

Apyron Arsenic Treatment Unit – Reliable Technology for Arsenic Safe Water

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Abstract

Apyron Technologies Inc. has developed Arsenic Treatment Unit (ATU) in which Aqua-Bind™ media is used for ground water arsenic reduction. These prototype units are field tested both in Bangladesh and in India. The results of laboratory testing of the treated water have proven the effectiveness of the arsenic removal technology. The test results of the treated water have been consistently below 10 ppb of arsenic. This highly effective arsenic treatment system is user friendly and is easily adaptable in the rural settings of Bangladesh. The spent media is non-hazardous to the environment and does not pose any risk to the users.

INTRODUCTION

Arsenic is a naturally occurring element in rocks, soils and the waters that contact them. Other major sources of arsenic include agricultural run-off and industrial effluents from metallurgy, glassware/ceramics, dyes, herbicides/pesticides, petroleum refining, wood/hide preservatives, fertilizers, and phosphate detergents. Recognized as a toxic element for centuries, arsenic today is a recognized major human health concern because it can contribute to long term morbidity and mortality.

Bangladesh is the largest alluvial delta of the world and the country is crisscrossed by hundreds of rivers. This huge supply of water is contaminated by human, animal and industrial pollutants resulting in high incidence of diarrheal diseases. So, the need of supplying people with safe drinking water was given the priority in the seventies and ground water lifted by hand pump was thought to be a better option than drinking surface water. The Bangladesh Government and UNICEF embarked on a program to install thousands of tube wells throughout the country. These tube wells were introduced into the ground water in good faith and saved countless lives from waterborne diseases. At that time ground water was not tested systematically for arsenic and for the last 20-30 years water from shallow aquifers was extensively used for drinking water in rural areas. By 1993 it was found that, the ground water is contaminated by highly soluble arsenic and the problem of chronic arsenic poisoning surfaced.

More than 97% of the Bangladesh population of 130 million drinks water supplied from groundwater and estimates are that as many as 77 million people are consuming water high in arsenic. In terms of population exposed it is the most serious ground water arsenic problem in the world. Similarly, more than 90% of the rural population of India is dependent upon groundwater for drinking (i.e., well water). Some estimates have indicated that 1 in 10 people in some areas of India are exposed to high concentrations of arsenic in well water. However total population exposed in India is less than Bangladesh. In addition, the World Health Organization, whose guidelines are 10 $\mu\text{g/L}$, has compiled reported cases of arsenic in drinking water in countries such as Argentina, China, Chile, Ghana, Hungary, Mexico, Thailand and the United States.

Background

To protect people from this serious health hazards the Government of Bangladesh, through its various agencies, has been working hand in hand with WHO, World Bank, UNICEF, DFID and other organizations. Many foreign companies and local entrepreneurs have come forward with systems to mitigate the problem of arsenic poisoning. Apyron Technologies Inc. (ATI) USA has developed a unique unit, which on available evidence can assure arsenic safe ground water.

The Apyron solution to this crisis is a specialty media designed for arsenic reduction. Historically, common adsorbents such as activated alumina, zeolites, and even granular activated carbon (GAC), have been used commercially to remove arsenic. However, Apyron Technologies, Inc. (ATI) has developed an inorganic granular metal oxide-based media that can *selectively* remove As(III) and As(V) from water, which makes the media more effective than commonly used adsorbents. The *selective* adsorbent is manufactured using a unique binder technology, which greatly enhances its surface properties and creates a composite particle with a unique surface, pore properties, and chemical characteristics that

enable arsenic adsorption capacities many times greater than conventional materials.

Test Description Summaries

To date, ATI has performed arsenic removal field-testing in Bangladesh for four separate villages using groundwater via tube-wells for drinking water. Another similar field test is on going in four villages in India. The technologies employed in each test are the same, with the variances occurring in the water quality and the arsenic concentrations being treated. The testing, performance and costs are described later in this paper. The field-testing performed in Bangladesh and India for the tube-well drinking water is the most comprehensive testing performed and represents the most challenging application of the technology.

