

# Arsenic Water Treatment

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Our goal is to provide expertise to municipalities and community water suppliers to facilitate their decisions as they comply with the new EPA Arsenic Rule. This rule will be costly to comply with. The American Water Works Association estimates that the nationwide annual cost of compliance with the Arsenic Rule will be over 1.4 billion dollars. The Association of California Water Agencies estimates the capital cost of treatment facilities required by California systems to comply with the EPA treatment standard at 500 million dollars, assuming that California adopts the same standard as the EPA. If California adopts a lower standard, the capital requirements would be far higher. In summary, water industry groups agree that the Arsenic Rule will be the most costly of the EPA's drinking water rules.

Properly designed and optimized treatment plants can significantly reduce both the capital cost and the annual cost of operation and maintenance of these plants. Nolte's Water Resource Group has decades of experience in the design, manufacture, and operation of potable water treatment plants, primarily for small systems. Because approximately 97% of the systems (nationwide) to be impacted by the Arsenic Rule are systems serving fewer than 10,000 people, our experience with small systems is especially relevant.

Nolte's approach to helping our clients comply with the Arsenic Rule is to identify the most cost effective technology for their system, recognizing that each system will have unique needs and goals. We use a systematic approach to evaluating the best technology for each site, summarized as follows:

- Determine Arsenic speciation and water characteristics
- Conduct bench scale studies
- Conduct pilot studies
- Complete system design

## **Determine Arsenic speciation and water characteristics**

Determining the raw water characteristics is the first step in solving an arsenic problem. First the species, or oxidation state, of the arsenic present in the raw water must be ascertained. Second, other key constituents and characteristics must be measured to determine which treatment processes are viable for use on each water source. The pH, alkalinity, and presence of competing ions must be determined, along with filtration tests to determine the amount of particulate arsenic (larger than 0.45 microns), if any.

Arsenic will occasionally be present in particulate form, but usually exists in solution as either arsenite ( $\text{As}^{+3}$ ), or arsenate ( $\text{As}^{+5}$ ). In some cases, all of the arsenic present will be the pentavalent (arsenate) species, but usually both species are present. Arsenite can only be removed by reverse osmosis, adsorptive media, or by ion exchange, whereas

arsenate can be removed by co-precipitation. Also, adsorptive medias are typically more efficient at removing arsenate than arsenite. For this reason, it is usually cost effective to oxidize arsenite to the pentavalent state, after which it can be removed by filtration. Chlorine, potassium permanganate, ozone, hydrogen peroxide or other oxidants can be utilized to oxidize the arsenite.

Accurate determination of the speciation is very important and should be performed at the wellhead at the time of sampling. The test requires special equipment and testing personnel must be well trained in the protocol to ensure accuracy. The water characterization data is the basis of the evaluation and design work to follow, therefore, the accuracy of the tests is paramount. Nolte Associates, Inc. can perform these tests if preferred by the client.

**Arsenic Treatment Processes**

The USEPA has recommended five best available technologies (BATs) and three small system compliance technologies (SSCTs) for arsenic treatment to comply with the new MCL (maximum contaminant level) of 10 micrograms per liter (mg/l), or parts per billion (ppb) (See Table 1). The listed BATs are: modified lime softening, modified coagulation/filtration, anion exchange, oxidation/filtration, and activated alumina. Listed SSCTs include Point of Use (POU) reverse osmosis, POU activated alumina, and coagulation assisted microfiltration.

TABLE 1<sup>1</sup>  
EPA BAT/SSCT Arsenic Treatment Technologies

	TYPE	REMOVAL EFFICIENCY	OTHER CONTAMINANTS REMOVED
Modified Lime Softening	BAT, SSCT	90%	Metals, Inorganic Chemicals
Modified Coagulation/Filtration	BAT, SSCT	95%	Physically large contaminants
Anion Exchange	BAT, SSCT	95%	Anions
Oxidation Filtration	BAT, SSCT	95%	Metals (eg iron and manganese)
Activated Alumina	BAT, SSCT	95%	Anions
POU Reverse Osmosis	SSCT	90%	Inorganic Chemicals and large organics
POU Activated Alumina	SSCT	90%	Anions
Coagulation assisted microfiltration	SSCT	90%	Physically large contaminants

In addition, other technologies such as adsorbent media are viable that are not listed in Exhibit 1. These and other technologies may become BATs or SSCTs in the future.

