb after 55 days of installation	<30	3377	766	712.83	977.78	776	91	.00
Iron in treated water in ppb after 78 days of installation	67	4681	1011	712.83	1309.17	1154	89	.00

One of the concerns with BTU is concentration of aluminum in treated water. But in this study, the mean concentration of aluminum is 47 ppb in the treated water, which is within safe limit. Only in case of 2 BTUs, aluminum concentration was found to be above 300 ppb, above the recommended level of 200 ppb set by WHO (WHO, 1993). This study has another component (2<sup>nd</sup> phase) to follow up health effects, as the role of aluminum is still controversial.

**Table 5 : Basic statistics of aluminum and manganese concentration in treated water**

Parameter	No of Household	Minimum (ppb)	Maximum (ppb)	Mean (ppb)	Median	Mode	Std. Deviation
Aluminum	60	0	680	47	20	20	108.91
Manganese	60	0	1697	703	683	622	370.94

Average Manganese concentration in the treated water was unexpectedly high and above the recommended level of Manganese in drinking water. On our visit to the BTU users after this finding, they were found to be using the chemicals as per as our instructions. So reasons for presence of excess manganese need to be further studied.

Minimum concentration of Manganese ion in treated water was 0 ppb and maximum concentration was 1697 ppb, mean concentration was 703 ppb (Median=683 ppb, Mode = 622 ppb, SD =370.94). Only 2 (i.e., 3.33%) samples out of 60 contained Manganese less than or equal to 100 ppb, the Bangladesh drinking water standard. Five percent, 5 percent, 6.67percent, 10 percent, 50 percent, 20 percent of samples contained 101-200, 201-300,301-400,401-500,501-1000 and >1000 ppb of dissolved Manganese, respectively, in treated water (see Tables 5 and 7).

**Table 6 : Aluminum in treated water**

Aluminum	No of Samples	Percent
<=200ppb	58	96.67
>=200 ppb	2	3.33
Total	60	100

**Table 7 : Manganese in treated water**

Manganese	No of samples	Percent
<=100ppb	2	3.33
101-200ppb	3	5
201-300ppb	3	5
301-400ppb	4	6.67
401-500ppb	6	10
501-1000ppb	30	50
>1000 ppb	12	20
Total	60	100

**Bacterial Contamination of treated water**

Tables 8 and 9 show the bacterial contamination in treated water.

**Table 8 : Basic statistics of bacterial concentration in treated water**

Description	No of samples	Minimum	Maximum	Mean	Std. Deviation
Total coliform (#/100 ml) in treated water after 100 days of installation	60	0	1600	286	5.94
Faecal coliform (#/100ml) in treated water after 100 days of installation.	60	0	1600	66	241.63

**Table 9: Concentration of Coliform (TC) group**

TC group #/100 ml	Total Coliform (TC)		Faecal Coliform (FC)	
	# of Sample	Percent	# of Sample	Percent
0	8	13.3	26	43.33
1-100	33	55	27	45
101-250	7	11.7	4	6.67
251-500	2	3.33	1	1.67
501-1000	2	3.33	1	1.67
>1000	8	13.3	1	1.67
Total	60	100	60	100

Mean concentration of total coliform of treated water was 286 ( $\pm 6$ ) and that of faecal coliform was 66 ( $\pm 242$ ). In 8 (i.e., 13.33%) BTUs there were no TC and in 26 (43.33%) BTUs there were no FC. 55, 11.67, 3.33, 3.33 and 13.33 percent of samples contained 1-100, 101-250, 251-500, 501-1000 and >1000 unit (#/100 ml) TC, respectively (Table 8); and 45, 6.67, 1.67, 1.67 and 1.67 percent of samples contained 1-100, 101-250, 251-500, 501-1000 and >1000 unit (#/100 ml) FC (Table 9), respectively.

#### **pH Values of Raw and Treated Water**

The pH values of the BTU treated water samples were tested in this study and pH was found to marginally decrease following the addition of the aluminum sulphate coagulant. A total of 11 samples were tested for pH. Minimum pH in raw water is 6.65 and the maximum value of pH in raw water is 8.25. The mean concentration of pH is 7.35 ( $\pm .4361$ ). Mean pH of 11 samples of treated water

was 7.21 ( $\pm$  .4906). Minimum value of pH in treated water was 6.4 and the maximum value was 8.02 (Table 10).

**Table 10: pH of raw and treated water**

Description	No of samples tested	Minimum	Maximum	Mean	Standard Deviation
pH in raw water	11	6.65	8.25	7.35	.4361
pH in treated water	11	6.4	8.08	7.21	.4906

## RECOMMENDATIONS

Based on the quantitative and qualitative (FGD and In-depth study) information derived from this study, the following recommendations have been made:

- (1) BTU can be used as an arsenic removal device at household level if it fulfills the basic criteria.
- (2) The BTU should be stronger structurally. The quality of the buckets should be improved.
- (3) Arsenic contaminated water should be allowed to stand for more than 3 hours until the coagulated flocs settle down the red bucket and upper water of red bucket looks crystal color.
- (4) Given the discrepancies in different study results, BTU can be promoted where the water iron content is high.
- (5) Alternative water options for arsenic mitigation should be region-specific, based on the water criteria of the areas. Area-specific characteristics of water should be known or attempt should be made to know it.
- (6) Iron salt  $[\text{FeCl}_3/\text{Fe}(\text{SO}_4)_3]$  may be used instead of Alum to avoid controversy.
- (7) BTU should be promoted if the arsenic concentration of the raw water is within 500 ppb.
- (8) BTU should not be promoted in any community on large scale without strong monitoring support.
- (9) At least 1 female caretaker should be trained from each household using BTU.
- (10) BTU chemicals should be made available locally.



- (11) The sand used in the filter column should be strictly coarse sand retained on #30 mesh (DPHE/Danida, 1999).
- (12) The proportion of alum and potassium permanganate should be strictly maintained as per suggestion and chemicals should be supplied in selected condition.
- (13) Sand should be washed and boiled with water after every 15 days.
- (14) Awareness should be built up in the community before they are provided with BTUs

## REFERENCES

- BBS (1997), Bangladesh Bureau of Statistics (1997), 8<sup>th</sup> Edition: Statistical Year Book of Bangladesh, BBS, Statistics Division, Ministry of Planning, Government of the People's Republic of Bangladesh.
- DPHE/Danida (1999) Quarterly Progress Report for DPHE-Danida Arsenic Mitigation Pilot Project, Bangladesh, September 1999.
- Sarker, A. et al. (2000), Bucket Treatment unit for arsenic removal'. Preprints of the 26<sup>th</sup> WEDC Conference, Dhaka, Bangladesh 2000.
- SOES/DCH (1998), A Report on Groundwater Arsenic Contamination in Bangladesh by SOES, Jadavpur University and DCH, Bangladesh.
- WHO (1993) Guidelines for drinking-water quality, Second Edition, Volume 2, health criteria and other supporting information, WHO, Geneva

# **Evaluation of Performance of Sono 3-Kolshi Filter for Arsenic Removal from Groundwater Using Zero Valent Iron Through Laboratory and Field Studies**

**A.K. M. MUNIR and S. B. RASUL**

Sono Diagnostics Centre  
Environment Initiative, Kushtia, Bangladesh

**M. HABIBUDDOWLA**

140 Northwood Road,  
Frankfort, KY 40601, USA

**M. ALAUDDIN**

Department of Chemistry,  
Wagner College, Staten Island New York, USA,

**A. HUSSAM**

Department of Chemistry, George Mason University,  
Virginia, Fairfax, VA 220 30, USA

and

**A.H. KHAN**

Department of Chemistry, University of Dhaka,  
Dhaka - 1000, Bangladesh

## ***Abstract***

*A three-pitcher (locally known as '3-Kolshi') water filtration system made from locally available materials was tested for its efficacy in removing arsenic, other trace metals and anions from the groundwater of Bangladesh and the disposal of the filtering materials after the breakthrough was studied. In this filter, the first Kolshi has cast iron turnings, and sand, the second Kolshi has wood charcoal and sand as the active ingredients. About 6000 L of groundwater containing 80 - 1900 µg/L of arsenic was filtered. The filtered water contained about 10 µg/L As(total), no detectable As(III), and significantly reduced major, minor and trace*

metals. The filtration process was monitored for a year by measuring As (total), As(III), 23 other metals, 9 anions, pH, conductivity, temperature and flow rate. The complete conversion of  $Fe^0$  to nonmagnetic hydrous ferric oxide (HFO) as the most active component for arsenic removal is indicative of an oxidizing environment sustained by continuous diffusion of air through the porous Kolshi. All parameters indicate that the water quality meets and exceeds USEPA, WHO, and Bangladesh standards. The effect of flow rate on arsenic removal has been studied separately for three tube wells with arsenic concentration of 166-212, 211-238 and 1435-1642  $\mu\text{g/L}$  (ppb) over a period of 48 months. The results demonstrate that the optimum flow rate is about 7 L/hr for achieving an arsenic concentration down to the level of 7-13 ppb from the initial level of about 200 ppb. The optimum flow rate is 8.4 L/hr for achieving an arsenic concentration of about 20 ppb from the initial level of 1600 ppb. Any possibility of pathogenic contamination during the use of the system as a household utility can be removed with a 4-litre hot water cycle, once in a week. This contamination is not inherent to the system. Leaching experiment on solid wastes from 3-Kolshi filter, with rain water at pH 4 and 7, showed no release of arsenic above 16  $\mu\text{g/L}$  of the leachate, which is the detection limit of ICP-AES method for arsenic. The release of other trace metals was also not very significant.

At its present capacity, five people can use the system for about five months at a consumption rate of 50 L/day. Regeneration of the system to its original efficiency can be achieved by changing the sand in the Kolshi. These low-cost units (ca. US \$ 5.0- 6.0) are being used by people in the arsenic affected areas of Bangladesh in large numbers. Further studies on the improvement of the design and the initial treatment of the filtering materials are in progress.

## INTRODUCTION

Recent measurements show that in many parts of the Ganges and Brahmaputra basin more than 60% of the shallow and deep tubewell water contains arsenic above the WHO guideline value of 10  $\mu\text{g/L}$  and more than 30% of the tubewells contains arsenic above the Bangladesh standard of 50  $\mu\text{g/L}$  (Chatterjee, *et. al.*, 1995; Das *et. al.*, 1995). It is estimated that of the 125 million people of Bangladesh, between 35-77 million are drinking groundwater containing more than 50  $\mu\text{g/L}$  of arsenic. The contaminated water is widely hand-pumped from a depth of 30 - 200 feet using shallow tubewells. According to WHO estimate, there are about 2.5 million tubewells, although the unofficial estimate is about 10 million (Smith *et. al.* 2000). The prolonged drinking of this water has caused serious health hazard in the form of hyperkeratosis on the palms and feet (Choudhury *et. al.*, 1998). Long term exposure to low concentrations of arsenic has been reported to cause cancer of bladder, skin and other internal

organs (International Agency for Research on Cancer, 1980). The health hazard caused by drinking arsenic affected water can be arrested by drinking arsenic-free water because the biological half-life of arsenic appears to be between ten hours and four days (National Research Council, 2000; Goyer *et. al.*, 1996; Tam *et. al.*, 1979). There are no known cures for arsenicosis. Since 97% of population depend on groundwater, provision of safe drinking and cooking water warrants immediate development of water purification systems appropriate for rural Bangladesh.

This work is motivated by the urgency of the current crisis and the need for a simple and low-cost technique for the removal of arsenic from the groundwater of Bangladesh. Considering the vulnerability of vast population to adverse health effects of arsenic, developing an appropriate, affordable household filtration system is a major step in combating the current calamity. Recently, we have reported such a method and the physicochemical basis for the purification of arsenic contaminated groundwater (Khan *et. al.*, 2000). The arsenic filtration system assembled by using locally available materials has been widely accepted and promoted by various non-governmental organizations in the arsenic affected areas of Bangladesh in large numbers (est. 20,000 units are in use). This paper presents the results of a one-year critical evaluation of the 3- Kolshi filtration system based on measurements of As(III), As(total), 23 major, minor and trace metals, 9 anions, pH, conductivity and flow rate.

## METHODOLOGY

### Filtration System Setup

The filtration system described here and in our earlier report (Khan *et. al.*, 2000) is based on fired unglazed clay pitchers (hereafter called by its local Bengali name 'Kolshi') used by more than 80% of the population as a reservoir for drinking and cooking water. Figure 1 shows the photograph of the filtration system used in this study. In a three Kolshi (3-Kolshi) filtration system, the Kolshis (top, middle, and bottom) are placed on top of each other in a steel or bamboo frame for ease of maintenance. Each Kolshi has a volume of about 18 liters. The top and middle Kolshi has small holes (~ 0.5 cm diameter) which are covered with pieces of synthetic (polyester) material from inside. The holes are made for free flow junction nozzles connected from outside. These nozzles can be easily altered to adjust flow rate.



**Figure 1: Picture of a 3-Kolshi-filtration setup. This particular setup was used to filter 6000 L of arsenic contaminated groundwater. The computerized electrochemical analyzer for the measurement of arsenic is shown in the background,**

About half kilograms of small brickette pieces (grade A red bricks, 2-3 cm pieces) were spread on the clothes. The middle Kolshi was then filled with 2 kg sand (from local Garai river), 1 kg wood charcoal (ca. 1 cm pieces from cooking wood) and 2 kg brickette pieces. The top Kolshi has 3-kg of cast iron turnings (from local machine shop or iron works) placed uniformly on the brickette and 2 kg of sand on top of the iron turnings. All the filtering materials are pre-cleaned to remove any unwanted dirt before the filter unit is assembled. Tubewell water is poured slowly on the top Kolshi and collected at the bottom Kolshi. The filtration system is used for pure drinking water after discarding initial 3-4 batches (ca. 10-L each) of water. Experience shows that covering the middle and bottom Kolshis with small pieces of synthetic clothes placed on perforated earthen covers (available from the same Kolshi makers), can prevent accidental

leakage and dust. Users are advised to follow general precautions such as the placement of the filtration unit in a secured place, always keeping the top opening of the Kolshis covered with clean clothes and practice hygiene rules in handling drinking and cooking water. The filtered water was collected for analysis by decanting into pre-washed HDP (high-density polyethylene) sample collection bottles and analyzed immediately for As(III) and As(total) by the computerized electrochemical analyzer.

### Analytical methods and procedure

Details of analytical methods and procedure for the measurement of As(III), As(V), Fe(soluble), pH,  $E_h$ , and conductivity were described earlier (Khan *et al.*, 2000). It should be noted that water samples were collected before and after filtration in acid pre-washed HDP bottles and promptly analyzed for As(III), As(total), and Fe (total) without further filtration. This ensures almost real time analytical data for actual drinking water. Samples for ICPAES (Inductively Coupled Plasma Atomic Emission Spectroscopy) analysis of 24 metals were preserved in 250-mL HDP bottles acidified with 1.0 mL concentrated HCl (AnalaR) without a headspace. Samples for anion analysis were preserved without acid.

Selective measurements of As(III) were performed by a computer controlled electrochemical analyzer (Model HQ-2040, Advanced Analytics, Virginia, USA) following a modified EPA method [Method 7063: Arsenic in Aqueous Samples and Extracts by Anodic Stripping Voltammetry (ASV) (Pyles, *et al.*, 1999)]. As(total) was measured by the same technique after chemical reduction of As(V) to As(III). Detail procedure, analytical merits and method validation are described elsewhere (Khan *et al.*, 2000; Rasul *et al.*, 1999; Davis *et al.*, 1978; Sun *et al.*, 1997). A continuous flow hydride generation atomic absorption spectrometer (Buck Scientific, Model 210 VGP at Intronics Technology Center, Dhaka, Bangladesh), a Perkin-Elmer model 5100 Zeeman-effect atomic absorption spectrometer with a graphite furnace (AASGF-Z), and model A-60 autosampler (at GMU, USA) were used for regular measurement checkup and cross validation of field measurements. A 24-trace metal profile of water samples before and after filtration was measured by a direct reading Echelle ICPAES with radial and axial view (Leeman Labs, NH, USA). The anion analysis of preserved water samples was performed by a Lachat QuickChem Model 6000 Ion Chromatograph (Zellweger Analytics, WI, USA). Total alkalinity, and the concentrations of  $H_2CO_3$  (aq),  $CO_3^{2-}$  and  $HCO_3^-$  were determined from acid base micro-titration of groundwater.

To study the effect of flow rate on arsenic removal efficiency, two tubewells from the same area were selected, one having the initial concentration of total arsenic of about 200 ppb and the other, about 1400 ppb. Other parameters such as pH and conductivity were almost the same for the two samples.

The analytical quality control of the method is maintained through quality control chart of analysis with the same method over a period, apart from independent method approach of analytical validation.

## RESULTS AND DISCUSSION

### Nature of groundwater

In Bangladesh, the groundwater chemistry is not very well known. The development of any filtration system requires a relatively clear understanding of the composition of the water being filtered. The present work was carried out in Kushtia Sadar with a population of about 400,000 thousand in 316 km<sup>2</sup> (Stat, 1994). It is now known that over 40% of the tubewells in Kushtia are contaminated with arsenic (total) above 50 µg/L, of which 43-98% is present in the as more toxic As(III) (Rasul *et. al.*, 1999). Table 1 shows the composition of six replicates of anoxic groundwater obtained from two tubewells used for the present filtration studies. The elemental compositions are shown as the concentration range and the anion compositions are the average of three replicates. Except for the total arsenic concentrations (80 -1900 µg/L), the water from these wells are representative of the drinking water from this area. Typically, the groundwater has high soluble iron that, upon leaving for 2-6 hours in an oxic environment, forms a brownish colloidal hydrous ferric oxide making the water turbid. Spectrophotometric measurement of turbidity at 450-nm shows 30% decrease in transmittance from a clear solution in 4 hours (Rasul *et. al.*, 2000). The water is also high in calcium and magnesium and thus can be regarded as hard water. The choice of these two tubewells for the present study was prompted by the high concentrations of arsenic and other minerals that clog many commercial filters and constitute a stringent test for the long-term effectiveness of the 3-Kolshi filtration system. Table 1 also lists the composition of the 3-Kolshi filtered tubewell water as discussed later.

The concentrations of anions, NO<sub>2</sub><sup>-</sup>, NO<sub>3</sub><sup>-</sup>, SO<sub>4</sub><sup>2-</sup>, Cl<sup>-</sup>, F<sup>-</sup>, Br<sup>-</sup>, and PO<sub>4</sub><sup>3-</sup>, listed in Table 1, were obtained by ion chromatography of water preserved without acid. The concentration of these anions may be underestimated due to the precipitation of groundwater, which has affected the multivalent anions ( SO<sub>4</sub><sup>2-</sup> and PO<sub>4</sub><sup>3-</sup> ) more than the monovalent anions (Cl<sup>-</sup>, F<sup>-</sup>, NO<sub>2</sub><sup>-</sup>, and NO<sub>3</sub><sup>-</sup>). The concentrations of CO<sub>3</sub><sup>2-</sup>, H<sub>2</sub>CO<sub>3</sub>(aq), and HCO<sub>3</sub><sup>-</sup> were based on acid-base titration of fresh groundwater (Snoeyink *et. al.*, 1980). To understand the chemical speciation of groundwater, a computational geochemical model, MINEQL+ (Schecher *et. al.*, 1998) was used with the inputs as shown in Table 1.

**Table 1: Composition of typical groundwater from two tubewells and the 3-Kolshi filtered tubewell water.**

Species and Parameters	Groundwater mg/L	3-Kolshi water mg/L
Aluminum, Al	<0.015-0.052	<0.015-0.033
Antimony, Sb	<0.013-0.017	<0.013
Arsenic. As (total)	0.08-1.900	0.012 0.010
As(III)	0.073 -1.170	<0.002
Barium, Ba	0.161-0.170	0.05 - 0.063
Beryllium, Be	<0.001	<0.001
Cadmium, Cd	<0.001	<0.001
Calcium, Ca	111-117	56 - 65
Chromium, Cr	<0.002	<0.002
Cobalt, Co	<0.002	<0.002
Copper, Cu	0.004-0.009	0.005
Iron, Fe	6.77-7.19	0.010 - 0.49
Lead, Pb	<0.004-0.005	<0.004 - 0.006
Magnesium, Mg	21.4-23.1	19 - 27
Manganese, Mn	0.69-0.74	< 0.002
Molybdenum, Mo	0.001-0.003	0.001-0.003
Nickel, Ni	<0.002	<0.002
Potassium, K	1.88-2.45	1.88-2.45
Selenium, Se	<0.012	<0.012
Silver, Ag	<0.002	<0.002
Sodium, Na	18.2-20.4	20.1 - 92.4
Strontium, Sr	0.280-0.297	0.18-0.37
Thallium, Tl	<0.067	<0.067
Tin, Sn	<0.002-0.01	<0.002-0.01
Vanadium, V	<0.001	0.004-0.009
Zinc, Zn	0.012-0.021	0.011
pH	6.9-7.2	7.7 0.2
Conductivity S-cm)	570 46	365 66
Temperature,oC	27-29	27 - 30
NO <sub>2</sub> (-)	0.469	< ic
NO <sub>3</sub> (-)	0.980	0.823
SO <sub>4</sub> (2-)	0.424	2.43
Cl(-)	3.273	5.9 - 110
Br(-)	<ic	0.028
F(-)	0.27	0.47
PO <sub>4</sub> (3-)	0.023	0.068
CO <sub>3</sub> (2-)	0.29	1.47
H <sub>2</sub> CO <sub>3</sub> (aq)	148	18.3
HCO <sub>3</sub> (-)	560	432

<ic : below the detection limit of ion chromatographic system.

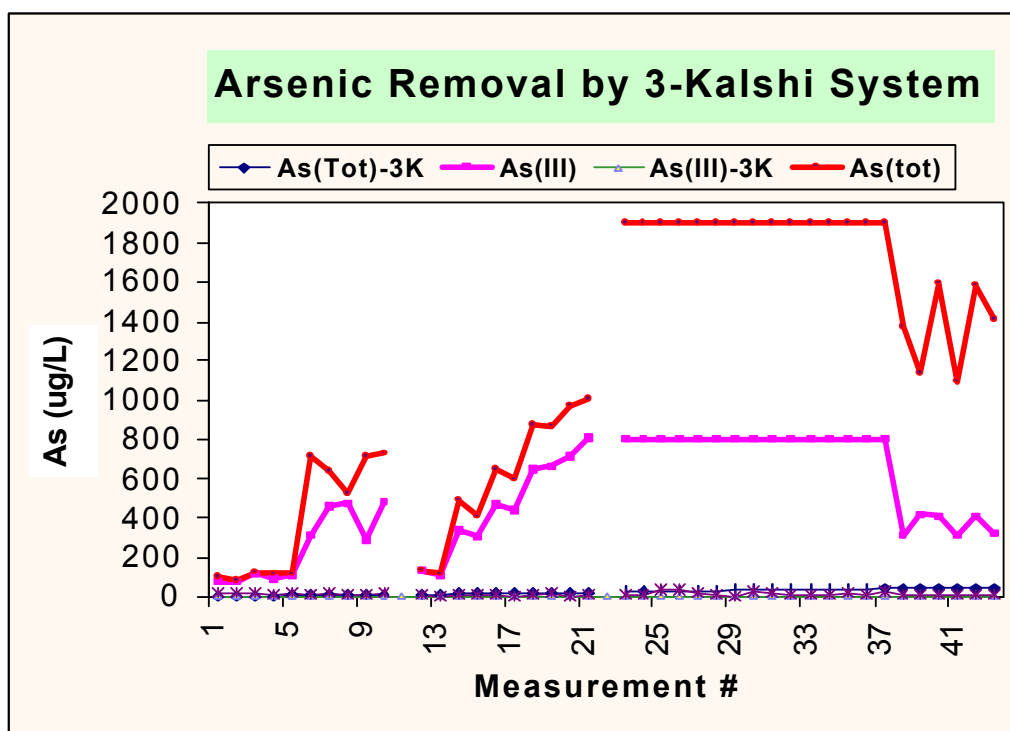


The speciation model shows  $\text{Ca}^{2+}$ ,  $\text{Fe}^{2+}$ ,  $\text{K}^+$ ,  $\text{Mg}^{2+}$ ,  $\text{Mn}^{2+}$ ,  $\text{Na}^+$ ,  $\text{Sr}^{2+}$ ,  $\text{Zn}^{2+}$ ,  $\text{Cl}^-$ ,  $\text{CO}_3^{2-}$ ,  $\text{F}^-$ ,  $\text{SO}_4^{2-}$ ,  $\text{NO}_3^-$ , and  $\text{NO}_2^-$  as the major components and  $\text{H}_3\text{AsO}_3(\text{aq})$ ,  $\text{HASO}_4^{2-}$ ,  $\text{H}_2\text{ASO}_4^-$ ,  $\text{CaHCO}_3^+$ ,  $\text{CaCO}_3(\text{aq})$ ,  $\text{MgCO}_3(\text{aq})$ ,  $\text{MgHCO}_3^+$ ,  $\text{MnHCO}_3^+$ ,  $\text{H}_2\text{CO}_3(\text{aq})$ , and  $\text{HCO}_3^-$  as the major species (concentration  $>10^{-6}$  M) under anoxic condition. The model also predicts that the concentration of Fe(total), Mn(total), Al, Ca, Ba, and  $\text{CO}_3^{2-}$  exceeds their solubility product limits for minerals - hematite ( $\text{Fe}_2\text{O}_3$ ), bixbyite ( $\text{Mn}(\text{OH})_3$ ), diaspore ( $\text{Al}(\text{OH})_3, 2\text{H}_2\text{O}$ ), Calcite ( $\text{CaCO}_3$ ), and Dolomite ( $\text{CaMg}(\text{CO}_3)_2$ ), and thus precipitate out under oxic condition (Rasul *et. al.*, 2000). Similar oxic conditions prevail in the 3-Kolshi filtration system.

### Effectiveness of Arsenic Filtration System

Figure 2 shows the effectiveness of the 3-Kolshi filtration system for the removal of As(III) and As(total) from 6000 L of groundwater. The numbers indicate measurement at regular intervals except for the breaks at 10th and 22nd measurements. The first break was due to the change in the filter plug in the middle-Kolshi and the second break was caused by the breakage of the top-Kolshi, which was replaced with new sand. These changes, however, did not decrease the arsenic removal efficiency as shown in Figure 2. Measurements 1-5 were due to the filtration of original groundwater containing 80-100  $\mu\text{g/L}$  As(total) and 75  $\mu\text{g/L}$  As(III). The filtered water contained 17  $\mu\text{g/L}$  As(total) and  $<2$   $\mu\text{g/L}$  As(III). At this point the same groundwater was spiked with arsenite (As(III):  $\text{As}_2\text{O}_3$  dissolved in dilute NaOH and neutralized) and arsenate (As(V) in  $\text{Na}_2\text{HAsO}_4$ ) to increase the concentrations of As(total) and As(III) at indicted levels. In order to facilitate and observe the 50  $\mu\text{g/L}$  breakthrough, a 6-L groundwater spiked with 10,000  $\mu\text{g/L}$  of arsenate was filtered. The resulting effluent contained arsenic at a level of 22  $\mu\text{g/L}$  As(total) (not shown in Figure 2). Clearly, no breakthrough appeared. The total volume of water filtered from this tubewell was ca. 4850 L. Measurements 24-38 were made with groundwater from another tubewell (Harishankarpur, Kushtia Sadar) which was known to have a maximum of 1900  $\mu\text{g/L}$  As(total) and 800  $\mu\text{g/L}$  As(III). Clinically identified arsenical keratosis patients are reported in this location. Measurements 24-38 were carried out in quick successions so as to maintain the high concentration of arsenic species. Concentrations of both As(total) and As(III) were found to fluctuate in this location when water was collected at long irregular intervals as shown by the remaining data. The total volume of water filtered from this tubewell was ca. 1000 L. In all cases the filtered water contained,  $12 \pm 10$   $\mu\text{g/L}$  As(total), which is close to the WHO guideline value of 10  $\mu\text{g/L}$  and no detectable As(III), irrespective of the input levels of As(total) and spiking. In continuation with our previous work, measurements of total soluble Fe, pH, conductivity and flow rate were made intermittently to judge the quality

of water. These results and the elemental composition are summarized in Table 1. We also note that the filtered water remained clear for months in clear plastic water bottles. Table 1 shows that the concentrations of Fe decreased significantly and sometimes below the detection limit of ICPAES. The concentration of Mn also decreased to less than 2  $\mu\text{g/L}$ . Therefore, these two metals are quantitatively removed by the filtration system as their hydroxide precipitates. While the concentration of Ca and Ba are decreased to half, the concentration of Mg did not change. The concentration of Na also did not change (except one high reading) while the concentration of K has increased slightly. This could be an indication of a very weak dissolution or ion exchange dissolution of sand minerals (Langmuir, 1997). A slight increase in V concentration in the filtered water is an indication of presence of V in cast-iron turnings. Zinc concentration was decreased by half. The concentrations of all other trace metals did not change or remained below the detection limit of ICPAES.



