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The Role of Iron-Rich Sylhet Sand in Removing Arsenic from Water

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Abstract: Arsenic in ground water was first detected in Bangladesh at Chapai Nawabgonj district in 1993. In the context of prevalence of high concentrations of arsenic in tube-well water, a wide range of technologies has been developed but most of them have limitations. In the quest, naturally available iron-rich Sylhet sand was selected in this study as filter bed material to observe the effectiveness in removing arsenic from water. Experiment shows that the Sylhet sand contains a significant quantity of iron (29.4 mg/g), which may play a vital role in removing arsenic through adsorption. Laboratory column tests were conducted using synthetic trivalent arsenic concentration of 200 µg/L and maintaining a constant pH of 8.0 and the experiment was performed on three different forms of sand bed such as normal, burnt and extracted sand bed. Observation shows that the normal and burnt sand bed readily able to remove arsenic and bed volume of 255 and 315 are found respectively up to 50 µg/L arsenic level whereas extracted shows zero bed volume. Hence the iron-rich Sylhet sand bed may be a promising option for arsenic removal and proper design will ease the pavement to make the technology more effective.

Key words: Arsenic, bed volume, adsorption, concentration, iron-rich sand.

Introduction

In the early 1970's nearly one quarter of a million children died each year in Bangladesh and West Bengal from water-borne diseases. In response to this problem, approximately four million tube-wells have been drilled during the last 30 years to provide reliable, pathogen-free drinking water. This was initiated by the UNICEF and promoted by the DPHE in a move to motivate people to practice better hygiene. In addition to the government and international initiatives, the non-government organizations and private entrepreneurs also installed tube-wells for rural water supply in Bangladesh. Arsenic in ground water was first detected in Bangladesh at Chapai Nawabgonj district in 1993. Since then arsenic contamination problem has been reported from almost every part of the country. Some of the large diameter production wells in the districts like Satkhira, Meherpur, Magura, Chuadanga and Chapai Nawabgonj are also reported to be contaminated with high arsenic (Ahmed, 2001). A study by BUET and BCSIR first indicated that ground water in North-Eastern part of Bangladesh is also contaminated with arsenic. Arsenic was also found in deeper aquifers in that zone (Badruzzaman et al., 1997). According to the survey report of DPHE (1997-2000), 268 upazillas are arsenic affected out of 507 Upazillas in Bangladesh. It is estimated that approximately 27% of the wells are contaminated with levels above 50 µg/L, the current drinking water standard for arsenic in Bangladesh. The population exposed to arsenic from exceeding Bangladesh and WHO drinking water standard are estimated to be within 28-35 million and 46-57 million respectively and a total of 13,333 arsenicosis patients has been identified (DPHE/DFID/BGS, 2000; EES & DCH, 2000). Arsenic problem is now treated as a severe problem in Bangladesh and immediate measures need to

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be taken to provide arsenic safe drinking water in the affected areas. Different treatment technologies for arsenic removal from ground water are now available but all have some limitations from the point of view of raw materials availability, cost effectiveness as well as operation and maintenance. This research work is motivated by the need to develop a simple, low cost technique for the removal of arsenic from the ground water of Bangladesh by using locally available materials. Earlier a study was conducted by BUET with iron-coated sand in removing arsenic from ground water and they got satisfactory result. With the encouragement from such study this research work is conducted to observe the effectiveness of locally available iron-rich Sylhet sand in removing arsenic from water. The outcome of the study will ease the way to develop a cheap arsenic removal technology for low-income community of Bangladesh.

Previous Study in Relevant Field

Several iron salts based arsenic removal technologies are already established in this country for materials availability and its promising results. Ferric salts have been found effective in removing arsenic from water (Cheng et al., 1994; Hering et al., 1996). Ferric salts are found more effective in removing arsenic than alum or any other salt on a weight basis and effective over a wider range of pH. Pentavalent arsenic can be more effectively removed than trivalent arsenic. A number of household arsenic removal units currently being tested in Bangladesh are based on coagulation with iron salts. Bangladesh Council of Scientific and Industrial Research (BCSIR) developed an arsenic removal system, which was based on coagulation with iron salts. Australian Nuclear Science and Technology Organization (ANSTO) have developed an arsenic removal system based on co-precipitation with ferric sulfate (Khoe and Emett, 1999). For higher concentration of arsenic exceeding 0.5 mg/L, the system also involves pre-oxidation of As(III) to As(V) in a solar tray. The arsenic removal system introduced in Bangladesh by the Stevens Institute of Technology (New Jersey, USA) is also based on coagulation with iron salts.