<sup>1</sup> USEPA

Due to the negative factors associated with modified lime softening, anion exchange, reverse osmosis, and activated alumina, (see detailed description of each treatment process) only modified coagulation/filtration, oxidation/filtration, and adsorbent treatment technologies are likely to be used extensively for full scale plants, especially by small systems.

### **Modified Lime Softening**

In this process, calcium hydroxide is added to precipitate calcium carbonate. Other compounds including arsenic co-precipitate along with the calcium carbonate. This process will generate a large amount of sludge, and also must be operated at high pH levels (approx. 10.5) to be effective in arsenic removal. Consequently, it would be necessary to lower the pH by feeding acid before sending treated water to the system. The components of the system would include chemical tanks and feed pumps, mixing/reaction tanks for the precipitation process, and filters to remove the precipitated solids. The large amount and characteristics of the chemicals required for this process make it unattractive for use with small systems. Consideration must be given to the amount and characteristics of the wastes produced by the process.

### **Modified Coagulation/Filtration**

In this process, arsenite must first be oxidized to the arsenate state. Then, coagulation chemicals are added (alum, iron salts [ferric sulfate or ferric chloride], or polymers) to destabilize the suspended particles to produce filterable solids. Iron salts have usually been found to be more effective than alum, and are also effective over a wider pH range than alum. Polymers are usually employed in addition to iron salts to enhance the effectiveness of the coagulation process and to reduce the required dosage of iron salts.

Coagulants change the surface charge of the solids, allowing agglomeration into larger, more filterable solids. Arsenate is removed by adsorption to the precipitated ferric hydroxide resulting from oxidizing either the natural iron present in the raw water, or by adsorption to the ferric precipitates caused by injecting iron salts. If there is an insufficient amount of natural iron present in the water, iron salts must be added to create the ferric hydroxide floc. Adsorption is most effective at a pH of 7.0 or lower. The adsorption efficiency drops significantly at a pH above 8.5.

The removal of arsenic to the non-detect level is possible with this process. Pilot studies and data from operating facilities indicate that arsenic removal is proportional to the amount of the iron present, either naturally occurring or added iron in the form of iron salts.

If the amount of precipitated solids is high, a settling step, or a clarification step may be necessary to reduce the amount of solids loading onto the filters. Treatment plants without settling or clarification are known as direct filtration plants.

The components of this system include chemical tanks and feed pumps, mixing/reaction tanks, and filters. Periodically, the filters require backwashing, which generates wastewater.

### **Anion Exchange**

This process consists of passing water through pressure vessels containing ion<sup>2</sup> exchange resin. When water is passed through the resin, anions are exchanged for functional groups in the resin. The resin has a finite capacity for the exchange of ions, based on the type of resin and the site specific water characteristics. The process is reversible, which means that after the resin capacity is reached (exhaustion), it can be regenerated with brine to near its original state. The frequency of regeneration depends on the amount of anions in the source water, including arsenic, phosphate, sulfate, fluoride, selenium, nitrate, etc.

The components of this system include ion exchange tanks and a regeneration system, plus appurtenant equipment. The issues relating to disposal of brine waste must be resolved for this process to be viable.

### **Oxidation Filtration**

Oxidation Filtration is commonly used to treat groundwater containing iron and/or manganese. Chemicals used as oxidants are chlorine, ozone, potassium permanganate, and other commonly used oxidants. The oxidation process used to remove iron and manganese leads to the formation of hydroxides that remove soluble arsenic by co-precipitation or by adsorption reactions. The efficiency of arsenic removal with this process depends on the amount of iron in the water. Arsenic co-precipitation during manganese precipitation is relatively ineffective when compared to iron, which means that iron must be added to the water (ferric chloride or ferric sulfate) if sufficient iron is not present in the raw water. When iron salts are added, this process is essentially the same as the Modified Coagulation/Filtration process.