**Figure 2: Arsenic removal efficiency of a 3-Kolshi filtration system. The 3-Kolshi filtered data (-3K) are shown near abscissa. See text for details data (-3K)**

The pH of the filtered water increased by one unit, possibly a result of decarbonation. This is also evident from the decrease in bicarbonate concentration. A 36% decrease in solution conductivity is indicative of substantial removal of ionic components from solution. Anion concentrations in

the filtered water are generally low (except for one high reading for  $\text{Cl}^-$ ) and had no consequence either on the filtration system or on speciation. Water chemistry shown in Table 1 is in agreement with our previous findings at the early stage of filtration system development, which indicates the consistency and reproducibility of the 3-Kolshi filtration system. Except for occasional variations in non-toxic species (Na and Fe), and a change in flow rate, the 3-Kolshi system has performed well.

The 3-Kolshi system described here was used to filter about 6000 L of groundwater after which the effluent arsenic increased to about 60  $\mu\text{g/L}$  As(total) without a clear rise in concentration as would be expected from classical breakthrough experiments (not shown in Figure 2). In some cases, the system may not function adequately due to clogging of the outlets and overloading of sand with fine hydrous ferric oxide (HFO:  $\text{Fe}_2\text{O}_3 \cdot 2-3 \text{H}_2\text{O}$ ) precipitates.

### Effect of the Flow Rate on Arsenic Removal

After the report of the Phase II program (Rapid Assessment-2001) as discussed below, it was realized that the control of the flow rate and its effect on arsenic removal by 3-Kolshi filter needs further improvement. Accordingly, three tube wells [one in the house of one of the authors (AKM Munir), one in his Clinic, and a third one] with arsenic concentrations of 166 - 212  $\mu\text{g/L}$ , 211 - 238  $\mu\text{g/L}$ , and 1435 - 1642  $\mu\text{g/L}$ , respectively (varying over a period of 4-8 months, September 2000 - April 2001) were studied with 3-Kolshi filter. Flow rates were fixed at 7.2, 8.4, 9.6 and 11.8 L/hr. The filter sets were newly designed with flow rate adjustable free flow junctions. The results of this study are given in Table 2, as preliminary findings since the study is still continuing to find the breakthrough stage for different flow rates.

**Table 2: Effect of flow rate on Arsenic Removal by 3-Kolshi Filter System (period: September 2000-April 2001) (n=19, No. of measurements.)**

Tube wells Water		Tube wells Water			Filtered Water		
TW	Flow Rate (L/hr)	pH	Conductivity $\mu\text{S/cm}$	As(total) $\mu\text{g/L}$	pH	Conductivity	As(total) $\mu\text{g/L}$
TW1	7.2	6.0-7.0	452 - 525	166-212	6.5-6.9	411 - 483	7-13
TW2	7.2	6.6-7.1	488 - 546	211-238	6.3-6.5	3.2 - 342	7-13
TW3	11.8	6.6-7.1	466 - 503	1438-642	6.5-6.8	443 - 558	35-114*
	8.4	6.7-6.9	492 - 499	1455-1588	6.6-6.8	442 - 459	18-20

\* This was almost the break-through point at the flow rate of 11.8L/hr. At this point when the flow rate was adjusted to 8.4 L/hr., the removal efficiency of the same filter unit for the same water was recovered to the permissible level of 20  $\mu\text{g/L}$  of total Arsenic, 2.5 times lower than the MCL value of 50  $\mu\text{g/L}$ .

The results in Table 3 clearly indicate that by adjusting the flow rate to about 7 L/hr, maximum efficiency can be attained with arsenic content in the filtered water to be about 10 ppb, irrespective of the initial concentration of arsenic (200-1600 ppb as tested), while the other water quality parameters remain within acceptable limits. The filter units under this condition have been used for about 8 months, without any break-through yet. The filtered water satisfies the needs for drinking and cooking water, in a family of 5 members. A 4L hot water cycle (wash) per week keeps the filter water free from pathogenic load as tested by human consumption without any health complication.

Experience shows that gentle poking of the outlet filters with a fine sewing needle can restore the flow rate. Regeneration of the system to its original efficiency can be obtained by changing the sand in the Kolshi. The drinking water production rate (6-7 L/hour) is adequate for drinking and cooking purpose of a family of 4 to 5. At this capacity, five people can use the system for five months at 50 L/day consumption. Further improvements in flow rate by redesigning the outlet system with a free flow junction are in progress. One of the present concerns with any filtration system is the disposal of the solid waste produced. We estimate that the concentration of As(total) accumulated in sand and HFO is 350 mg As/kg of solid at the break-through point. Since the filtration system requires no chemical regeneration steps (e.g., in regeneration of activated alumina column for arsenic mitigation) the wastes produced by Kolshi are self-contained. Preliminary experiments involving Dutch Total Available Leaching Procedure (TALP) of sand and mixed waste from 3-Kolshi show 15 µg/L and 25 µg/L of As(total) at pH 7 and pH 4, respectively (ASTM, 1992; Price *et. al.*, 1997). Similar results (<16 µg/L by ICPAES) were obtained for leaching with rainwater instead of deionized water. ICPAES data of same solutions shows no increase in concentrations of other metals compared to that of the filtered water (Hussam *et. al.*, 2000).

### **Role of Iron in Arsenic Removal**

Iron is present in the filtration system as zero valent iron,  $Fe^0$ , in the top Kolshi and in groundwater mostly as soluble Fe(II) species. Since the filtered water is nearly free from iron, therefore the oxidation products of zero valent iron and the oxidation of Fe(II) species to HFO (Dzombak *et. al.*, 1990) are quantitatively retained in the top and middle Kolshi. Previously, we reasoned that arsenate was quantitatively removed by compound formation or adsorption on HFO (Khan *et. al.*, 2000). In both cases, the excess arsenic removal capacity increases linearly after each Kolshi of filtration. This is due to the accumulation of HFO formed from freshly available soluble iron in groundwater. We calculate that the excess capacity due to compound formation ( $FeAsO_4(s)$ ) is 1.2 mg As/mg Fe and for adsorption, 0.037mg As/mg Fe. Because the excess capacity is a measure of

under used efficiency of arsenic removal, a very large volume of groundwater can be filtered before overloading the system.

The role of various forms of zero valent iron was studied by several groups as a means to remediate environmental contaminants such as arsenic, dissolved heavy metals and chlorinated hydrocarbons (Lackovic *et. al.*, 2000; Driehaus *et. al.*, 1998; Shokes *et. al.*, 1999; Ponder *et. al.*, 1999; Roberts *et. al.*, 1996). Studies by others were aimed at mitigating EPA superfund sites containing high concentrations (mg/L) of arsenic from industrial wastes and artificial waste water (Nikolaidis *et. al.*, 1998). To assess the role of  $\text{Fe}^0$ , two experiments were performed. The experiments involve one filtration column made of 50-mL plastic hypodermic syringe filled with 25.0 g sand and the other filled with 15.0 g cast-iron turnings. About 500 mL of groundwater spiked with 500  $\mu\text{g/L}$  As(total) was filtered through these columns. The effluents from the sand column had 250  $\mu\text{g/L}$  As(total) and that of 20  $\mu\text{g/L}$  As(total) from the column containing cast iron turnings. Therefore, in comparison to sand, the  $\text{Fe}^0$  has significant higher capacity to remove arsenic even when no visible HFO formation was observed. At the end of the present 3-Kolshi experiment, it was found that  $\text{Fe}^0$  in the top Kolshi was turned into a solid cemented brownish iron oxide with visible pores throughout the mass. The solid mass was completely non-magnetic. It is clear that extensive oxidation of  $\text{Fe}^0$  took place inside the Kolshi, which was sustained by a continuous diffusion of air and water vapor through the porous ceramic Kolshi. There exist various mechanistic pathways for the chemical and physical transformation of  $\text{Fe}^0$  surface (Ponder *et. al.*, 1999; Raven *et. al.*, 1998, Lackovic *et.al.*, 2000). It appears, however, HFO formation by sustained oxidation of  $\text{Fe}^0$  and Fe(II), formation of a positively charged double-layer in presence of excess Fe(II)/Fe(III) on the HFO surface and subsequent specific adsorption of arsenate ( $\text{H}_2\text{AsO}_4^-$  and  $\text{HAsO}_4^{2-}$ ) are the primary mechanisms for the removal of arsenic (Dzombak *et. al.*, 1990; Gullledge *et. al.*, 1973; Pierce, *et. al.*, 1982). Moreover, in presence of a high concentration of  $\text{Ca}^{2+}$  the positive charge density of the HFO colloids can increase and thus enhances adsorption of arsenate: ( $\text{H}_2\text{AsO}_4^-$ ,  $\text{HAsO}_4^{2-}$  and  $\text{AsO}_4^{3-}$ ) (Wilkie *et. al.* 1996). It is also noted that the oxidizing environment has removed all traces of Mn(II), and  $\text{NO}_2^-$  from the groundwater.

### **Leaching of Arsenic and Other Trace Metals from 3-Kolshi Waste**

At the break-trough point of the 3-Kolshi filter (6000 L, at the flow rate of 5 L/hr and initial concentration of 1400 ppb of arsenic), the arsenic content in the waste (sand + HFO) from the first and the second Kolshi was estimated to be 350 mg/kg of the solid. This material was used in column to perform leaching experiments with rainwater (pH=4 and 7), following the EPA protocols. The distribution of different trace elements including arsenic in the leachates is given in Table 3.

The analysis of the leachates was done with ICP-AES. The detection limit of the method is 0.005 mg/L for other trace metals while for arsenic it is 0.016 mg/L. These results thus indicate that surface dispersion of the wastes from 3-Kolshi filter will not contaminate the natural environment above the background level.

**Table 3: Trace Element Distribution of leachates from 2 and 3- Kalshi Wastes by EPA Protocols. Measurement by Inductively Couple Plasma Atomic Emission Spectroscopy (ICP-AES)\***

Element	Conc. (mg/L) at pH = 7 3-K, Sand	Conc. (mg/L) at pH = 4 3-K, Sand	Conc. (mg/L) at pH = 7 2-K, Sand + Iron	Conc. (mg/L) at pH = 4 2-K, Sand + Iron
Al	0.028	0.02	0.049	0.014
As	<0.016	<0.016	<0.016	<0.016
Ag				
Ba	0.002	0.007	0.006	0.009
Be				
Ca	2.65	8.39	4.89	8.13
Co				
Cr				
Cu	0.005	0.018	0.007	0.008
Fe	0.02	0.031	0.041	0.051
Mg	0.2	1.03	0.519	0.831
Mn	0.013	0.081	0.005	0.047
Mo			0.001	
Ni	0.002	0.009	0.003	0.005
Pb			0.005	
K	0.82	1.26	0.608	0.527
Na	2.64	0.750	3.35	1.85
Se				
Sr	0.006	0.017	0.014	0.02
Sn	0.007	0.011	0.003	0.006
Tl				
V				
Zn	0.011	0.038	0.013	0.021

\*Blank spaces show concentration below the detection limit (bdl) of the ICP-AES. bdl are generally below 0.005 mg/L. For As the bdl is 0.016 mg/L or 16 ppb. Kalshi wastes were collected and extracted at SDCEI, Kushtia according to EPA protocol. ICP-AES measurement was done at the NREPC, Kentucky, USA by Mr. M. Habibuddowla.

### Quality of Filtered Water

Table 4 shows the inorganic quality parameters of filtered water in comparison to the requirements set by USEPA, WHO and Bangladesh guideline values. Clearly, the water obtained from the 3-Kolshi filtration system meets and exceeds

international drinking water standards. Recently, the 3-Kolshi filtration system underwent a series of tests commissioned by the technical advisory group of Bangladesh Arsenic Mitigation Water Supply Project (BAMWSP) and found to perform consistently well throughout, passing the 50 µg/L threshold at all wells where it was tested (Rapid Assessment, 2001).

**Table 4: Drinking water Inorganic Quality Parameters: Comparison of 3-Kolshi Water with those of USEPA, World Health Organization (WHO) and Bangladesh Standards**

Constituent	USEPA (MCL)	WHO, Guideline	Bangladesh Guideline	3-Kolshi water
Arsenic (total)- mg/L	0.05	0.01	0.05	0.012 ± 0.010
Iron (total) - mg/L	0.3	0.3	.3 (1.0)	0.010 - 0.49
Sodium - mg/L		200		20.1- 92.4
Calcium - mg/L			75 (200)	59.1 ± 7.5
Copper - mg/L	1.3 1.	0 - 2.0	1.5	0.005
Manganese - mg/L	0.05	0.1 - 0.5	0.1 (0.5)	<0.001
Zinc - mg/L	5	3.0	5 (15)	0.011
Aluminum -mg/L	0.05-0.2	0.2	0.1(0.2)	<0.015- 0.033
Lead -mg/L	0.015	0.01	0.10	<0.004 -0.006
Chromium, mg/L	0.1	0.05	0.05	<0.002 <0.013
Cadmium, mg/L	0.005	0.003	0.01	<0.001
Barium, mg/L	2.0	0.7	1.0	.063± 0.01
Antimony, mg/L	0.006	0.005		<0.013
Molybdenum, mg/L		0.07		0.003
Nickel, mg/	0.1	0.02		<0.002
Selenium, mg/L	0.050	0.01		<0.012
Silver, mg/L	0.1			<0.002
pH	6.5-8.5	6.5-8.5	6.5-8.5	7.7 0.2
Sulfate, mg/L	250		100	2.43
Fluoride, mg/L	4.0		1.0	0.47
Chloride, mg/L	250	250	200 (600)	5.9 - 110
Bromide, mg/L	10		10	0.028
Nitrite, mg/L	1			0.001 (< ic)
Phosphate, mg/L			6	0.068
Total dissolved solids (TDS), mg/L	500	1000	500 (1500)	208

- Bangladesh standard values are given as maximum desirable concentration with maximum permissible concentration in parentheses. TDS for 3-kolshi was calculated from the conductivity data excluding silica present in the filtered water. '<' symbol indicates below the detection limits of ICPAES. Anions -  $\text{SO}_4^{2-}$ , F,  $\text{Cl}^-$   $\text{Br}^-$ ,  $\text{NO}_3^-$ , and  $\text{PO}_4^{3-}$  were measured by ion chromatography of samples collected at 5000 L of filtration.
- <ic - below the detection limit of ion chromatography.
- Secondary maximum contaminant level

The report shows average arsenic concentration 9-16  $\mu\text{g/L}$  As(total) in the filtered water and an average flow rate of 5.0 L/hour irrespective of water chemistry from four distinctly different locations (Sitakundu, Hajiganj, Iswardi, and alaroa) in Bangladesh. These results are consistent with our present and previous findings. In the Phase II of Rapid Assessment Program, Sono 3-Kolshi filter passed 100% of the treated water below 50 ppb of arsenic ( $\sim 10$  ppb) on the average with the initial mean value of 450 ppb and with the flow rate of 3.3 L/hr. The water quality parameters do not include information on the presence of pathogenic bacteria because groundwater is presumed to be free from such bacterial load. The pathogenic contamination of the filtered water as reported in Phase II of the rapid assessment program, is not intrinsic to the system. It is due to the user's conditions of operation of the system. It can however, be completely removed by a 4-litre hot water cycle per week on the system. Many such 3-Kolshi systems are now in regular use (Fig. 3) throughout Bangladesh including SDCEI, and authors home. The 3-Kolshi water is clear, light tasting and free from the metallic taste of groundwater generally associated with high iron and calcium, and without any health complication arising from regular consumption of this filtered water.



Figure 3 : One 3-Kolshi filter unit in domestic use.



## CONCLUSIONS

The arsenic filtration system presented here is promising because it is based on a clear physicochemical principle, uses locally available materials and without adding chemicals. A possible scale up of the system to a community based rural and urban pure drinking water supply has been planned. We believe the 3-Kolshi system can be very effective for filtration of toxic groundwater in Bangladesh and in many parts of the world where clay pitchers are used for preserving drinking water.

## ACKNOWLEDGMENTS

The authors would like to acknowledge assistance from Mr. Abu Shyeed, Mr. M. Rahman and Mr. S. Washe of SDCEI, Kushtia, during the experiment. The authors gratefully acknowledge Dr. D. Chakraborty for anion analysis and Mr. Edward. Colley and Mr. Thomas A. Head Jr., of DES, NREPC, Commonwealth of Kentucky for the permission to use the facilities. The analytical method validation services provided by the Intronics Technology Center (ITC), Dhaka are thankfully acknowledged.

## REFERENCES

- American Society for Testing and Materials. 1992. *ASTM Designation: D 3987-85, Standard Test Method for Shake Extraction of Solid Waste with Water*, ASTM, West Conshohocken, PA, 4p.
- Chatterjee, A., Das, D., Mandal, B. K., Chowdhury, T. R., Samanta, G., and Chakraborti, D. 1995. Arsenic in groundwater in six districts of West Bengal, India: the biggest arsenic calamity in the World. Part 1 - arsenic species in drinking water and urine of the affected people. *Analyst*, 120, 643- 650.
- Choudhury, U. K., Biswas, B. K., Dhar, R. K., Samanta, G., Mandal, B. K., Chowdhury, T. R., Chakraborti, D., Kabir, S. and Roy, S. 1998. *Proc. Third. Int. Conf. on Arsenic Exposure Health Effects, San Diego. pp. 165.*
- Das, D., Chatterjee, A., Mandal, B. K., Samanta, G., Chakraborti, D. and Chanda, A. 1995. Arsenic in groundwater in six districts of West Bengal, India: the biggest arsenic calamity in the World. Part 2 - arsenic concentration in drinking water, hair, nail, urine, skin-scale and liver tissue (biopsy) of the affected people. *Analyst*. 120, 917-924.
- Davis, P. H., Dulude, G. R., Griffin, R. M., Matson, W. R., and Zink, E. W. 1978. Determination of total arsenic at the nanogram level by high-speed anodic stripping voltammetry. *Anal. Chem.* 50, 137-143.

- Driehaus, W., Jekel, M. and Hildebrandt, U. J. 1998. Granular ferric hydroxide - a new adsorbent for the removal of arsenic from natural water. *Water SRT-Aqua*, **47(1)**, 30-35.
- Dzombak, D. A. and Morel, F. M. M. 1990. *Surface Complexation Modeling: Hydrous Ferric Oxide*. Wiley- Interscience, New York. pp 89-95.
- Gulledge, J. H. and O'Connor, J. T. 1973. Removal of arsenic (V) from water by adsorption on alumina and ferric hydroxide. *Jour. AWWA*. **65, S** 548-552.
- Goyer, R. A. 1996. *Toxic effects of metals. In Casarett and Duull's. Part II. The Basic Science of Poisoning*, 5 th ed. Klaassen, C. D., Ed., McGraw-Hill, New York. 696-698.
- Hussam, A, Habibuddowla, M., Alauddin, M., Khan, A. H., Munir, A. K. M., and Rahman. M. 2000. *Trace Element Distribution of Wastes from Simple Arsenic Filtration Units*. Prepublication Report. Sono Diagnostic Center Environment Initiative, Kushtia, Bangladesh.
- International Agency for Research on Cancer. 1980. Some Metals and Metallic Compounds; *IARC Monographs on Evaluation of Carcinogenic Risk of Chemicals to Humans*, "IARC: Lyons, France, 23 (1980).
- Khan, A. H., Rasul, S. B., Munir, A. K. M., Habibuddowla, M., Alauddin, M., Newaz, S. S. and Hussam, A. 2000. Appraisal of a simple arsenic removal method for groundwater of Bangladesh. *J. Environ. Sci. and Health*. **A 35(7)**, 1021-1041.
- Khan, A. H., Rasul, S. B., Munir, A. K. M., Habibuddowla, M., Alauddin, M., and Hussam, A. 2000. On Two Simple Arsenic Removal Methods for Groundwater of Bangladesh. *Bangladesh Environmental Network Conference, Dhaka, Bangladesh, January 14 (2000)*.
- Lackovic, J. A., Nikolaidis, N. P. and Dobbs, G. 2000. Inorganic Arsenic Removal by Zero-Valent Iron. *Environ. Eng. Sci.* **17(1)**, 29-39.
- Langmuir, D. 1997. *Aqueous Environmental Geochemistry*. Prentice Hall, New Jersey. pp. 334- 337.
- Nikolaidis, N., and Dobb, G. 1998. *Arsenic Remediation Technology - AsRT*. Environmental Research Institute, University of Connecticut, United Technologies Research Center, and Apex Environmental Inc., <http://www.eng2.uconn.edu/~nikos/asrt-brochure.html>.
- National Research Council. 2000. *Arsenic in Drinking Water*. National Academic Press, Washington, D. C. USA. pp. 164.
- Pierce, M. and Moore, C. B. 1982. Adsorption of arsenite and arsenate on amorphous iron hydroxide. *Water Res.* **16, S** 1247-1253.
- Ponder, S. M., Darab, J. C. and Mallouk, T. E. 1999. Remediation of Cr(VI) and Pb(II) by nanoscale Fe-zero. *Environ. Sci. Technol.* **es 9911420**. ASAP Web Edition..

- Price, W.A. 1997. *DRAFT Guidelines and Recommended Methods for the Prediction of Metal Leaching and Acid Rock Drainage at Minesites in British Columbia*, British Columbia Ministry of Employment and Investment, Energy and Minerals Division, Smithers, BC, (April), 143p
- Pyles, S. and Miller, E. L. 1999. *Quantifying Arsenic in Aqueous Solutions by Anodic Stripping Voltammetry*. EMSL-LV.ORD/USEPA; [www.epa.gov/testmethods/7xxx.html](http://www.epa.gov/testmethods/7xxx.html).
- Rapid Assessment of Household Level Arsenic Removal Technologies, *Phase I-Final Draft Report, Jan 2001, WS Atkins International Limited for BAMWSP/DFID/Water Aid. Dhaka, Bangladesh.*
- Rasul, S. B., Ahmed, N., Munir, A. K. M., Washe, S., Khaliquzzaman, M., Khan, A. H. and Hussam, A. 1999. Speciation of Arsenic in Groundwater of Bangladesh. *Arsenic in Bangladesh Groundwater; World's Greatest Arsenic Calamity, International Conference. Wagner College, NY, Feb. 27-28, (1999).*
- Rasul, S. B., Munir, A. K. M., Ahmed, N., Washe, S., Alauddin, M., Khan, A. H., Khair, M. A. and Hussam, A. 1999. *Electrochemical Measurement and Speciation of Inorganic Arsenic in Groundwater of Bangladesh*. Prepublication Report. Sono Diagnostic Center Environment Initiative, Kushtia, Bangladesh.
- Rasul, S. B., Munir, A. K. M., Habibuddowla, M., Khan, A. H., Alauddin, M., and Hussam, A. 2000. *Natural Attenuation of Arsenic in Groundwater of Bangladesh: Experimental Measurement and Chemical Speciation Model*. Prepublication Report, Sono Diagnostic Center Environment Initiative, Kushtia, Bangladesh.
- Raven, K. P., Jain, A. and Loeppert, R. H. 1998. Arsenite and arsenate adsorption on ferrihydrite: Kinetics, equilibrium, and adsorption envelopes. *Environ. Sci. Technol.* **32**, 344-349.
- Roberts, L. A., Totten, L. A., Arnold, W. A., Burris, D. R. and Campbell, T. J. 1996. Reductive Elimination of Chlorinated Ethylenes by Zero-Valent Metals. *Environ. Sci. Technol.* **30(8)**, 2654-2659.
- Schecher, W. D. and McAvoy, D. C. 1998. *MINEQL+: A Chemical Equilibrium Program for Personal Computers, User's Manual, Version 4.0*. Environmental Research Software, Hallowell, ME 04347.
- Shokes, T. E. and Moller, G. 1999. Removal of dissolved heavy metals from acid rock drainage using iron metal. *Environ. Sci. Technol.* **33**, 282-287.
- Smith, A. H., Lingas, E. O. and Rahman, M. 2000. *Contamination of drinking-water by arsenic in Bangladesh: a public health emergency*. Bulletin of the World Health Organization, **78(9)**, 1093-1103.
- Snoeyink, V. L. and Jenkins, D. 1980. *Water Chemistry*. John Wiley and Sons. New York.

- Sun, Y-C., Mierzwa and Yang, M-H. 1997. New method of gold-film electrode preparation for anodic stripping voltammetric determination of arsenic (III and V) in seawater. *Talanta*. **44**, 1379-1387.
- Statistical Pocketbook of Bangladesh. 1994. *Bangladesh Bureau of Statistics, Government of Bangladesh (1994)*.
- Tam, G. K. H., Charbonneau, S. M., Bryce, F., Pomroy, C., Sandi, E. 1979. Metabolism of inorganic arsenic ( $^{74}\text{As}$ ) in human following oral injection. *Toxicol. Appl. Pharmacol.*, **50**, 319-322.
- Wilkie, A. J. and Herring, J. 1986. Adsorption of arsenic onto hydrous ferric oxide: effects of adsorbate/adsorbent ratios and co-occurring solutes. *Colloid and Surfaces A: Physicochem. Eng.Aspects*. **107**, 97-110.

## **Rapid Assessment of Technologies for Arsenic Removal at the Household Level**

**David Sutherland**

WS Atkins International Ltd.,  
Woodcote Grove, Ashley Road, Epsom, Surrey, KT18 5BW, UK

**Md. Obaidul Kabir**

BETS, House 44, Road 3A, Dhanmondi R/A,  
Dhaka-1209, Bangladesh  
and

**Naved Ahmed Chowdhury**

ITDG, House 32, Road 13A, Dhanmondi R/A,  
Dhaka-1209, Bangladesh

### ***Abstract***

*This paper reviews the results and conclusions from a DFID funded project 'Rapid Assessment of Household Level Arsenic Removal Technologies', carried out in association with the Bangladesh Arsenic Mitigation Water Supply Project. Nine technologies were assessed under this project. The project comprised two phases. Phase I sought to identify whether the nine technologies removed arsenic to below the Bangladesh Guideline Standard of 0.05 mg/L, under idealised field operating conditions. Phase II looked at arsenic removal under householder operation and considered the treatment of other water chemistry parameters, bacteriological contamination and the opinions of the householders who used the technologies. This paper considers the priorities in adoption of technologies, which are most effective in the treatment of groundwater and most acceptable to the potential users. It is argued that before a technology should be adopted it should be assessed against a given set of criteria (in the form of questions). These are: Does it work? Does it create any further chemical/biological problems? Is it acceptable to potential users? If not, why not? The issue of cost should only be brought into consideration if the technologies pass the preceding criteria. Five of the nine technologies (Alcan*

*enhanced activated alumina, BUET activated alumina, Sono 3-kolshi, Stevens Institute technology and the Tetrahedron) comfortably passed the arsenic removal test. Two others (DPHE/Danida 2-bucket system and GARNET) passed the arsenic removal test under certain conditions and two (Ardash filter and passive sedimentation) failed the test. The performance of the seven that were further assessed was variable, with most requiring some modification to design or use or a change of attitudes to hygiene by the users. The main concerns, particularly for the lower cost technologies, related to apparently high levels of faecal contamination, low flow rates, the use of chemical reagents, long waiting times within the filtration process and the maintenance of the technologies.*

## **INTRODUCTION**

This paper seeks to present nine technologies which were assessed as part of a DFID funded 'Rapid Assessment of Household Level Arsenic Mitigation Technologies' carried out under the Bangladesh Arsenic Mitigation Water Supply Project (BAMWSP) between November 2000 and March 2001. The rapid assessment considered many different aspects relating to the use of the technologies, and this paper seeks to summarise these aspects in the context of assessing the problems and prospects of water treatment and its sustainability.

The project was carried out with the premise that treatment of arsenic contaminated water is only one of many mitigation measures available. Other measures include use of surface water sources, rainwater harvesting, hand-dug wells, deeper wells and community supplies from uncontaminated wells. However, in the short term, treatment is potentially the most effective solution. Some of the cheaper technologies are, indeed, presented as only a short-term crisis measure.

The sustainability of these technologies is not just a function of the inherent robustness of the technology and of the treatment process used, but a function of the infrastructure and support services provided in support of the users of the technologies. If a technology needs little in the way of spare parts or reagents, then it may be sustainable. However, the fact that a technology may need a constant supply of reagents and spare parts does not mean that it is unsustainable, so long as the support services for the technologies are local and effective.

The aim of this paper is twofold:

1. Illustrate the performance and acceptability of the nine technologies, and
2. Show key issues that need to be considered if a technology is to be considered as a realistic and sustainable solution to water supply in arsenic affected areas.

