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Use of ArsenX^{np}, a hybrid anion exchanger, for arsenic removal in remote villages in the Indian subcontinent

Sudipta Sarkar [a], Lee M. Blaney [a], Anirban Gupta [b], Debabrata Ghosh [b], Arup K. SenGupta [a,*]

[a] *Department of Civil and Environmental Engineering, Lehigh University, Bethlehem, PA 18015, USA*
[b] *Environmental Engineering Cell, Civil Engineering Department, Bengal Engineering and Science University, Howrah, India*

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Abstract

Many of the arsenic removal units operating in remote villages of West Bengal, India now use a hybrid anion exchanger (HAIX) which are essentially spherical anion exchange resin beads containing dispersed nanoparticles of hydrated ferric oxide (HFO). HAIX, now commercially available as ArsenX^{np}, offers a very high selectivity for sorption of oxyanions of arsenic due to the Donnan membrane effect. The sorption columns used in the field for removal of arsenic are either single column or split-column design. The sorption columns allow flow of atmospheric oxygen, thereby promoting oxidation of dissolved Fe(II) species of arsenic-contaminated raw water to insoluble Fe(III) oxides or HFO particulates. Apart from the usual role played by the sorbents like ArsenX^{np} or activated alumina towards arsenic removal, HFO particulates also aid in the treatment process. Each unit is attached to a hand-pump driven well and capable of providing arsenic-safe water to three hundred (300) households or approximately one thousand villagers. No chemical addition, pH adjustment or electricity is required to run these units. On average, every unit runs for more than 20,000 bed volumes before a breakthrough of 50 μg/L of arsenic, the maximum contaminant level in drinking water in India, is reached. In addition to arsenic removal, significant iron removal is also achieved throughout the run. Upon exhaustion, the media is withdrawn and taken to a central regeneration facility where 2% NaCl and 2% NaOH solution are used for regeneration. Subsequently, the regenerated resin is reloaded into the well-head sorption column. Following regeneration, the spent solutions, containing high arsenic concentration, are transformed into solids residuals and contained in a way to avoid any significant arsenic leaching. Laboratory investigations confirmed that the regenerated ArsenX^{np} is amenable to reuse for multiple cycles without any significant loss in capacity.

Keywords: Arsenic; Hybrid ion exchanger; Ion exchange; ArsenX^{np}; Groundwater

1. Introduction

Arsenic present in drinking water drawn from underground sources is the cause of wide-spread arsenic poisoning affecting nearly 100 million people living in Bangladesh and West Bengal, a neighboring

* Corresponding author. Present address: Fritz Laboratory, 13 E Packer Avenue, Bethlehem, PA 18015, USA; Tel.: +1 610 758 3534; fax: +1 610 758 6405.
E-mail address: arup.sengupta@lehigh.edu (A.K. SenGupta).

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Indian state [1–4]. While the maximum contaminant level (MCL) of arsenic in drinking water is 50 μg/L [5,6] in India, arsenic concentrations in this region well exceed the MCL. Health effects related to arsenic ingestion through drinking water take a long time before becoming fatal and life-threatening [7]. Average annual precipitation in this geographic location is significantly high, often exceeding 1500 mm/year. But poor sanitation practices which prevail in this area have contaminated surface waters leading to a potential risk of water borne diseases if used as drinking water without appropriate treatment. On the other hand, relative abundance and ease of finding bacteriologically safe groundwater sources promoted the wide-spread use of wells with hand pumps as drinking water sources. There remain thousands of villages where arsenic-laced ground water is the only viable source of drinking water.

Several treatment technologies and equipment have been developed for removal of arsenic from water. It is well known that hydrated oxides of polyvalent metals like Fe(III), Al(III), Ti(IV) and Zr(IV) exhibit ligand sorption properties by forming inner-sphere complexes [8–13]. A non-regenerable adsorption media, granulated ferric hydroxide (GFH) has been widely used in many places including West Bengal, India [14]. It has also been reported that the above-mentioned metal oxides, when dispersed within a polymeric host material, offer tunable behaviors for sorption of a wide variety of anionic ligands and transition metal cations [15–18]. One such hybrid sorbent, produced by dispersing hydrated ferric oxide (HFO) nanoparticles inside a polymeric anion exchanger host material, exhibits high affinity for removal of arsenic from natural waters due to the Donnan membrane effect exerted by the host material [18–20]. The hybrid anion exchanger (HAIX) is now commercially available as ArsenX^{np} from SolmeteX Co. in Northborough, MA and Purolite Co. in Philadelphia, PA; however, no endorsement is implied. Earlier investigations showed that the chelating polymers with nitrogen donor atoms, when loaded with copper(II), are very selective to inorganic arsenic species and also are reusable [21–23]. However, high price of the parent chelating polymer was a major obstacle toward wider applications related to water and wastewater treatment.

Since 1997, Bengal Engineering and Science University, Howrah, India and Lehigh University, USA have collaborated to develop a sustainable solution to combat the arsenic problem in West Bengal, India. Under this initiative, about 160 well-head arsenic removal systems have been installed. These units are community based and serve about 250–300 families; additionally, the units require no electricity, chemical addition or pH adjustments. The adsorbent media used commonly is activated alumina. Characteristics and performance of these units have been previously reported [24]. Since 2004, ArsenX^{np} media, along with activated alumina has been utilized in the units. The primary objective of this article is to present the performance of ArsenX^{np} for arsenic removal over a long period of run in the field, regenerability of the media, and elucidation of arsenic removal mechanism and containment strategies of arsenic removed.

2. Experimental

2.1. Well-head treatment units

The main component of the well-head treatment unit is an adsorption column (diameter 35 cm, height 2 m), which is a gravity-fed system operating in downflow mode. Apart from the adsorption column, there is a coarse-sand filter to contain the backwash waste water from the column, which contains arsenic-laden precipitates of ferric hydroxide or hydrated ferric oxide (HFO). The adsorption column mounted on top of a hand-pump driven well is a stainless steel (SS304) cylindrical tank with two distinct functional regions. At the top of the tank, there are atmospheric vent connections to allow passage of atmospheric oxygen. The inlet water is sprayed in and is further divided in fine droplets by means of a splash distributor installed at the top of the tank. Sufficient volume is kept at the top of the tank to facilitate longer residence time to allow oxidation of dissolved Fe(II) species to insoluble Fe(III) species before the well water enters the second region, which contains fixed-bed of sorbent media supported by graded gravels. Ultimately, arsenic-safe treated water is collected at the bottom of the unit. The sorbent used is ArsenX^{np}. The necessary constructional and operational features of the adsorption column are schematically indicated in Fig. 1a. The amount of sorbent employed in each column is approximately 100 kg. The design flow rate through the column is 8–10 L/minute. The column is routinely backwashed every morning for about 10–15 min in order to drive out precipitated HFO particles and to