Low Cost - Sustainable - High Capacity Potable Water Treatment Media for Arsenic Removal

Rajiv Banavali, Jose Antonio Trejo and Garth R. Parker
Rohm and Haas Company, Spring House, PA USA

Introduction

According to the World Health Organization (WHO), arsenic (As) contaminated drinking water affects tens of millions of people in more than twenty countries. Arsenic poisoning is most prevalent in poorest villages in South Asia, particularly Bangladesh, eastern India, Nepal, and Vietnam. Traditional village life is based on farming in these areas and depends on monsoons. The social fabric is held together through strong family ties and religion. Extended families live in close proximity, often with half a dozen or more people in houses made of clay, locally produced bricks, or corrugated tin. In most villages, no electricity is available. Water is usually supplied by a hand pump in the backyard or near-by tube wells. Many of these wells deliver water which exceeds the WHO arsenic limit for potable water by a factor of 10–100. At least half of Bangladesh's 15 million tube wells exceed the levels considered safe.

Under such dire circumstances, a treatment to remove arsenic must be very low cost, convenient for women and children to use, and not subject to the introduction of pathogens. In all likelihood, a device or system should be placed directly in the home and should be easily available whenever water is needed for drinking or cooking. Additionally, the removal and safe disposal of arsenic-contaminated wastes which result from the treatment is also needed. The design criteria, shown in Figure 1, were to achieve low cost, use of indigenous materials, high performance, ease of use, non-hazardous residuals, and relatively safe disposal.

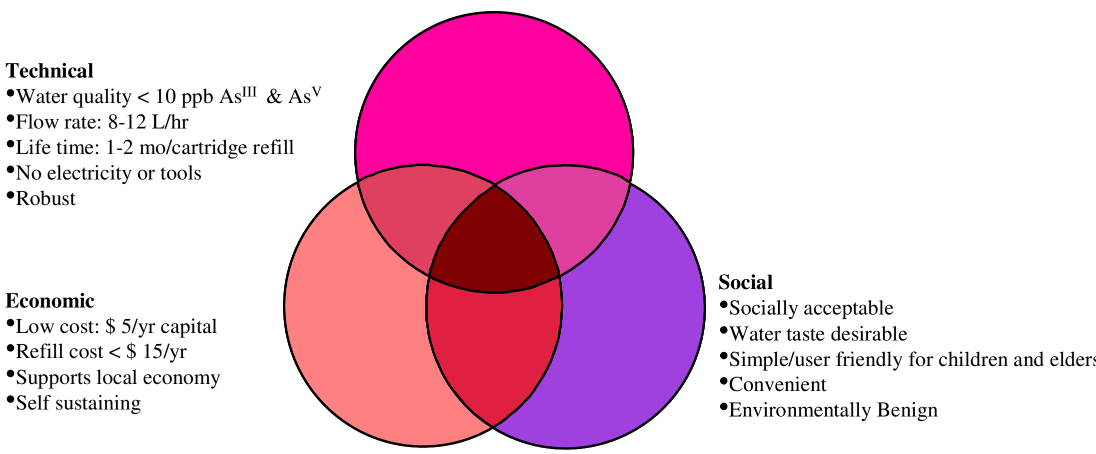

Figure 1: Sustainable chemistry cycle concept.

Novel Media

We have developed a novel media and potable water treatment system which meets our design criteria. This media can be used at the household scale, with design adaptability for larger scale community use, to remove arsenic from contaminated groundwater. The technology uses a modified limestone as the media support with an iron oxide coating. This media is unique because it efficiently removes arsenic and several other metal contaminants using a locally available raw material. The resulting drinking water quality complies with drinking water standards. The media, when fully loaded with arsenic, is considered a non-hazardous waste and can be easily disposed. The spent media when incorporated into concrete passes the US Environmental Protection Agency Toxicity Characteristic Leaching Procedure (TCLP) and California Wet tests.