**TECHNOLOGIES**

The nine technologies included in the rapid assessment are described in Table 1. Photographs of each are attached at the end of this paper. The treatment processes used included enhanced and regular activated alumina, resin columns, metallic iron and coagulation.

**Table 1 : The technologies included in rapid assessment**

<b>TECHNOLOGY</b>	<b>PROCESS</b>
Alcan Enhanced Activated Alumina (AL)	Adsorption to enhanced activated alumina (AAFS-50)
Ardasha Filter (AR)	Passive sedimentation and adsorption to clay/carbonised organic matter candle
BUET Activated Alumina (BUET)	Oxidation, adsorption to sand filter and activated alumina
DPHE/Danida 2-bucket System (DPHE/DANIDA)	Oxidation, coagulation and adsorption through sand candle
GARNET Home-made Filter (GARNET)	Passive coagulation with iron (from brick chips) and adsorption to sand
Passive Sedimentation (PASSIVE SEDIM.)	Passive sedimentation
Sono 3-kolshi Method (SONO)	Passive coagulation with Fe and/or adsorption to sand matrix
Stevens Institute Method (STEVENS)	Enhanced coagulation and co-precipitation (ferrous sulphate), filtration and adsorption to sand filter
Tetrahedron (TETRAHEDRON)	Ion exchange resin

Photographs of Alcan enhanced activated alumina filter, BUET activated alumina filter, GARNET home-made filter, DPHE-Danida Bucket Treatment Unit, Steven's Institute of Technology, Tetrahedron ion exchange filter and Sono 3-Kolshi filter are shown in Figures 1 through 7.



**Figure 1 : Alcan enhanced activated alumina filter**



**Figure 2: BUET activated alumina filter**



**Figure 3: GARNET home-made filter**





Figure 4 : DPHE-Danida Bucket Treatment Unit (BTU)



Figure 5: Steven's Institute of Technology



Figure 6: Tetrahedron Ion Exchange Resin Filter



Figure 7: Sono 3-Kolshi Filter

## **METHODOLOGY**

During Phase I, three replicates of each of the nine technologies were tested at twenty different wells (five in each of four areas of Bangladesh). Tests included arsenic, ferrous iron, total iron, total manganese, total aluminium, phosphate, nitrate, fluoride, chloride, sulphide, turbidity, redox, pH, conductivity, dissolved oxygen, sulphate and alkalinity. Technologies were operated by the field testing teams according to strict operating instructions and timing schedule.

During Phase II, three areas were used for the assessment (Satkhira, Iswardi and Hajiganj). In each area, twenty one wells were included in the assessment. At each well, three different technologies were used over a thirty day period. The same water chemistry tests were carried out as in Phase I but under normal operating conditions by the householders at each well. In addition, bacteriological testing of faecal coliforms was carried out. A social assessment was done with the householders to illicit their opinions of the technologies with regard to ease of operation and maintenance, flow rates, timeliness of water supply, quality of treated water (e.g. taste and smell).

## **PRESENTATION OF RESULTS**

This paper has used the results from the rapid assessment to put forward the idea that there is a process through which technologies should be evaluated, selections made and areas for improvement identified. This process requires answers to specific questions. If the answer to any of the questions for any of the technologies is clearly inadequate, then it is recommended that the technology should not be considered as a short/medium term solution to the arsenic problem. The key questions are seen as:

1. Does the technology reduce arsenic to below the Bangladesh Guideline Standard (0.05mg/L)?
2. Does the technology create any problems regarding major water chemistry parameters?
3. Does the technology create any bacteriological problems?
4. Is the technology acceptable to users?
5. If not, (a) Why not?  
(b) Are the reasons for unacceptability easy to address?
6. What is the cost/basis of cost of the technology?
7. What are the most appropriate financing options?

Each answer to each question for each technology, represents one box in Table 2. The darkness of the shading of each box represents the degree of concern relating to each answer for each technology.

When looking at the Table 3, the darkness of shading across the rows gives the degree of concern for each issue and the darkness of shading down each column gives the degree of concern for each technology.

**Table 2 : Degree of concern related to technologies under assessment**

	No cause for concern
	Some cause for concern. Issues need rethinking.
	Significant cause for concern. Issues need addressing and design and/or operation modifications required
	Technology not acceptable on these grounds. Proceed no further

## RESULTS

It is clear from the Table 3 that, overall, the most acceptable technologies are the Alcan, Tetrahedron, Sono and Stevens. It is also clear that arsenic removal and other water chemistry issues are, in many ways the least points of concern – the technologies do what they are designed to do on the whole.

The major issues relating to the prospects for the technologies and for sustainable use are the risk of bacteriological contamination and the acceptability of the technologies to prospective users. The main reasons why some technologies are not acceptable to the users are the amount of work needed to operate and maintain the technologies, the amount of time that they have to wait for water and the volumes of water that are available on a daily basis. These issues were highlighted in a rapid assessment. It is likely that they will become ever more a barrier to use in the longer term as householders become impatient with the volume of work and waiting times.

The amount of work required for, and the volumes of water produced by, the Alcan and Tetrahedron are considerably less than for the other technologies. However, they are considerably more expensive and this was a big barrier to acceptability.

**Table 3 : Relative performance of technologies**

Question	Alcan	Ardasha	BUET	DPHE/ Danida	Garnet	Passive Sedim.	Sono	Stevens	Tetra Hedron
Does the technology reduce arsenic to below the Bangladesh Guideline Standard (0.05mg/L)?	Yes (100% samples)	No (<5% samples)	Yes (99.5% samples)	Yes (but only below groundwater As<0.12mg/L)	Yes (but only when operate exactly according to instructions 75% samples If not, then 43% samples)	No (0% samples)	Yes (99% samples)	Yes (>90% samples)	Yes (>80% samples)
Does the technology create any problems regarding major water chemistry parameters?	No	-	No	Yes – manganese and aluminium significantly increased to above Bangladesh Guideline Standards	No	-	No	No	No
Does the technology create any bacteriological problems?	Some Temporary contamination on at times. Slight design changes and instructions to users	-	Yes Contamination in sand filter. Further research required	Yes Contamination in sand filter. Further research required.	Yes Contamination in sand filter. Further research required.	-	Yes Contamination in sand filter. Further research required	Very little Mainly from outlet pipe trailing on ground.	No

**Table 3 : Relative performance of technologies ( Contd. )**

Question	Alcan	Ardasha	BUET	DPHE/ Danida	Garnet	Passive Sedim.	Sono	Stevens	Tetra Hedron
Is the technology acceptable to users? If not, (a) Why not? (b) Are the reasons for unacceptability easy to address?	Yes (1 <sup>st</sup> favourite) Only concern is cost.	-	No (7 <sup>th</sup> favourite) Too tall and unstable difficult to use. Redesign required	Fairly acceptable (3 <sup>rd</sup> favourite) Bothersome use (reagents), waiting times. Maybe reconsider reagents.	No (6 <sup>th</sup> favourite) Slow flow rates (not enough As free water), heavy. Further research on materials/ design.	-	Yes (2 <sup>nd</sup> favourite) Main concerns difficult to move and slow flow rates.	Fairly acceptable (5 <sup>th</sup> favourite) Main concerns are cleaning frequency taste, need for additional reagents.	Fairly acceptable (4 <sup>th</sup> favourite) Main concerns are taste and smell and cost
What are the volumes of water produced in 12 hours?	>3600 litres Enough for >100 families	-	50 litres Enough for 1.5 families	43 litres Enough for 1 family	13 litres Not enough for 1 family	-	40 litres Enough for 1 family	169 litres Enough for 5 families	624 Enough for >20 families

## DISCUSSION

The rapid assessment illustrated that there are many different ways to successfully approach arsenic removal from groundwater at a household level. However, it also showed that arsenic removal is just one small element in the production of a successful and acceptable technology.

Many would argue that, given that the technologies are mainly designed to be a short/medium solution, bacteriological contamination is potentially a far more serious and immediate hazard to health than drinking untreated water. There are recommendations made for each of the technologies where there are problems with bacteriological contamination. These principally concern regular cleaning with hypochlorite to minimise contamination and a hygiene education programme as part of the distribution of technologies. This adds further stages to the water treatment process and potentially further reduces acceptability of the technologies to users.

In most cases, the process has been proven to be effective in the removal of arsenic and it is problems in the design of the technology to accommodate that process which has caused a reduction in acceptability. The more expensive technologies have gone for a much higher specification which has reduced the number of inconveniences to users and increased the performance in terms of volumes of water available.

There is some room for a trade off between cost and performance. However, lower cost should not be made the priority if it results in a technology which is unacceptable to users, does not produce sufficient water and which may deliver water of a lower quality and containing faecal coliforms. The Stevens is a good example of a lower cost technology that does perform well on all water quality issues (including microbiology) but needs some refinement to make it more acceptable to users, particularly with regard to cleaning. The Sono is highly acceptable and affordable, but the issue of contamination needs close scrutiny before mass production. It is believed that a smaller, less expensive version of the Alcan has been produced and is currently being evaluated. This is an example of where modifications to design to address the points of concern have been made.

The cost of water supply for these technologies has not been finally determined. The capital costs have been identified, but the regularity of replacement (following break through) has not yet been finally identified. This is important in the calculation of costs over a period of time and defining average costs per litre of water in the short to medium term.

The cost issue is one that varies in importance depending upon the financing arrangements that are proposed. For example, if the financing arrangements are for market sector, private purchase, then whether or not the more expensive units

(in terms of capital costs) are the cheapest in terms of cost per litre is immaterial. The vast majority of potential individual households will be unable to afford the capital costs. A group of households could potentially afford it if community supply was an acceptable option to users.

However, if some form of subsidy or public provision of technologies was the proposed arrangement, then the issue of cost is potentially a less crucial issue in terms of purchasing power. Value for money, rather than affordability, becomes more important.

## CONCLUSIONS AND RECOMMENDATIONS

There are a variety of processes which have been developed and which do remove arsenic. However, how these processes are packaged, in terms of engineering, can have a big influence on the treatment of other water quality parameters (both chemistry and microbiology) and on the acceptability of the technologies to potential users.

In many cases, refinements are needed to the technologies. This is not surprising as these technologies were among the first to be developed at this scale to address the groundwater arsenic problem. The important first step is to be sure that they remove arsenic. Once this has been proven, then it essentially a question of 'market testing' to identify ergonomic and other concerns of the users and to modify design to address these concerns. This rapid assessment was part of this on-going process of refinement and the process needs to be continued, particularly in relation to:

- reducing the risk of bacteriological contamination,
- increasing the acceptability of the technologies to users.

The issue of cost should not be a constraining factor until the process for introduction of these technologies, and associated financing arrangements, has been identified.

## **In-situ Removal of Arsenic - Experiences of DPHE-Danida Pilot Project**

**Anisur Rahman Sarkar and Omar Twabur Rahman**

Arsenic Mitigation Component,  
Danida SPS for Water Supply and Sanitation,  
Dhaka, Bangladesh

### ***Abstract***

*Two well-known methods of iron removal were tried to see their effectiveness in removing arsenic. One of these was in-situ sedimentation and the other was conventional iron removal technique. The analysis of the preliminary results revealed that both the methods are capable of bringing down arsenic level to Bangladesh standard when the raw water concentration is of the order of 0.1mg/l. The higher values could however, be reduced to halves of their originals. The former contamination level accounts for 50% of the total contaminated tubewells in most of the arsenic problem area. The promotion of these methods can bring a good range of coverage in arsenic mitigation in the country. The methods being chemical free are likely to be well accepted by the people. The methods may, however, be further improved for wider range of effectiveness and need to be field-tested for acceptability by the target group before mass scale promotion.*

### **INTRODUCTION**

The occurrence of arsenic in groundwater of Bangladesh is a major problem of the country. The contamination is of large scale and 8 years have passed since arsenic came into picture. Various organizations are still searching ways and means to address the problem. Treatment of arsenic contaminated water through appropriate technology is one of the options to mitigate arsenic problem. The latest but insignificant development with low-cost mitigation



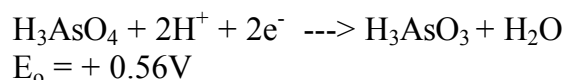
options demanded further investigations to identify immediate solution for the arsenic problem. With this end in view DPHE-Danida Arsenic Mitigation Pilot Project (AMPP) carried out action research on in-situ arsenic removal technology and on conventional iron-cum-arsenic removal technology (DPHE-Danida, 2000). For low concentrations of arsenic in the raw water the methods appeared to be promising and still having room for further improvement to broaden their spectrum. The process technology of in-situ removal and its experimental results would be presented here.

## THE PROCESSES TECHNOLOGY

The prevalent occurrence of arsenic species in Bangladesh ground water are that of As(III) and As(V). There are significant differences in the chemical behaviours of these species during removal techniques. The literature on arsenic concludes from its removal behaviour that As(III) cannot be separated from water effectively as easy and complete as pentavalent, As(V) (Jekel,1994). So oxidation of arsenite to arsenate is considered a prerequisite for any treatment method to be efficient. Dissolved oxygen is preferred oxidant if a catalytic process is possible, otherwise oxidants like potassium permanganate can be selected (Jekel,1994). Precipitation of As<sup>5+</sup> both by aluminium or ferric hydroxide is the method of arsenic removal, but dosing, filtration, and disposal of sludge are points of concern in operation.

### Oxidation of Arsenic(III)

The redox reaction of the As(III) /As(V) system is described by the equation:



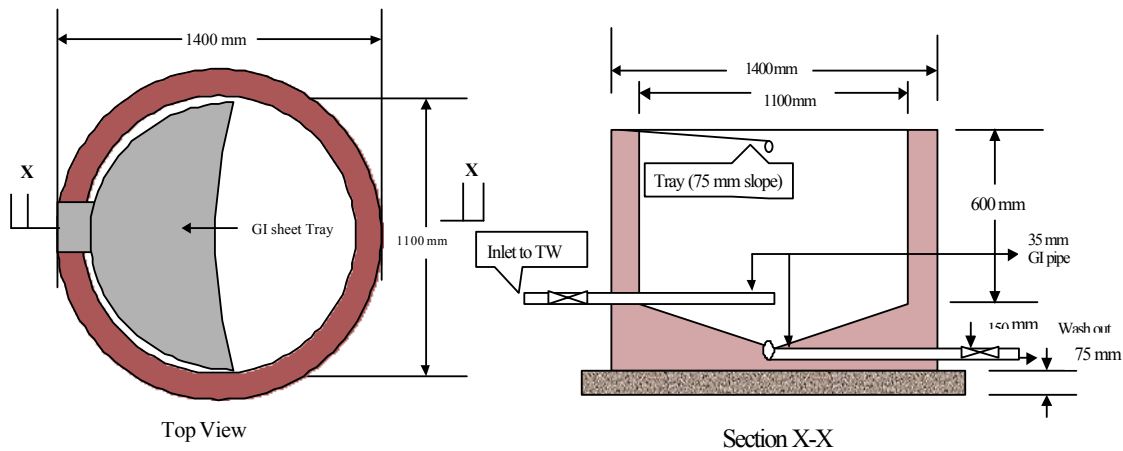
When Nernst formula is applied for the redox potential at pH 7, a value of +0.14V is calculated for the same concentration of the both forms. For a 99% oxidation of arsenic, however, +0.206V is necessary, indicating an easy oxidation of As(III), even by dissolved oxygen. However, the kinetics of a homogenous oxidation by O<sub>2</sub> is very slow (25-30% per 24hrs). As the effective removal of arsenic from water requires complete oxidation of As(III), special oxidation step is required to accelerate the oxidation process. There are number of means of oxidation, however, for drinking water treatment the residuals of oxidants, oxidation by-products, and the oxidation of other inorganic and organic constituents in water are to be checked very carefully.

## **IN-SITU SEDIMENTATION OF ARSENIC**

The technology of in-situ removal has successfully been used for iron removal. The process technology is to allow oxygenated water to run back into the iron and arsenic contaminated aquifer through the same tubewell. This allows forming coating of iron hydroxide on sand grain around the strainer and while pumping again arsenic and iron reduces to acceptable limit. In case of ground water with low iron content, solution of ferric chloride/sulfate at low pH may be injected to achieve the same situation. Natural oxidation in the water phase of trivalent arsenic to pentavalent arsenic is a very slow process. Solid-liquid interfaces, however tend to catalyze most chemical reactions and likely the arsenic oxidation also. In the aquifer the solid-liquid interfaces are abundant and by introducing oxygen to the aquifer arsenite will be oxidized to arsenate. Arsenate is much less mobile than arsenite as it tend to co-precipitate out with metallic cations or to adsorb onto solid surfaces. Ferri-iron is known to facilitate the arsenic oxidation both by catalytic effects and by direct reaction. The aquifer, over time, is expected to be conditioned improving arsenic removal.

## **DESIGN AND INSTALLATION**

A cylindrical tank with effective capacity of 500 litres was designed attached to tubewell with provision of wash out and returning the pumped water to the tubewell again. (Figure 1) The tank could be filled up to the required level with water from the TW by manually or using an electric pump. A contact aerator was designed to aerate the water during filling the tank. An arrangement was made to allow back flow of aerated water to the tube well through a pipe located 15-cm above the bottom of the tank to avoid iron flocs settled in the tank to flow back to the aquifer and clog the screen. The pipe was fitted with a gate valve and connected to the tube well pipe with a tee. There was an outlet at the bottom of the tank for wash out iron sludge. Necessary controlling valves, fittings and cover to the tank were provided for sanitary protection of whole setup including the tubewell. The cost of each setup could be accommodated within Tk. 2000 except the pumping unit. Manual operation of the unit was possible. Three such setups were installed in Majdee area attached to shallow tubewells (screen depth 10-12m) having arsenic concentration of 0.11 mg /l, 0.52 mg /l and 1.27 mg /l respectively. The iron concentrations of the respective tubewells were 1.02mg/l, 2.35mg/l and 1.04mg/l.



**Figure 1 : Feed Water Tank**

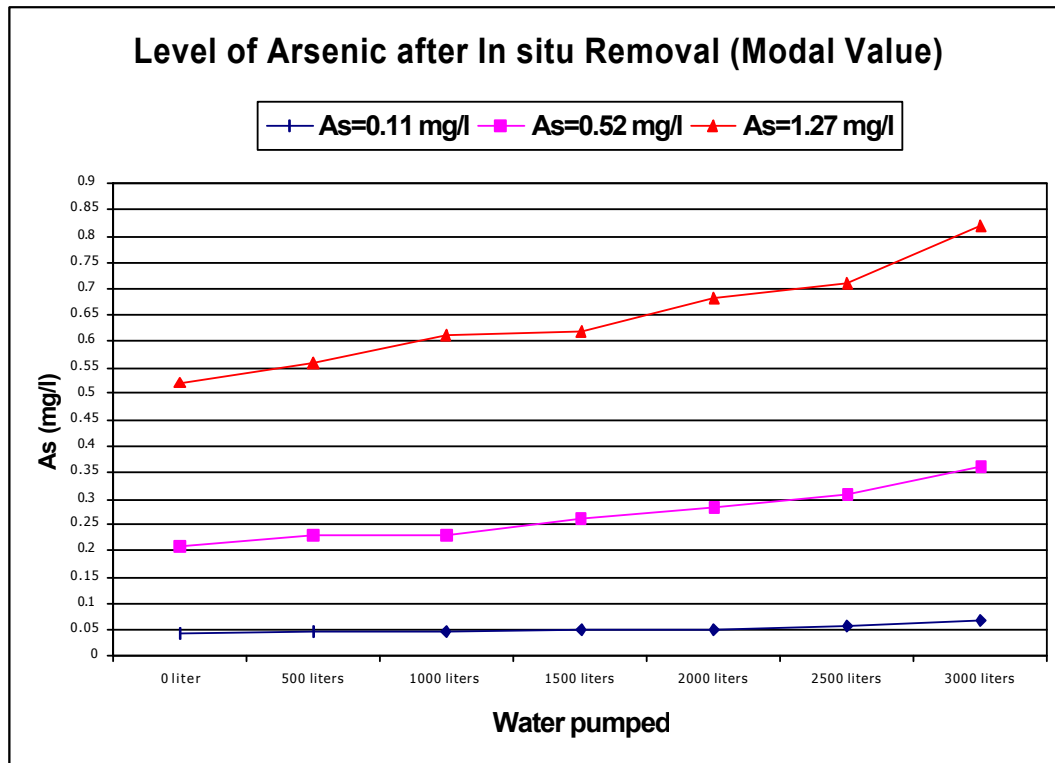
## OPERATION AND MONITORING

The operation of all the units were planned in such a way that every day at 6:00PM 500 litres of aerated water was allowed to flow back to the aquifer of each tubewell. The tubewells were left undisturbed for 12 hrs. Next day morning from 6:00AM water was pumped and samples were taken at every 500 litres of water pumped till 3000 litres of water was pumped. The samples were sent to the laboratory and tested for arsenic and iron. The process was continued for 1 month for all the installations and then monitoring was done once in a day at 5:00PM after normal use of the tubewell and continued for another month.

## RESULTS AND DISCUSSION

Water quality test results showed that the arsenic concentrations in the following day reduced to more than 50% in all the cases and remained so till 2500 litres of water was pumped. Then the arsenic level gradually increased to its original level. Although it was expected that over time with the continuation of the process the aquifer be conditioned and the removal efficiency would be increased but no such changes could be traced during the monitoring period. The modalities of the results are presented graphically in Figure 2. The oxygen level of the aerated water could be raised to 5mg/l with the present design of the contact aerator. Arsenic species ( $\text{As}^{3+}$  and  $\text{As}^{5+}$ ) of the raw water and treated

water were measured but the results so far obtained were inconsistent. As a result the effectiveness of oxidation of  $As^{3+}$  to  $As^{5+}$  in the solid liquid interface could not be ascertained fully. The reduction of the arsenic level up to 50% indicated that the adsorption/co-precipitation mechanism was active in the processes and this could be made efficient further through enhanced aeration of the feed water. In all cases the iron concentration was reduced to minimum level.



**Figure 2 : Arsenic Treatment Efficiency with Different Concentrations of Raw Water**

## RECOMMENDATION

In order to increase the efficiency of the process in removing arsenic the experiments can be repeated giving extra care to the following points:

- Oxygen level of the feed water is to be increased with sprinkler type aerator;
- Precise measurement of arsenic species of both raw water and treated water;
- Monitoring of oxygen level of feed water and pumped water;
- To increase iron content of the raw water to 10 times higher than arsenic;
- Prolong test of the process to see conditioning of aquifer if any.

## CONCLUSIONS

The analysis of the preliminary results revealed that the method is not promising for higher concentration of arsenic but capable of bringing down arsenic level to Bangladesh standard when the raw water concentration is of the order of 0.1mg/l. The values higher than this could however, be reduced to halves of their originals. The contamination level of 0.1mg/l accounts for 50% of the total contaminated tubewells in most of the arsenic problem area. As such the promotion of the method can bring a good range of coverage in arsenic mitigation in the country. The method being chemical free is likely to be accepted by the people. There is, however, scope for further improvement of the method for wider range of effectiveness and the option needs to be field-tested for acceptability by the target group before mass scale promotion.

## REFERENCES

- DPHE-Danida (2000) Arsenic Mitigation Pilot Project, Bangladesh, Quarterly Progress Reports, September 1999, December 1999, February 2000.
- Jekel, M. R. (1994), Removal of arsenic in drinking water treatment, In: Arsenic in the Environment, Ed. Nriagu, J. O., John Wiley & Sons, Inc., 1994.

# A Study of Arsenic Treatment Technologies and Leaching Characteristics of Arsenic Contaminated Sludge

Nikita Eriksen-Hamel and Begum Kamrun Nahar Zinia  
Bangladesh Consultants Ltd, Dhaka, Bangladesh

## **Abstract**

*The arsenic crisis of Bangladesh has led to massive concerted efforts of NGOs and donor agencies in mitigating the disaster. Most of the focus has been on awareness building and the development and distribution of arsenic removal treatment systems. The disposal of arsenic concentrated sludge generated from the treatment process is one issue that has received little attention from the sponsors of the technologies and the users. This study was aimed at determining whether the present sludge disposal methods are safe and arsenic does not return to contaminate the environment. The present research investigated 15 NGO-led arsenic mitigation projects in 11 districts. Qualitative data were collected from interviews with villagers and NGOs, while soil and sludge samples were collected from the field sites. Samples were analysed at the BUET Environmental Laboratory and a toxicity characteristic leaching test was conducted to determine the quantity of mobile arsenic in the sludge samples. This study has concluded that the arsenic treatment units rendered the majority of the arsenic into a stable and non-mobile phase. No hazardous leachate was identified from the sludge produced from these units. Therefore, present arsenic-sludge disposal methods appear to be safe and not to contribute to recontamination of the environment. It is hoped that this study will lay the groundwork for informed public debate on arsenic treatment technologies and more particularly on long-term consequences of sludge disposal methods.*

## COMPARISON OF DIFFERENT TYPES OF ARSENIC TREATMENT UNITS AND TREATMENT ALTERNATIVES

A comparison of the different types of arsenic treatment units in operation and treatment alternatives is provided in Table 1. The cost of each unit, treatment capacity, maintenance requirements and acceptability by users are compared. All the units, except the iron removal unit, have comparable and sufficient arsenic removal capabilities (greater than 90% arsenic removal). The possibility of arsenic leaching from the sludge/waste generated from the treatment processes is dependent on the type of removal mechanism and the ultimate sludge disposal method. These issues are covered in the next section.

**Table 1: Comparison of different types of arsenic treatment units and treatment alternatives**

Type of Unit	Removal Mechanism	Daily Capacity	Cost (Taka)	Complaints by Users
3-Pitcher Filter	Adsorption by iron chips and sand	25-40 L One Family	250-300	Clogging of pitcher
Chari Filter	Adsorption by iron chips and sand	25-40 L One Family	300-400	No complaints
Tubewell Sand Filter	Adsorption by iron chips and sand	20 Families	5,000	No complaints
3-Pitcher Brick Filter	Adsorption by brick and sand	25-40 L One Family	300	No complaints
Bucket Treatment Unit (BTU)	Oxidation and coagulation followed by settling	20 L One Family	300-400	Leaking of buckets, Lack of chemical
Fill and Draw	Same as BTU	20 Families or 1 School	10,000	No complaints
HYBRID	Coagulation with lime and alum, followed by settling	25 L One Family	550	No complaints
SIDKO	Adsorption by granular $\text{Fe}(\text{OH})_3$	200 Families	2,00,000	Too expensive and difficult Maintenance
Iron Removal Plant	Aeration, sedimentation and rapid filtration	10 Families	8,000	Partial removal of arsenic only

## **SLUDGE DISPOSAL METHODS**

An evaluation of sludge disposal methods was undertaken to determine whether the present methods lead to recontamination of the environment. Results of leaching test of sludge or soil samples would indicate whether the arsenic is bound to the adsorbent material or whether it leaches back into the environment. It was decided that direct observation of disposal practices in the field would be necessary. Both quantitative and qualitative data were collected during field visits. The method for obtaining data and the testing procedure followed are summarised below.

### **Methodology and Testing**

At the start of each field visit an interview took place with the NGO project coordinators. During this interview data were collected about the project size, extent of problem, number of units in place, and removal methods for each unit. Questions were also asked about the sludge disposal methods suggested by the NGO to the users.

Visits were then made to the users and further questions were asked. The interviews with the users provided information about the method of use, ease of use of the unit and the maintenance of the unit. Information regarding location, frequency and method of sludge disposal were also collected. It was found, except for a few exceptions, that the users followed the method of disposal suggested by the NGOs. This information was used to determine whether a sludge sample should be collected for analysis.

A sample of the sludge or left-over residuals was collected from each type of unit at least once and from each NGO. The location and methodology of collecting the sample varied depending on the situation. Ideally, the collection method should have remained the same but differences in disposal methods, lack of available sludge and sludge collection systems made the sampling procedure vary. There were four types of sampling methods; (I) collecting the absorbent media from the treatment unit, (II) collecting the absorbent media from the disposal site, (III) collecting the material on which the sludge was disposed (in the case of liquid sludge), (IV) collecting absorbent media from a sludge storage system. In all cases, a predominately solid phase sample of approximately 100g was collected into a plastic-sampling jar with a scoop or by hand. No sample preservation techniques were used when transporting samples from the field to the laboratory. The time between sample collection and sample testing averaged about one week. During this time samples remained in storage containers.

