

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

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### *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.

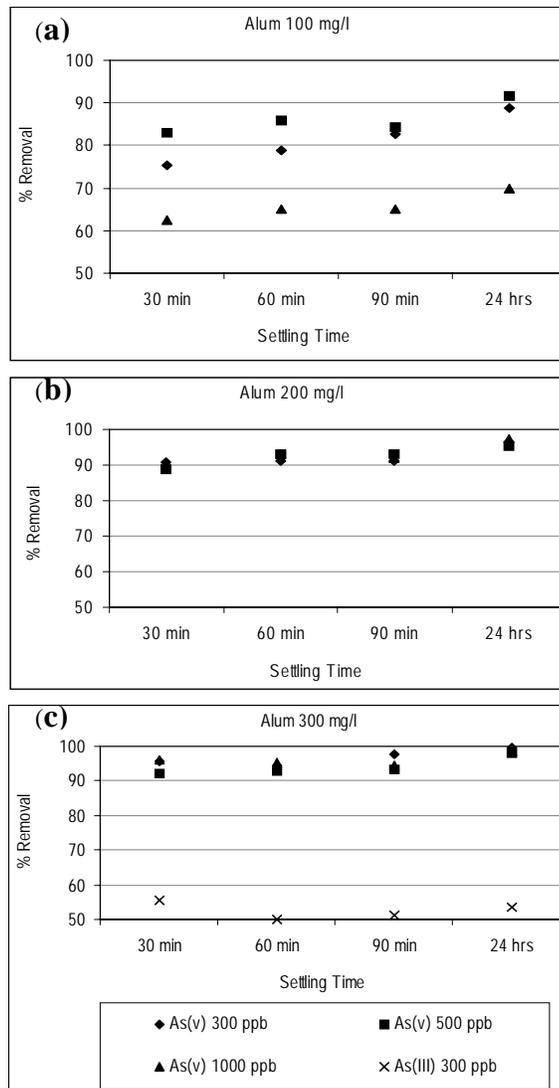
**Table 1: Detailed Characterization of Groundwater used in Laboratory Experiments**

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

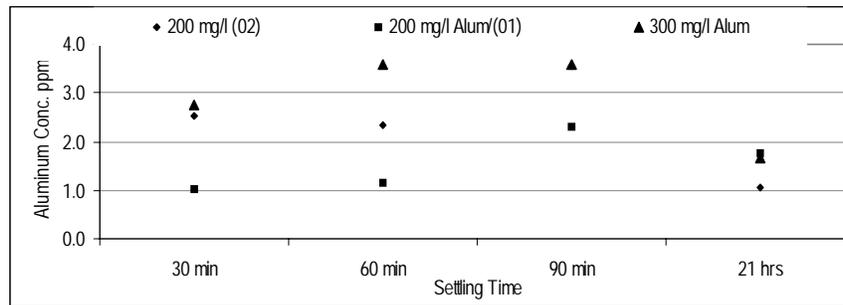
Figure 1 shows removal of As(III) and As(V), present at different initial



**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.

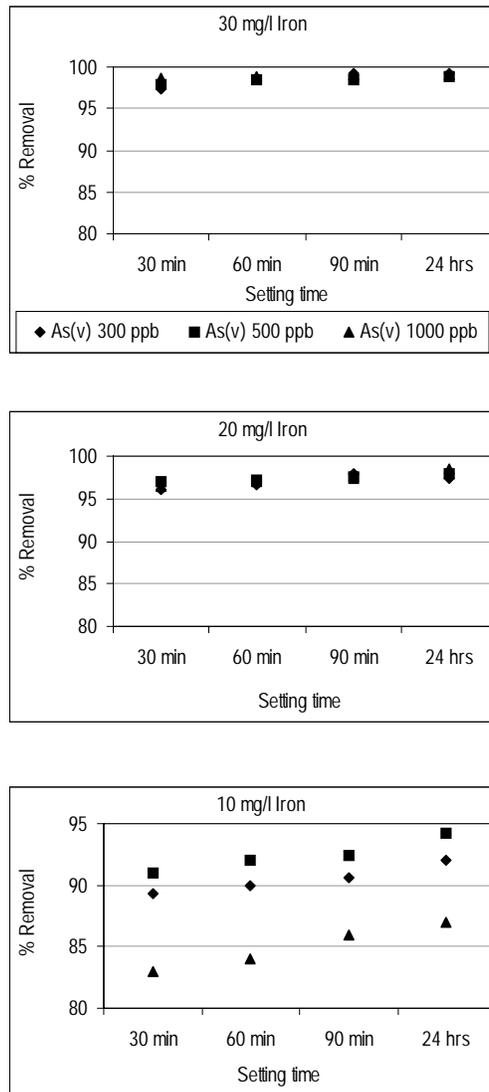


**Fig. 2: Residual aluminum concentration in water treated with Alum (Initial As(V) Concentration = 500ppb)**

### 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

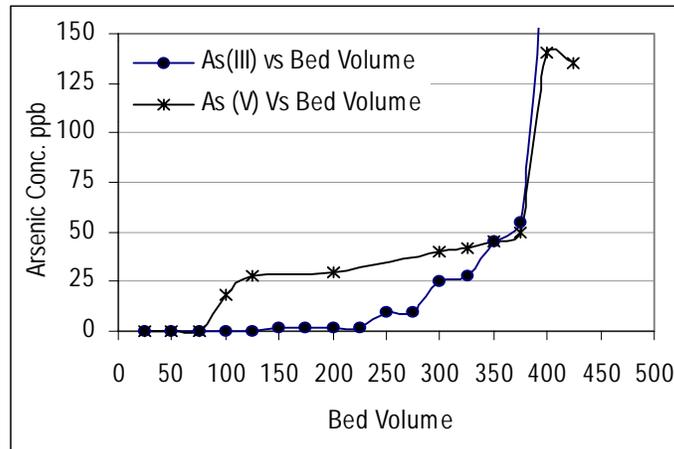
different doses of arsenite (Ali et al., 2001). In all cases, high color concentrations ranging from 30 to 80 Pt.-Co. units were recorded.

