An Overview of Arsenic Removal Technologies in Bangladesh and India

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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 preteatment 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:

$$H_3AsO_3 + ½O_2 = H_2AsO_4^- + 2H^+ \quad (1)$$

$$H_3AsO_3 + HClO = HAsO_4^{--} + Cl^- + 3H^+ \quad (2)$$

$$3H_3AsO_3 + 2KMnO_4 = 3HAsO_4^{--} + 2MnO_2^+ + 2K^+ + 4H^+ + H_2O \quad (3)$$

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 $CaCO_3$ 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-PRECIPITATION AND ADSORPTION PROCESSES

Water treatment with coagulants such as aluminium alum, $Al_2(SO_4)_3.18H_2O$, ferric chloride , $FeCl_3$ and ferric sulfate $Fe_2(SO_4)_3.7H_2O$ 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 coagualted 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:

$$Al_2(SO_4)_3.18H_2O \quad = \quad 2Al^{+++} + 3SO_4^{++} + 18H_2O \qquad (4)$$

Aluminium precipitation(acidic):

$$2Al^{+++} + 6H_2O = 2Al(OH)_3 + 6H^+ \qquad (5)$$

Co-precipitation (Non-stoichiometric, non-defined product):

$$H_2AsO_4^- + Al(OH)_3 = \text{Al-As (complex)} + \text{Other Products} \qquad (6)$$

Arsenic adsorbed on aluminiun hydroxide focs 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 [$\equiv FeOH^o$] represents oxide surface site(Mok and Wai, 1994; Hering et al., 1996).

$$Fe(OH)_3\,(s) + H_3AsO_4 \rightarrow FeAsO_4.2H_2O + H_2O \qquad (7)$$

$$\equiv FeOH^o + AsO_4^{3-} + 3\,H^+ \rightarrow \equiv FeH_2AsO_4 + H_2O \qquad (8)$$

$$\equiv FeOH^o + AsO_4^{3-} + 2\,H^+ \rightarrow \equiv FeHAsO_4^- + H_2O \qquad (9)$$

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.

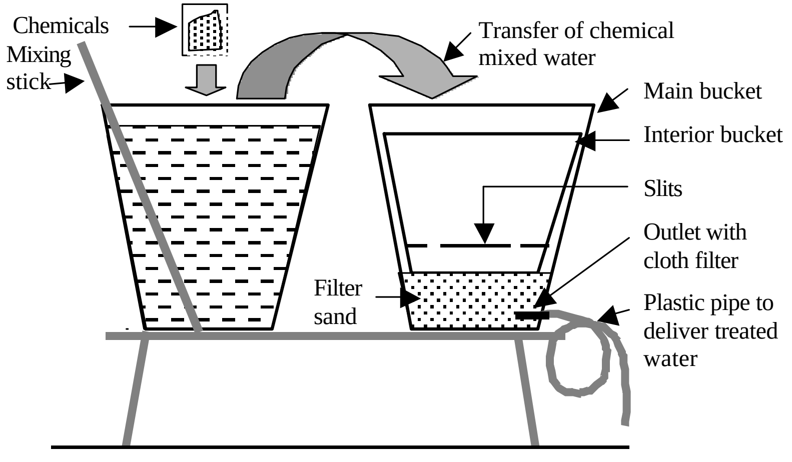

Figure 1 : Stevens Institute Technology

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.

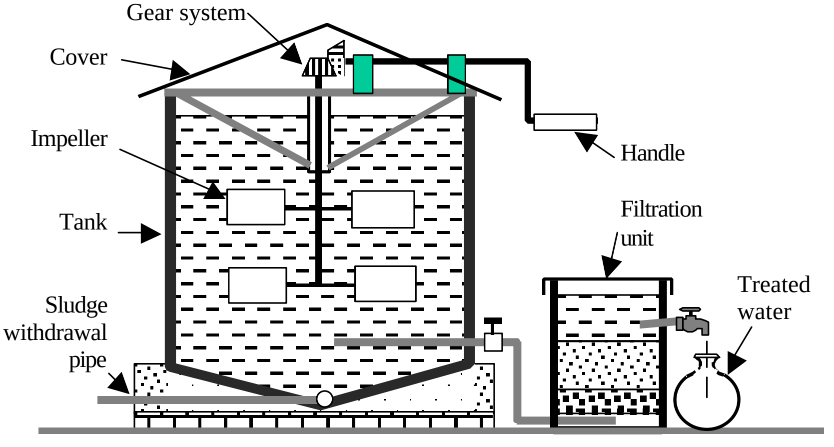

Figure 2 : DPHE-Danida Fill and Draw arsenic removal unit

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 300μg/L. The treatment process involves addition of sodium hypochloride (Cl_2), and aluminum alum in diluted form, mixing, flocculation, sedimentation and up flow filtration in a compact unit.