The types of materials collected by sampling method I was sand, brick, and iron chips. These were collected directly from the units primarily because there



had not been any recent disposal of material or the location of disposal was too arbitrary to be precise. Sampling method II was used when the location of disposed adsorbent media (usually sand) could be found. This sampling procedure provides the best opportunity to examine of whether there is leaching of the arsenic out of the adsorbent media into the ground. Sampling procedure III is similar to procedure II except that it was used when a liquid sludge had been disposed of. Cow-dung and soil samples, on which the liquid sludge was poured onto, were collected. A leaching test of these samples would indicate whether the liquid sludge binds to the cowdung/soil particles or leaches into the environment. In two cases, NGOs had developed a sludge collection system. The sludge was collected in pitchers or buckets and stored for further remediation. To date the NGOs have not developed a remediation process although credit should be given to them for taking steps to control indiscriminate sludge disposal. Sampling procedure IV collected the saturated sand from 3-pitcher unit from the spent pitchers in these storage areas.

The leaching test that was determined to be appropriate for this project was the Toxicity Characteristic Leaching Procedure (TCLP, USEPA method 1311). The TCLP is designed to determine the mobility of both organic and inorganic analytes present in liquid, solid and multi-phase wastes (USEPA, 1992). The Bangladesh University of Engineering and Technology (BUET) Environmental Engineering Laboratory was contracted to perform the leaching tests. Three initial samples were tested at a private laboratory, Intronic Technology Centre (ITC). However, BUET was chosen to perform the rest of the tests because of its good reputation and better laboratory facilities.

Typically, the TCLP test removes the mobile component of any analyte present in the solid phase. The solid phase sample is extracted with an amount of extraction fluid equal to 20 times the weight of the solid phase. The extraction fluid employed is a function of the alkalinity of the solid phase of the waste (USEPA, 1992). The resultant extract from the TCLP test is the leachate. This leachate was analysed by atomic absorption spectrophotometer. The lower detection limit for this test is 0.001 mg/L. The reported concentration of arsenic in the leachate is precise to  $\pm 10\%$ .

## **RESULTS AND DISCUSSION**

The results from the TCLP tests are presented in Table 2. The type of material tested, the arsenic concentration in the leachate, the sampling procedure, treatment unit of origin and the sponsoring agencies are also indicated in the table. The types of adsorbent media tested have been grouped together for better comparison.

**Table 2: Results of TCLP tests performed on sludge/soil generated from arsenic removal units**

Sample No.	Sample Type	Arsenic Concentration in TCLP Extraction Fluid (mg/L)	Sampling Procedure	Arsenic Treatment Unit	Name of the sponsoring agencies and Location
1	Iron Chips	<0.001	I	TWSF	DCH, Pabna
2	Iron Chips	<0.001	I	Chari Filter	DCH, Pabna
3	Sand	0.002	I	TWSF	DCH, Pabna
4	Sand	0.001	I	Chari Filter	DCH, Pabna
5	Sand	0.002	II	Pitcher Filter	AFV, Rajshahi
6	Sand	<0.001	I	Chari Filter	DCH, Pabna
7	Coarse Sand	<0.001	IV	Pitcher Filter	BRAC, Jhikargachha
8	Fine Sand	0.003	IV	Pitcher Filter	BRAC, Jhikargachha
9	Brick	0.005	I	Brick Pitcher Filter	Grameen, Kachua
10	Cow Dung	0.002	III	BTU	NGO Forum, Manikganj
11	Soil	0.006	III	BTU	VERC, Nawabganj
12	Soil	0.012	III	Fill & Draw	Danida, Maijdi
13	Cow Dung	0.007	III	BTU	Danida, Maijdi
14	Soil	0.003	III	BTU	NGO Forum, Sylhet
15	Cowdung	0.001	III	Hybrid Filter	Hybrid, Singair
16	Soil	0.013	III	Brick Pitcher Filter (Wash Water)	Grameen, Kachua
17	Soil	0.043	III	Alum Settling	MCC, Maijdi
18*	Sand& Iron	<0.001	I	Pitcher Filter	BRAC, Sonargaon
19*	Sand	<0.001	I	Safi Filter	BRAC, Sonargaon
20*	Sand	<0.001	II	Pitcher Filter	BRAC, Sonargaon

\*Note: These samples were tested at Intronic Technology Centre

It was observed that in almost all cases arsenic leaching was observed, although the concentration in the TCLP extraction fluid was very small. The highest leachate concentration observed was 0.043 mg/L. This was from an “alum settling method” developed by MCC. On the other hand, iron chips from the “Chari” and “tubewell sand filter” indicated almost no leaching at all.

Additionally the total arsenic contents of some randomly selected soil/sludge samples have been determined and are presented in Table 3 along with the concentration of arsenic in TCLP extraction fluid. From Table 3, it can be inferred that leaching rate is independent of arsenic content in the original residual.

**Table 3 : Comparison of total arsenic concentration in sludge/soil samples & corresponding arsenic concentration in the TCLP extraction fluid**

Sample No.	Sample Type	Arsenic Content in Dry Solids (mg/Kg dry wt.)	Arsenic Concentration in TCLP Extraction Fluid (mg/L)	Sampling Procedure	Arsenic Treatment Unit
2	Iron Chips	7.09	<0.001	I	Chari Filter
4	Sand	6.55	0.001	I	Chari Filter
7	Coarse Sand	1.63	<0.001	IV	Pitcher Filter
8	Fine Sand	3.44	0.003	IV	Pitcher Filter
9	Brick	15.16	0.005	I	Brick Pitcher Filter
12	Soil	14.46	0.012	III	Fill and Draw
14	Soil	12.62	0.003	III	BTU
16	Soil	8.50	0.013	III	Brick Pitcher Filter (Wash Water)

These initial results give the impression that leaching of arsenic from sludge/soil generated from arsenic removal processes is not a major problem. A USEPA criterion for leachate concentrations was used to make a comparison of the level of toxicity of these samples. According to the criteria, if arsenic concentration in the extraction fluid exceeds 5 mg/L, the waste is considered as a “hazardous waste”. It is observed that the leachate concentrations of all the samples are over 100 times less than the USEPA hazardous waste criteria, and according to this criteria none of the samples can be classed as “hazardous”. No comparable criterion exists in Bangladesh.

However, the leachate concentrations are all well below the drinking water criteria of 0.05 mg/L. It should also be noted that further dilution may occur after leaching of arsenic from sludge/soil, further reducing the arsenic concentration in the leachate. With these arguments in mind, it is safe to assume that no dangerous level of arsenic leaching is occurring from the sludge from

various treatment processes in use. The arsenic being removed from the drinking water remains in a stable and non-mobile form in the sludge.

As to the specific methods of disposal that are characteristic to each treatment type, it can be noted that there appears to be no significant difference between the different disposal methods. The alum settling method developed by MCC had a leachate concentration that was significantly higher than all other samples. There are a few possible explanations. The first is that there might not have been sufficient oxidation of arsenite into arsenate prior to settling. The arsenite are more likely to be mobile and leach out of the soil sample. Another explanation could be possible experimental error. However, it should be noted that even a leachate concentration in the order of 0.05 mg/L is still 100 times less than the hazardous waste criteria and is still within drinking water criteria.

## **CONCLUSIONS**

Field observations and interviews with the sponsoring agencies, particularly NGOs, and beneficiaries of arsenic treatment units have indicated that there is much promising and fruitful work being done to tackle the overwhelming arsenic contamination problem. Many arsenic awareness programs and mitigation projects are in operation and are being expanded by local and international NGOs. It is important to note that the success of many small-scale projects (less than 20 units) has shown a good potential for expansion. Equally important is the observation that even large scale projects (over 1000 units) have had similar successes and have not been hampered by the bureaucracy that often characterises these projects. All the treatment units in operation successfully reduce high levels of arsenic in tubewell water below the 0.05mg/L drinking water standard.

## **Evaluation of Arsenic Mitigation Technologies for Use in Bangladesh**

**Roy K. Boerschke and Donna K. Stewart**

Ontario Centre for Environmental Technology Advancement (OCETA),  
63 Polson St., 2<sup>nd</sup> Floor, Toronto, Ontario, Canada. M5A 1A4.

### ***Abstract***

*Arsenic contamination of groundwater sources for the rural population of Bangladesh has become a major health issue. Central to any arsenic mitigation effort will be the availability of viable and cost effective technologies for treating arsenic contaminated water. The Environmental Technology Verification – Arsenic Mitigation (ETV-AM) Program is multi year, CIDA funded initiative designed to work in association with the Government of Bangladesh (GoB) and other international and national development partners working in the arsenic mitigation sector. The initiative is an intensive program designed to assess technologies based upon a rigorous performance criterion, followed by verification under conditions of actual use. Only those technologies meeting the specific requirements of Bangladesh will be implemented. The primary objective of ETV-AM is to complete a thorough assessment and verification of arsenic mitigation technologies that are currently being utilized or proposed for use in Bangladesh, based upon standards established in association with the GoB. In addition, ETV-AM will institutionalize a mechanism by which all proposed future technologies can be evaluated. All technology options are screened based upon a weighted decision matrix that integrates technical, social and fiscal parameters. A limited number of technologies that best meet the requirements of Bangladesh, based upon the screening protocol, are advanced through a funded assessment and verification program. Assessment and verification is based upon technical standards established in association with the GoB. In addition, social and fiscal criteria specific to Bangladesh are evaluated. Technologies wishing to bypass the ETV-AM process must still meet all requirements of technology assessment and verification based upon the technical standards established by the ETV-AM Program.*

## INTRODUCTION

Contamination of groundwater with arsenic has become a public health crisis in Bangladesh. Groundwater is the primary source of drinking water for the inhabitants of rural Bangladesh, with approximately 95 percent of the population consuming water obtained from bore hole wells (tube wells). Conservative estimates indicate that in excess of 21 million people are consuming water containing arsenic concentrations above 50 $\mu$ g/L, the recommended limit in Bangladesh<sup>(1)</sup>.

The effects associated with the chronic ingestion of arsenic contaminated water are unclear. Epidemiological studies have indicated a correlation between the ingestion of inorganic arsenic and health effects<sup>(2,3)</sup>. Studies indicate the incidences of skin cancer and cancer of specific internal organs increases with increased exposure to inorganic arsenic<sup>(4)</sup>. In addition, non-cancerous effects have been reported for skin, vascular and gastrointestinal systems<sup>(4)</sup>. To date, approximately 150,000 patients have been diagnosed with symptoms of arsenic poisoning in Bangladesh<sup>(1)</sup>, with numerous deaths being associated with complications resulting from arsenicosis.

The issues surrounding the arsenic crisis cannot be understated. In addition to the potential enormous cost with respect to human lives, issues associated with quality of life, social interactions, and potential losses of revenue from both lost productivity and income generated from exports of crops must be emphasized<sup>(5)</sup>. Inaccurate information has also help feed the crisis attitude and in many instances has significantly impacted the ability of donors to assist in addressing the situation.

Many efforts have been undertaken in an attempt to provide relief to individuals consuming arsenic contaminated water. The Government of Bangladesh (GoB), as well as national and international development partners, in an attempt to determine possible options for arsenic mitigation has been inundated with technology options by vendors and institutions. Some technology options have been adopted without rigorous testing and have failed when applied in the field. The application and subsequent failure of technologies have severe social consequences. Failure of technologies has led many communities to lose faith, and has severely damaged the hard-earned credibility and goodwill of implementing agencies. In addition, the failure of technologies has resulted in unwillingness by many development partners to commit funds to arsenic mitigation, specifically the implementation of remedial technology options without appropriate control procedures.

The application and subsequent failure of technologies that have not undergone rigorous technical reviews clearly indicate the urgent need to introduce a technology assessment and verification program in Bangladesh.

Through an intensive program designed to assess technologies based upon a rigorous performance criterion, followed by verification under conditions of actual use, only those technologies meeting the specific requirements of Bangladesh will be implemented.

The Environmental Technology Verification – Arsenic Mitigation Program (ETV-AM) is an initiative focused upon the development and implementation of a mechanism through which a formal assessment and verification of arsenic mitigation technologies can be undertaken in a recognized, systematic manner.

### **ETV-AM PROGRAM OVERVIEW**

The GoB, working with national and international development partners, has undertaken arsenic mitigation projects in Bangladesh to address the public health crisis resulting from contamination of the groundwater. A key element of the mitigation strategy is to identify viable arsenic removal technologies for application at the household and extended household level in Bangladesh. The purpose of the ETV-AM Program is to complement the current GoB initiatives by evaluating the appropriateness and applicability to Bangladesh of technologies for removing arsenic from groundwater using a rigorous technology assessment and verification process.

Through ETV-AM, OCETA in collaboration with the GoB, international agencies, academic institutions and NGOs, has begun to establish a comprehensive technology verification process for reviewing proposed groundwater arsenic mitigation technologies. Following development of the technology verification process, ETV-AM will work with the GoB and national and international development partners in performing detailed screening to identify the best candidate arsenic mitigation technologies, with subsequent formal assessment and verification.

The ETV-AM Program encompasses two phases (Figure 1). Phase I consists of three stages:

- i. Stage 1 – Screening
- ii. Stage 2 – Laboratory Performance Evaluation and Review
- iii. Stage 3 – Field Testing and Verification

Evaluation of proposed arsenic mitigation technologies is based upon internationally recognized technical protocols. In addition, technologies are evaluated on social and economic parameters specific to Bangladesh.

The goal of Phase I is to identify suitable technologies for arsenic mitigation of drinking water using a rigid assessment and verification program. To meet the Program goal for Phase I, the following objectives were established:

1. Develop detailed criteria for screening, assessing and verifying arsenic mitigation water treatment technologies in association with the GoB and stakeholders;
2. Screen candidate technologies based upon the criteria;
3. Conduct laboratory tests to validate the efficacy of the technologies based upon the established technical protocols, and identify possible changes that may enhance a given technology, as required;
4. Organize independent third party verification of vendor performance claims against an established protocol(s); and
5. Perform field verification of technologies under actual operational conditions and identify strengths and weaknesses of candidate technologies under field conditions.

Working in association with the GoB, the ETV-AM Program has developed a mechanism through which the following tasks can be undertaken in a systematic manner (Figure 1).

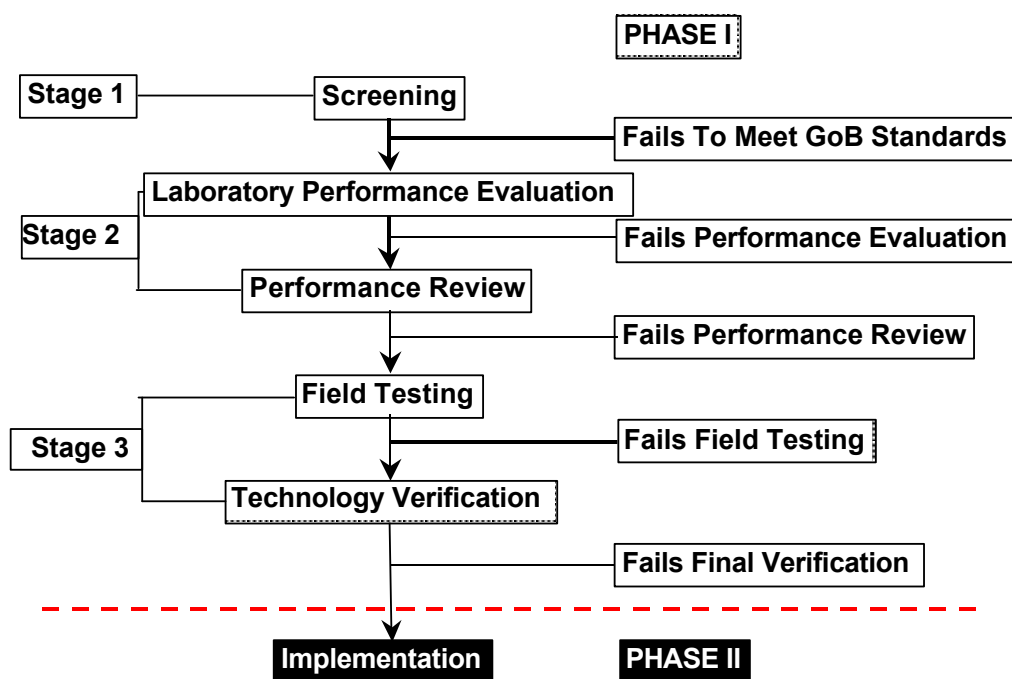


Figure 1 : Stages in Phase I of the ETV-AM program



## **ETV-AM PROGRAM COMPONENTS**

### **Registration**

The initial stage that must be undertaken by all proponents is registration of their proposed technologies with the GoB. The registration mechanism will be the first stage of a controlled pathway through which arsenic mitigation technology applications will be processed. ETV-AM is working with the GoB through the Bangladesh Arsenic Mitigation Water Supply Project (BAMWSP) implementing the mechanism through which technology registration will be undertaken.

Technology proponents will be required to provide specific technical, social and fiscal information. Technologies brought forward without the necessary documentation (i.e. 'Black box' technologies) will not be accepted. A detailed application for all potential applicants is required because it provides the GoB and implementing agencies an information source upon which to base their evaluations and provides a common reference upon which all parties can fallback. ETV-AM, in association with the GoB and development partners has produced an electronic application, which will be used as the basis for a formal application.

Technology proponents are offered two possible courses for verification:

- i. Proponents are invited to participate in the ETV-AM process. The ETV-AM process is designed to screen all technology applicants based upon a series of technical, social and fiscal parameters specific to Bangladesh, through which a limited number of technologies shall emerge. The technologies that emerge from the screening process will be those that best demonstrate themselves with respect to the parameters identified, thus having the greatest potential for long-term viability. The ETV-AM Program absorbs costs associated with assessment and field verification of the technologies emerging from the screening process. It must be noted that technologies will be screened based upon criteria established by OCETA, in association with BAMWSP and national and international development partners, and reflect parameters that are viewed to most significantly impact the viability of technology options.
- ii. Proponents may proceed directly to the technology assessment and the field verification stages of the process, bypassing the ETV-AM screening stage. Proponents choosing to bypass the screening stage will undergo assessment and field verification based upon the technical standards established by the ETV-AM Program, and will be required to absorb all costs associated with the necessary assessment and field verification.

## Screening

The formal screening of the technologies is based upon a decision matrix that integrates technical, social and fiscal criteria. The criteria are evaluated using recognized protocols, and when necessary, tailored to meet the specific needs of Bangladesh. The proposed matrix for ETV-AM incorporates a two-tier mechanism designed to allow for both the recognition of key parameters being met and for the weighted assessment of technologies.

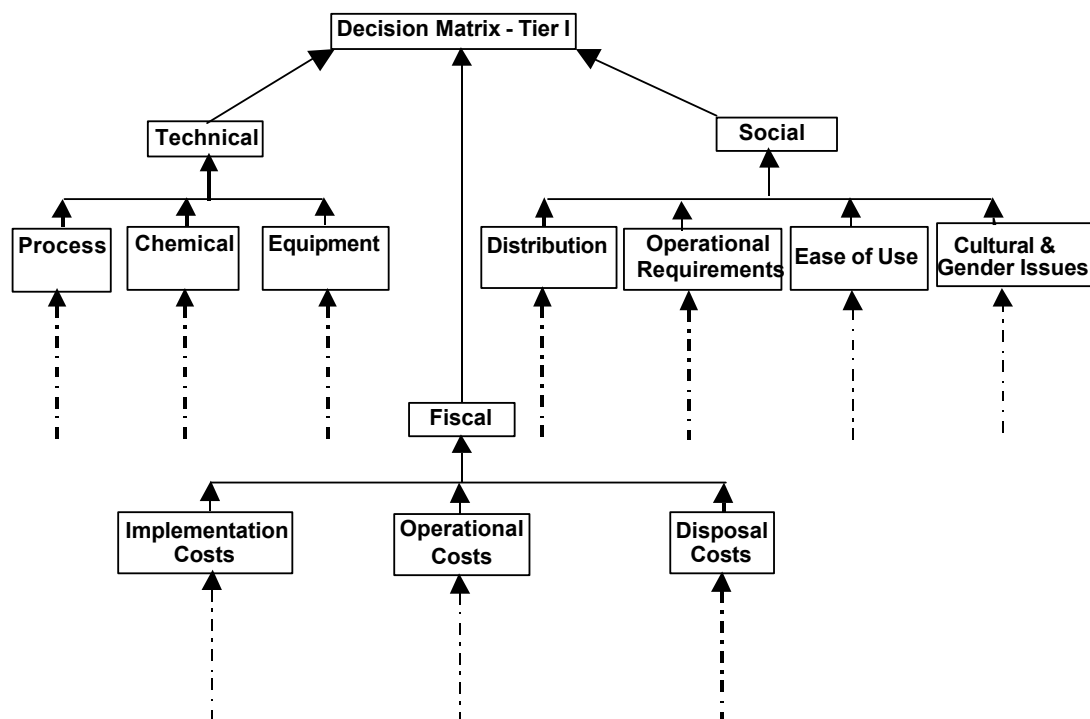
### *Tier I – Decision Matrix*

Tier I screening involves a detailed examination and consideration of the candidate technologies. Technologies will be scored based upon the established criteria as to their suitability for use in Bangladesh. The screening will consider the following aspects of the treatment system (Figure 2):

- *treatment/process* – including chemical/physical mechanisms, expected treatment performance, potential limitations on performance, process chemical requirements, power requirements, flow dynamics, hardware requirements, servicing requirements, media regeneration and waste disposal requirements;
- *social/cultural compatibility* – including feasibility of distributing the equipment and materials, ease of system use by women, and feasibility of local system maintenance;
- *capital/operating costs* – including installation/startup costs, operating and maintenance costs, and costs related to disposal of spent units and/or chemical wastes.

An objective scoring system has been developed to accomplish the screening, which results in an overall relative ranking of the candidate technologies in each end use category, based on the above-mentioned features of each treatment system. Technologies with the highest ranking will be those that can provide the most effective treatment, with the fewest potential problems, the greatest convenience and the lowest annualized cost<sup>(6)</sup>.

Based on the ranking of candidate technologies in each category, the top 10 to 20 technologies will be selected for a further, more detailed evaluation in Tier II.



**Figure 2. Fundamental Tier I Decision Matrix utilized to evaluate arsenic mitigation technologies for the screening stage of ETV-AM.**

### *Tier II – Cost Benefit*

The second tier of screening involves a quantitative cost-benefit evaluation of each candidate technology retained from Tier I. Each technology is evaluated according to its end use category. The Tier II evaluation considers the same types of information considered in Tier I, but with more precise quantitation of the costs and benefits associated with the technology.

For the purpose of this evaluation, the end use scenarios are precisely defined in terms of typical numbers of people and/or families served, treated water use rates, initial water quality conditions, site accessibility and social/cultural aspects. The technologies are evaluated in the context of these three reference scenarios. Cost to the consumer is estimated for each technology, to include annualized installation and startup costs, operating and maintenance costs, and costs for proper disposal of waste materials. The sum of these costs represents the overall system cost, expressed on a per capita basis.

The benefit to the consumer is estimated as a health risk reduction (e.g., from arsenic removal) minus any new health risk produced (e.g., from other elements added to the water, or from handling/disposal of process/waste chemicals). Risk quotients are used to quantify health risk, using standard risk assessment methodology, and considering both cancer and other health effects.

Factors contributing to the estimate of risk reduction include<sup>(7)</sup>:

- the likelihood of consumers bypassing the treatment system, based on ease of use and social/cultural considerations, and the quality of alternate water supplies;
- the likelihood of system failure due to factors such as possible process chemical instability, difficulties in maintaining the system in working order, or variability in effective lifespan of treatment media;
- the expected frequency of handling of toxic process and/or waste chemicals, their toxic properties and possible exposure routes;
- the expected concentrations and toxic properties of any process chemicals that might be elevated in treated water.

The cost-benefit ratio for each technology are calculated as the risk quotient reduction that it produces, divided by the overall annualized cost of the technology on a per capita basis. The top few technologies in each end use category are selected for subsequent laboratory and field verification.

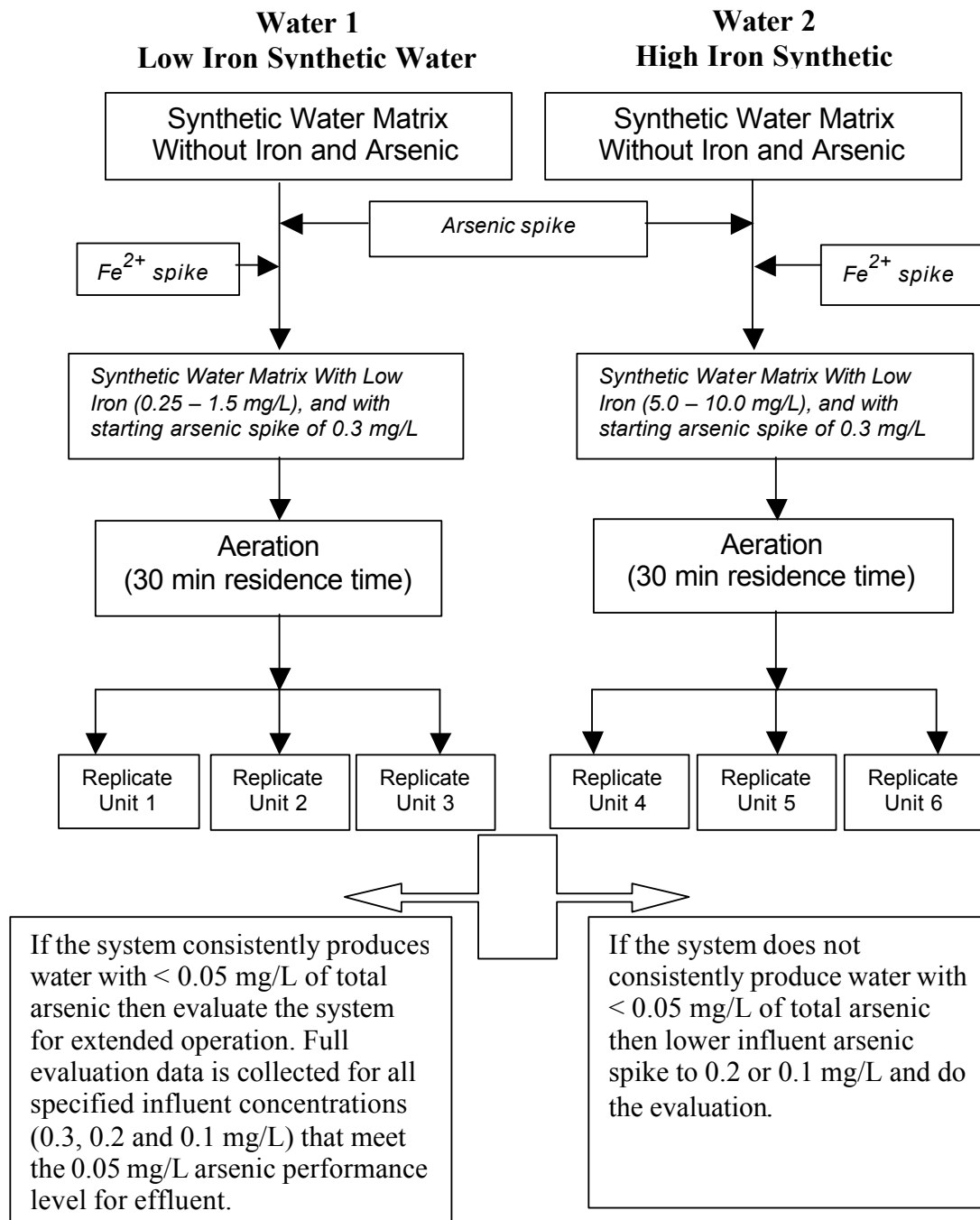
### **Laboratory Performance Evaluation**

The Laboratory Performance Evaluation (laboratory testing) allows all technologies to be evaluated under standardized conditions using synthetic water matrices developed from water quality data for shallow well aquifers (<150 m in depth, zone of arsenic contamination) in Bangladesh. This phase of the Program is designed to generate data in the laboratory that then undergoes third party review (Verification) to ascertain data quality and evaluate the conclusions.

The central concepts associated with the Laboratory Performance Evaluation are<sup>(8)</sup>:

1. The use of the synthetic water with characteristics similar to Bangladesh groundwater with regimes of low and high iron content;
2. Influent arsenic concentrations and speciation reflective of the distribution pattern observed in contaminated wells in Bangladesh;
3. The simulation of pumping and water usage in Bangladesh and its effect on the redox potential of Bangladesh groundwater;
4. The use of multiple (replicate) units of the same treatment system to evaluate consistency of performance between units;
5. Duration of testing to reflect water usage in households and extended households of Bangladesh;
6. Evaluation of the quality of the treated water primarily in terms of arsenic and other inorganic, organic and bacteriological water quality issues;
7. Definition of cycles of operation and evaluation of performance in-cycle and from cycle to cycle; and
8. Quantification and characterization of process waste.