The benefits of ATI's Aqua-Bind™ media are:

- Removal of Both Arsenic (III) and Arsenic (V)
- Treats Arsenic levels from 25 to >4,000 ppb in the presence of Iron up to 15 ppm
- Reduced Contact Times (Rapid kinetics ideal for POU/POE systems)
- Operational over Wide pH Ranges (6-8) & Temperatures (0 to > 100°C)
- Non-Leachable, allows Non-hazardous Disposal of Spent Media (per EPA TLCP)
- NSF 61 Certified for use in drinking water applications
- Resistant to microbial growth
- Highly Selective for As, Even With Competing Ions (Sulfates, Silica, Ca, etc.)

TECHNOLOGY DESCRIPTION

Overall Definition

The technology is based upon the Aqua-Bind™ Arsenic media, which consists of highly activated hybrid aluminas and alumina composites, which are produced using proprietary technology. These materials are employed to produce particles with enhanced pore and surface properties for cost-effective removal of contaminants. By controlling the pore size, the particles become selective for specific ions, which for this demonstration were arsenic ions.

For point of entry (POE) / point of use (POU) systems, the capabilities of the Aqua-Bind™ Arsenic media are especially useful in meeting the following concerns:

- Arsenic species** The primary arsenate species in the pH range of 6-9 is monovalent H_2AsO_4^- and divalent HAsO_4^{2-} . Uncharged arsenious acid (H_3AsO_3) is the predominant species of trivalent arsenic found in groundwater. The oxidized form of arsenic is much more readily removed with conventional technologies, usually requiring an oxidation/pre-treatment step to enhance removal of As (III). Because arsenic can be found in either form and selected Aqua-Bind™ media can remove both types, it is ideally suited for POE/POU systems.
- Kinetics** Given the relatively compact size of treatment systems for rural areas or household, effective adsorbents must be very rapid, allowing efficient removal of arsenic to low levels. Unlike fixed-bed adsorption processes, such as in centralized larger systems where contact times of five minutes or more are not unusual, the contact time in a POU device is often less than 15 seconds. This presents a much greater challenge for a 90+ percent removal of arsenic from 50 mg/l to less than 5 mg/l. However, as shown in the test results presented later in this document, ATI's Aqua-Bind™ Arsenic media is able to meet the adsorption kinetic requirements while still retaining its removal efficiency.
- Influent water quality** Like any technology, the water quality profile plays an important role in proper selection and overall performance. Primary adsorption performance parameters include arsenic concentration and species, pH and contact time. Secondary performance factors include the presence and influence of other species that can compete with arsenic adsorption, occupy adsorption sites or foul the media. Adsorption capacities can vary widely depending on influent concentrations of these parameters. Test results show that the Aqua-Bind™ Arsenic media are highly selective and retain their adsorption capacities even in the presence of high concentrations of other negatively charged species.

Groundwater from Tube-Wells

The overall objective of the demonstration project for Bangladesh and India was evaluation of the capability of the adsorbent to remove arsenic from tube-well water supplies and the ability of the associated design to meet its specifications. The treatment units have been operated successfully for the past two years and do provide a practical and low cost system for treating tube-well water in rural areas affected by groundwater contaminated with arsenic.

The demonstration units used for the field-testing in Bangladesh and India were designed and constructed by Apyron as prototype units. The units were installed in various villagers under the supervision and observation of Apyron personnel, and site monitoring provided by BAMWSP in Bangladesh and the Public Health & Engineering Directorate of the Government of West Bengal in India.

The arsenic treatment unit (ATU) consists of a cylindrical adsorber vessel with two proprietary ATI media. The composition of the Aqua-Bind™ Arsenic media is aluminum oxide (Al_2O_3) and Manganese Oxide (Mn_2O_3) and is non-hazardous. The column receives water under slight pressure from the lift pump. Water flows in the down-flow direction through the two chamber housing to capture particulate iron and adsorb arsenic. The water exits through a discharge hose into the designated container, at approximately 15 liters per minute. Figure 1 is a schematic of the process flow diagram.