These iron-based arsenic removal systems can potentially make use of the naturally occurring high iron concentration in ground water to its advantage. The use of naturally occurring iron precipitates in ground water in Bangladesh is a promising method of removing arsenic by adsorption. The iron precipitates [$Fe(OH)_3$] formed by oxidation of dissolved iron [$Fe(OH)_2$] present in ground water, as discussed above, have the affinity for the adsorption of arsenic. Only aeration and settling of tube well water rich in dissolved iron has been found to remove upto 25 percent of arsenic. The SORAS (Solar Oxidation and Removal of Arsenic) system has been found quite effective in arsenic removal if iron is present in water (EAWAG/SANDEC, 1999). Nikolaidis and Lackovic (1998) removed 97 percent arsenic by adsorption on a mixture of iron fillings 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 three-pitcher (Kalshi) system uses the same principles of arsenic removal by iron fillings with sand (Munir et al., 2001). The zerovalent iron used in three-pitcher system has a very high capacity to adsorb arsenic and the system is being widely used in Bangladesh and Nepal. Granular ferric hydroxide based arsenic removal plants installed in Bangladesh and India have been found to have very high arsenic adsorption capacity (Pal, 2001). The plants have been successfully operating for last few years.

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 (adsorb arsenic) 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 claim to have very high arsenic removal capacity and produces non-toxic spent granular ferric hydroxide.

BUET has constructed and tested iron-coated sand-based small-scale unit for the removal of arsenic from ground water. Iron coated sand has been prepared following a procedure similar to that adopted by a previous study (Joshi and Choudhury, 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 μg/L. 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 five regeneration cycles. It was interesting to note that iron-coated sand is equally effective in removing both As(III) and As(V).

Methodology

Sand Sample Collection

The sand used for column study was collected from Sharighat of Jaintapur Thana. The sand was collected from five feet below the riverbed. The sand is commercially defined as medium grain sand.

Physical and Chemical Properties Analysis

A mineral soil is a physical mixture of inorganic particles, decaying organic matter, air and water. The larger mineral fragments usually are embedded in and coated with clay and other colloidal materials. Where the larger mineral particles predominate, the soil is gravelly or sandy; where the mineral colloids are dominant, the soil is clay-like. All gradations between these extremes are found in nature. Organic matter acts as a binding agent between individual particles, thereby encouraging the formation of clumps of soil or aggregates.

Physical property of iron-rich Sylhet sand was determined in the geotechnical laboratory of Civil & Environmental Engineering Department of Shahjalal University of Science and Technology, Sylhet. This study includes Fineness modulus determination, Effective size determination, Uniformity coefficient determination, Specific gravity and Bulk density determination (Table 1).

Table 1: Physical properties of iron-rich Sylhet sand

Serial No.	*Physical property parameter*	*Unit*	*Value*
1.	Fineness modulus	–	1.88
2.	Effective size (d_{10})	Mm	0.80
3.	Uniformity coefficient, Cu	–	1.904
4.	Coefficient of curvature, Cc	–	0.92
5.	Specific gravity	–	2.91 at 27°C
6.	Bulk density	gm/cc	1.334

Chemical properties analysis includes iron content determination, sulfate and phosphate determination of that sand (Table 2). To determine these properties HACH-4000 UV-VIS spectrophotometer was used. The test is performed in the environmental pollution control laboratory of Civil & Environmental Engineering Department of Shahjalal University, Sylhet.

Table 2: Chemical properties of naturally iron-rich Sylhet sand

Chemical property parameter	*Unit*	*Values*
Sulfate	mg/g of sand	23
Phosphate	mg/g of sand	2.464
Iron	mg/g of sand	29.4

Column Study

A synthetic raw water having arsenic concentration of 200 µg/l with constant pH of 8 was passed (down flow) through three different column bed (normal sand bed, burnt sand bed and extracted sand bed) that was installed in the water supply and sewerage engineering laboratory of Shahjalal University of Science and Technology, Sylhet. The composition of laboratory tap water is shown in Table 3. The normal sand bed was prepared by using the Sylhet sand that is directly obtained from the nature. Besides, the burnt sand bed is prepared by using the Sylhet sand that is heated at high temperature of 600°C in a furnace. The extracted sand bed is that one where Sylhet sand is used after proper digestion with acid.