Figure 3 illustrates the overall experimental methodology for performance evaluation of technologies.



**Figure 3. Overall outline of the experimental methodology**

Note: If the system treats successfully at 0.3 mg/L influent arsenic concentration, higher concentrations of arsenic spiked water are then used to test limits of system performance in the same manner outlined in the overall experimental methodology.

## Performance Review

The Verification Process will assist, as a minimum, in the determination of mandatory criteria (scientific soundness of technology, environmental benefits, etc) and any limitations to the arsenic mitigation technology and the validation of the data. The Statistical Analysis Worksheets (SAWs) are a tool to assist the Verification Entity (VE) in evaluating data supplied by the applicant or a testing agency. The SAWs are used to aid the VE in determining whether the data support the arsenic mitigation performance claim(s) made by the applicant.

The Verification Protocol (VP) is designed for use by a VE responsible for the validation of data and information that support the performance of any environmental technology. The verification process follows procedures and principles developed for the ETV process. All client technologies require third party independent data to support their performance claims and these are then verified by a different third party independent verification entity. It is designed for personnel who have expertise in the development or use of arsenic mitigation technologies. The Protocol may also prove useful to agencies and personnel who are involved in the development and evaluation of arsenic mitigation technologies.

The VP consists of five sections:

*Section 1* - Review of Application, guides the VE through a review of the Formal Application Form and all other information and documents provided by the applicant. The VE should determine if adequate data or information is (or will be) provided. Section 1 ensures that the VE has a full understanding of the technology and claims to be verified.

*Section 2* -Review of Technology, allows the VE to review the specific technology for which the performance claim(s) is being made. The objective at this stage is to ensure that the described technology meets the verification criteria.

*Section 3* -Review of Data, involves the review of the verification study design, data validity and acceptability concerning the specific technology performance claim(s) being made. A series of Criteria Checklist tables allow the VE to determine the quality of the data provided with regards to statistical evaluation or mathematical analysis to support the performance claim(s).

*Section 4* -Summarizes the results of statistical evaluation made on the performance claim(s).

*Section 5* -Provides guidance on final report preparation.

Technologies that successfully complete the performance review will have a “Technology Fact Sheet”, advising the GoB and development partners of the following:

- A description of the technology
- Performance claim(s)
- The fundamental principles behind the technology
- Operating parameters
- Anticipated cost of implementing the technology
- Possible restrictions associated with the technology

### **Field Testing**

Field Testing is the final stage of evaluation to determine conclusively that the technologies perform according to their performance claims under varying conditions.

The goals of the field test program are listed below<sup>(9,10,11)</sup>:

- Evaluate the performance of a technology at pseudo steady state at a given well;
- Define performance under field conditions;
- Evaluation of technology-society interface of the technology;
- Not to summarily dismiss technologies with limited arsenic removal capacity;
- Provide guidance for choice of technology appropriate for use at a given well.

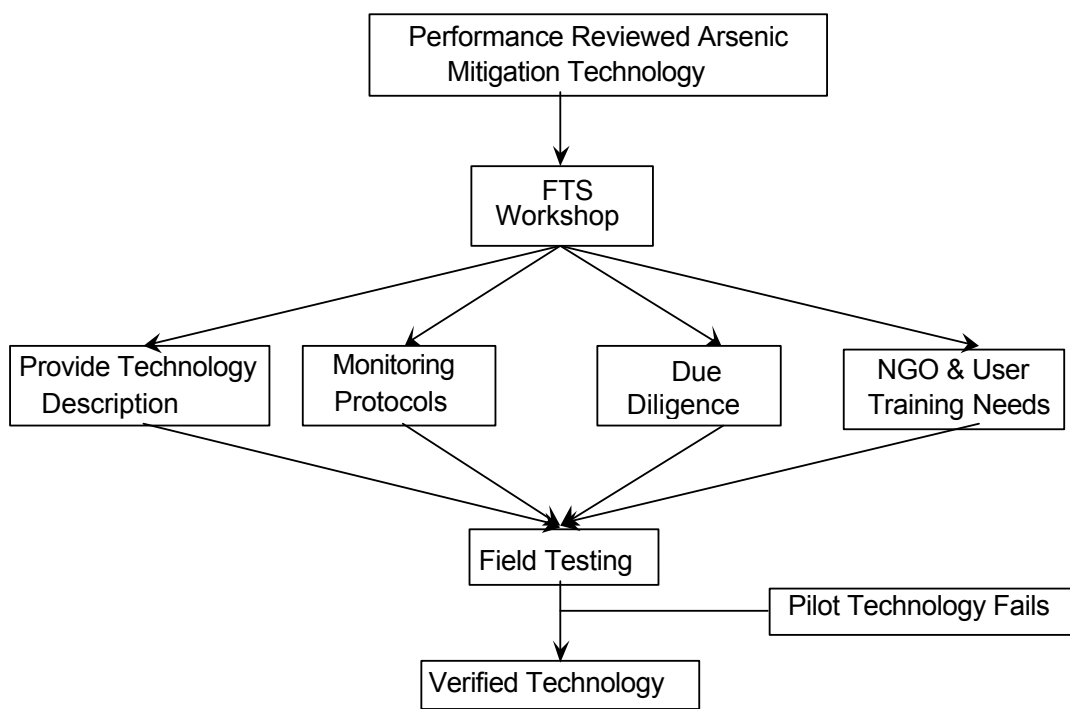
Figure 4 outlines the steps in the Field Testing Stage (FTS) for any candidate technology. Technologies successfully completing a performance review will have Technology Fact Sheets forwarded to development partners. Stage 3 commences with a workshop, involving GoB and development partners participating in the field verification of the technology(ies). Workshops focus upon addressing major components associated with the performance of the FVS: (1) technology overview, (2) required monitoring protocol, (3) performing socio-economic and environmental due diligence, and (4) training.

### ***Technology Overview***

Agencies undertaking field verification are provided with a detailed description of the candidate technology to be piloted, including the chemical and physical aspects of the technology, how these parameters are related to the criteria, and strengths and weaknesses of the technology identified during assessment.

The technology overview is designed to facilitate a better understanding of the candidate technology(ies) by agencies responsible for the field verification and ultimate implementation of the technology(ies). Technology overview is also

used as a means for enhancing possible technologies and operational procedures through a feedback mechanism.



**Figure 4 : Stage 3 - Field verification of certified arsenic mitigation technologies.**

### *Technical Monitoring*

The field-testing program generates performance data for verification and assesses the potential impact of the water quality parameters on technology performance<sup>(9)</sup>. The parameters chosen for inclusion in the analytical reporting reflect the expected water matrix in Bangladesh. The initial phase of the field evaluation program collects data required for verification of technology performance under field conditions. Technology performance can be impacted by interfering ions present in the water matrix (e.g. iron, phosphate, sulphates). Wellhead technologies lack the upstream pre-treatment train (e.g. sand filters, activated carbon) found in large-scale treatment plants. The experimental plan considers the impact of the interfering ions on the potential technology types that may be considered. The protocol recognizes performance curves generated under field conditions will differ from those derived in the laboratory using a synthetic matrix. Sufficient data is collected to generate new performance curves under field conditions.

Technologies are operated in accordance with the manufacturer's operating instructions. The manufacturer and/or laboratory tests provide cycle estimates. Refinements to cycle estimates occur during the field assessment as additional



data is collected. The field assessment evaluates the technology's abilities to perform the following<sup>(9)</sup>:

- (a) Reduce the effluent arsenic concentration to below 50 ppb, the Bangladesh standard for drinking water;
- (b) Remove constituents near or at water quality guidelines. GoB Water Quality Objectives (WQO) will be used whenever possible. Constituent not noted in the WQO will be assessed using Canadian drinking water standards;
- (c) Generate chemical by-products;
- (d) Produce water at an acceptable rate over the entire cycle;
- (e) Generate non-hazardous residuals.

Limited quantification and characterization of waste by-products is also undertaken during the field-testing stage.

### ***Social Monitoring***

“Soft” parameters must also be identified and assessed during field-testing of technologies. Input from individuals, families or communities regarding a given technology are important in determining long-term acceptance from a social perspective. The best technologies must not only meet the hard and fast quantitative parameters, but must also be ones that can be used by the target population.

The project has developed a 'social protocol', or standard set of indicators, to assess and measure objectively and quantitatively the social, cultural and gender dimensions for arsenic mitigation technologies in Bangladesh<sup>(10)</sup>. It is intended to establish a norm, which is used to measure the speed of technology diffusion, its acceptance in terms of ease of use, social and cultural values, water distribution and access in terms of power structure and other relevant issues.

An analytical framework provides a perspective and guideline for inclusion or exclusion of empirical issues and concepts in the final protocol. The framework deals with the cultural context, social structure, power structure, and gender relations at the community level. Perceptions and attitudes of end users of the technology, water users, technology providers, opinion leaders and other agents are captured in the framework. In short, the framework brings together in a logically consistent way the levels of analysis, range of issues and concepts relevant for the protocol.

The analytical framework guides the second order task of fleshing out a set of indicators for use in the protocol, with several questionnaires and checklists having been developed for field trials with a view to ensuring that indicators are empirically relevant.

### ***Economic Monitoring***

The costs anticipated for all technologies include capital cost items, installation/start-up costs, operating and maintenance costs, waste disposal costs, and costs associated with risk. The Fiscal Protocol evaluates all these factors in a systematic manner<sup>(11)</sup>.

Capital cost items include the treatment unit hardware, any storage reservoirs to be purchased, and any pipes and plumbing to be purchased. These capital costs are amortized over the expected lifespan of the equipment.

Installation/start-up costs include costs for the delivery and professional installation of the equipment, and for training of local users and caretakers in operating and maintenance procedures. These costs are computed from professional hours times hourly rates, plus expenses. Equipment delivery/installation costs are amortized over the expected lifespan of the equipment. Training costs are amortized over a period representing the time between training sessions. Training sessions should be repeated at some defined frequency to ensure ongoing proper use and maintenance of the system.

Operating and maintenance costs include costs for caretaker salaries and service visits (based on hourly rates and hours per annum), and for replacement parts and media (including pick-up or delivery costs). These costs are expected to recur each year and are not amortized.

Waste disposal costs include costs for waste pick-up by, or delivery to, a disposal facility, any pre-disposal treatment costs, and any disposal fees. These costs are expressed per unit volume of waste generated and are computed separately for different waste streams if the different streams have different associated costs. While waste disposal facilities do not exist at present, such facilities will be part of the required infrastructure, and typical costs for use of such facilities are assumed.

It is possible that some costs are dependent on geographical location (e.g., accessibility) or on raw water quality (e.g., media use and waste generation dependent on iron in water). If such variations are expected to have a strong influence on overall cost, separate scenarios are considered to capture this variation in the cost analysis.

For up-front capital costs and installation/start-up costs, the amortization includes compound interest charges, on the assumption that a payment plan will spread these payments over the lifetime of the equipment. Training sessions are also assumed to have a lifetime, i.e., they are repeated/updated periodically, at least with each system installation. Depending on system complexity, more frequent sessions may be needed.

Based on a purchase price (PV), amortization over a number of years (Y) and annual interest rate (X), the annualized cost (R) can be expressed as follows<sup>(12)</sup>:

$$R = PV/(1 + X)^Y$$

The units of R are Tk per annum.

The probability of a potential impact and associated cost are integrated into the overall formula. Risk associated with any variable, such as; the transport of the technology or required chemicals, use of chemicals, operational accidents, negligence, and disposal of byproducts, are calculated and added to the unit cost.

### ***Training Development Partners***

The desire of people to have the necessary tools to develop their own knowledge base and determine their own destinies is critical in all development activities. Working with development partners, ETV-AM provides a mechanism through which important information regarding arsenic mitigation technologies can be disseminated by agencies currently on the ground in Bangladesh, thus providing people with the information people required for informed decision-making.

### **Environmental Technology Verification**

Technologies completing field-testing are exposed to a final verification process that closely matches the initial Performance Review process. The additional component of the review is a detailed comparison of technology performance between the laboratory and the field. In addition to providing information regarding performance differences between the two testing environments, it provides a mechanism for review and possible modification of the laboratory performance testing.

Technologies that successfully complete the final verification processes are then recognized as verified technologies within Bangladesh. A verification report is prepared that includes a final “Technology Fact Sheet” containing the concluding information regarding the following factors:

- A description of the technology
- Performance claim(s)
- The fundamental principles behind the technology
- Operating parameters
- Anticipated cost of implementing the technology
- Possible restrictions associated with the technology

## CONCLUSIONS

Technologies for providing safe drinking water are known and being applied throughout the world. Groundwater can be treated using physical, chemical and/or biological methods. Furthermore, many regions of the world have adopted cost-effective “traditional” technologies, allowing for the delivery of clean, safe drinking water. The challenge lies in identifying the most suitable technologies for treating arsenic contaminated groundwater in Bangladesh. Technical and economic viability, indigenous capacity, in association with cultural sensitivity is of the essence for successful implementation of any technology. ETV-AM has been implemented to apply a systematic evaluation of arsenic technologies based upon technical, social and fiscal parameters relevant to Bangladesh. The importance is not just in finding a solution for Bangladesh, but finding a solution that is both viable and sustainable in the context of the nation.

## ACKNOWLEDGEMENTS

The authors would like to thank the members of the ETV-AM Team from OCETA, ETV Canada, Beak International Inc, and various subcontractors for their contributions towards the various components of the Program, upon which this document is based. The authors would also like to acknowledge the Government of Canada, through the Canadian International Development Agency for the ETV-AM grant.

## REFERENCES

---

1. DPHE/BGS, 2000. Groundwater Studies for Arsenic Contamination in Bangladesh. Draft Final Report. British Geological Survey (BGS) Technical Report WC/00/19, Volume 3.
2. Chen, C.J., Wang, C.J. 1990. Ecological Correlation Between Arsenic Level in Well Water and Age-adjusted Mortality from Malignant Neoplasms. *Cancer Research*. 50(17): 5470-5474.
3. Brown, K.G., Chen, C-J. 1994. Observed Dose Response for Internal Cancer and Arsenic in Drinking Water in the Blackfoot Disease Epidemic Region of Taiwan. *Ed. Sci. Technol. Lett.* 153-169.
4. US EPA, 1998. Research Plan for Arsenic in Drinking Water. Office of Research and Development National Center for Environmental Assessment U.S. Environmental Protection Agency. Cincinnati, OH 45268.

5. Stewart, D.K. and Boerschke, R.K. 2001. Potential impact of arsenic on social and economic parameters in Bangladesh. Submitted.
6. OCETA. 2001. ETV-AM Tier I Screening Protocol: Decision Matrix. Toronto, On. (Pending).
7. OCETA. 2001. ETV-AM Tier II Screening Protocol: Cost Benefit Analysis. Toronto, On. (Pending).
8. OCETA. 2001. ETV-AM Laboratory Performance Evaluation Protocol. Toronto, On. (Pending).
9. OCETA. 2001. ETV-AM Field Testing Protocol. Toronto, On. (Pending).
10. OCETA. 2001. ETV-AM Social Evaluation Protocol. Toronto, On. (Pending).
11. OCETA. 2001. ETV-AM Fiscal Due Diligence and Risk Assessment Protocol. Toronto, On. (Pending).
12. Shim, J.K., J.G. Siegel and A.J. Simon. 1986. *The Vest-Pocket MBA*. Prentice Hall Inc., NJ.

## **A Simple Household Device to Remove Arsenic from Groundwater and Two Years Performance Report of Arsenic Removal Plant for Treating Groundwater with Community Participation**

**Dipankar Das, Amit Chatterjee, Gautam Samanta, Tarit Roy Chowdhury, Badal Kumar Mandal, Ratan Dhar, Chitta Ranjan Chanda, Dilip Lodh, Partha Pratim Chowdhury, Gautam Kumar Basu, Bhajan Kumar Biswas, Uttam Kumar Chowdhury, Mohammad Mahmudur Rahman, Kunal Paul and Dipankar Chakraborti**

School of Environmental Studies,  
Jadavpur University, Calcutta-700 032, India.

### ***Abstract***

*School of Environmental Studies (SOES) household device for arsenic removal from contaminated water was developed in 1993. The system consists of a filter, tablet, two earthen jars or plastic jars. Tablet contains iron salt, oxidizing agent and activated charcoal. The filter is made of mainly purified fly ash with binder. One tablet is sufficient for 20 liters of contaminated water having arsenic up to 1000  $\mu\text{g/l}$ . The sludge after arsenic removal, rich in arsenic, is disposed to soil with cow-dung and arsenic is eliminated from the sludge as volatile arsenic species through the microbes in the cow-dung. Everyday in natural process tons and tons of arsenic, selenium, mercury are eliminated in volatile organic forms through activities of the microbes in soil/sediment. After our successful laboratory testing several units were taken to arsenic affected villages in six districts of West Bengal and tested with contaminated hand tube-wells (arsenic range 300-950  $\mu\text{g/l}$ ) from about 100 families. The efficiency was found in the range of 93-100%. SOES jointly with CSIR (Council of Scientific & Industrial Research), Govt. of India filed for 3 national patents (patents are now cleared) in*

31st December 1994. CSIR then requested Public Health Engineering Department (PHED); Govt. of West Bengal to test this system in the arsenic affected villages and to submit a performance report. CSIR decided that if Govt. of West Bengal after field test finds the system suitable, CSIR would begin bulk manufacture of the system. Govt. of West Bengal received 300 units during December 1995 from SOES but till today their test report has not been received. In the meantime various national and international organizations tested the system in laboratory as well as in the field and found arsenic removal efficiency is between 93 and 100%. World Health Organization (WHO) then purchased 50 units for use in Bangladesh from CSIR. Asia Arsenic Network (AAN), Japan also purchased 300 units for use in Bangladesh and WHO Bangladesh wanted to purchase additional 500 units during January 1997. When more demand of the system started coming from national and international organizations CSIR decided to test efficiency of the system for one year in field level before they decide to begin bulk manufacture. CSIR took a couple of years to take field trial decision. Responsibility was given to NEERI (National Environmental Engineering Research Institute), Nagpur, India to test the efficiency of the device by installing the units in 150 families in two blocks (Deganga and Gaighata) of North 24 Parganas district, who will use the device for one year (field trial started during July 1998). CSIR decided that NEERI will test 100% of the samples while SOES and PHED, Government of West Bengal each will analyze 10% of the same field samples (SOES analyzed 100% of the field samples from its own fund). Final responsibility was given to National Physical Laboratory (NPL), New Delhi (a CSIR institute) for processing and evaluation of the report. Field test was completed during May 2000. Final report has not yet been received.

The pity when millions are drinking arsenic contaminated water in the arsenic affected villages of West Bengal, we have not yet got the clearance from Govt. of West Bengal or CSIR-India whether we could use our system in arsenic affected villages. Field report of SOES shows that if villagers are made aware and trained how to use the household device developed by SOES, the system can be an effective way to produce arsenic safe water for household purpose. Some of the points that may be highlighted for SOES system are: (a) about US \$ 10 is required for one year to get 20 liters of water per day. (b) since the tablet contains an oxidizing agent water will be safe with respect to microbial contamination (c) after addition of tablet contaminated water turns black due to suspended charcoal and clear water after filtration it is easy to know (from presence of suspended black particles) whether there is any leakage from the upper jar (d) water after passing through the system meets the specification of WHO water quality criteria.

In this paper we will also report the performance of seven arsenic removal plants from two organizations for about two years for treating arsenic

*contaminated hand tube-well water with community participation. Our overall finding from these two studies suggest that in villages of India and Bangladesh even a highly successful technology may not succeed unless it fits in the rural circumstances and is well accepted by the rural mass. Development of such technology is only possible when a combination is made between technocrats and villagers with proper village level participation.*

## **INTRODUCTION**

There are 20 countries where groundwater arsenic contamination episodes in the world are known. However, the world's 4 biggest cases of groundwater contamination and the worst sufferings of the people have been in Asia. In order of magnitude these are Bangladesh, West Bengal-India, Inner Mongolia - P.R. China and Taiwan. In all these countries, more and more groundwater withdrawal is taking place because of agricultural irrigation. We have made a green revolution at the cost of underground water.

Most arsenic affected areas are located in South East Asia, Bangladesh and West Bengal-India. More than 130 million people in Bangladesh and India countries are at risk. Nine districts in West Bengal, India and 47 districts in Bangladesh have arsenic level in groundwater above the maximum permissible limit of 50  $\mu\text{g/l}$ . The guideline value of arsenic in drinking water of WHO is 10  $\mu\text{g/l}$ . The area and population of the 47 districts in Bangladesh and 9 districts of West Bengal are 112407  $\text{km}^2$  and 93.4 million, and 38.865  $\text{km}^2$  and 42.7 million, respectively.

### **Available Techniques for Removal of Arsenic from Groundwater**

A variety of treatment technologies like co-precipitation, adsorption, ion exchange and membrane process have been demonstrated to be effective in removing arsenic from contaminated natural groundwater. However, question remains regarding the efficiency and applicability/ appropriateness of the technologies - particularly because of low influent arsenic concentration and differences in source water composition. Besides, the system must be economically viable and socially acceptable. Techniques available for removal of arsenic from contaminated water are based on mainly four principles:

- A. Oxidation of arsenic (III) to arsenic (V) adding suitable oxidizing agent followed by coagulation- sedimentation-filtration (co-precipitation).
- B. Adsorption using  $\text{Al}_2\text{O}_3$ , Iron filings (zero valent iron), hydrated iron oxide.
- C. Ion exchange through suitable cation and anion exchanger.
- D. Osmosis or electrodialysis (membrane filter)



Various organizations in West Bengal are using mostly principles A and B both for community water supply and as household device in arsenic affected areas. Name of the agencies, location where they are working and principles are given in Table 1.

**Table 1 : Location of household devices installed and agencies involved**

Organization	Type	Principle	Where installed	Comment
Public Health Engineering Department (PHED), Government of West Bengal	Community	A	Sujapur, Malda, Uttar Dhalita and Gobardanga in North 24-Parganas	Technically successful. But long term field evaluation report through independent body is not available mainly to know whether the technology is accepted by the villagers with their cultural, socio-economic, awareness and educational background
All India Institute of Hygiene and Public Health (AIHH&PH), Government of India	Community	A	Kochua, Habra II, North 24-Parganas; Dattapukur, Barasat, North 24-Parganas; 4 villages in Tehatta block, Nadia and a few more	Technically successful. But long term field evaluation report through independent body is not available mainly to know whether the technology is accepted by the villagers with their cultural, socio-economic, awareness and educational background
	Household		Not known	
B.E. College, Howrah (Amal Filter)	Community	B	4 villages in North 24-Parganas and 4 villages Tehatta block in Nadia and a few more	Technically successful. But long term field evaluation report through independent body is not available mainly to know whether the technology is accepted by the villagers with their cultural, socio-economic, awareness and educational background
	Household		Not known	
School of Environmental Studies with CSIR, New Delhi	Household	A	150 families used for one year in Deganga and Gaighata blocks of North 24-Parganas.	Long-term (one-year) field evaluation done. Monitoring agencies were NEERI (major, 100%), PHED (10%), SOES (100%). Overall data will be evaluated by NPL (National Physical Laboratory, CSIR), New Delhi. Project Funded by CSIR, New Delhi. Evaluation report not yet received.

### **Activities of Other Organizations/Institutes/Laboratories for Removal of Arsenic from Groundwater in Other Parts of the World**

The processes used in arsenic affected areas of Chile and Taiwan for removing arsenic from drinking water at full-scale treatment plant (for high-level arsenic removal) is coagulation. Addition of iron or aluminum coagulants to water facilitates the conversion of soluble arsenic species into insoluble reaction products, which are formed through adsorption mechanisms onto coagulated floc. Because good floc formation followed by filtration is crucial to arsenic removal, a high turbidity effluent indicates poor floc formation and is likely to reduce the efficiency of arsenic removal.

The University of Connecticut (patent pending) has claimed a novel and cost effective Arsenic Remediation Technology (AsRT) for the immobilization of inorganic arsenic such as arsenates and arsenites. The technology uses iron filings (zero valent iron) and sand to reduce inorganic arsenic species to iron co-precipitates, mixed precipitates, and in conjunction with sulfates to arsenopyrites.

In Hungary, the arsenic contamination from groundwater sources (artesian wells) caused serious problem (400000 people are at risk) and ways of removing arsenic have been investigated for about a decade now. A promising, inexpensive solution to the problem was adopted. The arsenic concentration of even high organic matter containing artesian waters can readily be reduced to under the 0.05 mg/l limit, by using the  $Mg(OH)_2$  method either on large-scale or in households. The procedure is simple (only needs adding of MgO or  $MgCl_2$  and NaOH), efficient and safe. Although a few more devices are available to remove arsenic from ground water but most are on the basis of the principles as described in A, B, C, and D.

### **SIMPLE HOUSEHOLD DEVICE OF SCHOOL OF ENVIRONMENTAL STUDIES TO REMOVE ARSENIC FROM GROUNDWATER**

This is the only household device in West Bengal which had undergone field trial (one year) in the arsenic affected villages (150 families used the system) to know its efficiency and acceptability. From this village trial result, we expect to know the drawback of the device, modifications (if any) needed and whether at all to use these in the affected villages.

### **Background (We Got the Basic Idea of Filter-Tablet System for Arsenic Removal From Villagers)**

During our field survey we noticed that in some arsenic affected villages many families due to high iron in their tubewell water can not drink the water directly. To make it drinkable they just keep the water after withdraw from tubewell for sometime, when a brown precipitate settles at the bottom, the users decant the

upper clear water or use a common filter to arrest the floc. We had observed that by this technique (if the tubewell water contains higher dissolved iron) 60-70% of arsenic is removed. We got the idea from the villagers and then made some modification for a household device using filter and tablet to remove almost 93-100% of arsenic from contaminated water. We started of our own and soon we got financial assistance from Council of Scientific & Industrial Research (CSIR), New Delhi. Finally, jointly with CSIR, we made 3 Indian patents and one international patent filed for Bangladesh. The 3 patents are:

- (a) A Composition useful for the removal of arsenic from water and tablets/capsules made from the said composition.

Inventors: Dipankar Chakraborti, Dipankar Das, Amit Chatterjee, Gautam Samanta

- (b) Composition useful for making water filter candle and water filter candle made thereof.

Inventors: Dipankar Chakraborti, Dipankar Das, Amit Chatterjee, Gautam Samanta

- (c) An improved process for the removal of arsenic from water.

Inventors: Dipankar Chakraborti, Dipankar Das, Amit Chatterjee, Gautam Samanta

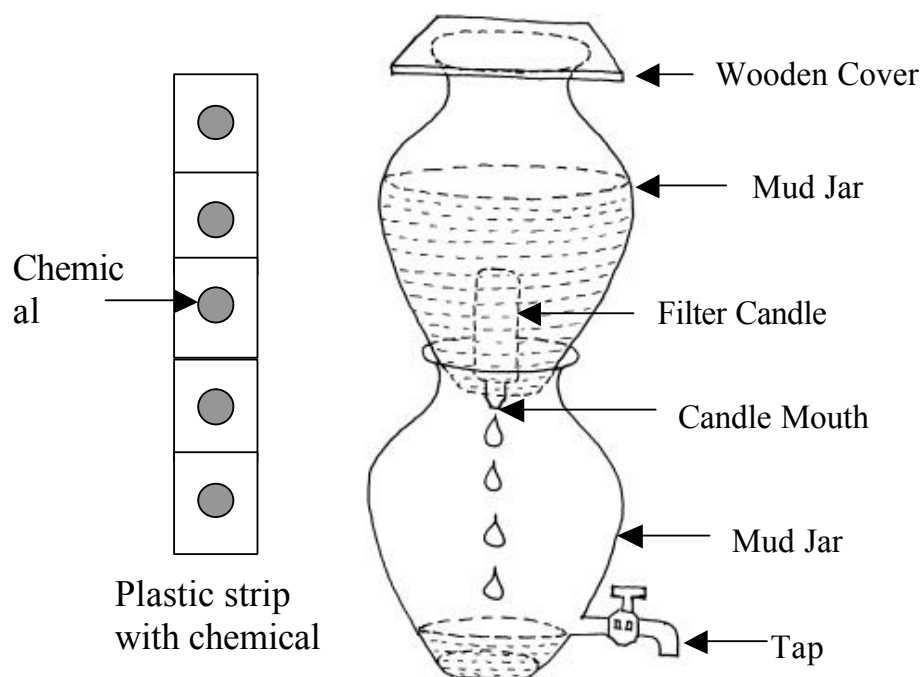
Figures 1 and 2 show our Filter- Tablet System.

