

# ARSENIC REMOVAL IN REMOTE COMMUNITIES – USING MEDIA ADSORPTION



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## ABSTRACT

On behalf of the Western Australian Department of Housing, Parsons Brinckerhoff manages essential services to 91 remote Aboriginal communities through the Remote Area Essential Services Program (RAESP). The water treatment team at Parsons Brinckerhoff, Perth, designs systems to produce water from the community bores that meets Australian Drinking Water Guideline (ADWG) standards.

At some places in Western Australia, arsenic levels in community water supplies exceed the level set in the ADWG. This paper discusses the options available for removing arsenic, and their suitability for extremely remote communities.

The final design was based on installing adsorption media in a 3.0 m shipping container, to maintain a minimal footprint and protect the plant from the environment.

When exhausted, the adsorption media is removed from the vessel and either stored on site to minimise disposal costs or disposed of safely, once a year, into land fill.

## 1.0 INTRODUCTION

Arsenic (As), a naturally occurring element, is introduced into water when minerals and ores are dissolved. When arsenic dissolves in water it forms oxyanions, trivalent arsenite As(III) under reducing conditions or pentavalent arsenate As(V) under oxidising conditions. The design of a water treatment plant (WTP) to produce safe drinking water for remote communities that may be hundreds of kilometres apart must be sustainable, innovative, durable and low-maintenance.

The Indigenous community in this study has three production bores. Two low-yielding bores supply the community with potable water. The third, high-yielding bore, was taken offline due to elevated levels of arsenic. The RAESP program is seeking to bring the third bore back online and lower the arsenic levels to satisfy the community's growing demand for water. The community's arsenic levels were tested and found to be as high as 0.02 mg/L, double the 0.01 mg/L limit the ADWG recommends for health. In developing an arsenic-removal process, Parsons Brinckerhoff considered process complexity, reliability, cost efficiency and the disposal method for any waste stream.

This paper discusses the methodology adopted for selecting and designing a suitable process, the options analysis and the final design of the water treatment plant.

## 2.0 METHODOLOGY

The community in this study is located in the Kimberley region of Western Australia. The current service provider for remote communities in that region manages services that include maintenance, repair and capital works to improve the quality of life for the Indigenous people. Its maintenance program is typically based on a six-week cycle.

Consequently, Parsons Brinckerhoff's first criterion for the WTP design was that the plant must require minimal maintenance. Next, as the plant will be operated and maintained by the service provider, the plant had to be simple to operate and maintain.

Third, the WTP design had to be robust, to withstand the harsh conditions of the Western Australian outback, and it had to be efficient - that is, it had to use minimal energy, minimal consumables and minimal physical labour for maintenance. Finally, the waste stream had to pose a negligible contamination risk to the environment.

With all the above criteria to be considered, the technology options that were investigated were: coagulation and precipitation, reverse osmosis, ion exchange, in situ groundwater treatment and adsorption.

## **2.1 Coagulation and precipitation**

The process of coagulation and precipitation involves adding a coagulant to the drinking water, then clarifying and filtering it. When the source water has a pH of <7.5, arsenic can be removed with equal efficiency by both aluminium and iron coagulants; when the pH is >7.5, iron coagulant is more efficient than aluminium (Brandt, Johnson, Ratnayaka, 2009). The source water has a pH of approximately 8, making an iron-based coagulant more suitable. Coagulation has been shown to be less efficient for removing arsenite than for removing arsenate. Chlorine, ozone, chlorine dioxide or potassium permanganate can be added before coagulation to oxidise arsenite and convert it to arsenate, creating another control point.

However, adding a pH control, coagulant optimisation and redox control for oxidation would require an intensive control system. This would increase operating and maintenance costs and increase the potential for failure because the plant would be unmanned for six weeks at a time. Maintaining the system would be too complex and the plant would need a larger footprint. The process of removal of arsenic by coagulation and filtration was not explored further.

## **2.2 Reverse osmosis**

Reverse osmosis (RO) can remove arsenic and other impurities from drinking water. Water is forced through membranes at high pressure, leaving the contaminants on one side of the membrane and treated water on the other. Although a valid treatment option, RO was quickly abandoned due to silica fouling issues and because 35% of the available water would become a waste stream containing much higher levels of arsenic (approximately 0.05 mg/L). The waste stream would also need to be contained, complicating the design and creating an environmental sustainability problem.