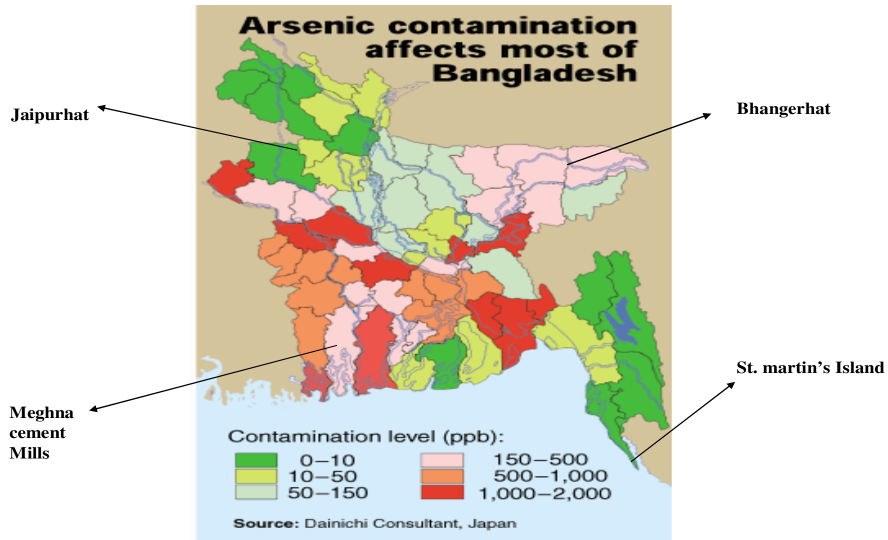

Figure 2: Arsenic Contamination and Major Limestone Deposits in Bangladesh

The map in Figure 2 above shows both the arsenic problem and availability of limestone. Bangladesh has deposits of limestone that are used to produce cement. Limestone deposits from coral and the shells of marine organisms are found near the land surface at St. Martin's Island at the southernmost tip of the country. Limestone also is found at Takerghat, in the northeastern part of the country, where it is mined in a quarry and in the subsurface at Joypurhat. The Jaipurhat Limestone Mining and Cement Works extract more than one million tons per year of limestone to operate its cement plant. Two other cement plants use about 1.1 million tons per year of limestone. In addition, a recent 25 km conveyer belt has been constructed to move limestone from nearby India to a large cement plant in Bangladesh, at the rate of 960 metric tons/hour. Even if all households in Bangladesh used our media (under the conditions as stated), only a fraction of the limestone Bangladesh currently uses annually would be required. Moreover, since much of the waste media could be recycled, there would be virtually no net loss of imported limestone. Our media consists of iron oxides limestone mixtures with the right balance to achieve high capacity for arsenic removal, less kinetic limitations than the commercially available iron oxides and a pH balance delivered by the limestone with good buffering capacity.

This unique combination not only permits the media to remove arsenic selectively from water but also other toxic metals which are removed by the pH effect and Ca delivered by the limestone material. Metals such as Hg, Pb, Cd, Fe are removed simultaneously with the arsenic. It is also important to mention that the removal of As(V) and As(III) by this media has been also demonstrated in field trials with great success. The arsenic removal efficiency of native limestone is virtually independent of pH values (ranging from 4 to10), making it highly suitable as a base media for a wide variety of water quality. No other technology can match this pH range adaptability. All of the materials are locally and regionally available or they will be manufactured directly in Bangladesh or India, thus contributing to the self-reliance and economy of the region. The components are highly cost-effective for this application.

Experimental

Materials: Iron oxide coated limestone (LS-FE) prepared in our laboratory, commercially available Granular Ferric Hydroxide (GFH).

Laboratory test solution: NSF-Challenge water with 100 µg/L As(V), 20 mg/L SiO_2, 140 µg/L PO_4^{3-}, adjusted to pH 7.5. The solution was stored in a 125 L polypropylene tank.

Laboratory test conditions: 1 cm ID glass column filled with 8 mL of media, giving a bed height of 10 cm. The solution was pumped through the column at a flow rate of 5 mL/min, giving a 1.6 min Empty Bed Contact Time (EBCT). Samples of effluent were taken at least every 6 hr using a fraction collector and tested for As using ICP-OES. Our breakthrough criteria is an effluent As concentration of 10 µg/L.

Field study test conditions: A system similar to that depicted in Figure 4 was installed in the home of a family in India at 24 South Parganas District located south of Kolkata. Raw water was obtained from the home's backyard well with a hand pump and transferred to a storage reservoir. Water flows by gravity through a media cartridge located under the storage reservoir and then up to a spigot for consumption. The cartridge used in the trial was 4 inch diameter PVC pipe packed with 0.5 L of untreated limestone and 1.5 L of LS-Fe. The gravity fed flow rate was approximately 250 mL/min (8 min EBCT). The flow was intermittent to simulate real use conditions. Samples were taken and measured for As using a Hach Field Test Kit and were sent to a local laboratory in Kolkata for quantitative results for As and other metals.