Pilot studies and data from operating facilities indicate that arsenic removal is proportional to the amount of the iron present, either naturally occurring or added iron in the form of iron salts.

Research of oxidation filtration facilities has primarily focused on greensand filtration, although similar results are expected from oxide coated silica media. Greensand is glauconite, a naturally occurring mineral found as sand sized particles that is green in color and has ion exchange properties. The glauconite sand is treated with potassium permanganate until the sand grains are coated with manganese dioxide. The arsenic removal process includes oxidation, ion exchange, and adsorption.

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<sup>2</sup> ion (an atom or molecule that has lost or gained an electron and thus acquired an electrical charge)

The components of this system include either gravity or pressure vessels containing greensand, plus chemical tanks and feed pumps. Periodically, the filters require backwashing, which generates wastewater.

### **Activated Alumina**

Activated alumina is aluminum oxide ( $\text{Al}_2\text{O}_3$ ) that has been heated to temperatures between 300 and 700 degrees C. Activated alumina has been used for arsenic removal for many years, and significant data exists from operating installations. Activated alumina is an ion exchange process similar to anion exchange, but it is more selective for arsenic and less selective for other anions compared to ion exchange resin. However, it will also remove selenium, fluoride, chloride, sulfates, and other anions. However, activated alumina requires regeneration with caustic soda, followed by neutralization with acid, which causes a waste disposal problem. Also, the material loses approximately 5% exchange capacity with each regeneration. These factors make it unattractive, especially for small systems.

### **POU Reverse Osmosis**

RO equipment for industrial and home use has been widely available for years. A number of manufacturers offer under the counter RO equipment for home use, and numerous manufacturers offer industrial RO equipment.

This process will remove approximately 90 % of the arsenic and other anions as well as cations, along with any particulate matter that may be present. Raw water under pressure is forced through a plastic membrane, which is permeable to water molecules, but not ions. The solution that passes through the membrane is called permeate, and the solution that is rejected by the membrane is called reject water. The amount of reject water produced depends on the raw water analysis, and can be up to several times the amount of permeate. For this reason, the wastewater issues caused by RO eliminate this process for most community-sized systems. However, because a home POU unit produces only a few gallons a day of permeate for drinking and cooking, the amount of reject water is also relatively small which can be disposed of to a sewer or to a septic tank, in most communities.

Another limitation of RO is that iron and manganese must be removed before introduction to the RO unit, as these constituents will rapidly foul the membrane, usually irreversibly. Other constituents such as calcium or silica can cause membrane fouling as well. For each water supply, an analysis of the fouling characteristics of the water must be evaluated to determine the viability of RO.

### **POU Activated Alumina**

Limited performance data exists on these POU devices. The process of arsenic removal is the same as described above. However, with the small POU devices, the activated alumina, once exhausted, is disposed of and replaced with new material.

Due to the limited operational data available, most states have yet not taken a position on the possible use of these devices

### **Coagulation Assisted Microfiltration**

This process is the same as the Modified Coagulation/Filtration process described earlier, except that microfiltration is used instead of media filtration. Given that microfiltration is an absolute barrier to any particles larger than 0.1 to 0.2 microns in size, the arsenic removal efficiency is higher than with media filters. Also, less coagulant will be required with microfilters compared to media filters because of the tighter pore size and greater filter efficiency. However, microfiltration equipment costs considerably more than conventional media filters. The membranes can also be fouled by iron or manganese if these constituents are not oxidized before contacting the membranes.

The components of this system include microfilter membranes, either operating under pressure or under suction, plus chemical tanks and feed pumps. Periodically, the filters require backwashing, which generates wastewater.