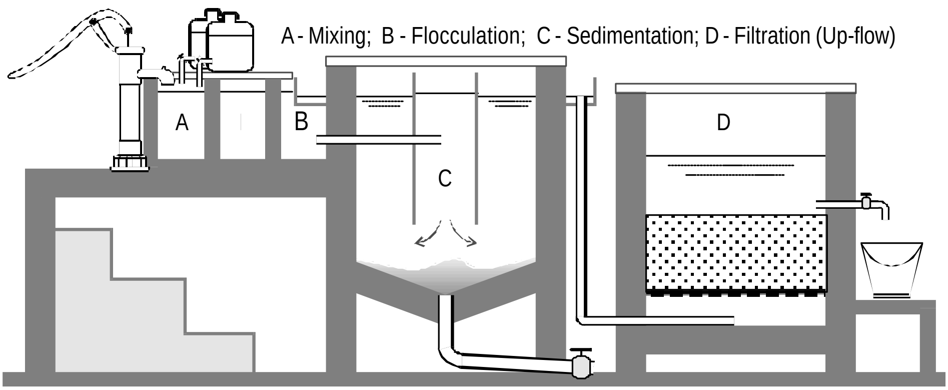

Figure 3 : Arsenic removal plants attached to tubewell (designed and constructed in India)

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 μg/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 mg/L are unsafe for having high concentration of arsenic.

The iron precipitates [$Fe(OH)_3$] formed by oxidation of dissolved iron [$Fe(OH)_2$] 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.

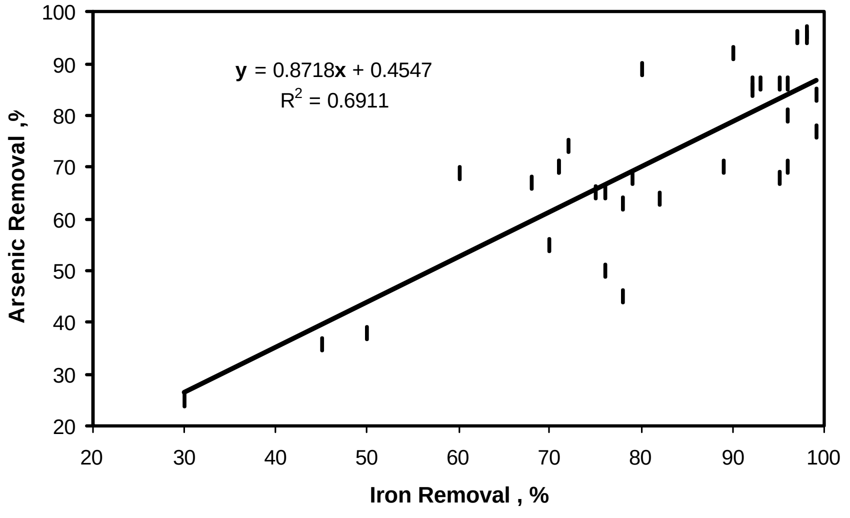

Figure 4: Correlation between Fe and As Removal in Treatment Plants

Some medium scale Fe-As removal plants of capacities 2000-3000 m^3/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 Alumia

Activated alumia, Al_2O_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^{TM} 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 arrsenic 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 habour 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

$$2\mathbf{R}\text{-Cl} + HAsO_4^{--} = \mathbf{R}_2HAsO_4 + 2Cl^- \qquad (10)$$

Regeneration

$$\mathbf{R}_2HAsO_4 + 2N^+ + 2Cl^- = 2\mathbf{R}\text{-}Cl + HAsO_4^{--} + 2Na^+ \qquad (11)$$

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

Technologies	Advantages	Disadvantages
Oxidation/ Precipitation		
▪ Air Oxidation	• Relatively simple, low-cost but slow process	• The processes remove only a part of arsenic
▪ Chemical oxidation	• Relatively simple and rapid process • Oxidizes other impurities and kills microbes	
Coagulation Coprecipitation :		
• Alum Coagulation	• Relatively low capital cost,	• Produces toxic sludges • Low removal of As(III)
• Iron Coagulation	• Relatively simple operation • Common Chemicals available	• Pre-oxidation may be required
Sorption Techniques		
• Actvated Alumina	• Relatively well known and commercially available	• Produces toxic solid waste • Replacement/regeneration required
• Iron Coated Sand	• Well defined technique • Plenty possibilities and scope of development	• High tech operation and maintenance
• Ion Exchange Resin		• Relatively high cost
• Other Sorbents		
Membrane Techniques		
• Nanofiltration	• Well defined and high removal efficiency	• Very high capital and running cost
• Reverse osmosis	• No toxic solid wastes produced	• High tech operation and maintenance
• Electrodialysis	• Capable of removal of other contaminants	• Toxic wastewater produced

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 Alumia
- 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-! 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 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 nonofiltration 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).

Young, E (1996), Cleaning up arsenic and old waste, *New Scientist*, 14 December : 22.