Laboratory Results

A comparison under laboratory conditions was done with two different materials: our novel iron hydrous oxide coated limestone (LS-FE) and GFH. Because the media is envisioned for a point of use application, high flow rate, short EBCT conditions were used in this study. Laboratory column testing of the LS-FE demonstrated improved capacity for As removal relative to standard media such as GFH, as indicated in Figure 3 and Table 1, where LS-FE treated 8× as much water. The capacity at high flow rate of the LS-FEe media is 1.7 g-As/L of media. LS-Fe was superior to GFH when high flow conditions are required.

Table 1. Bed volumes to Arsenic Breakthrough
GFH and Iron Coated Limestone.
Influent 100 µg/L As(V), EBCT = 1.6 min.

Media	Breakthrough Volume (BV)	Breakthrough Capacity (g As/L media)
GFH	1880	0.24
Iron coated limestone	15600	1.72

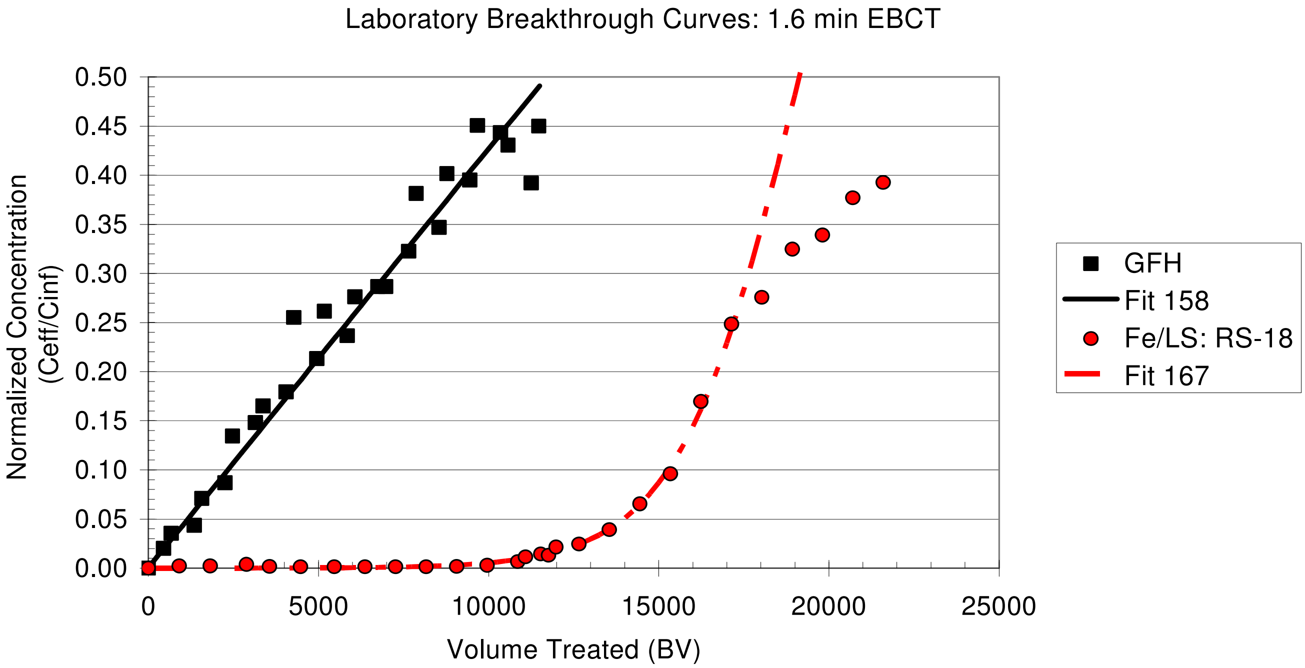

Figure 3. Laboratory Breakthrough Curves.
Influent 100 µg/L As(V). EBCT = 1.6 min.

Field Trial Results

The top of Figure 4 shows a photograph of the raw and treated water from the field trial in India. There is clearly a significant improvement of the aesthetic appearance of the water after treatment. Table 4 provides the results from the outside analytical laboratory. After 300 L were treated, the effluent As concentration was non detectable at <1 µg/L, representing >99.3% removal. The total As (both As(III) and As(V)) removal capacity is about 1.5 mg/g media.