### **ADSORBENT MEDIA**

There are numerous adsorbent media available at this time, with more in the testing or development stage. Granular ferric hydroxide (GFH) in particular has been widely tested, and is the technology used at approximately 20 full scale treatment plants in Germany, which adopted a 10 ppb arsenic standard in 1996.

### **Granular Ferric Hydroxide**

GFH is a granular media developed in Germany that removes arsenic by adsorption. It is highly selective for arsenic, with phosphate, chromium, and uranium also competing for adsorption sites. It is currently non-regenerable in the field. Once exhausted, the media is disposed of in a landfill. Toxicity Characteristics Leaching Procedure (TCLP) tests have indicated that the exhausted media is non-hazardous, based on EPA standards<sup>3</sup>. Depending on the pH, the amount of arsenic in the raw water, and other water characteristics, several months to a several years of operation may be attained before replacement of the media is required.

GFH has demonstrated the ability to remove both arsenite and arsenate, without oxidation, at pH ranges less than 8.0. Removal efficiencies are much higher at a lower pH. For example, media life of up to four times longer is expected at a pH of 7 instead of a pH of 8. Influent water parameters are: arsenic < 50 ppb, combined iron and manganese < 0.3 ppm, and relatively free of particulate matter, which would foul the media. Due to the cost of the GFH, this technology is more applicable to small systems, mainly due to the simplicity of the process.

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<sup>3</sup> California has more stringent standards. See section on Waste.

The typical configuration of a GFH system for a community system is to utilize three pressure vessels, operated either in parallel or in series in a lead – lag – standby mode. In the latter mode, one tank would always be in standby. Once the lead tank is exhausted, it is put on standby and the media is replaced. The lag tank would become the lead tank, and the standby tank would become the lag tank. Periodically, every two weeks more or less, the online filters would be backwashed briefly to restratify the media.

### **Metal oxide coated sand**

In addition to GFH, other adsorbent media are available, including iron oxide coated activated alumina, iron oxide coated sand, and several others. For applications where adsorbent medias are being considered, these other adsorbent media may also be considered. The performance of each will depend upon the water characteristics.

### **Backwashing**

Backwashing the media filters in the Modified Coagulation/Filtration process, the Oxidation/Filtration process, or the microfilters in the Coagulation assisted microfiltration process will produce significant volumes of wastewater which must either be recycled or discharged to a wastewater treatment plant. If recycled, a reclaim tank and recycle pump system would be required. Solids would accumulate in the reclaim tank for periodic removal by vacuum truck for disposal offsite, or would be discharged onsite to a drying bed. After drying, the solid waste would be disposed of to a landfill.

### **Waste**

Waste disposal issues can be difficult to resolve and must be given strong consideration in the early planning stages of a project. If there is no economical solution to the waste disposal issue, the project may not be viable. Waste disposal methods typically used for liquid wastes include evaporation ponds and drying beds, mechanical dewatering, storage lagoons, and discharge to a wastewater treatment plant. Solid waste disposal methods include sanitary landfill disposal and hazardous waste landfill disposal.

Due to the land requirements for evaporation ponds and storage lagoons, only small systems can utilize these methods. Typically for larger plants, mechanical means of dewatering are used.

As stated previously, the EPA TCLP test is used in most states to determine whether liquid and solid residuals may be disposed of in sanitary landfills. Most residuals will pass the TCLP test. However, California has more stringent requirements for landfill disposal. Recent studies have indicated that all of the residuals from arsenic treatment plants will be considered hazardous waste, requiring disposal in Class 1 landfills. Currently there are only three Class 1 landfills in California, and all three are located in the southern part of the state.

Nolte's Water Resource Group has met the challenge presented by waste disposal numerous times. Nolte also has extensive experience with all potable water system components and technologies in addition to arsenic, including:

- Iron and manganese removal
- Surface water treatment
- Distribution system design and modeling
- Storage reservoir design

We also provide the following services:

- Permitting
- Assistance in obtaining funding
- Plant Audits
- Startup and trouble shooting services

### **Iron and Manganese Removal**

Nolte's Water Resources Group personnel have designed over 20 iron and manganese removal plants, utilizing manganese greensand treatment and oxide coated silica sand treatment. Pre-aeration has been utilized where significant amounts of hydrogen sulfide or other gases are present, and pre-oxidation with chlorine or potassium permanganate is normally utilized. Filter types utilized have included both horizontal and vertical pressure filters, as well as gravity filters. Iron and manganese removal plants normally include wastewater recycling and disposal facilities.