### **What is the filter?**

We made the filter by using fly ash, clay, charcoal etc. Due to use of fly ash, the filter becomes very strong and quite porous. While preparing the filter we heat it above 1400<sup>0</sup> C in a furnace with charcoal to remove most of the volatile toxic compounds. We made many experiments before using fly ash to know whether it is safe to use fly ash from toxicity point of view. We are now making the filter by hand mixing in small scale. Pore size and strength of filters are not same in all batches. We feel when we will make large-scale with automatic system we will make it better.

### **What is the tablet?**

The black colored tablet contains Fe<sup>3+</sup> salt, an oxidizing agent and activated charcoal. We spent about a year to get the shape of these chemicals compounds in the form of a tablet. The tablet can be supplied in pouch or in a box. After addition of the tablet to the arsenic contaminated water, water turns black due to presence of carbon and after filtration it is easy to know (from suspended black particles) whether there is any leakage from the filter. We are still making the tablets by hand mixing, so size and quality are not same in all batches. We hope to make it better when large-scale preparation will be done. We have observed that after preparation of tablet it remains almost the same even more then 15 months.



**Figure 1: Arsenic removal Filter-Tablet system of School of Environmental Studies, Jadavpur University**

**How to Use the Filter and Tablet System to Remove Arsenic from Contaminated Water?**

We have used two earthen pots or plastic jars for the purpose. The system is for 20 liters of contaminated water. We feel 20 liter is sufficient for drinking and cooking for a family of 4. The capacity of the system can be increased.

The earthen or plastic container is placed on some suitable place at home. The user will use a plastic bucket or similar container for 20 liters of water. One black tablet from pouch or box is added to the container and 20 liters of water from tubewell pumped in it. The tablet will dissolve immediately making the water black in appearance. For better mixing a wooden or plastic handle can be used. It was then kept for settling about an hour and then poured in the upper jar of the filtering system (it is better to collect the water with tablet in the evening and pour in upper jar of filtering system before going to bed). Immediately clear water will come out as drops from the upper jar to the lower reservoir. If black particles are visible after filtration then there is a possibility of some leakage and filtering system to be checked. The filtered water is safe to drink. Usually 93-

100% arsenic is removed. The black floc containing activated charcoal, arsenic on iron oxy-hydroxide will be deposited on the surface of the candle filter.



**Figure 2 : Photograph of arsenic removal filter-tablet system**

### **When to Clean the Filter and Where to Dispose the Floc?**

When the filtration rate becomes slow, the filter is to be cleaned. The simple procedure is to pour water in upper jar and clean the filter in the upper container. A brush can be used to rub the candle-filter. As the filter is of a strong material brushing will not damage the filter. Even after such cleaning if the flow rate drops again within a few days then candle filter should be removed from the pot and cleaned thoroughly. The washings of the filter rich in arsenic are disposed at the back yard making a hole on the surface soil and some cow-dung is added to it.

### **Why Cow-Dung is to be Added to the Disposed Area of Arsenic Rich-Floc?**

It is a burning question how and where to dispose the arsenic rich floc. Many are of the opinion that arsenic rich floc, if disposed on soil, may contaminate the aquifer again. I am not diluting the problem but for your information from only Deganga block with an area of 201 km<sup>2</sup>, about 3000 shallow tubewell in use for irrigation are depositing about 6.4 tons of arsenic to the soil each per year. We had analysed the soil at least from 100 sites and found none of the soil has arsenic above 10 mg/kg (normal concentration about 5.6 mg/kg). Most probably microbes eliminate arsenic falling on soil. We have no idea about long-term effect of such huge amount of arsenic depositing on soil.

In our laboratory we performed a 2-year long experiment and found that cow-dung can eliminate arsenic in volatile form (Jadavpur University, 1995). Thus arsenic will go to air. Some people even asked whether air would be contaminated or not. For information, everyday tons of arsenic, mercury and selenium are eliminated as volatile compounds from soil/sediment by natural bi-methylation by microbes. These volatile organometal compounds ultimately decompose and fall in our environment. Of course sea is our best sink.

### **Some Preliminary Results from Our University Laboratory Tap Water (Source Underground Water) After Passing Through Our Filter-Tablet System**

To know whether after passing through our Filter-Tablet system the quality of water matches to international standard or not, we made a few preliminary experiments to know the quality of water. Table 2 shows some physical and chemical parameters of filtered water, and compares them with the WHO standard. Since the principle of our technique is co-precipitation we expected that all essential elements will be removed from water but we found still some amount remains and we desire that.

**Table 2 : Some physical and chemical parameters of filtered water and compared to international standard\***

Parameters	WHO Standard	Before Filtration	After Filtration
pH	6.5 - 8.5	7.8	7.7
Specific Conductance ( $\mu\text{Mhos cm}^{-1}$ )	-	72 mg/l	75 mg/l
Chloride	250.0 mg/l	806.67 mg/l	872.25 mg/l
Sulfate	400.0 mg/l	23.5 mg/l	22.7 mg/l
Phosphate	-	0.220 mg/l	0.205 mg/l
Hardness ( $\text{CaCO}_3$ )	500 mg/l	500 mg/l	460 mg/l
Sodium	200 mg/l	387.5 mg/l	392.5 mg/l
Potassium	-	6.4 mg/l	6.5 mg/l
Calcium	100 mg/l	202.5 mg/l	205.0 mg/l
Arsenic	0.01 mg/l	<0.003 mg/l	<0.003 mg/l
Iron	0.30 mg/l	2.361 mg/l	0.040 mg/l
Cadmium	0.005 mg/l	0.003 mg/l	0.0012 mg/l
Cobalt	-	0.008 mg/l	0.0016 mg/l
Chromium	0.05 mg/l	0.014 mg/l	0.002 mg/l
Copper	1.0 mg/l	0.033 mg/l	0.003 mg/l
Lead	0.05 mg/l	0.020 mg/l	0.002 mg/l
Manganese	0.1 mg/l	1.423 mg/l	0.018 mg/l
Zinc	5.0 mg/l	0.080 mg/l	0.006 mg/l

\* Source: University tap water

### **Field Trial Data to Prove that the Filter-Tablet System is Suitable to Eliminate Arsenic from Groundwater**

Scientists from School of Environmental Studies went to six arsenic affected districts during 1993-1995 to see how the technique works in field level. We installed the filtering system in 20 families in each of the six affected districts (North 24-Parganas, South 24-Parganas, Nadia, Bardhaman, Murshidabad and Malda) having elevated level of arsenic in their hand-tubewells (range 360-980  $\mu\text{g/l}$ ). Results show arsenic removal of 93-100% and that the quality of water is potable.

**Analytical Report from Various Other Agencies about Suitability of Our Arsenic Removal System**

After being satisfied by our laboratory and field trial we sent the system to various nationally recognized scientific institutes for evaluation. The agencies involved and summery of their findings are as follows:

<b>National Agencies</b>	<b>Findings (official report )</b>
Industrial Toxicological Research Center, Govt. of India, Lucknow	95-97% removal of arsenic (Report of May 10, 1994)
National Test House, Govt.of India, Calcutta	97.5% (Report of December 8, 1995)
National Environmental Engineering Research Institute (CSIR Institute), Nagpur	93% (Report of July 5, 1995)

**Analytical Report of International Agencies (Test done when the Arsenic Removal Systems Were in Operating Condition in the Arsenic Affected Villages)**

Dr. Hironaka from AAN-Japan and Dr. Shoko Oshikawa of AAN Thailand Bureau came to the village to test our units where we installed our experimental household system. Their findings are summarized below:

<b>International Agencies</b>	<b>Findings ( official report )</b>
Asia Arsenic Network (AAN), Japan (Analyst: Dr. Hiromi Hironaka)	98.5% (Report of February 8, 1996)
Asia Arsenic Network (AAN), Thailand Bureau (Analyst: Dr. Shoko Oshikawa)	95% (Report of March 13, 1996)

Being satisfied with our arsenic removal system, AAN-Japan purchased 300 units from CSIR-New Delhi and installed them in Bangladesh. Dr. Chakraborti went to Bangladesh to install the filtering units.

World Health Organization after purchasing 50 filtering system from CSIR, further ordered 500 filtering system for Bangladesh (Ref. BAN CWS 001/C 27th January, 1997, New Delhi, India)



### **Evaluation Report of West Bengal Government (PHED, West Bengal)**

Public Health Engineering Department (PHED) after discussing with CSIR representative and SOES decided to test 300 filtering units in arsenic affected villages of W. Bengal. During 29th December 1995 PHED, West Bengal ordered 300 Filter-Tablet system from CSIR through School of Environmental Studies, Jadavpur University (Memo No. 24324-24325/3/6/A/95 dt. Cal 29/12/95 of the purchase) for evaluation. We have not yet received any detailed study report from PHED, West Bengal except only one letter (based on 4 experiments) which mentioned, "However, it only removes 50% of the arsenic in water and that may not fruitful to serve the purpose" (Memo No. 869/2/BST dated Barasat 19/3/1996).

### **One-Year Project for Evaluation of "Arsenic Removal Filter-Tablet" System Through 150 Families in 2 Blocks Of North-24-Parganas by CSIR.**

This was the project funded by CSIR, Govt. of India. CSIR decided 100% analysis of the field trial samples would be done by the NEERI, Nagpur and partly by PHED, Govt. of West Bengal (10%) and SOES (10%). Although SOES was financed by CSIR for 10% analysis, but SOES from its own fund had analyzed 100% of field trial samples. According to the project proposal, National Physical Laboratory (NPL), CSIR, New Delhi through CSIR would process and evaluate results. Official field trial sanction (no. 800(0028)/97/EMR II) from CSIR came to SOES during March 1997. For reason unknown to us field trial started during July 1998 and field trial completed during May 2000. Evaluation report from NPL has not yet been received.

### **SOES Opinion About the Device**

From our field report we can comment now that Field Trial through actual users is the sure test of a technology. We learnt more about drawback of our system; we also learnt what villagers need through interactions with villagers. Laboratory result, field trial result through our experts may show 100% efficiency but users may use it in a different way so that the system may not be as efficient as it should be. For success of the technology we need to aware and educate the user before, during and after installation of the system.

### **A Few Examples - How Villagers Used Our Filter -Tablet System**

1. In earthen pot/ plastic jar some users fitted the filter to the outside of the pot with up side down.

2. One user added 5 tablets for 20 liter of water to get better quality of water. When we asked why did he do this, he replied that if one tablet would produce good water five tablets will make even better water.
3. In our laboratory experiment we found tablets are effective at least up to 15 months (as we kept in dark). Some of the villagers kept the tablet container near the oven or outside where sun rays directly falls on tablet container, thus power of oxidation of tablet is partially lost due to decomposition of oxidizing agent and arsenic removal efficiency decreased.
4. Villagers time and again did not use the system for a few days and so the system went dry causing problem when they started again. If they had kept some water in the container with filter valve closed, this problem would not happen.

## **CONCLUSION**

Although we have devised "Filter- Tablet System" to remove arsenic from groundwater nevertheless we believe this is to be used in emergency in affected villages for West Bengal-India and Bangladesh. Co-precipitation not only will remove arsenic but also other essential elements from water. The actual solution in these two countries would be achieved through proper watershed management utilizing our available surface water. Per capita available surface water of Bangladesh alone is 11000 m<sup>3</sup>, the second highest in the world. For West Bengal wet land comprises an area of about 4000 km<sup>2</sup>. In these two countries rainwater, surface water, flooded river basins, Ox-Bow lakes, dug-wells are plenty. In this millennium when technology is known and scientists, technologists are making potable water from wastewater why should we neglect our vast available surface water resource and opt for groundwater- a source for our natural balance.

## **TWO YEARS PERFORMANCE REPORT OF ARSENIC REMOVAL PLANT FOR TREATING GROUND WATER WITH COMMUNITY PARTICIPATION**

School of Environmental Studies; Jadavpur University, Calcutta is the scientific adviser to a project funded by Japan Government to Chandranath Basu Seva Sangha, village-Betai, Block Tehatta, District Nadia. The goal of the project was:

1. To assess the magnitude of arsenic calamity in Tehatta Block through water analysis.

2. Field survey with medical team to know the extent of people's suffering.
3. Green coloring of safe tubewells and red coloring of arsenic contaminated tubewells. Green tube-wells to be rechecked every 6 months.
4. To find out the possibility of alternative source of drinking water (rainwater, river water, pond water, lake water, dug-well, ring-wells etc. after proper purification) with peoples participation.
5. Arsenic removal from contaminated hand tubewell adopting suitable technology with people's participation.

Although School of Environmental studies at the beginning was advisor to the project but later on, considering the importance and outcome of the project also funded the same project. Japan Govt. provided Rs. 15 lakhs and SOES also matched almost equal amount.

The project started from October 1997 and still in progress. School of Environmental Studies, Jadavpur University is supervising, advising, analysing water and biological samples; visiting the villages with medical team. So far about 7000 water samples had been analyzed, along with 1500 hair, nail and 1000 urine samples. Patients were identified and registered.

The report here will only highlight the suitability of 2 arsenic removal technologies installed in 7 locations in Betai and run with people's participation.

### **At Present Two Arsenic Removal Technologies are Well-known in West Bengal for Community Use**

Chandranath Basu Seva Sangha spent 4 lakhs Rupees for installation of 8 units, 4 from each AIIH&PH, Calcutta and B.E. College, Howrah

- A. All India Institute of Hygiene and Public Health (AIIH&PH), Calcutta system - described as oxidation of arsenite followed by coprecipitation, where bleaching powder, aluminium sulfate are in use in a hand pump attached Model. About Rs. 40,000 is required for building each unit. At the beginning AIIH&PH people came for building and installed one unit but we made subsequent units.
- B. The system developed by Environmental Engineering Laboratory, Civil Engineering Department, Bengal Engineering College, Howrah 711103. In this system aluminium oxide is in use as adsorbent for arsenic removal in hand pump-attached model. The cost of each unit is Rs. 60,000. B.E. College technicians came with the units and installed them. One technical person also visited the sites about once a month to observe the problem of each unit.

### Our Observation

On principle both the techniques are technically sound and flawless if properly used. Both the systems are known for many years and are used in many countries all over the world. The scientists of these two institutes (AIIH&PH & BE College) made a novel attempt to adopt it to arsenic affected villages for removal of arsenic from groundwater considering local need and difficulties.

School of Environmental Studies suggested Chandranath Basu Seva Sangha to install 4 AIIH&PH and 4 BE College's units in Betai. 7 units, 4 from BE College and 3 from AIIH&PH were installed in Betai during last one year. One unit of AIIH&PH was recommended for installation in a very highly arsenic affected area in Bangaon, North 24-Parganas.

School of Environmental Studies is monitoring the arsenic concentration in raw and filtered water fortnightly and also bacteriological suitability of the water was checked once in a month. Dr. Chakraborti visited the plants several times. Collections of samples with preservative for arsenic analysis and for bacteriological analysis in sterilized bottle were done. Samples were analyzed as soon as possible after collection. Samples were kept refrigerated until analysed.

Table 3 shows the arsenic concentration in treated water of the 7 units during the last two years. Out of these seven units, except one unit (No. 2), all others showed some problems including high arsenic in treated water. Our results of microbiological analysis showed unsuitability of the water (total plate count above permissible limit) (except unit No 2). Even villagers observed small worms in finished water and that only happened after the instruments were not in working condition for couple of days and immediately after regeneration.

Each unit except one (No. 2) showed some problems. The write up below describes merits and demerits of the individual units.

**Unit-1:** Ashram Campus, Dangapara, Betai  
 Caretaker: Ram Krishna  
 Type of Unit: B.E. College  
 Families using: 200

The unit remains inactive at least a couple of days during every month. Reasons are many: tubewell head broken; leakage from valve; washer not functioning; water is not coming on pumping from underground etc. On two occasions, arsenic in finished water was found to be higher than maximum permissible limit (0.05 mg/l) during our study. Time and again it has been observed that the finished water turns brown after sometime [i.e. precipitation  $\text{Fe}(\text{OH})_3$ ]. This indicates that the  $\text{Al}_2\text{O}_3$  bed was not washed properly. People do not understand the importance of back washing the  $\text{Al}_2\text{O}_3$  column. This is the unit where about 500 families use the plant for water. It appears that the  $\text{Al}_2\text{O}_3$  bed is getting exhausted. Still we do not know the money to be required for

**Table-3 Water Report From Treatment Plant (B.E. College and AIH&PH) installed in Betai, Nadia**

SL. No	Place	Type of Unit	Arsenic concentration in mg/l							
			Raw	04/07/99	10.08.99	02.02.2000	20.02.2000	15.04.2000	07.05.2000	21.05.2000
1	Ashram Campus Betai, Dangapara, Caretaker: Ram Krishna User: 200 families	B.E. College	0.170	<0.003	0.131	<0.003	<0.003	<0.003	0.121	Not function ing
2	Ikhola Para, Betai, Caretaker: Khitish Chandra Adhikari User: 60 families	B.E. College	0.122	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003
3	B.R. Ambedkar College, Betai, Caretaker: Prof. M.C. Moullick User: 100 families	B.E. College	0.327	0.056	<0.003	<0.003	<0.003	Not function- ing	<0.003	0.035
4	Kharemath (Purba), Jitpur Caretaker: Mangal Biswas, User: 50 families	B.E. College	0.235	Not functioning	0.187	0.069	0.012	Not function- ing	Not function ing	Not function ing
5**	Jitpur (Tabu para) Caretaker: Dilip Poddar, User: 60 families	AIH&PH	0.051	0.045	Not function- ing	Not function- ing	0.006	0.005	<0.003	Not function ing
6	Haripur (Chitka), Betai User: 300 families	AIH&PH	0.463	Not functioning	Not function- ing	Not function- ing	Not function- ing	0.052	0.092	0.035
7	Muktadaha Para, Betai Caretaker: Jitendra Ghosh, User: 150 families	AIH&PH	0.149	Not functioning	Not function- ing	Not function- ing	0.024	0.043	0.088	0.081

\*\* All surrounding tubewells are quite contaminated. For the plant a new tubewell was installed and luckily the tubewell shows arsenic 0.051

**Table-3 Water Report From Treatment Plant (B.E. College and AIH&PH) installed in Betai, Nadia (Continued)**

Sl. No	Place	Type of Unit	Arsenic concentration in mg/l							
			Raw	04.08.2000	5.10.2000	7.01.2001	23.02.2001	25.03.2001		
1	Ashram Campus Betai, Dangapara, Caretaker: Ram Krishna User: 200 families	B.E. College	0.170	0.016	0.020	0.029	0.035	0.030		
2	Itkholra Para, Betai, Caretaker: Khitish Chandra Adhikari User: 60 families	B.E. College	0.122	<0.003	<0.003	<0.003	<0.003	<0.003		
3	B.R. Ambedkar College, Betai, Caretaker: Prof. M.C. Moulick User: 100 families	B.E. College	0.327	<0.003	0.037	<0.003	0.057	<0.003		
4	Kharernath (Purba), Jipur Caretaker: Mangal Biswas, User: 50 families	B.E. College	0.235	Not functioning	Not functioning	0.096	0.110	0.131		
5**	Jipur (Tabu para) Caretaker: Dilip Poddar, User: 60 families	AIH&PH	0.051	0.042	<0.003	0.036	<0.003	<0.003		
6	Haripur (Chitka), Betai User: 300 families	AIH&PH	0.463	0.120	0.098	0.135	0.110	0.077		
7	Muktadaha Para, Betai Caretaker: Jitendra Ghosh, User: 150 families	AIH&PH	0.149	0.11	0.088	0.075	0.065	0.028		

regeneration and also for replacement of  $Al_2O_3$  in final stage. It was found that water leaks from time to time from the solder joint. We do not know how long the structure will stand. Too much pressure is on the treatment plant. When the system is in working condition bacteriological study shows satisfactory result but when the system was not used for few days due to technical problem and started again the bacteriological count becomes unsatisfactory.

**Unit-2:** Itknola Para, Betai  
Caretaker- Khitish Chandra Adhikarai  
Type of unit: B.E. College  
Families using: 60

The unit is running for the last 10 months. The performance of this unit is flawless. One person is doing the maintenance and operation. There is also no leakage from soldering joints. Only 35-40 families drink water from this unit. The villagers of this area are better educated and conscious. All pay Rs. 5/- as maintenance cost. Pressure on the instrument is minimum. This can be the example of how one unit can ideally work if proper maintenance is done and not roughly handled. No bacteriological problem was noticed.

**Unit-3:** B. R. Ambedkar College, Betai  
Caretaker- Prof. M. C. Moulick  
Type of unit: B.E. College  
Using: College students and 150 families

Although Principal of B. R. Ambedkar college, Prof. M. C. Moulick is taking care of the unit, it showed arsenic above 0.05 mg/l two times and according to Dr. Moulick, time to time, there is leakage from soldering area. The instrument also did not function properly a few times. According to Dr. Moulick frequent backwash is necessary now, which was not needed so frequently earlier. This unit also has other problems as described with Unit 1. Bacteriological problem was similar as in Unit 1.

**Unit-4:** Kharermath (Purba), Jitpur, Betai  
Caretaker- Mangal Biswas  
Type of unit: B.E. College  
Families using: 50

The performance of this BE College unit is the poorest among all 4 units. This is not functioning at all. Most of the time the system is not in working condition. Reasons are many but non co-operation among a section of villagers appears to be the main reason. During our last 2 years observation of this unit,

the system was not in working condition about a year (negligence partly from BE.College, Shibpur and partly from the villagers) and all the time (measured 6 times) water coming out from the plant had arsenic above 0.05 mg/l.

**Unit-5:** Jitpur (Tabu Para), Betai  
Caretaker- Dilip Poddar  
Type of unit: AIIH&PH  
Families using: 60

When we went to the site on 21st May 2000, the system was not working. When asked for the reason, it was told that due to gusty wind the aluminum sheet covering both the tanks was removed and the  $Al_2(SO_4)_3$  and bleaching powder containers went away like a football due to strong wind. It was further reported that understanding and co-operations among villagers are needed to run the system smoothly. This is the system where the input water has arsenic concentration of 0.051 mg/l. Nearby hand tubewell was not available for connection, so new tubewell was installed and fortunately the tube-well was found to have low arsenic. Bacteriological problem was noticed when the system was not cleaned after every week and also if bleaching powder suspension do not drop.

**Unit-6:** Haripur (Chika), Betai  
Type of unit: AIIH&PH  
Families using: 300

Along with the same inconveniences as reported for No. 5, some villagers further complained that due to precipitation from the bleaching powder container, the hole of dropping tap blocks and sometimes there was no inflow of bleaching powder solution for a prolonged period. The villagers are not aware of the importance of bleaching powder addition. Bacteriological problem is similar as mentioned for Unit 5.

**Unit-7:** Muktadaha Para, Betai  
Caretaker: Jitendra Ghosh  
Type of unit: AIIH&PH  
Families using: 150

This unit is located close to the Ashram. Although the villagers at the beginning were getting water free of cost but after a couple of months it was decided that every family will pay Rs. 5.0 per month for purchase of bleaching powder, aluminum sulfate and salary of Mr. Ghosh who maintains it. The villagers agreed to this suggestion. We expected a better management. The caretaker of the unit is a young boy Jitendra Ghosh (M/20). I asked him the difficulties and also the good side to run the unit. Mr. Jitendra Ghosh told me:



- (a) It was decided that Mr. Ghosh would be paid some money to run the unit. The villagers think as he is paid for this, it is his duty to fill-up the tank and villagers prefer to come and collect water. Mr. Ghosh told time to time he fills up the tank without knowing that he has not added required amount of bleaching powder and aluminum sulfate (as he feels within 15 to 20 minutes).
- (b) Although each family promised that they would pay Rs. 5/- per month, most of them do not pay. Mr. Ghosh never got his salary.
- (c) Mr. Ghosh told no one would clean the plant if he does not do it.
- (d) The villagers do not care whether aluminum sulfate and bleaching powder are falling in the system or not. They believe that water coming from tap of the plant is good for drinking.
- (e) To clean the unit it takes about 4 hours and after every 15 days when he cleans the tank he observes very dirty (brown) condition of the pebbles and time and again he finds small red colored worms.
- (f) After he fills-up the tank he observes some oily substance at the surface. We had also noticed it on 21st May 2000 during our field visit.
- (g) Anima Ghosh of the area told that she found once small red-colored worm when she took water for drinking from the unit.
- (h) Mr. Ghosh feels that after cleaning, the system remains good for one week but after that the inner tank slowly turns dirty and he find worms inside the tank.

### **Who Will Help the People in the Arsenic Affected Villages to Get Safe Water?**

The villagers of Betai came to know from local leaders that government would supply tap-water in the area in the near future and government had already sanctioned money for the area. Thus villagers told that they would get water free of cost, so they are least interested to pay Rs. 5/- per month in community participation project. It is our findings that many piped water supply schemes are arsenic contaminated in arsenic affected areas of West Bengal but villagers do not understand that and government hides the truth and do not initiate projects with peoples participation for safe water.

### **CONCLUSION**

In villages of India and Bangladesh even a highly successful technology may not succeed in rural areas unless it fits in the rural circumstances and is well accepted by the rural mass. Development of such technology is only possible when a combination is made between technocrats and villagers with proper village level participation.

# An Overview of Arsenic Removal Technologies in Bangladesh and India

**M. Feroze Ahmed**

Department of Civil Engineering

Bangladesh University of Engineering & Technology, Dhaka-1000, Bangladesh

## ***Abstract***

*In the context of prevalence of high concentrations of arsenic in tubewell water, a wide range technologies has been tried for the removal of arsenic from drinking water. The most common technologies utilized the conventional processes of oxidation, co-precipitation and adsorption onto coagulated flocs, adsorption onto sorptive media, ion exchange and membrane techniques for arsenic removal. The conventional technologies have been scaled down to meet the requirements of households and communities and suit the rural environment. Some technologies utilized indigenous materials for arsenic removal. This paper presents a short review of the technologies used for arsenic removal in Bangladesh and India.*

## **INTRODUCTION**

Groundwater is available in shallow aquifers in adequate quantity in the flood plains for development tubewell based water supply for scattered rural population. Bangladesh and West Bengal in India achieved remarkable successes by providing drinking water at low-cost to the rural population through sinking of shallow tubewells in flood plain aquifers. Unfortunately arsenic contamination of shallow tubewell water in excess of acceptable limit has become a major public health problem in both the countries. Thousands of people have already shown the symptoms of arsenic poisoning and several

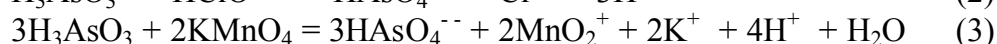
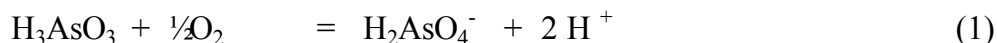
millions are at risk of arsenic contamination from drinking tubewell water. Arsenic toxicity has no known effective medicine for treatment, but drinking of arsenic free water can help the arsenic affected people to get rid of the symptoms of arsenic toxicity. Hence, provision of arsenic free water is urgently needed to mitigate arsenic toxicity and protection of health and well being of rural people living in acute arsenic problem areas of Bangladesh and India. The alternative options available for water supply in the arsenic affected areas include arsenic avoidance and treatment of arsenic contaminated ground water. Treatment of surface waters by low-cost methods, rain water harvesting and water from deep aquifers would be potential sources of water supply to avoid arsenic ingestion through shallow tubewell water. The use of alternative sources will require a major technological shift in water supply. Treatment of arsenic contaminated well water is an alternative option to make use of a huge number of tubewells likely to be declared abandoned for yielding water with high arsenic content.

There are several methods available for removal of arsenic from water in large conventional treatment plants. The most commonly used technologies include oxidation, co-precipitation and adsorption onto coagulated flocs, lime treatment, adsorption onto sorptive media, ion exchange resin and membrane techniques (Cheng et al., 1994; Hering et al., 1996, 1997; Kartinen and Martin, 1995; Shen, 1973; Joshi and Chaudhuri, 1996). A detailed review of arsenic removal technologies is presented by Sorg and Logsdon (1978). Jackel (1994) has documented several advances in arsenic removal technologies. In view of the lowering the drinking water standards by USEPA, a review of arsenic removal technologies was made to consider the economic factors involved in implementing lower drinking water standards for arsenic (Chen et al., 1999). Many of the arsenic removal technologies have been discussed in details in AWWA reference book (Pontious, 1990). A comprehensive review of low-cost, well-water treatment technologies for arsenic removal with the list of companies and organizations involved in arsenic removal technologies has been compiled by Murcott (2000) with contact detail.