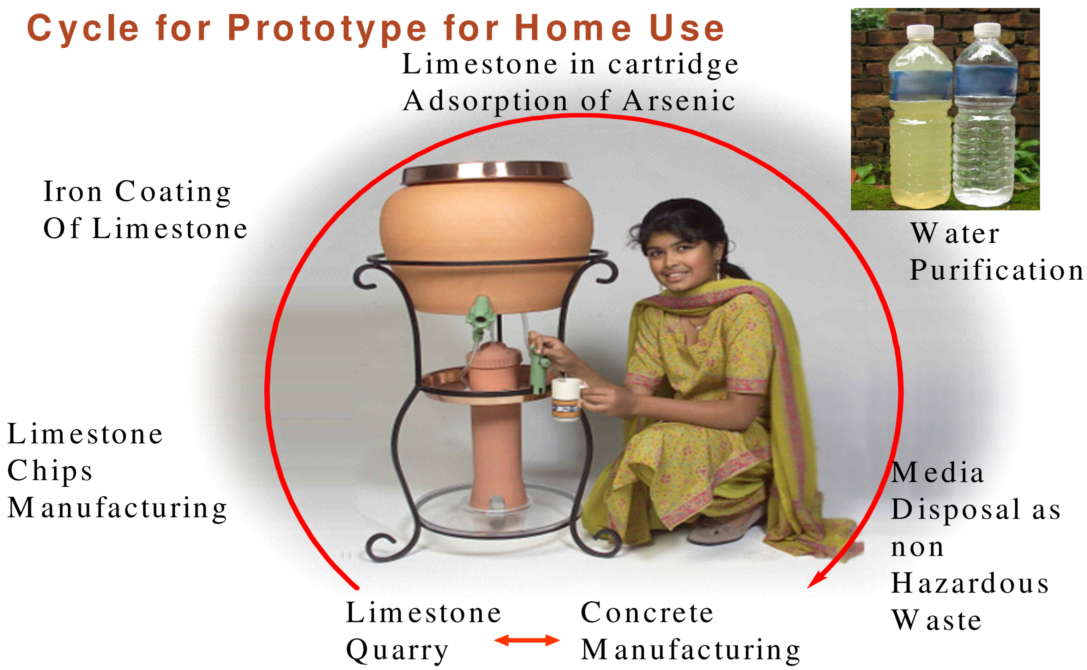

Figure 4: Sustainable Process using Iron Coated Limestone.

Table 4. Field Trial – Water Quality

Test Parameters	Unit	Influent	Effluent (at 300 L)	Removal (%)
Calcium as Ca	mg/L	122	109	10
Magnesium as Mg	mg/L	95	66	30
Iron as Fe	µg/L	7157	1008	86
Arsenic as As	µg/L	136.7	<1.0	>99.3
Manganese as Mn	µg/L	850	160	81
Zinc as Zn	µg/L	320	<70	>80

Not detected: Al, Sb, Cd, Cr, Co, Pb, Ni, Se, Sn and Hg.
Detection Limits: As-1.0 µg/L; Al-500 µg/L; Sb-10 µg/L; Cd-5.0 µg/L; Cr-10 µg/L; Co-500 µg/L; Pb-50 µg/L; Mn-100 µg/L; Ni-90 µg/L; Se-10 µg/L; Sn-10 µg/L; Zn-70 µg/L; Hg-2.5 µg/L.

Theoretical Modeling

The performance of the media was also modeled using the computer program PHREEQC, freely available from the US Geological Survey. This program was designed to model aqueous speciation reactions as well as redox, ion exchange, surface complexation, precipitation, and volatilization reactions for geochemical systems. However, it can also be used to model various ion exchange and adsorption processes in columns.

The modeling served several purposes. It demonstrated that the starting solutions were oversaturated with aqueous CO_2 species relative to atmospheric CO_2 levels, that the solution could spontaneously emit CO_2 to obtain equilibrium, substantially changing the solution pH. The model demonstrated the sensitivity of As adsorption by Fe surfaces to the local pH. The model also demonstrated quantitatively the impact of other species such as SiO_2 and PO_4^{3-} on

As adsorption. Overall, the model was extremely useful in understanding the performance of the new media.

Conclusions

The iron coated limestone has unique properties and has a high capacity for arsenic removal under laboratory and field trial conditions. The unique combination permits selective removal of arsenic through a complexation mechanism and other metals through pH precipitation and Ca complex formation. It is possible to recycle the used limestone into construction materials passing the TCLP method (As < 0.05 mg/L). This leads to an overall sustainable process.

References

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3. Bothe, Jr. J.V., and Brown, P.W., 1999, “Arsenic immobilization by calcium arsenate formation”: Environmental Science and Technology, v. 33, no. 21, p. 3808-3811.