



Studies have confirmed that arsenic is removed effectively by precipitation with iron.

Arsenic in Drinking Water

Part 4: Arsenic Removal Methods

Editor's Note: Part 1 of this series provided a timeline for the development of a drinking water standard for arsenic. It also summarized the political and public reactions to the U.S. EPA decision to delay and withdraw the arsenic rule.

Part 2 dealt with human exposure and advances in knowledge concerning human health effects of exposure to arsenic.

Part 3 summarized early data on the occurrence of arsenic in U.S. waters.

Conventional Treatment: Precipitation with Iron, Aluminum

As early as 1972, prior to the start of the U.S. Environmental Protection Agency (EPA) review of the arsenic standard, arsenic removal studies (Gulledge and O'Connor) demonstrated that following oxidation to arsenate ion, As V, arsenic could be readily removed (90 to 98 percent) by conventional water treatment processes utilizing chemical coagulants, such as iron and aluminum. Iron precipitates were found to be particularly effective in adsorbing or coprecipitating arsenic. Subsequent studies have

repeatedly confirmed effective removal by precipitation with iron. As a result, where arsenic removal is practiced, it generally is removed along with precipitated iron. Where dissolved (ferrous) iron is absent in the source water, the addition of an iron coagulant, followed by iron hydroxide precipitation and filtration is used to remove arsenic with great efficiency and at low cost.

Numerous variations on the direct use of iron and aluminum coagulants have been or are currently being tested. Whether the coagulant/adsorbent is dissolved, previously precipitated or attached to a proprietary medium, most of the methods currently under development reportedly are successful in achieving effective arsenic removals.

Alternative Arsenic Removal Techniques

Less commonly used arsenic removal techniques include anion exchange and adsorption on activated alumina. Both produce arsenic-bearing brines or rinse waters that may require evaporation for volume reduction prior to their ultimate disposal.

While suitable for small, household treatment systems where the medium is replaced on a prescribed schedule, greater process control and more comprehensive monitoring would be required to maintain continuously effective arsenic removal using either of these processes in a community water treatment system.

Even more costly water treatment techniques such as reverse osmosis and electro dialysis have been used to develop some cost estimates of the potential economic impact of a national program of arsenic removal. Membrane separation processes might prove economically feasible if other water quality objectives such as the reduction of dissolved solids and nitrate ion concentrations were required in addition to arsenic removal.

USEPA-Designated Best Available Treatment Processes

USEPA offers the following seven processes as "best available treatment" (BAT) for the removal of arsenic V. While arsenic may be predominately in the oxidized As V form in surface waters, any reduced As III first should be oxidized to As V by pretreatment. As III oxidation is particularly important for groundwater sources where reducing conditions normally prevail. It may be accomplished by prechlorination, chloramination, the addition of potassium permanganate or contact with previously precipitated manganese dioxide, MnO_2 .



Using aerators to treat groundwaters for iron and manganese removal is effective for removing arsenic since precipitated ferric and manganic oxides readily adsorb As V.

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The settling basin for filter backwash water at Morton accumulates iron sludge and provides a habitat for ducks.

Conventional Treatment

Aeration / Filtration

Treatment of groundwaters for iron and manganese removal is highly effective for arsenic removal since precipitated ferric and manganic oxides readily adsorb As V. The arsenic is recovered in the relatively small volume of sludge settled from the filter backwash water. As little as 1 or 2 mg Fe/L in or added to the well water should result in meeting the maximum contaminant level for arsenic. Monitoring for iron removal might be used to confirm effective arsenic removal.

Coagulation / Filtration

Conventional surface water treatment employing iron or alum coagulants forms hydrous ferric or aluminum oxides. Consistent arsenic removals should be achieved using low dosages of iron or conventional dosages of alum. Operationally, monitoring of finished water turbidity should confirm effective arsenic removal.

Lime Softening

Precipitation of hardness by lime with supplementary coagulant addition may result in the formation of a mixed precipitate of iron, aluminum and magnesium oxides along with calcium carbonate. Arsenic would be merely a trace component of the large quantity of softening sludge produced. Again, a relationship between arsenic and turbidity in the finished water should be established for purposes of operational monitoring of effective arsenic removal.

Adsorption Media

Anion Exchange

AsO_2^- (As III) and AsO_3^- (As V) are exchanged for chloride ion on strongly basic anion exchange resin. The use of a salt (NaCl) regenerant results in the production of an arsenic-bearing brine. The breakthrough of sulfate ion may signal the loss of treatment unit capacity for As V removal.

Activated Alumina

Adsorption of As V on aluminum oxide (AlO_2) at pH 6 may require relatively low hydraulic surface loading rates. Following

backwash, the medium is regenerated first with sodium hydroxide, then rinsed with sulfuric acid. If fluoride is present in the source water, its removal may be helpful in confirming arsenic removal.