## **2.3 Ion exchange**

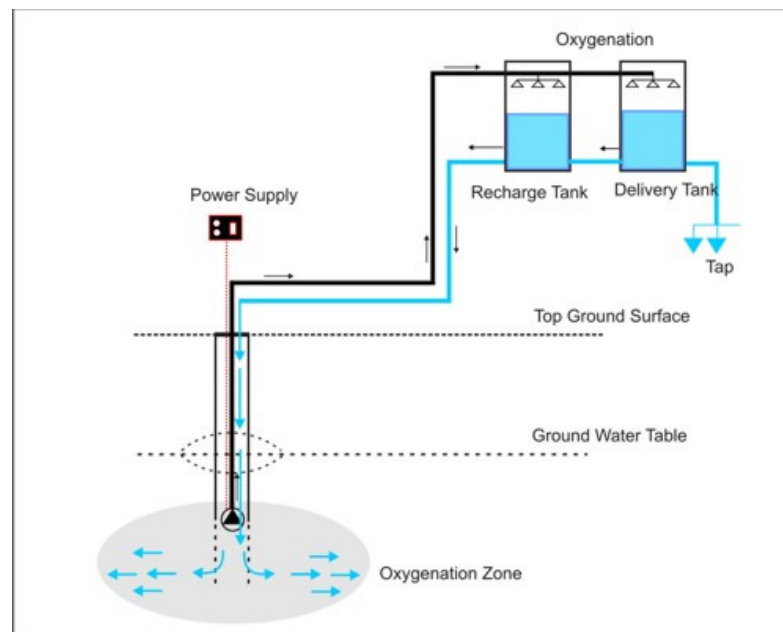
Pentavalent arsenic is present in drinking water as dihydrogen arsenate ( $\text{H}_2\text{AsO}_4^-$ ) and monohydrogen arsenate ( $\text{HAsO}_4^{2-}$ ), so it is possible to remove arsenic by anion exchange. When arsenic-laden water passes through a strong base anion resin, arsenate ions are exchanged for other anions on the resin. This process was thoroughly investigated, as it is much simpler than either coagulation or reverse osmosis. Ion exchange resins investigated included Resintech's ASM-10-HP and MIEX resin.

Using ion exchange creates some problems - the resins require regeneration, they produce a wastewater stream, and arsenic can be released back into the environment. The process would require pre-treatment to remove organics, suspended solids and other contaminants that would foul the resins and decrease their effectiveness. Ion exchange was also rejected.

## 2.4 In situ groundwater plant

Investigations to find a more suitable treatment process revealed Dr Bhaskar Sen Gupta's subterranean arsenic removal (SAR) technology. The SAR process takes the oxidation and filtration process used in aboveground water treatment plants and transfers it underground into the aquifer.

Groundwater is extracted into a tank at ground level, aerated and re-injected into the bore underground (see Figure 1). Aeration causes the oxidation of arsenite to arsenate, ferrous to ferric ( $\text{Fe}^{3+}$ ) and manganese (II) ( $\text{Mn}^{2+}$ ) to manganese (IV) ( $\text{Mn}^{4+}$ ). This creates an arsenate co-precipitated with the  $\text{Fe}^{3+}$  and, to a lesser extent,  $\text{Mn}^{4+}$  precipitates, reducing the content of arsenic in the bore water. The water is then filtered by the surrounding sand, removing the contaminants. The oxidation process is enhanced by bacteria in the subsurface. The re-injection of aerated water into the bore creates an oxidation zone where physical, chemical and biological processes are intensified, increasing the effectiveness of the oxidation process and, ultimately, the removal of arsenic (Sengupta, n.d.).



**Figure 1:** Schematic diagram of an SAR plant

The main advantages of implementing this system in a remote community are that the process requires no chemical input, does not produce a waste stream, is a simple design and has a minimal footprint. Because the arsenic and iron flocs filter through the sand, sludge handling is not needed, and the total volume of contaminants filtered into the sand is insignificant compared to the surrounding groundwater area. The simplicity of the design minimises operating and maintenance costs.

However, when Dr Gupta reviewed the quality of the water at the remote community, he advised that the combined levels of  $\text{Fe}^{3+}$  and  $\text{Mn}^{4+}$  were too low to create a stable reaction in the water supply. This process option was also eliminated.

Discussions with Dr Gupta revealed a process more suited to removing arsenic from the community's drinking water - adsorption. He also suggested using titanium-based media to increase adsorption's effectiveness.