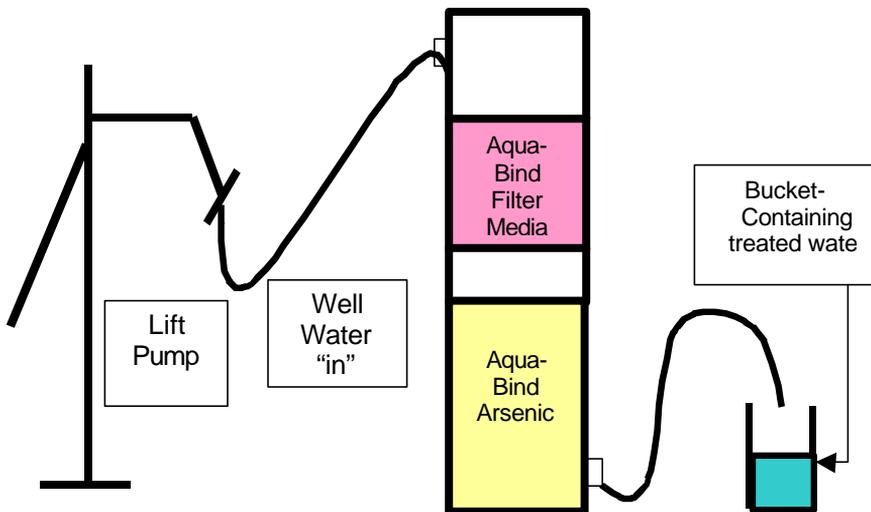


Figure 1: Schematic diagram of arsenic treatment unit

Periodically (approximately once every two weeks) the ATU is “backwashed” to remove the suspended solids and filtered iron. The suspended solids and iron are captured in a filter bag for disposal. The Aqua-Bind™ Arsenic media is designed for 6 months service (dependent on the arsenic concentration) before change-out. Fresh media is installed and the ATU is returned to service.

There are currently twelve (12) ATU operating units in West Bengal, India, three (3) in 24 N Paragnas, and nine (9) in the Malda District. Similarly, there are four (4) ATU operating units in Bangladesh, one each at Nilkanda in Sonargaon, Gobra at Gopalganj, Bhaberchar at Munshigonj and Gulbahar at Chandpur. The experience from operating these units (and others) have helped Apyron to gain specific understanding of the water quality issues and variability of the water quality that may be specific to each site. This understanding is critical to the successful deployment of an arsenic removal system, not only for tube-wells but for other applications as well. Selected examples of testing for the Aqua-Bind™ Arsenic media for other applications are described below:

PERFORMANCE

Groundwater from Tube-wells

The Indian demonstration units have operated successfully for over 2 years, in some cases treating in excess of 200,000 liters of water for every six months. During the period of operation for this system, arsenic concentrations in the pre-treated water ranged from 1000 microg/liter to 3500 microg/liter, with an average of 2500 microg/liter. The treated water effluent contained arsenic concentrations below detection limits (i.e., below 10 microg/L). This was achieved with water containing competing ions such as Ca^{+2} and Mg^{+2} , and up to 10 mg/L of Fe^{+2} . While testing, field personnel discovered wide variations in groundwater chemistry in the region and the need to address tube-well water containing high concentrations of both dissolved iron and arsenic. Iron concentrations were observed at over 25,000 ppb (25 mg/L) in some wells. Figure 2 illustrates arsenic concentration versus time from a treatment unit located in Adahata, West Bengal.

In Bangladesh the ATU at Nilkanda, Sonargaon is in use for the last seven months treating more than 150,000 liters of water. During the period of operation for this system, arsenic concentrations in the pre-treated water ranged from 152 ppb to 900 ppb, with an average of 399 ppb. The treated water effluent contained arsenic concentrations below detection limits (i.e., below 5 ppb). This was achieved with water containing competing ions such as Ca^{+2} and Mg^{+2} , and up to 4 mg/L of Fe^{+2} .