Membrane Processes

Reverse Osmosis

Under high pressure, reverse osmosis (RO) membranes reject a portion of arsenic, sulfate, nitrate and other ions from relatively particle-free, pretreated water. Arsenic removal by reverse osmosis membranes may be related to overall total dissolved solids reduction. The arsenic removed is recovered in a large volume of RO concentrate. Membrane effectiveness is affected by suspended solids, scaling by carbonates, silicates and sulfates, hydrogen sulfide and the tendency of the source water to support microbial growth.

Electrodialysis Reversal

Similar to reverse osmosis.

Coagulation/filtration and lime softening are not designated as BAT for systems with fewer than 500 service connections. Instead, EPA has defined "small system compliance technologies" (SSCTs) that limit the treatment technology for arsenic removal for these smaller communities. These limitations are based on the presumption that smaller communities will not be able to provide "appropriate" operation and maintenance. Accordingly, reverse osmosis and electrodialysis reversal also are not BAT for these systems.

POE/POU Treatment

EPA will allow small water utilities to utilize point-of-entry/point-of-use devices to meet enforceable drinking water standards. These utilities would own, operate and maintain the devices plus ensure compliance with the MCLs. Pilot testing on the source water would be required. The utilities might have to seek revisions to local ordinances to require consumers to provide access to the installed devices for maintenance. Frequent sampling and additional staff may be required. Currently, USEPA asserts that POE/POU treatment can be less expensive than central treatment for communities up to 250 people.

Proprietary Media

Water treatment equipment manufacturers are offering package plants containing proprietary media for arsenic removal. Filtronics' "Electromedia" and General Filter's GFH (granular ferric hydroxide) media are examples. The former medium is backwashed and continually reused; the latter is replaced after exhaustion.

Another medium undergoing testing at the University of Missouri-Columbia utilizes triple reverse burn (TRB) char prepared from a subbituminous coal. After service, this medium can be reduced to ash.

USEPA Arsenic Removal Study: "Plant A" Results

Starting in 1998, EPA began monitoring arsenic removals at a central Illinois water treatment plant identified only as "Plant A."



Consistent arsenic removal should be achieved using low dosages of iron or conventional dosages of alum prior to filtration.

The water system for this community has treated groundwater for the removal of iron and manganese since 1970. EPA monitoring results showed that, unintentionally but incidental to the treatment provided for iron removal, arsenic concentrations were reduced from 20.3 $\mu\text{g/L}$ to less than 3 $\mu\text{g/L}$, the lowest arsenic standard under consideration by EPA. The incremental cost for the highly effective (91 percent average) removal of arsenic at Plant A was zero. It appears that this utility, with three identical conventional iron removal plants, has been effectively removing arsenic from its groundwater for more than 30 years. In the Midwestern United States, thousands of iron removal plants essentially use the same standard process as Plant A, one of the three operated by the Village of Morton.

Disposal of Arsenic-Bearing Treatment Plant Residues

As expected, the arsenic removed at Morton's Plant A is recovered as a minor constituent of the iron hydroxide sludge settled from filter backwash water. This has created a secondary concern over the practice of land disposal of the water treatment plant residues and raised the question of whether the Plant A sludge required regulation as a hazardous waste. Until recently, the water treatment plant residue was discharged to the municipal wastewater collection system and subsequently was combined with the wastewater sludge. The blended sludges ultimately were disposed of on farm land.

The EPA Toxicity Characteristic Leaching Procedure (TCLP) test has indicated that the sludge from Plant A is not readily leached and should be accepted in nonhazardous landfills.

The results from the Plant A study demonstrate that coprecipitation of arsenic with iron provides a stable and inexpensive means for effectively removing arsenic from groundwater. This

treatment procedure also minimizes the costs of disposing of the treatment plant sludge residues.

Implications for the Feasibility of Meeting More Stringent Arsenic Standards

As of June, 2001, EPA has cited a \$200 million annual cost to municipalities, states and industry of meeting the 10 $\mu\text{g/L}$ arsenic standard by 2006. One assumption made is that the cost of meeting still more restrictive (lower) standards would be exponentially greater for a given utility. This is not likely true in the case of arsenic when more than 95 percent removals are being observed even at older, conventional plants not specifically designed for arsenic removal. Still further reductions in arsenic may require only increased iron coagulant dosages and, as a result, arsenic removal may be essentially independent of the physical facilities required.