Graduated glass column of 1 cm^2 cross-sectional area was used and a mechanism was fitted to the bottom of the column to control the outflow in need (Figure 1). A special gravel filter was placed at the bottom to retain sand and to avoid quick clogging of the sand bed at the bottom of the filter. To obtain sufficient head the feed tank was placed on a high platform.

The salt arsenic trioxide (As_2O_3) was used for stock solution of As(III) preparation. HCl acid and NaOH solutions were added to the water to adjust the pH of water to desired value. The experimental conditions are presented in Table 4 for arsenic removal study.

Table 3: Composition of laboratory tap water

Serial No.	*Water quality parameter*	*Unit*	*Concentration*
1.	pH	–	6.5
2.	CO_2	Mg/L	12
3.	Total alkalinity as $CaCO_3$	Mg/L	82
4.	As	µg/L	0.00
5.	Fe	Mg/L	0.20
6.	SO_4	Mg/L	0.50
7.	PO_4	Mg/L	0.196

Table 4: Experimental conditions for arsenic removal study

Type of sand bed	*Bed height(cm)*	*pH*	*As(III) conc in synthetic raw water (µg/L)*
Normal	10	8	200
Burnt	10	8	200
Extracted	10	8	200

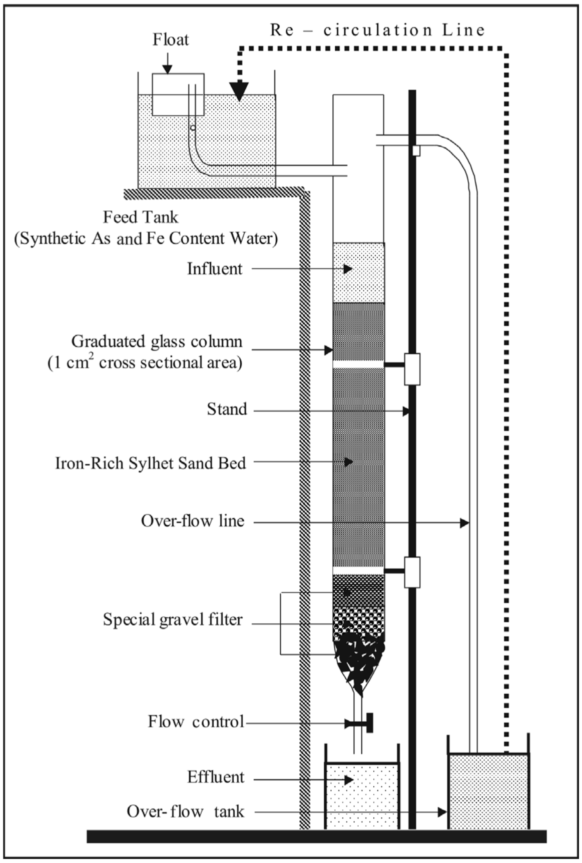

Figure 1: Schematic presentation of the experimental setup of adsorption column.

The treated water was collected in a plastic bucket placed at the bottom of the sand column. All samples collected in plastic bottle were acidified with HCl acid for preservation. The effluent quality was monitored for arsenic concentration. The run was terminated when either the arsenic content of the effluent exceeded the MCL of 50 µg/L or the flow rate reduced to about 1 ml/cm^2/min.

The water samples collected during the experimental investigation were analyzed for a number of water quality parameters following standard methods. Arsenic concentrations were measured by standard SDDC method. The absorbance was determined by HACH-4000 UV-VIS spectrophotometer. pH was determined using pHmeter (Ehamp pH tester, Hanna), Phosphate, sulfate and iron concentration were determined with the aid of HACH-4000 UV-VIS spectrophotometer. Titration method was used to measure the carbon dioxide concentration and alkalinity of water samples.

Effectiveness Determination

Effectiveness of sand bed in a filter column in removing arsenic was determined in terms of empty bed volume (BV) up to arsenic maximum contaminant level (MCL) which is the ratio of the quantity of water treated (ΣQ) up to arsenic MCL in the effluent and the volumes (V) of sand packed in the column. The results were also expressed in terms of quantity of adsorbed arsenic by sand (mg/g). The adsorption of arsenic per unit weight of iron content in sand bed was also calculated (mg/mg) during the study.