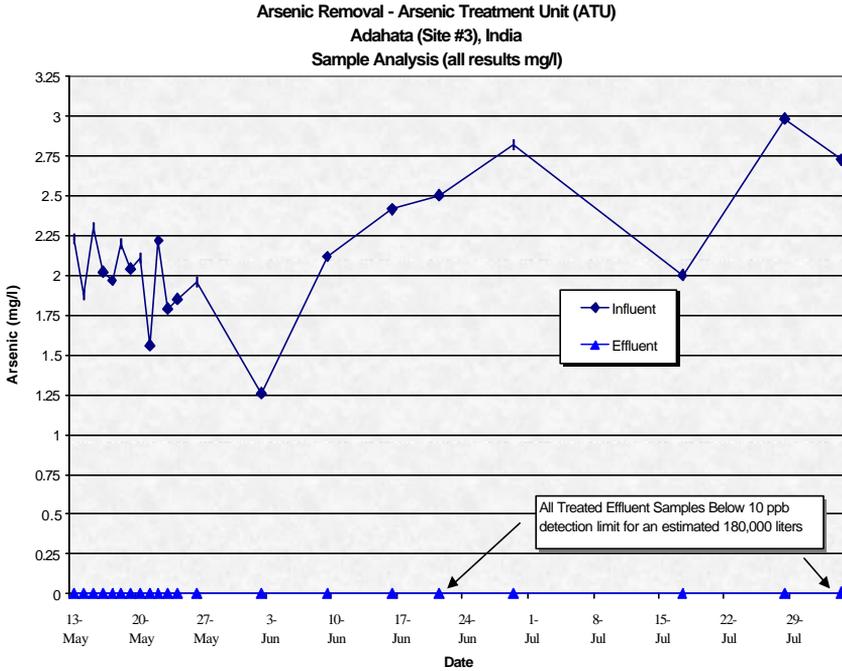


Figure 2: Tube-well results from site No.3 in Adahata, India

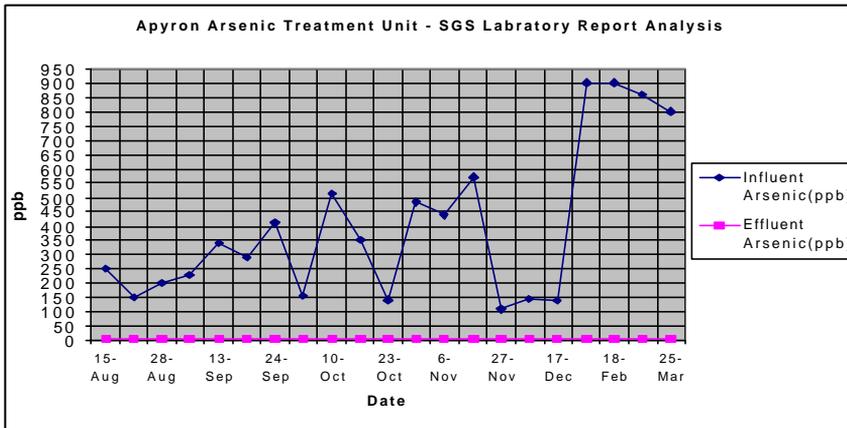


Figure 3: Tube well results from Site No. 1 at Nilkanda, Sonargaon, Bangladesh

The leachate from the media was tested in accordance with U.S. Environmental Protection Agency (EPA) Toxic Characteristic Leaching Procedure (TCLP) methods and found to contain arsenic well below the acceptance criteria. As an example, two samples from the demonstrations leached 0.03 and <0.5 mg/liter arsenic, well below the EPA criteria of <5.0 mg/liter.

Table 1 : Results of TCLP Tests

Spent Media TCLP Results – solid residuals (Backwash and Spent Media)		
Parameter	Results (mg/L)	TCLP Limit (mg/L)
Backwash Solids	0.0185	5.0
Backwash Solids	0.0537	5.0
Spent Media	0.032	5.0

COST

Methodology

The objective of the cost analysis is to provide guidelines for estimating cost of operation using Aqua-Bind™ Arsenic removal media for Tube-well groundwater treatment. Key assumptions for the applications are described below:

1. Costs are based on treating 2000 liters per day in an existing tube-well system that employs a hand pump to pump the groundwater to the surface for use.
2. Influent arsenic concentration is assumed to be 0.5 mg/L and effluent is assumed to be treated to below 10 ppb (mg/L).
3. The unit is operated and maintained by the users (i.e., villagers) themselves after receiving training on the system.
4. The Aqua-Bind™ Arsenic removal media is replaced every six months and is the only operating cost used in the analysis.
5. Costs are based on using the Aqua-Bind™ XP Arsenic media, which is used for As (III) and As (V).
6. Sampling and laboratory costs are not included.
7. Based on previous test results, the spent media is NOT considered as hazardous waste and no additional costs for waste disposal are added.
8. Capital costs are annualized at 15% interest rate.