Alternately, as indicated in Part 3 of this series, a more restrictive, state-mandated arsenic standard would require a greater proportion of water utilities to reduce influent arsenic concentrations. Therefore, to more accurately assess the impact of a more stringent arsenic standard, a nationwide, multi-year program of finished water monitoring is required to fully define the number of supplies potentially impacted. This should be accompanied by detailed data on existing treatment facilities plus other pending finished water quality problems (e.g., DBP, radium) that have yet to be addressed. These latter data would facilitate a rational assessment of the appropriate treatment modifications required and permit a more equitable assessment of the portion of the cost that should be allocated to arsenic removal alone.

Many of the smaller (predominantly, rural) utilities impacted by the arsenic rule face other MCL violations often due to the presence of agricultural chemicals such as nitrite, nitrate and atrazine. Their compliance needs might be addressed by providing treatment, nominally, to address their most critical health issue. A dispassionate assessment of small system treatment needs may show that these water utilities require the construction of treatment facilities to meet the requirements of existing regulations independent of the need to reduce arsenic concentrations.

Arsenic Removal in Albuquerque, N.M.

Since the groundwater source for Albuquerque, N.M., contains 52 $\mu\text{g/L}$ of arsenic, treatment facilities are being designed to rectify this situation. Following pilot scale evaluation of three options (coprecipitation with iron, anion exchange and activated alumina) coprecipitation of arsenic with ferric hydroxide formed from the addition of ferric chloride was selected. Pilot studies indicated that arsenic concentrations could be reduced to less than 2 $\mu\text{g/L}$ (96 percent arsenic removal) by the addition of 5 to 22 mg/L of ferric chloride. This result is consistent both with the laboratory results and with the full-scale arsenic removal experience at Morton, Ill.

While the treatment plant planned for Albuquerque is more elegant (e.g., skid-mounted microfiltration units, lamella thickeners, recessed plate filter press) than Morton's Plant A, the process and the predicted results are essentially the same.

Anion exchange was rejected because it requires the use of large quantities of sodium chloride. The arsenic-bearing brine pro-



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duced in regenerating the anion exchange resin was classified as a hazardous waste, further increasing brine disposal costs.

The use of activated alumina would require the addition of sulfuric acid to lower the pH of Albuquerque's alkaline water. Final treatment then would require the addition of sodium hydroxide to neutralize the treated water. As with anion exchange, arsenic adsorption on activated alumina would generate a brine classified as a hazardous waste.

Not only is the estimated capital cost of an iron precipitation facility lower, but also the estimated annual operation and maintenance costs reportedly would be 60 percent of the other alternatives. While a great deal of research has been done in recent years on the effectiveness of alternate processes for arsenic removal, little attention previously was focussed on the potential capital and operating costs of some of these alternatives.

Summary of Treatment Options

A range of appropriate technology for the removal of arsenic from many, if not most, community water supplies exists. Among the options is iron removal, one of the most common processes used in the treatment of both ground and surface waters in the United States. Coagulation with aluminum sulfate also is effective although requisite chemical dosages may be higher and the effective pH range somewhat narrower.

The incremental costs for the removal of arsenic in those communities already having filtration facilities should represent only a small fraction of the total cost of producing and delivering safe drinking water.

In many cases, where citizens and community leaders have been reluctant or financially unable to support the cost of providing treatment to meet existing regulatory requirements, the need for arsenic removal may provide an additional incentive to either provide comprehensive treatment, seek a more secure alternate water source or purchase water from a regional water commission. The latter option is being adopted rapidly throughout the midwestern United States as smaller communities confront the cost and legal implications of meeting an increasing number of health-based regulatory requirements. Progressively, experience is confirming the expected economic benefits of the regionalization of these water supplies. As in other United States industries, in drinking water production and distribution, substantial economies of scale are achieved with the management and operation of larger-capacity water facilities.

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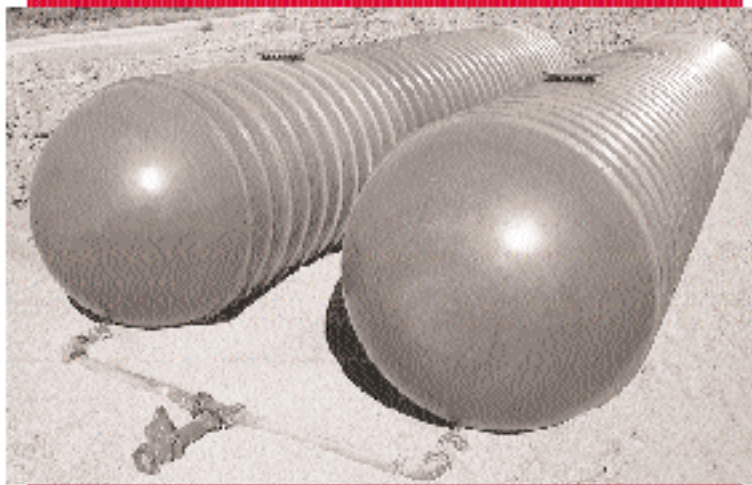
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