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.

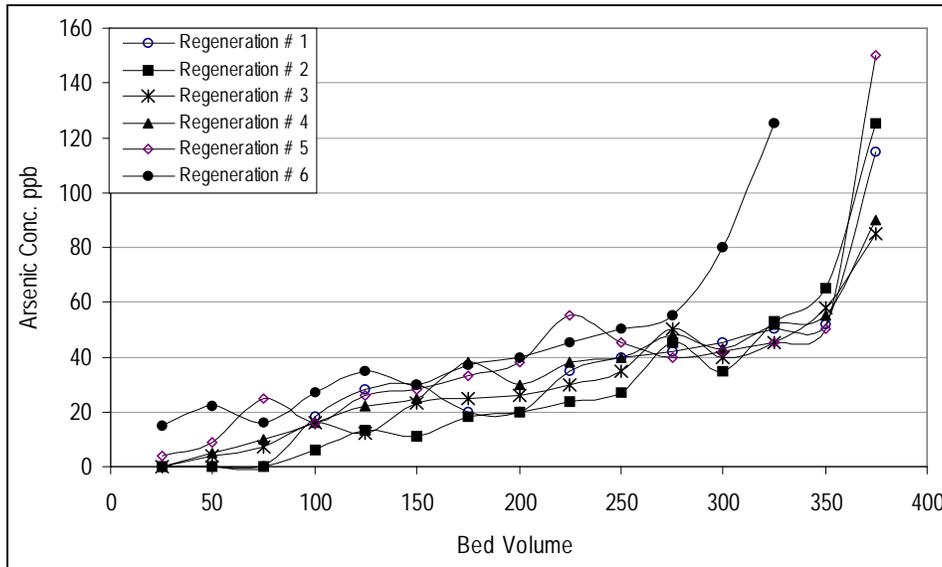


**Fig. 4:** Arsenic concentration as a function of bed volume of water passed through a 40-cm iron coated sand bed

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).

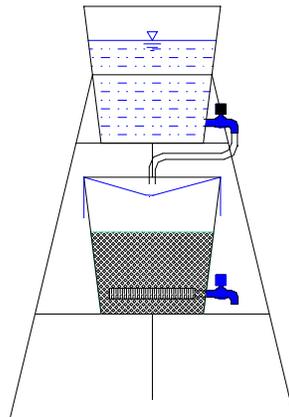
The arsenic removal technique based on ferric chloride coagulation appeared to be suitable for development of household arsenic removal units. The technique based on sorptive filtration through iron-coated sand also appeared to be an effective means of arsenic removal from groundwater. Although initial 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



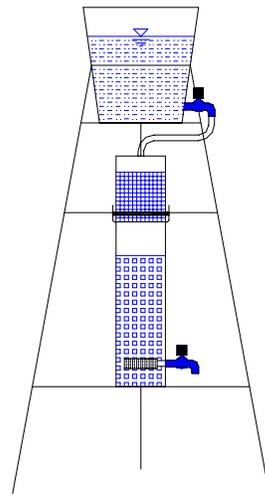
**Fig. 6: Household arsenic removal unit based on ferric chloride coagulation**

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**

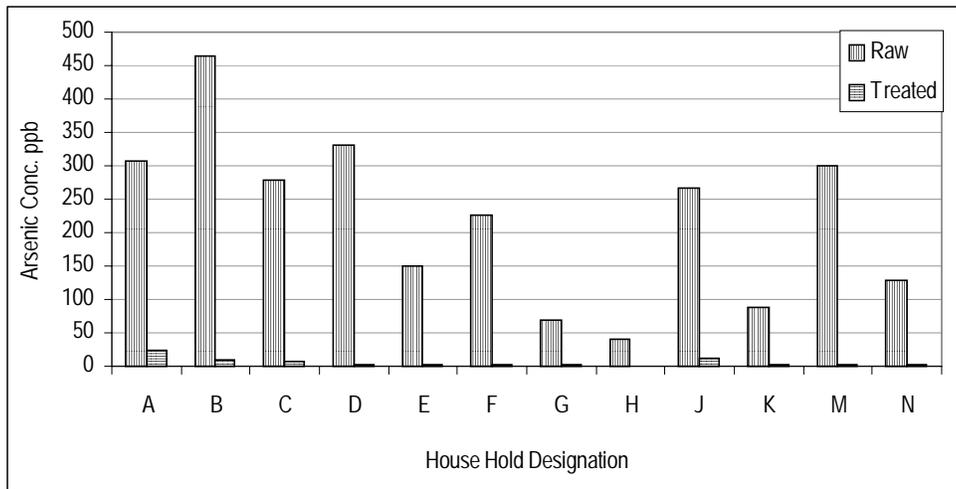
The field-testing started on 21<sup>st</sup> July 2000 with installation of three such units in three different households in the village. The arsenic concentration in the tubewells located at these households are 450 ppb, 640 ppb, and 375 ppb. On 11<sup>th</sup> August 2000, two more arsenic removal 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.

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