The costs for the tube-well drinking water for arsenic treatment using the Aqua-Bind™ media are less than TK. 0.05 per liter of water treated at an average arsenic concentration of 500 ppb. Figure 4 illustrates the cost per liter of water in

Bangladesh Taka for various concentration of arsenic. The Figure also provides annual cost of treated water per family assuming there are 5 members per family using at least 5 liters/day/person. The cost per liter for a 600 ppb arsenic contaminated tube well serving four hundred persons is TK0.05/liter. For a family of five using 5liters of drinking water each then the total cost is TK.450 / yearly or about TK1.25/day/family. Field observation indicates water use is lower about 3 liters/person implying the water cost to TK. 0.75/day/family.

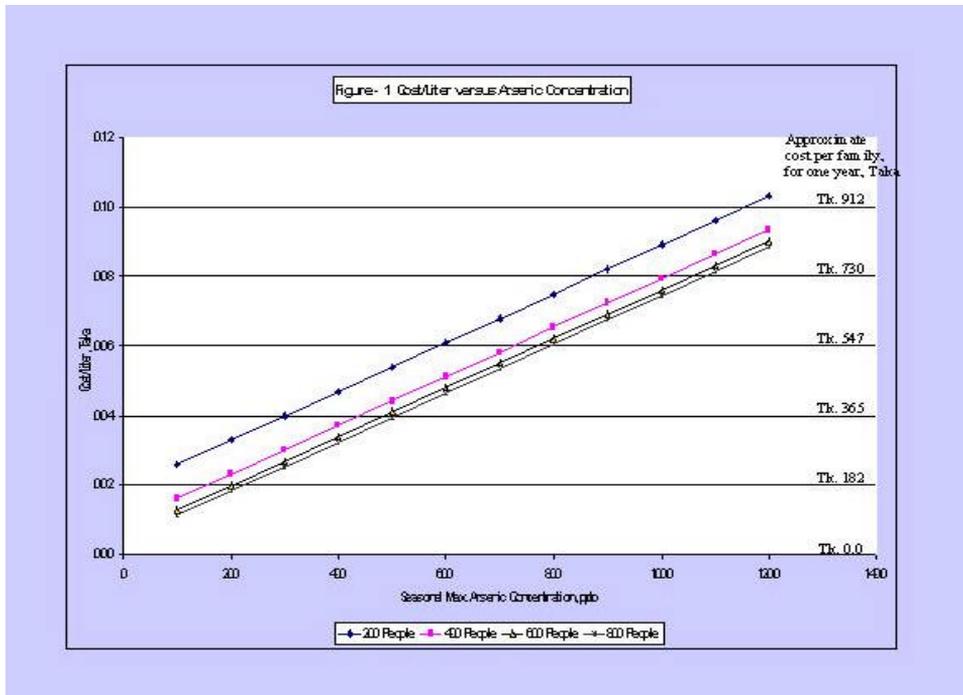


Figure 4: Cost per liter versus Arsenic Concentration

Technology Applicability

The results of the tube-well testing in Bangladesh and India have established the ability of the Aqua-Bind™ Arsenic media to successfully remove arsenic in the groundwater used for drinking water. The treatment system is easy to use and maintain, and does not impede the normal flow from the tube-well. The users have provided the routine bi-weekly maintenance involving backwashing of the media, which takes less than 15-20 minutes of their time. Given the success of this and other testing, a whole family of Aqua-Bind™ Arsenic media have been developed and tested for applications such as potable water, industrial water, remediation, and specialty uses.

Aqua-Bind™ Arsenic XP is a high performance composite material specifically designed for a wide range of arsenic removal applications. It is ideally suited for the most demanding applications involving high arsenic concentrations and high hardness where short contact times are essential. Exhibiting unique properties resulting in efficient removal of both arsenic (III) and arsenic (V), the material does not require either pre- or post-treatment, and it is NSF 61 Certified for use in drinking water applications.