## 2.5 Adsorption

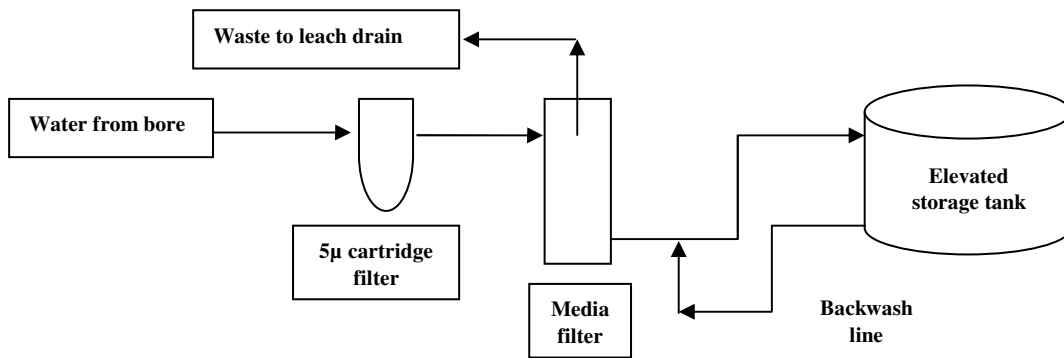
In the adsorption process, arsenic ions adhere to a solid surface and are extracted from the water. The surface is typically a metallic-based granulated media, held in a pressure vessel. Arsenic-laden water travels through the vessel and makes contact with the media. Arsenic is adsorbed onto the media, and effluent leaving the pressure vessel has considerably lower arsenic levels. The adsorption process, unlike the ion exchange process, does not release an anion in place of the arsenic, so there is no risk of increasing anion levels in the water.

The medium chosen must not require regeneration (thus avoiding problems associated with disposing of the waste stream). It must be able to be disposed of and replaced after exhaustion, achieve optimum process with a pH of 8, be able to adsorb arsenic ions, and, most importantly, arsenic must be its top removal priority, followed by other metals and ions.

Activated alumina and granulated ferric hydroxide are typically used for the adsorption of arsenic from drinking water. Activated alumina is more effective in removing arsenate than arsenite; therefore, an oxidation process would be necessary to convert As(III) to As(V). Activated alumina is highly pH-dependent, with an optimum removal range between pH 5.5 and 6.5. The community's water has a pH of approximately 8, so it would require a pH adjustment before it entered the pressure vessel, increasing the system's complexity and its operating and maintenance costs. Activated alumina was rejected.

DOW Chemical Company was approached to provide titanium-based granulated media that would suit the remote community's water quality, and was asked to prepare a projection of effluent quality based on a 12-month media replacement cycle. The company recommended Adsorbsia AS600 media. Adsorbsia is a titanium oxide medium that has a strong affinity for arsenic, lead and other heavy metals. It is designed to be non-regenerative, needs less maintenance, and is therefore ideal for a remote community. Once exhausted, the media are disposed of in landfill after they have been tested and passed the US Environmental Protection Agency's toxicity characteristic leaching procedure (TCLP) extraction protocol.

A process flow diagram of the system is shown in Figure 2.



**Figure 2:** *Arsenic-removal process flow diagram*

Over time, head loss will occur across the media, due to compaction and the filtration of particulates. A 5 µm particulate cartridge filter is installed upstream of the media pressure vessel to extend the cycle run time between backwashes. As a result, the backwash cycle can be undertaken during the routine six-week maintenance inspections, so it does not need to be automated.

An adjustable differential pressure switch is installed over the arsenic media bed and the 5 µm particulate cartridge filter, set to warn service providers via a remote telemetry connection that they will need to wash/change media and cartridge filters on their next six-weekly visit. The unit should be backwashed quarterly; backwashing is initiated manually. Treated water drawn from the elevated storage tank will expand the media using a total of five bed volumes. The backwash is suitable for disposal in leach drains as it will contain little to no arsenic contaminants.

A magnetic dual-direction flow meter is installed downstream from the media filter vessel for monitoring the treated water and the backwash flow rate. The arsenic-removal system is installed in a 3 m shipping container. The top of the unit needs to be accessible for media removal and replacement.

Access includes a hatch, ladder and railings to ensure the site complies with occupational health and safety (OHS) requirements. Figure 3 shows a roof modified by the service provider in the past.



**Figure 3:** *Expected system container fit-out/modifications*

### 3.0 CONCLUSION

Long-term consumption of water contaminated with arsenic at levels above the health limit recommended by the Australian Drinking Water Guidelines will have profound effects on health. Innovation is needed to design a system suitable for treating arsenic-contaminated water in a remote West Australian community, as the system needs to be sustainable, simple and effective, and to have minimal maintenance and operating costs.

Treatment options investigated by Parsons Brinckerhoff included coagulation and precipitation, reverse osmosis, ion exchange, an in situ groundwater treatment plant and an adsorption process. The adsorption process using DOW Chemicals' Adsorbisia AS600 titanium oxide media provided the best solution to a complex problem in a remote community. The only regular consumable is a 5 µm cartridge filter, which removes particulates to increase the adsorption unit's run cycles.

The arsenic-removal plant is currently under construction and due to be commissioned at the end of July 2012. It is expected that, after a year of operation, the plant's efficiency and the study findings will be confirmed.

The water treatment unit for removing arsenic is only one example of Parsons Brinckerhoff's use of options analysis to select the most suitable water treatment process for remote communities in Western Australia.

### 4.0 ACKNOWLEDGEMENTS

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