Some of these technologies can be reduced in scale and conveniently be applied at household and community levels for the removal of arsenic from contaminated tubewell water. During the last 2-3 years many small scale arsenic removal technologies have been developed, field tested and used under action research programs in Bangladesh and India. A short review of these technologies is intended to update the technological development in arsenic removal, understand the problems, prospects and limitations of different treatment processes and delineate the areas of further improvement for successful implementation and adaptation of technologies to rural conditions

## OXIDATION

Arsenic is present in groundwater in As(III) and As(V) forms in different proportions. Most treatment methods are effective in removing arsenic in pentavalent form and hence include an oxidation step as pretreatment to convert arsenite to arsenate. Arsenite can be oxidized by oxygen, ozone, free chlorine, hypochlorite, permanganate, hydrogen peroxide and fulton's reagent but Atmospheric oxygen, hypochloride and permanganate are commonly used for oxidation in developing countries:



Air oxidation of arsenic is very slow and can take weeks for oxidation (Pierce and Moore, 1982) but chemicals like chlorine and permanganate can rapidly oxidize arsenite to arsenate under wide range of conditions.

### Passive Sedimentation

Passive sedimentation received considerable attention because of rural people's habit of drinking stored water from pitchers. Oxidation of water during collection and subsequent storage in houses may cause a reduction in arsenic concentration in stored water (*Bashi Pani*). Experiments conducted in Bangladesh showed zero to high reduction in arsenic content by passive sedimentation. Arsenic reduction by plain sedimentation appears to be dependent on water quality particularly the presence of precipitating iron in water. Ahmed et al.(2000) showed that more than 50% reduction in arsenic content is possible by sedimentation of tubewell water containing 380-480 mg/L of alkalinity as CaCO<sub>3</sub> and 8-12 mg/L of iron but cannot be relied to reduce arsenic to desired level. Most studies showed a reduction of zero to 25% of the initial concentration of arsenic in groundwater. In rapid assessment of technologies passive sedimentation failed to reduce arsenic to the desired level of 50 µg/L in any well(BAMWSP, DFID, WaterAid , 2001).

### In-situ Oxidation

In-situ oxidation of arsenic and iron in the aquifer has been tried under DPHE-Danida Arsenic Mitigation Pilot Project. The aerated tubewell water is stored in a tank and released back into the aquifers through the tubewell by opening a valve in a pipe connecting the water tank to the tubewell pipe under the pump head. The dissolved oxygen in water oxidizes arsenite to less mobile arsenate and also the ferrous iron in the aquifer to ferric iron, resulting a reduction in arsenic content in tubewell water. The possible reactions of arsenate to ferric hydroxide are shown in Equations 7 to 8. Experimental results show that arsenic in the

tubewell water following in-situ oxidation is reduced to about half due to underground precipitation and adsorption on ferric iron.

### **Solar Oxidation**

SORAS is a simple method of solar oxidation of arsenic in transparent bottles to reduce arsenic content of drinking water ( Wegelin et al., 2000). Ultraviolet radiation can catalyze the process of oxidation of arsenite in presence of other oxidants like oxygen ( Young, 1996). Experiments in Bangladesh show that the process on average can reduce arsenic content of water to about one-third.

### **CO-PRECIPIATION AND ADSORPTION PROCESSES**

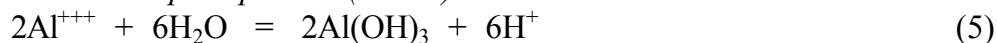
Water treatment with coagulants such as aluminium alum,  $\text{Al}_2(\text{SO}_4)_3 \cdot 18\text{H}_2\text{O}$ , ferric chloride,  $\text{FeCl}_3$  and ferric sulfate  $\text{Fe}_2(\text{SO}_4)_3 \cdot 7\text{H}_2\text{O}$  are effective in removing arsenic from water. Ferric salts have been found to be more effective in removing arsenic than alum on a weight basis and effective over a wider range of pH. In both cases pentavalent arsenic can be more effectively removed than trivalent arsenic.

In the coagulation-flocculation process aluminium sulfate, or ferric chloride, or ferric sulfate is added and dissolved in water under efficient stirring for one to few minutes. Aluminium or ferric hydroxide micro-flocs are formed rapidly. The water is then gently stirred for few minutes for agglomeration of micro-flocs into larger easily settable flocs. During this flocculation process all kinds of micro-particles and negatively charged ions are attached to the flocs by electrostatic attachment. Arsenic is also adsorbed onto coagulated flocs. As trivalent arsenic occurs in non-ionized form, it is not subject to significant removal. Oxidation of As(III) to As(V) is thus required as a pretreatment for efficient removal. This can be achieved by addition of bleaching powder (chlorine) or potassium permanganate as shown in Equations 2 and 3. The possible chemical equations of alum coagulation are as follows:

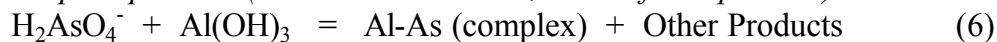
*Alum dissolution:*



*Aluminium precipitation(acidic):*

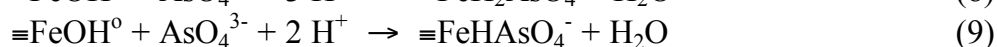
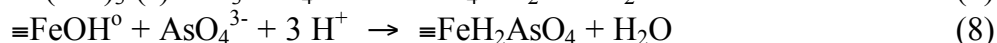
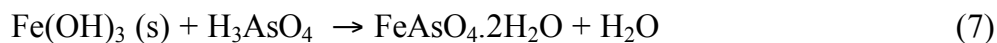


*Co-precipitation ( Non-stoichiometric, non-defined product):*



Arsenic adsorbed on aluminium hydroxide flocs as Al-As complex is removed by sedimentation. Filtration may be required to ensure complete removal of all flocs. Similar reactions take place in case of ferric chloride and ferric sulfate with the formation of Fe-As complex as end product which is removed by the process of sedimentation and filtration.

The possible reactions of arsenate with hydrous iron oxide are shown below where  $[=FeOH^0]$  represents oxide surface site (Mok and Wai, 1994; Hering et al., 1996).



Immobilization of arsenic by hydrous iron oxide, as shown in Eqs. 7 to 9, requires oxidation of arsenic species into As(V) form for higher efficiency. Arsenic removal is dependent on pH. In alum coagulation, the removal is most effective in the pH range 7.2-7.5 and in iron coagulation, efficient removal is achieved in a wider pH range usually between 6.0 and 8.5 (Ahmed and Raham, 2000).

### Bucket Treatment Unit

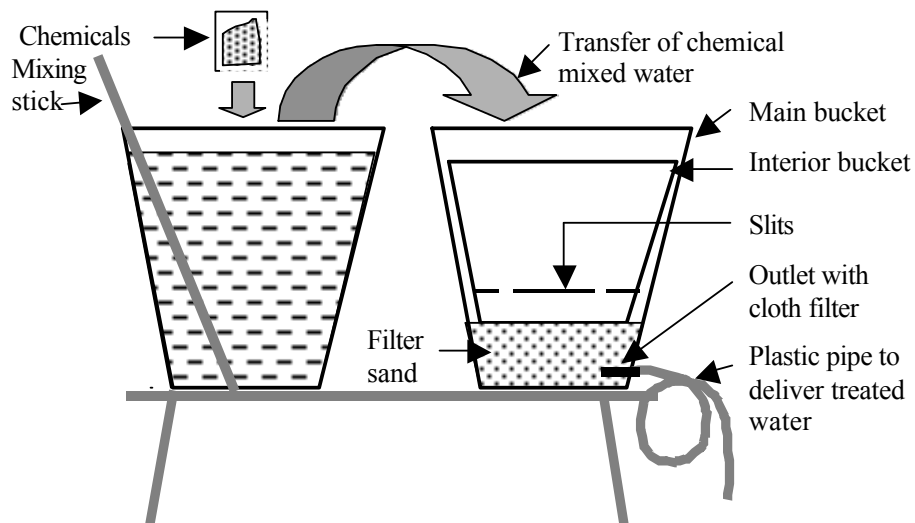
The Bucket Treatment Unit (BTU), developed by DPHE-Danida Project is based on the principles of coagulation, co-precipitation and adsorption processes. It consists of two buckets, each 20 liter capacity, placed one above the other. Chemicals are mixed manually with arsenic contaminated water in the upper red bucket by vigorous stirring with a wooden stick for 30 to 60 seconds and then flocculated by gentle stirring for about 90 second. The mixed water is then allowed to settle for 1- 2 hours. The water from the top red bucket is then allowed to flow into the lower green bucket via plastic pipe and a sand filter installed in the lower bucket. The flow is initiated by opening a valve fitted slightly above the bottom of the red bucket to avoid inflow of settled sludge in the upper bucket. The lower green bucket is practically a treated water container.

The DPHE-Danida project in Bangladesh distributed several thousands BTU units in rural areas of Bangladesh. These units are based on chemical doses of 200 mg/L aluminum sulfate and 2 mg/L of potassium permanganate supplied in crushed powder form. The units were reported to have very good performance in arsenic removal in both field and laboratory conditions ( Sarkar et al., 2000 and Kohnhorst and Paul, 2000). Extensive study of DPHE-Danida BTU under BAMWSP, DFID, WaterAid (2001) rapid assessment program showed mixed results. In many cases, the units under rural operating conditions fails to remove arsenic to the desired level of 0.05 mg/L in Bangladesh. Poor mixing and variable water quality particularly pH of groundwater in different locations of Bangladesh appeared to be the cause of poor performance in rapid assessment.

Bangladesh University of Engineering and Technology (BUET) modified the BTU and obtained better results by using 100 mg/L of ferric chloride and 1.4 mg/L of potassium permanganate in modified BTU units. The arsenic contents of treated water were mostly below 20 ppb and never exceeded 37 ppb while arsenic concentrations of tubewell water varied between 375 to 640 ppb. The BTU is a promising technology for arsenic removal at household level at low cost. It can be built by locally available materials and is effective in removing arsenic if operated properly.

### Stevens Institute Technology

This technology also uses two buckets, one to mix chemicals ( reported to be iron sulphate and calcium hypochloride) supplied in packets and the other to separate flocs by the processes of sedimentation and filtration. The second bucket has a second inner bucket with slits on the sides as shown in Figure 1 to help sedimentation and keeping the filter sand bed in place. The chemicals form visible large flocs on mixing by stirring with stick. Rapid assessment showed that the technology was effective in reducing arsenic levels to less than 0.05 mg/L in case of 80 to 95% of the samples tested (BAMWSP, DFID, WaterAid , 2001). The sand bed used for filtration is quickly clogged by flocs and requires washing atleast twice a week.



**Figure 1 : Stevens Institute Technology**

### BCSIR Filter Unit

Bangladesh Council of Scientific and Industrial Research (BCSIR) has developed an arsenic removal system, which uses the process of coagulation/co-precipitation with an iron based chemical followed by sand filtration. The unit did not take part in a comprehensive evaluation process.

### Fill and Draw Units

It is a community type treatment unit designed and installed under DPHE-Danida Arsenic Mitigation Pilot Project. It is 600 L capacity (effective) tank with slightly tapered bottom for collection and withdraw of settled sludge. The tank is fitted with a manually operated mixer with flat-blade impellers. The tank is filled with arsenic contaminated water and required quantity of oxidant and coagulant are added to the water. The water is then mixed for 30 seconds by rotating the mixing device at the rate of 60 rpm and left overnight for sedimentation. The water takes some times to become completely still which helps flocculation. The floc formation is caused by the hydraulic gradient of the rotating water in the tank. The settled water is then drawn through a pipe fitted at a level, few inches above the bottom of the tank and passed through a sand bed and finally collected through a tap for drinking purpose as shown in Figure 2. The mixing and flocculation processes in this unit are better controlled to effect higher removal of arsenic. The experimental units installed by DPHE-Danida project are serving the clusters of families and educational institutions.

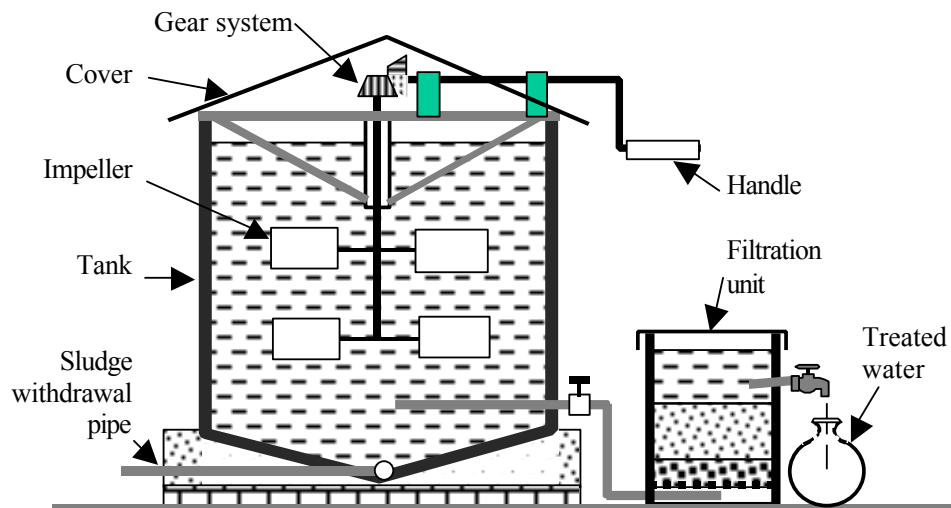
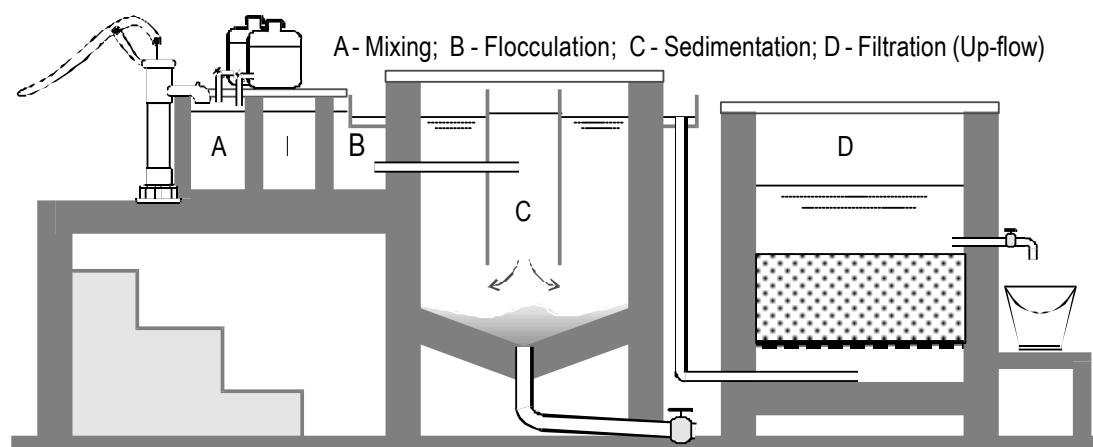


Figure 2 : DPHE-Danida Fill and Draw arsenic removal unit



### **Arsenic Removal Unit Attached to Tubewell**

The principles of arsenic removal by alum coagulation, sedimentation and filtration have been employed in a compact unit for water treatment in the village level in West Bengal, India. The arsenic removal plant attached to hand tubewell as shown in Figure 3 has been found effective in removing 90 percent arsenic from tubewell water having initial arsenic concentration of  $300\mu\text{g/L}$ . The treatment process involves addition of sodium hypochloride ( $\text{Cl}_2$ ), and aluminum alum in diluted form, mixing, flocculation, sedimentation and up flow filtration in a compact unit.

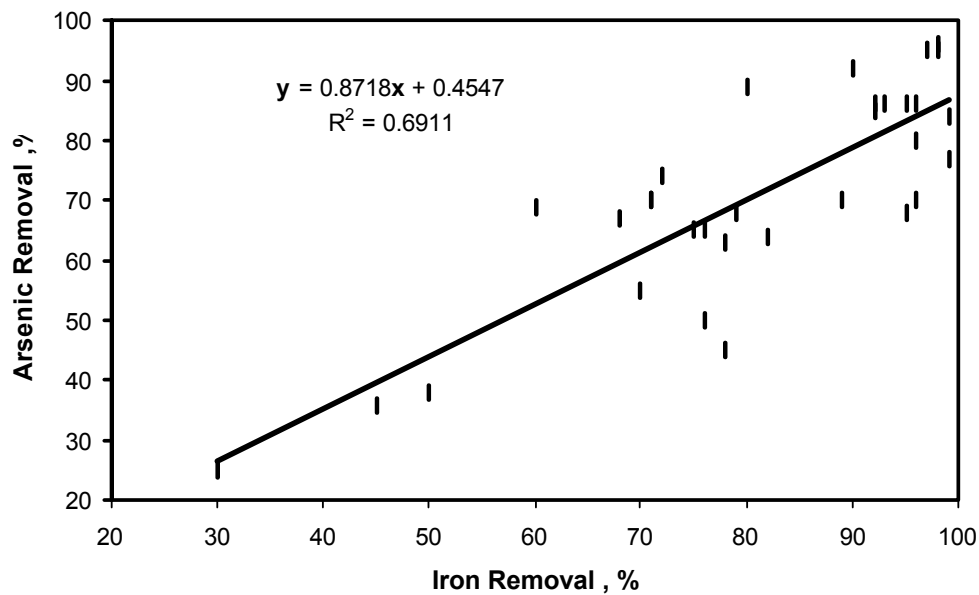


**Figure 3 : Arsenic removal plants attached to tubewell ( designed and constructed in India)**

### **Naturally Occurring Iron**

The use of naturally occurring iron precipitates in ground water in Bangladesh is a promising method of removing arsenic by adsorption. It has been found that hand tubewell water in 65% of the area in Bangladesh contains iron in excess of 2 mg/L and in many acute iron problem areas, the concentration of dissolved iron is higher than 15 mg/L. Although no good correlation between concentrations of iron and arsenic has been derived, iron and arsenic have been found to co-exist in ground water. Most of the tubewell water samples satisfying Bangladesh Drinking Water Standard for Iron ( 1 mg/L) also satisfy the standard for Arsenic ( $50\mu\text{g/L}$ ). Only about 50% of the samples having iron content 1 - 5 mg/L satisfy the standard for arsenic while 75% of the samples having iron content  $> 5\text{ mg/L}$  are unsafe for having high concentration of arsenic.

The iron precipitates  $[\text{Fe}(\text{OH})_3]$  formed by oxidation of dissolved iron  $[\text{Fe}(\text{OH})_2]$  present in groundwater, as discussed above, have the affinity for the adsorption of arsenic. Only aeration and sedimentation of tubewell water rich in dissolved iron has been found to remove arsenic. The Iron Removal Plants (IRPs) in Bangladesh constructed on the principles of aeration, sedimentation and filtration in a small units have been found to remove arsenic without any added chemicals. The conventional community type IRPs, depending on the operating principles, more or less work as Arsenic Removal Plants (ARPs) as well. A study suggests that As(III) is oxidized to As(V) in the IRPs to facilitate higher efficiency in arsenic removal in IRPs constructed in Noakhali ( Dahi and Liang, 1998). The Fe-As removal relationship with good correlation in some operating IRPs has been plotted in Figure 4. Results shows that most IRPs can lower arsenic content of tubewell water to half to one-fifth of the original concentrations. The efficiency of these community type Fe-As removal plants can be increased by increasing the contact time between arsenic species and iron flocs. Community participation in operation and maintenance in the local level is absolutely essential for effective use of these plants.



**Figure 4: Correlation between Fe and As Removal in Treatment Plants**

Some medium scale Fe-As removal plants of capacities 2000-3000 m<sup>3</sup>/d have been constructed for water supplies in district towns based on the same principle. The treatment processes involved in these plants include aeration, sedimentation and rapid sand filtration with provision for addition of chemical, if required.

These plants are working well except that treated water requirement for washing the filter beds is very high. Operations of small and medium size IRP-cum-ARPs in Bangladesh suggest that arsenic removal by co-precipitation and adsorption on natural iron flocs has good potential.

### **Chemical Packages**

In Bangladesh, different types of chemical packages have been distributed in the form of tea bags, small packets and powder or tablet form for the removal of arsenic from drinking water. The principles involved in arsenic removal by these chemicals involve oxidation, sorption and co-precipitation. Application methodology and efficiency of any of these chemicals have not been fully optimized by long experimentation. Quality assurance and dose control in rural condition are extremely difficult. The residuals of added chemicals in water after treatment can do equal harm. The use of unknown chemicals and patented process without adequate information should be totally discouraged.

### **SORPTIVE FILTRATION MEDIA**

Several sorptive media have been reported to remove arsenic from water. These are activated alumina, activated carbon, iron and manganese coated sand, kaolinite clay, hydrated ferric oxide, activated bauxite, titanium oxide, silicium oxide and many natural and synthetic media. The efficiency of all some sorptive media depend on the use of oxidizing agent as aids to sorption of arsenic. Saturation of media by different contaminants and components of water takes place at different times of operation depending on the specific sorption affinity of the medium to the given component. Saturation means that the efficiency in removing the desired impurities becomes zero.

#### **Activated Alumina**

Activated alumina,  $\text{Al}_2\text{O}_3$ , having good sorptive surface is an effective medium for arsenic removal. When water passes through a packed column of activated alumina, the impurities including arsenic present in water are adsorbed on the surfaces of activated alumina grains. Eventually the column becomes saturated, first at its upstream zone and later the saturated zone moves downstream towards the bottom end and finally the column get totally saturated.

Regeneration of saturated alumina is carried out by exposing the medium to 4% caustic soda, NaOH, either in batch or by flow through the column resulting in a high arsenic contaminated caustic waste water. The residual caustic soda is then washed out and the medium is neutralized with a 2% solution of sulfuric acid rinse. During the process about 5-10% alumina is lost and the capacity of the

regenerated medium is reduced by 30-40%. The activated alumina needs replacement after 3-4 regeneration. Like coagulation process, pre-chlorination improves the column capacity dramatically. Some of the activated alumina based sorptive media used in Bangladesh include:

- BUET Activated Alumina
- Alcan Enhanced Activated Alumina
- ARU of Project Earth Industries Inc., USA
- Apyron Arsenic Treatment Unit

The BUET and Alcan activated alumina have been extensively tested in field condition in different areas of Bangladesh under rapid assessment and found very effective in arsenic removal (BAMWSP, DFID, WaterAid, 2001). The Arsenic Removal Units (ARUs) of Project Earth Industries Inc. (USA) used hybrid aluminas and composite metal oxides as adsorption media and were able to treat 200-500 Bed Volume(BV) of water containing 550 g/L of arsenic and 14 mg/L of iron (Ahmed et al., 2000). The Apyron Technologies Inc. (ATI) also uses inorganic granular metal oxide based media that can selectively remove As(III) and As(V) from water. The Aqua-Bind™ arsenic media used by ATI consist of non-hazardous aluminium oxide and manganese oxide for cost-effective removal of arsenic. The proponents claimed that the units installed in India and Bangladesh consistently reduced arsenic to less than 10µg/L.

### **Granular Ferric Hydroxide**

M/S Pal Trockner(P) Ltd, India and Sidko Limited, Bangladesh installed several Granular Ferric Hydroxide based arsenic removal units in India and Bangladesh. The Granular Ferric Hydroxide (AdsorpAs®) is arsenic selective adsorbent developed by Technical University, Berlin, Germany. The unit requires iron removal as pre-treatment to avoid clogging of filter bed. The proponents of the unit claims to have very high arsenic removal capacity and produces non-toxic spent granular ferric hydroxide.

### **Read-F Arsenic Removal Unit**

Read-F is an adsorbent produced and promoted by Shin Nihon Salt Co. Ltd, Japan for arsenic removal in Bangladesh. Read-F displays high selectivity for arsenic ions under a broad range of conditions and effectively adsorbs both arsenite and arsenate without the need for pretreatment. The Read-F is Ethylene-vinyl alcohol copolymer(EVOH)-borne hydrous cerium oxide in which hydrous cerium oxide ( $CeO_2 \cdot n H_2O$ ), is the adsorbent. The material contains no organic solvent or other volatile substance and is not classified as hazardous material. Laboratory test at BUET and field testing of the materials at 4 sites under the supervision of BAMWSP showed that the adsorbent is highly efficient in removing arsenic from groundwater (SNSCL, 2000).

### **Iron Coated Sand**

BUET has constructed and tested iron coated sand based small scale unit for the removal of arsenic from groundwater. Iron coated sand has been prepared following a procedure similar to that adopted by Joshi and Choudhuri (1996). The iron content of the iron coated sand was found to be 25 mg/g of sand. Raw water having 300 µg/L of arsenic when filtered through iron coated sand becomes essentially arsenic-free. It was found that 350 bed volumes could be treated satisfying the Bangladesh drinking water standard of 50 ppb. The saturated medium is regenerated by passing 0.2N sodium hydroxide through the column or soaking the sand in 0.2N sodium hydroxide followed by washing with distilled water. No significant change in bed volume (BV) in arsenic removal was found after 5 regeneration cycles. It was interesting to note that iron coated sand is equally effective in removing both As(III) and As(V). Iron coated brick dust has also been developed in Bangladesh for arsenic removal from drinking water.

### **Indigenous Filters**

There are several filters available in Bangladesh that use indigenous material as arsenic adsorbent. Red soil rich in oxidized iron, clay minerals, iron ore, iron scrap or fillings and processed cellulose materials are known to have capacity for arsenic adsorption. Some of the filters manufactured using these materials include:

- Sono 3-Kolshi Filter
- Granet Home-made Filter
- Chari Filter
- Adarsha Filter
- Shafi Filter
- Bijoypur Clay/Processed Cellulose filter

The Sono 3-Kolshi filter uses zero valent iron fillings and coarse sand in the top Kolshi, wood coke and fine sand in the middle Kolshi while the bottom Kolshi is the collector of the filtered water (Khan et al., 2000). Earlier Nikolaidis and Lackovic (1998) showed that 97 % arsenic can be removed by adsorption on a mixture of zero valent iron fillings and sand and recommended that arsenic species could have been removed through formation of co-precipitates, mixed precipitates and by adsorption onto the ferric hydroxide solids. The Sono 3-Kolshi unit has been found to be very effective in removing arsenic but the media harbour growth of microorganism (BAMWSP, DFID and WaterAid, 2000). The one-time use unit becomes quickly clogged, if groundwater contains excessive iron.

The Garnet home-made filter contains relatively inert materials like brick chips and sand as filtering media. No chemical is added to the system. Air oxidation and adsorption on iron-rich brick chips and flocs of naturally present

iron in groundwater could be the reason for arsenic removal from groundwater. The unit produced inadequate quantity of water and did not show reliable results in different areas of Bangladesh and under different operating conditions. The Chari filter also uses brick chips and inert aggregates in different Charis as filter media. The effectiveness of this filter in arsenic removal is not known.

The Shafi and Adarsh filters use clay material as filter media in the form of candle. The Shafi filter was reported to have good arsenic removal capacity but suffered from clogging of filter media. The Adarsha filter participated in the rapid assessment program but failed to meet the technical criterion of reducing arsenic to acceptable level (BAMWSP, DFID and WaterAid, 2000). Bijoypur clay and treated cellulose were also found to adsorb arsenic from water (Khair, 2000).

### Cartridge Filters

Filter units with cartridges filled with soptive media or ion-exchange resins are readily available in the market. These unit remove arsenic like any other dissolved ions present in water. These units are not suitable for water having high impurities and iron in water. Presence of ions having higher affinity than arsenic can quickly saturate the media requiring regeneration or replacement. Two household filters were tested at BUET laboratories, These are:

- Chiyoda Arsenic Removal Unit, Japan
- Coolmart Water Purifier, Korea.

The Chiyoda Arsenic Removal Unit could treat 800 BV meeting the WHO guideline value of 10 µg/L and 1300 BV meeting the Bangladesh Standard of 50 µg/L when the feed water arsenic concentration was 300 µg/L. The Coolmart Water Purifier could treat only 20 L of water with a effluent arsenic content of 25 µg/L ( Ahmed et al., 2000). The initial and operation costs of these units are high and beyond the reach of the rural people.

### ION EXCHANGE

The process is similar to that of activated alumina, just the medium is a synthetic resin of more well defined ion exchange capacity. The process is normally used for removal of specific undesirable cation or anion from water. As the resin becomes exhausted, it needs to be regenerated. The arsenic exchange and regeneration equations with common salt solution as regeneration agent are as follows:

Arsenic exchange



Regeneration



Where **R** stands for ion exchange resin.

The arsenic removal capacity is dependent on sulfate and nitrate contents of raw water as sulfate and nitrate are exchanged before arsenic. The ion exchange process is less dependent on pH of water. The efficiency of ion exchange process is radically improved by pre-oxidation of As(III) to As(V) but the excess of oxidant often needs to be removed before the ion exchange in order to avoid the damage of sensitive resins. Development of ion specific resin for exclusive removal of arsenic can make the process very attractive.