Result and Discussion

Three-column bed with three different forms of iron-rich sand was installed and synthetic raw water having trivalent arsenic concentration of 200 µg/L and a constant pH of 8 was used to observe the adsorption characteristics of sand bed. The adsorption characteristics of three sand beds are represented in Figure 2. The study shows that the effluent arsenic concentration increases with the increase of bed volume and the nature of curve is quite different for different forms of sand bed such as normal, burnt and extracted. Iron has sorptive surface and arsenic is readily removed from the water due to its adsorption on the surface of iron-rich sand grain when water passes through it except that for extracted sand bed. In both the cases of normal and burnt sand beds, iron plays the vital role in removing arsenic from water as the Sylhet sand contains a significant quantity of iron (29.4 mg/g) and after certain bed volume the sand bed becomes exhausted and the effluent arsenic concentration exceeds the 50 µg/L level (MCL). On the other hand, extracted sand bed shows a little arsenic concentration at the beginning though the effluent arsenic concentration is found much higher than the MCL; the iron in raw water is mainly responsible for that.

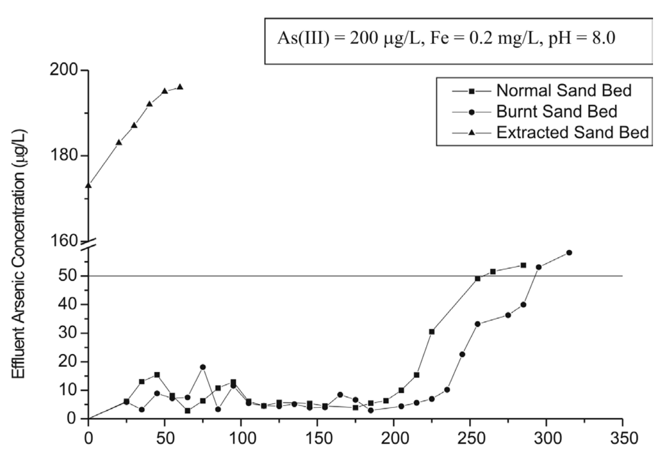

Figure 2: Arsenic adsorption curve for iron-rich Sylhet sand bed.

Table 5: Bed volume and quantity of adsorbed arsenic in iron-rich sand bed

Sand bed type	*Influent As(III) conc. (µg/l)*	*Influent iron conc. (mg/l)*	*Sand bed volume (cc)*	*pH*	*Avg. flow rate (ml/min)*	*EBCT (min)*	*Bed volume up to 50 µg/L*	*Adsorbed As(III) by sand (mg/g)*
Normal	200	0.2	10	8	8	1.25	255	0.036
Burnt	200	0.2	10	8	7	1.43	315	0.042
Extracted	200	0.2	10	8	9	1.11	0	0.000

The bed volumes of the normal, burnt and extracted sand bed are found to be 255, 315 and zero upto 50 µg/L arsenic level respectively (Table 5).

The burnt sand bed is found more effective as compared with normal one in this study. The average flow rate is found lower in that case which results high empty bed contact time (EBCT) and causes high adsorption on sand surface. A previous study got a bed volume of 350 by maintaining raw water As(III) concentration of 300 µg/L in their study by using artificial iron-coated sand having iron content of 25 mg/g which is closer to the present study (Ali et al., 2001). In present study, the presence of sulfate and phosphate in sand bed may influence the result of arsenic removal. The arsenic adsorbed in the normal and burnt sand beds is found to be 0.036 and 0.042 respectively in the present study and the higher adsorption of arsenic is found 0.0014 mg/mg of iron in sand bed in case of burnt sand bed.

Conclusion

An effective and low-cost arsenic removal technology is essential to combat against the adverse impact of arsenic contamination in Bangladesh. Iron-rich Sylhet sand can play effective role as it is easily available. This study reveals that the iron-rich sand bed is effective and proper design will enhance its performance. The study was conducted with trivalent arsenic and more research work with pentavalent arsenic as well as the effect of anions, pH and iron in water should be conducted to develop a viable household level arsenic treatment unit.

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