Aqua-Bind™ Arsenic HP is a high-capacity media for removal of arsenic (V) for POE systems where regeneration is not required. It is designed as a high capacity, discardable media that exhibits outstanding performance for arsenic (V), again without requiring any pre- or post-treatment. The material's ability is sustained even in the presence of competing ions such as sulfates, silica, calcium, and magnesium. It also displays excellent kinetic properties for arsenic uptake with very short contact times, from seconds to minutes over a wide operating range of water quality.

Aqua-Bind™ Arsenic EP is an economical media designed for small and large municipal water systems with the option for regeneration. This enhanced composite material is ideal as a low cost, better performing alternative to conventional activated alumina. The material is regenerable using conventional acid/base regeneration techniques prolonging the operating life and extending the frequency of change out. The material can be retrofitted easily into existing adsorption systems and is NSF 61 certified for drinking water applications.

Aqua-Bind™ Arsenic AL is a low cost activated alumina for standard applications in fixed bed adsorbers for arsenic removal. This material is optimal for low-level arsenic concentrations (< 25 ppb) within an operating pH range of 5.5 – 7.0 with 5-minute contact times. This material is amenable to regeneration as well.

Apyron materials can be manufactured to specific particle sizes that are adaptable to conventional filter housings, precoat cartridges, pleated nonwoven fabrics and conventional fiberglass POE cylindrical tanks. The Aqua-Bind™ Arsenic removal adsorbent media are easily adaptable and transferable to an assortment of water applications with arsenic concerns including municipal treatment plants, commercial or centralized water treatment systems, and home water filters for Point of Entry/Point of Use (POE/POU). These media may be employed in a variety of POE and POU systems and devices to meet the needs of end users for arsenic removal. The technology can be incorporated into existing treatment trains as an add-on component, such as a post-softening step for arsenic removal, or as a stand-alone technology.

For POU applications, the media can be formulated as a sole component or active ingredient to carbon blocks, carafes and other devices for achieving multiple functionality where arsenic reduction can be achieved along with other

health or aesthetic-related benefits. Some specific POE and POU configurations for arsenic adsorption media include:

- Household POE treatment vessels incorporating granular media for arsenic removal
- POU granular cartridges and carbon blocks (countertop and under-the-counter for general purpose, ice maker, etc.)
- Pre- and post- reverse osmosis cartridges
- Faucet-mount cartridges and blocks
- Water bottles, coolers, recreational filters and other specialty applications

Patents/Certifications/Associations

The Aqua-Bind™ products are manufactured and marketed for sale by Apyron Technologies, Inc. Numerous POE/POU units are being tested at locations across the US and across the world. The products are based on a technology that is patented in the U.S. and worldwide patents are pending.

Both Arsenic XP and EP are NSF 61 certified for drinking water application and Apyron is pursuing certification for other media. Apyron Technologies, Inc. is a member of the Water Quality Association and the American Water Works Association.

REGULATORY AND POLICY ISSUES

Worker Safety

The Aqua-Bind™ Arsenic media poses no chemical, physical or other health risks to personnel handling the media during installation, operation or removal. There is no special training that must be administered for users of the Aqua-Bind™ Arsenic media. Any necessary training is contingent upon the specific application for the media, and is NOT due to the media itself. Typical training includes replacement of the media and as stated above, no special precautions or safety practices are prescribed for this activity.

Environmental Safety/Waste Disposal

Based on previous testing of applications using the Aqua-Bind™ Arsenic media, the material forms a very strong chemical bond between the adsorbent and the arsenic that is highly resistant to leaching. Spent media have been tested several times by independent U. S. laboratories in accordance with standard Toxicity Characteristic Leaching Procedure (TCLP). Such tests have identified the spent media as non-hazardous (as classified by the EPA), allowing the media to be disposed along with sanitary waste in a controlled public landfill within the U.S.

CONCLUSIONS

Apyron ATU has been demonstrated both in laboratory and field to provide safe water with arsenic contamination bellow 10ppb. The laboratory results indicate the water is safe to drink and the spent media is non-hazardous to the environment.

Field-testing indicates ready acceptance of the filter, which is proved to produce good quality water, about 800 people now consumes ATU treated water in Bangladesh. However field tests to date have not required users to pay for the water. The backwashing is done by the villagers without difficulty. Maintenance problems in Bangladesh occur at the rate of 0.036/ week. Costs are very low, as the usage rate is high.