### **Surface Water Treatment**

Our experience with surface water treatment includes the design and startup of over 200 small to medium sized treatment plants over a period of almost three decades. Treatment processes utilized include microfiltration, conventional treatment, disinfection facilities including ozone, UV, and chlorine, plus gravity filters, pressure filters, and package plants.

### **Distribution System Design and Modeling**

Nolte has extensive distribution system design and modeling experience, including systems with multiple pressure zones. We use utilize the most cost-effective tools to achieve coordinated survey controls for the projects, including Global Positioning Satellites (GPS) where appropriate. Our survey data collectors allow us to convert instantly from GPS to conventional surveys and back again with the same equipment. In designing the distribution systems, we utilize WaterCad, including the Graphical User Interface feature. With this feature, network models can be viewed in graphical form or in customized tables. Tables can be customized to display input data and output results in a variety of forms, which highlight results that fall outside of acceptable ranges. With

this feature, the performance of distribution systems can be tested in several ways to evaluate reservoir capacity requirements, maximum day demand flows, fire flows, and pressure conditions. The performance of the future distribution system can be viewed first hand with these tools.

### **Storage Reservoir Design**

We have designed approximately 20 reservoirs in just the last five years alone. Our experience ranges designing tanks as small as 100,000 gallons to as large as 6 million gallons. We have designed bolted steel tanks, welded steel tanks, and prestressed concrete tanks.

### **Complete System Design**

Nolte is a full service engineering firm with the in-house capabilities and expertise to successfully complete any water or wastewater project. Our Water Resources Group has extensive experience in the design of all types of potable water treatment plants including arsenic removal treatment. Our experience includes surface water treatment utilizing membranes and various conventional treatment processes, and groundwater treatment including iron and manganese removal in addition to arsenic removal.

The multiple step design process includes these major steps: master planning, defining treatment options, preliminary design, and final design.

Master planning includes an analysis of the following as a minimum: water demand, existing system components, current and anticipated regulatory requirements, anticipated growth of the system area, treatment plant siting issues, client preferences and capabilities, and other factors.

After the master planning has been completed, the treatment options that are viable for the project are identified. Based on the results of the arsenic speciation and water characteristics, bench scale testing, and pilot testing, the treatment process is selected. Pilot testing provides the data necessary to design the full scale plant, including chemical type and dosage requirements, filter run times, wastewater volume data, and other site specific data.

Preparation of a Pre-Design Report follows the pilot testing step. This purpose of the Pre-Design Report is to ensure that the client, the regulatory agencies, and the designer understand and agree on the key features of the final design step to follow. Pre-Design Reports include, as a minimum, the following sections and content:

- Summary of the results of the bench and pilot testing already completed
- A description of the proposed treatment facilities including preliminary plant layout, hydraulic profile, and flow schematic
- A description and preliminary layout of the appurtenant equipment including chemical storage and feeding equipment, a laboratory, and pump stations
- Recommended plan of work including construction sequencing plan

- Summary of design criteria
- Projected construction schedule
- Engineer's estimate of construction and operation costs

The Pre-Design Report is typically submitted to the client at the 30 or 50% complete stage for review and comment before finalization. Copies of the final Pre-Design Report are sent to the client as well as to the appropriate regulatory agencies. Upon receipt of approval of the report, final design documents are prepared. Final documents include plans, specifications, engineering calculations, and construction cost estimates. Design drawing disciplines may include civil, structural, mechanical, electrical, instrumentation and control systems. Final documents are submitted in hard copy and electronic format, and are typically submitted at the 50, 90 and 100 percent completion stages.

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