Tetrahedron ion exchange resin filter tested under rapid assessment program in Bangladesh (BAMWSP, DFID and WaterAid, 2000) showed promising results in arsenic removal. The system needs pre-oxidation of arsenite by sodium hypochloride. The residual chlorine helps to minimize bacterial growth in the media. The saturated resin requires regeneration by recirculating NaCl solution. The liquid wastes rich in salt and arsenic produced during regeneration require special treatment. Some other ion exchange resins were demonstrated in Bangladesh but sufficient field test results are not available on the performance of those resins.

## MEMBRANE TECHNIQUES

Membrane techniques like reverse osmosis, nanofiltration and electrodialysis are capable of removing all kinds of dissolved solids including arsenic from water. In this process water is allowed to pass through special filter media which physically retain the impurities present in water. The water, for treatment by membrane techniques, shall be free from suspended solids and the arsenic in water shall be in pentavalent form. Most membranes, however, can not withstand oxidizing agent.

### **MRT-1000 and Reid System Ltd.**

Jago Corporation Limited promoted a household reverse osmosis water dispenser MRT-1000 manufactured by B & T Science Co. Limited, Taiwan. This system was tested at BUET and showed a arsenic (III) removal efficiency more than 80%. A wider spectrum reverse osmosis system named Reid System Limited was also promoted in Bangladesh. Experimental results showed that the system could effectively reduce arsenic content along with other impurities in water. The capital and operational costs of the reverse osmosis system would be relatively high.

### **Low-pressure Nanofiltration and Reverse Osmosis**

Oh et al.(2000) applied reverse osmosis and nanofiltration membrane processes for the treatment of arsenic contaminated water applying low pressure by bicycle pump. A nanofiltration membrane process coupled with a bicycle pump could be operated under condition of low recovery and low pressure range from 0.2 to 0.7 MPa. Arsenite was found to have lower rejection than arsenate in ionized forms and hence water containing higher arsenite requires pre-oxidation for reduction of total arsenic acceptable level. In tubewell water in Bangladesh the average ratio of arsenite to total arsenic was found to be 0.25. However, the reverse osmosis process coupled with a bicycle pump system operating at 4 Mpa can be used for arsenic removal because of its high arsenite rejection. The study concluded that low-pressure nanofiltration with pre-oxidation or reverse osmosis with a bicycle pump device could be used for the treatment of arsenic contaminated groundwater in rural areas ( Oh et al., 2000).

### **DISCUSSIONS**

A remarkable technological development in arsenic removal from rural water supply based on conventional arsenic removal processes has been taken place during last 2-3 years. A comparison of different arsenic removal processes is shown in Table 1.

All the technologies described in this paper have their merits and demerits and are being refined to make suitable in rural condition. The modifications based on the pilot-scale implementation of the technologies are in progress with the objectives to:

- improve effectiveness in arsenic removal
- reduce the capital and operation cost of the systems
- make the technology user friendly
- overcome maintenance problems
- resolve sludge and arsenic concentrates management problems.

Arsenic removal technologies have to compete with other technologies in which cost appears to a major determinant in the selection of a treatment option by the users. The rural people habituated in drinking tubewell water may find arsenic removal from tubewell water as a suitable option for water supply. In many arsenic affected areas, arsenic removal may be the only option in the absence of an alternative safe source of water supply.



**Table 1 : A comparison of main arsenic removal technologies**

<b>Technologies</b>	<b>Advantages</b>	<b>Disadvantages</b>
<b><u>Oxidation/ Precipitation</u></b>		
<ul style="list-style-type: none"> <li>▪ Air Oxidation</li> <li>▪ Chemical oxidation</li> </ul>	<ul style="list-style-type: none"> <li>• Relatively simple, low-cost but slow process</li> <li>• Relatively simple and rapid process</li> <li>• Oxidizes other impurities and kills microbes</li> </ul>	<ul style="list-style-type: none"> <li>• The processes remove only a part of arsenic</li> </ul>
<b><u>Coagulation Coprecipitation :</u></b>		
<ul style="list-style-type: none"> <li>• Alum Coagulation</li> <li>• Iron Coagulation</li> </ul>	<ul style="list-style-type: none"> <li>• Relatively low capital cost,</li> <li>• Relatively simple operation</li> <li>• Common Chemicals available</li> </ul>	<ul style="list-style-type: none"> <li>• Produces toxic sludges</li> <li>• Low removal of As(III)</li> <li>• Pre-oxidation may be required</li> </ul>
<b><u>Sorption Techniques</u></b>		
<ul style="list-style-type: none"> <li>• Activated Alumina</li> <li>• Iron Coated Sand</li> <li>• Ion Exchange Resin</li> <li>• Other Sorbents</li> </ul>	<ul style="list-style-type: none"> <li>• Relatively well known and commercially available</li> <li>• Well defined technique</li> <li>• Plenty possibilities and scope of development</li> </ul>	<ul style="list-style-type: none"> <li>• Produces toxic solid waste</li> <li>• Replacement/regeneration required</li> <li>• High tech operation and maintenance</li> <li>• Relatively high cost</li> </ul>
<b><u>Membrane Techniques</u></b>		
<ul style="list-style-type: none"> <li>• Nanofiltration</li> <li>• Reverse osmosis</li> <li>• Electrodialysis</li> </ul>	<ul style="list-style-type: none"> <li>• Well defined and high removal efficiency</li> <li>• No toxic solid wastes produced</li> <li>• Capable of removal of other contaminants</li> </ul>	<ul style="list-style-type: none"> <li>• Very high capital and running cost</li> <li>• High tech operation and maintenance</li> <li>• Toxic wastewater produced</li> </ul>

A rapid assessment of 9 household level arsenic removal technologies has been completed recently (BAMWSP, DFID and WaterAid, 2000). On the basis of this study the Technical Advisory Group (TAG) of Bangladesh Arsenic Mitigation Water Supply Project (BAWSP) has recently recommended the

following household arsenic removal technologies for experimental use in arsenic affected areas:

- Alcan Enhanced Activated Alumina
- BUET Activated Alumina
- Sono 3-Kolshi Method
- Stevens Institute Technology

The widely used DPHE/Danida two buckets system and Tetrahedron ion exchange resin filters will be reviewed when more information on performance of the systems and its revised version are available. Few more technologies in addition to technologies described in this paper are available for arsenic removal at household and community levels. These technologies need evaluation in respect of effectiveness in arsenic removal and community acceptance.

## CONCLUSION

The technologies found effective and safe for arsenic removal from tubewell water need promotion for wider implementation in the acute arsenic problem areas to avoid ingestion of excessive arsenic through tubewell water. The arsenic removal technologies are expected to improve further through adaptation in rural environment.

## REFERENCES

- Ahmed M.F and Rahaman M. M.(2000), *Water Supply and Sanitation - Low Income Urban Communities*, International Training Network (ITN) Centre, BUET.
- Ahmed. F. , Jalil, M.A., Ali, M.A., Hossain, M.D. and Badruzzaman, A.B.M. An overview of arsenic removal technologies in BUET, In *Bangladesh Environment-2000*, M.F.Ahmed (Ed.), Bangladesh Poribesh Andolon, 177-188.
- BAMWSP, DFID and WaterAid Bangladesh ( 2001), *Rapid Assessment of Household Level Arsenic Removal Technologies*, Phase-I and Phase-II, Final Report, WS Atkins International Limited.
- Chen, H.W., Frey, M.M., Clifford, D., McNeill, L.S. and Edwards, M., 1999, Arsenic treatment considerations, *Journal of American Water Works Association*, 91(3), 74-85.
- Cheng, C. R., Liang, S. Wang, H. C. and Beuhler, M. D. (1994), "Enhanced coagulation for arsenic removal", *J. American Water Works Association*, 86(9), p.79-90.

- Dahi, E and Liang, Q. ( 1998), “Arsenic Removal in Hand Pump Connected Iron Removal Plants in Noakhali, Bangladesh “ presented at *International Conference on Arsenic Pollution of Ground Water in Bangladesh : Causes, Effect and Remedies*, Dhaka, 8-12 February.
- Hering, J. G., Chen, P. Y., Wilkie, J. A., Elimelech, M. and Liang, S. (1996), Arsenic removal by ferric chloride, *J. American Water Works Association*, 88(4), p.155-167.
- Hering, J. G., Chen, P., Wilkie, J. A., Elimelech, M. (1997), Arsenic removal from drinking water during coagulation, *J. Env. Eng., ASCE*, 123(8), p.800-807.
- Jekel, M.R., 1994, Removal of arsenic in drinking water treatment. In J.O. Nriagu (Ed.) *Arsenic in the Environment, Part 1: Cycling and Characterization*, John Wiley & Sons, Inc., New York.
- Joshi, A. and Chaudhury, M. (1996), Removal of arsenic from groundwater by iron-oxide-coated sand, *ASCE Journal of Environmental Engineering*, 122(8), p.769-771.
- Kartinen, E. O. and Martin, C. J. (1995), An overview of arsenic removal processes, *J. Desalination*, 103, p.79-88.
- Khair, A.(2000) Factors responsible for the presence of arsenic in groundwater: Bangladesh context, In *Bangladesh Environment-2000*, M.F.Ahmed (Ed.), Bangladesh Poribesh Andolon, :198-209.
- Khan, A.H., Rasul, S.B., Munir, A.K.M., Alauddin, M. Habibuddowlah, M. and Hussam,A (2000). On two simple arsenic removal methods for groundwater of Bangladesh, In *Bangladesh Environment-2000*, M.F.Ahmed (Ed.), Bangladesh Poribesh Andolon, :151-173.
- Kohnhorst, A. and Paul, P (2000) , Testing simple arsenic removal methods, In *Water, Sanitation and Hygiene: Challenges of the Millennium*, Pre-prints of the 26 WEDC Conference, Dhaka, Bangladesh., 177-181.
- Mok, W.M., Wai, C.M. ( 1994). Mobilization of arsenic in Contaminated River Water in Arsenic in the Environment ( J.O. Nriagu Ed.), John Wiley & Sons Inc.
- Murcott, S. 2000 , A comprehensive review of low-cost, well-water treatment technologies for arsenic removal, <http://phys4.harvard.edu/~wilson,/murcott2.html>.
- Nikolaidis,N.P. and Lackovic, J. (1998), “Arsenic Remediation Technology-AsRT”, presented at *International Conference on Arsenic Pollution of Ground Water in Bangladesh: Causes, Effect and Remedies*, Dhaka, 8-12 February.
- Oh, J.I., Yamamoto, K., K., Kitawaki, H., Nakao, S., Sugawara, T., Rahaman, M.M. and Rahaman, M.H. (2000), Application of low-pressure nanofiltration coupled with a bicycle pump for the treatment of arsenic-contaminated groundwater, *Desalination*, **132** : 307-314.

- Oh, J.I., K., Urase, T., Kitawaki, H., Rahaman, M.M., Rahaman, M.H. and Yamamoto, K., Modelling of arsenic rejection considering affinity and steric hindrance effect in nonfiltration membranes, *Water Science and Technology*, **42**, 3-4 : 173-180.
- Pierce, M.L. and Moore, C.B. (1982), Adsorption of Arsenite and Arsenate on amorphous iron hydroxide, *Water Resources*, **16**, 1247-1253.
- Pontius, F.W.(Ed.),1990, Water Quality Treatment: a handbook of community water supplies, *American Water Works Association*, McGraw-Hill, New York.
- Sorg, T.J. and Logsdon, G.S. 1974, Treatment technology to meet the interim primary drinking water regulations for inorganics: Part 2, *Journal of the American Water Works Association*, 70(7), 379-393).
- Shen, Y. S. (1973), Study of arsenic removal from drinking water", *J. American Water Works Association*, 65(8), p.543-548.
- Shin Nihon Salt Co. Ltd. (2000), Report on Performance of Read-F Arsenic Removal Unit (ARU), October.
- Sarkar, A, Thogersen, Choudhury, Rahaman, Akhter and Choudhury (2000), Bucket Treatment unit for arsenic removal, In *Water, Sanitation and Hygiene: Challenges of the Millennium*, Pre-prints of the 26 WEDC Conference, Dhaka, Bangladesh., 308-310.
- Wegelin, M., Gechter, D., Hug, S., Mahmud, A., Motaleb, A. (2000) SORAS-a simple arsenic removal process ([http://phys4.harvard.edu/~wilson/mitigation/SORAS\\_Paper.html](http://phys4.harvard.edu/~wilson/mitigation/SORAS_Paper.html)).
- Young, E (1996), Cleaning up arsenic and old waste, *New Scientist*, 14 December : 22.

## **Policy Dimensions of the Arsenic Pollution Problem in Bangladesh**

**Zafar Adeel**

Environment and Sustainable Development  
The United Nations University, Tokyo, Japan

### **INTRODUCTION**

The arsenic pollution of groundwater has become a major disaster for West Bengal, India and Bangladesh. The alluvial aquifer that underlies the Ganges-Brahmaputra river basin contains arsenic in mineral form and has been widely tapped for obtaining drinking and irrigation water. Over a period of about 20-25 years about four million wells have been installed to utilize the groundwater from deeper aquifer layers, typically less than 200m deep (UNICEF, 1999). Exploitation of groundwater from these wells has resulted in mobilizing the arsenic and led to mass poisoning in the region, which is defined by the generic term arsenicosis (Rahman et al., 2001). Presence of arsenic from natural sources in the groundwater is not unusual and has been documented in other parts of the world. This paper will focus primarily on Bangladesh with the implicit understanding that the recommendations may well be applicable to other developing countries.

Bangladesh is a tropical country with a total surface area of about 144,000 km<sup>2</sup> and an estimated population of 129 million as of July 2000 (UN, 2000). Of the surface area available, about 70% is arable and about 10-15% comprises forests and woodlands. World Bank estimates put the contribution of the agricultural sector to national GDP at about 25%, while a vast majority (~76%) of the population lives in rural settings (World Bank, 2000). Incidentally, this rural population is the one most impacted by the arsenic contamination, largely because of lack of access to safe drinking water. Even in the cities only about half the population has access to safe water (UN, 2000). Recent estimates

indicate that more than 35 million people are potentially at risk from drinking contaminated water (Smith et al., 2000). This indeed brings the problem to a catastrophic scale that has not been experienced by humankind before.

The Bangladesh government, with support from international agencies and local and international NGO groups, have initiated a number of programmes to determine the extent of the problem. Considering the unprecedented scale of this disaster, it has been a major challenge to come up with a cohesive strategy to tackle the problem. This is particularly difficult due to the fact that the problem is multi-dimensional and involves a number of sectors. Another confounding factor is the scientific uncertainty in a number of aspects, including the exact mechanism of arsenic mobilization, exact delineation of arsenic contamination (with concentration levels and estimated water volume) and effective medical remedies for arsenicosis. This paper overviews the various dimensions of the problem and suggests some preliminary guidelines for developing a cohesive strategy.

## **RESEARCH GAPS**

A number of gaps in the scientific knowledge exist; only a few of them are described here. Firstly, the health impact of arsenic in the presence of other pollutants and iron has not been fully studied. It is quite important to know whether presence of other pollutants worsens the arsenicosis conditions or not. Secondly, ingestion of arsenic through other routes such as contaminated food has not been adequately studied. A vast majority of the contaminated groundwater is utilized for irrigation purposes. The potential uptake of arsenic into plants and foods from the irrigation water, retention in soils and leaching back to shallower aquifers have not been investigated. Thirdly, soil retention of arsenic can lead to arsenic-laden dust particles – these have not been explicitly studied as an ingestion route. Some of these issues highlight the need for carefully conducted scientific studies that describe the fate of arsenic in the natural environment and identify all potential routes of exposure.

## **POLICY DIMENSIONS**

### **Human Health Protection**

The impacts of arsenic pollution on human health – arsenicosis, keratosis, melanosis and others – are typically gradual. Some researchers have divided them into four categories or levels ranging from mild to severe (Oshikawa et al., 2001). The transition from one level to another occurs due to continued long term exposure to arsenic contaminated water. Some of the research work done by

Oshikawa et al. (2001) clearly indicates either improvement in health or halting further degradation when use of contaminated water is discontinued in the early stages of the disease. This has important implications for formulating a health protection policy. One may argue that provision of clean and affordable supply of freshwater is absolutely essential to halting the further impacts of the problem.

Implementing such a policy, however, poses several challenges for government agencies, civil society groups and international organizations. Firstly, convincing the general public that clean freshwater will help with the common epidemic is a difficult task. This difficulty has to be viewed in the context of similar publicity campaigns carried out in the 1970's and 1980's to promote that groundwater is the safest source of water. The credibility barrier so-created can be overcome through involvement of local communities in the development of such programmes. Secondly, providing clean freshwater at low cost or free of charge would require considerable investment in developing, managing and operating a reliable water supply system. Interim measures such as supplying bottled water may not be sustainable in the long-term. Needless to say, international funding agencies as well as bilateral donors can and have stepped in to assist in the process.

Another important public health issue is setting the standard for what is "clean" water. Currently, Bangladesh employs a drinking water standard of 50 ppb (or  $\mu\text{g/L}$ ) which is based on some earlier guidelines established by the World Health Organization (WHO, 1993). Many countries including Bangladesh have either kept this as the national standard or as an interim target, with the realization that significant impacts may also exist at lower concentrations in the 10-50 ppb range. It should also be noted that based on scientific information available on health impacts of arsenic contaminated water, a value lower than 10 ppb is advisable (WHO, 1999). However, such a value is still considered provisional in part due to the lack of widely acceptable analytical techniques. Existing scientific evidence should be weighed carefully and the drinking water standard for arsenic should be revised downwards. Obviously, this will have significant impacts in identifying and delineating the regions impacted by the arsenic groundwater pollution.

### **Social and Societal Aspects**

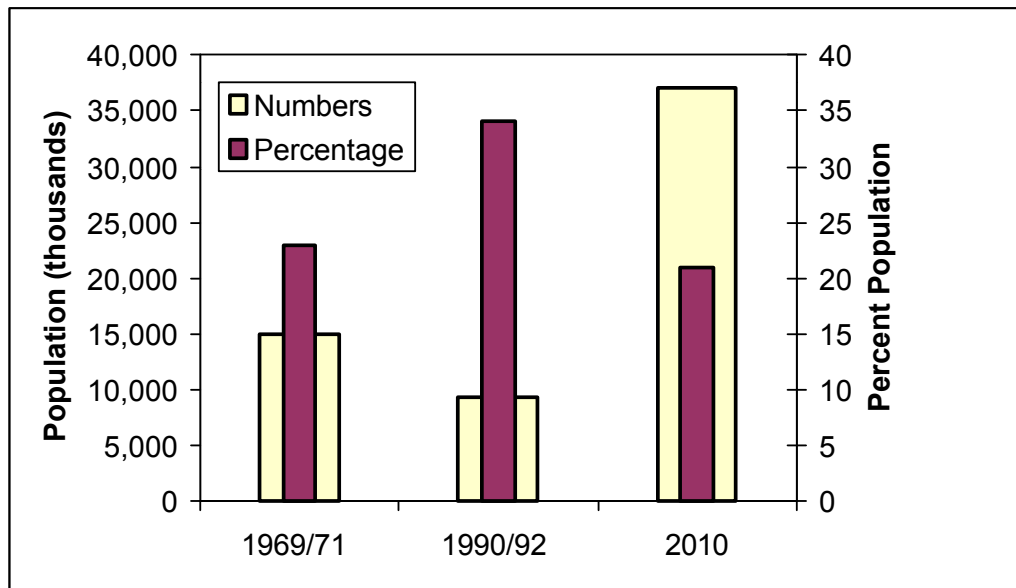
The arsenic contamination problem has triggered a number of social and societal problems that were unanticipated and are still not fully recognized. Recent studies confirm the fact that worst arsenic problems are encountered by the poorest fraction of the society (WHO, 2000) – particularly those who are already undernourished (please see Figure 1). There is also a certain social stigma associated with people affected by arsenicosis, with the disease wrongly attributed to sins in the current or past lifetimes. Yet another societal impact is that on livelihoods of families that lose head of the household or "bread-earners"

to the disease. There is a need for serious consideration of alternative livelihoods for people who may be affected by arsenicosis as well as for the orphans and widows of those who pass away.

It needs to be re-emphasized that raising public awareness on the arsenic pollution and related health problems is largely a societal problem. One has to overcome the obstacles mentioned earlier to make a public awareness campaign successful. Therefore, it is critical to fully engage the civil society in developing such campaigns and in implementing them. Numerous NGOs active in this area could be an invaluable asset in this respect.

### **Food Security**

Bangladesh currently faces a food security challenge. A recent report on State of the Environment in Asia and the Pacific (UN, 2000) projects approximately 37 million people will still be undernourished in the year 2010; please see Figure 1 for the temporal trend. The impacts of the arsenic pollution on this worsening food security have not been considered explicitly. It is also not clear whether arsenic in irrigation water is taken up by the plants or that a fraction of such uptake ends up in food. These issues of food security, both science- and policy-oriented, have to be considered in developing overall strategies to the arsenic contamination problem.



**Figure 1 : Undernourished population in Bangladesh (Source: UN, 2000)**



### Water Resource Management

Bangladesh has abundant water resources available to it – both in terms of surface water and groundwater, as shown in Table 1. The groundwater resources comprise approximately 10% of the water resources used in the country, although an estimate of the exact volume of groundwater contaminated with arsenic above WHO standards is not readily available. Figure 2 shows the sectoral distribution of freshwater and groundwater, respectively. It is obvious that a vast majority of groundwater is utilized by the agricultural sector.

**Table 1. Water resources in Bangladesh (Source: WRI, 2000)**

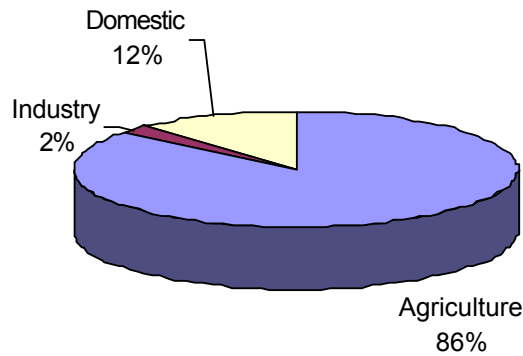
	<b>Average annual internal renewable water resources 2000</b>	<b>Annual withdrawals 1990</b>	<b>Average annual groundwater recharge 1990</b>	<b>Annual groundwater withdrawals 1990</b>
Total (km <sup>3</sup> )	105.0	14.6	21.0	10.7
Per capita (m <sup>3</sup> )	813	134	163	19.6

The abundance of available surface water, if managed appropriately, would obviate the need for utilization of groundwater in the first place. However, installing an infrastructure on a nation-wide basis for treatment and delivery of freshwater is a major undertaking. The overall approaches for remediating arsenic contamination problem, however, cannot be successful if they do not account for water availability as a broader resource management issue. In this respect, rainwater harvesting can be an important resource for drinking water – successful implementation has been undertaken in Bangladesh and Thailand (UNICEF, 2000; Oshikawa, 2001).

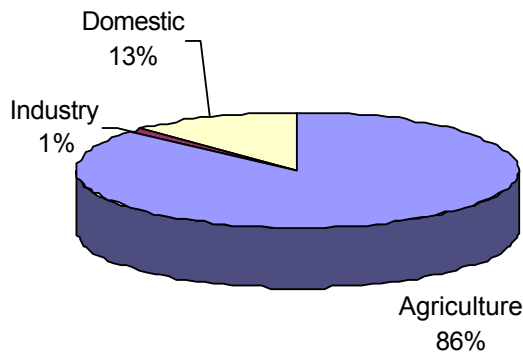
It is also important not to outright reject groundwater as a freshwater resource. It is possible that a number of “safe” non-domestic uses of this water may be found. More significantly, the potential for treating the groundwater for domestic purposes is immense. By treating the groundwater for arsenic contamination, it attains hygienically superior quality than readily-available surface water. A number of technologies are available for removing arsenic from groundwater to below the drinking water standards; these have been described in some detail in a number of other publications (e.g., WHO, 2000) and are a focus of this workshop. To be fully applicable, these technologies must be easy to operate, efficient under local climate conditions and cheap. The work done by the United Nations University in collaboration with BUET has methodically investigated a variety of options available and successfully applied them at pilot

scale in affected villages (Ali, et al., 2001). Nevertheless, scaling up the implementation of these technologies is a daunting task –both from technical and financial points of view – that can only be implemented if the international agencies, NGO groups and relevant government institutions join their resources.

### Total Water Usage



### Groundwater Usage



**Figure 2. Water usage in Bangladesh (Source: WRI, 2000)**

### Information Management

One major aspect of strategies to tackle the arsenic pollution problem is management and dissemination of information to various stakeholders, including researchers, policymakers, politicians, international donor agencies and the general public. The information can come in various forms including – but not limited to – data from groundwater monitoring, geographical distribution of arsenic contamination, medical facts about diseases triggered by drinking

arsenic-contaminated water, resources available for remediation activities and number of people impacted. Use of newer dissemination technologies, including the Internet, should be fully utilized.

Transparency in information management is also critical for fully understanding the problems and for developing a cohesive strategy. Openness and transparency can increase trust among government agencies, scientists and the public. At a minimum, it can create awareness as well as educate, alert, and prepare people about the risks they may face. Transparency between the government agencies and donors is also necessary, so that the needs and expectations about financial assistance of both are well understood.

## CONCLUSIONS

The arsenic pollution crisis in the region is indeed severe and is pushing the limits of our knowledge and the capacity to respond to it. Considering the various dimensions of the problem discussed earlier, it is essential to develop a cohesive strategy on a region- or nation-wide basis. Based on the discussion in this paper, the key elements of such a strategy can be summarized.

- *Raising Public Awareness* should be the starting point for any approach to deal with the arsenic problem;
- *Information Dissemination and Transparency* play a key role in effectiveness of remedial strategies while building the confidence of stakeholders, particularly general public;
- *Participation of the Civil Society* has to be a key element of designing, planning and implementing remediation strategies;
- *Improving Nutrition* and fighting undernourishment has to be a central element to fight arsenicosis;
- *Alternative Livelihoods* should be provided for those who are directly impacted by arsenic contamination as well as their immediate families;
- *Scientific Research* has to be emphasized to reduce uncertainty, with due consideration to local conditions;
- *Drinking Water Standards* have to be modified in view of the scientific research;
- *Water Resource Management* on a regional or national scale is essential to fully exploit the abundant surface water resources available – this has to include treated groundwater as a critical component;
- *Treatment Technologies* that are cheap, efficient and easy to use should be applied at a large scale as an interim or mid-term solution; and
- *Intra-governmental Coordination* is a must for effective implementation of the elements described here.

## REFERENCES

- Ali, M. A., Badruzzaman, A. B. M., Jalil, M. A., et al. (2001), Development of low-cost technologies for removal of arsenic from tubewell water Presented in: BUET-UNU International Workshop “Technologies For Arsenic Removal From Drinking Water,” 5-7 May 2001, Bangladesh University of Engineering and Technology, Dhaka.
- Oshikawa, S., A. Geater, and V. Chongsuvivatwong, 2001. Arsenicism in Ronpiburn, Thailand – Past, present and future. An International Workshop on Arsenic Pollution of Drinking Water in South Asia and China, March 10, 2001, Tokyo.
- Rahman, M.M., K. Paul, U.K. Chowdhury, B.K. Biswas, D. Lodh, G.K. Basu, S. Roy, R. Das, B. Ahmed. I. Kaies, A.K. Barua, S.K. Palit, Q. Quamruzzaman, and D. Chakraborti, 2001. Current Status of Arsenic Pollution and Health Impacts in West Bengal and Bangladesh. An International Workshop on Arsenic Pollution of Drinking Water in South Asia and China, March 10, 2001, Tokyo.
- Smith, A.H., E. O. Lingas, and M. Rahman, 2000. Contamination of drinking-water by arsenic in Bangladesh: a public health emergency. *Bulletin of the World Health Organization*, Vol. 78(9), pp 1093-1103.
- United Nations, 2000. *State of the Environment in Asia and the Pacific*. UN, New York.
- UNICEF, 1999. *Arsenic Mitigation in Bangladesh – Mediabrief*. United Nation’s Children’s Fund (UNICEF), New York.
- World Bank, 2000. *World Development Indicators 2000*. World Bank, Washington, DC.
- World Health Organization, 1993. *Guidelines for drinking-water quality*, 2nd ed. Vol. 1. Recommendations. WHO, Geneva, pp. 41-42.
- World Health Organization, 1999. *Fact Sheet No 210: Arsenic in drinking water*. WHO, Geneva, February 1999.
- World Health Organization, 2000. *Towards an Assessment of the Socioeconomic Impact of Arsenic Poisoning in Bangladesh*. WHO/SDE/WSH/00.4, WHO, Geneva.
- World Resources Institute (WRI), 2000. *World Resources 2000–2001- People and Ecosystems: The Fraying Web of Life*. WRI Washington, DC.