

# AMS Advances the Evaluation and Review of a More Stringent Federal Arsenic Standard with Its SafeGuard™ H2O Innovative and Cost-Effective Arsenic Removal Technology

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**EXECUTIVE SUMMARY:** It has been nearly 20 years since the U.S. Environmental Protection Agency (EPA) federal arsenic standard of 10 parts per billion (ppb) was put into place; however, the 2001 regulation remains the same today with the exception of New Hampshire and New Jersey that have implemented a more stringent maximum contaminant level (MCL) of 5 ppb at the state level (EPA, 2001). In 2018 the World Health Organization (WHO) stated that “Every effort should be made to keep arsenic concentrations as low as reasonably possible and below the guideline value of 10 ppb when resources are available.” At present, the USEPA is closely reviewing the federal MCL for arsenic.

Arsenic is one of the most difficult inorganic contaminants to remove. Historically, arsenic treatment technologies have struggled to economically treat at the 10 ppb standard, let alone the lower 5 ppb or 3 ppb limits that are under consideration. The chemical, physical, and biological process treatment systems to date have failed to provide a reliable, economical, simple-to-operate arsenic removal solution, capable of achieving regulatory compliance without incurring high initial investment and operating costs.

This paper aims to advance the evaluation and review of a more stringent federal arsenic standard by presenting evidence of an innovation in arsenic removal technology — Aqua Metrology Systems’ (AMS) SafeGuard™ H2O (SGH2O) — that is proven, validated and commercially available. The technology virtually eliminates arsenic and drastically reduces the cost of removing the toxic contaminant from water supplies when compared to alternative treatment technologies.

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## INTRODUCTION

Arsenic, a naturally occurring toxic metalloid, is a worldwide public health concern because it poses a serious threat to public health, usually through groundwater contamination. Arsenic can enter the water supply from natural deposits in the earth or from industrial and agricultural pollution.

Arsenic found in groundwater is normally in an inorganic form as a soluble oxyanion species with two valence states; arsenite [As(III)] and arsenate [As(V)]. In drinking water supplies, arsenic poses a threat to human health because it is a known carcinogen.

Drinking water with levels of arsenic above 10 ppb has been found in wells in more than 25 states in the U.S., potentially exposing 2.1 million people<sup>1</sup> to drinking water with toxic levels of arsenic.

In 2001, EPA lowered the MCL for arsenic in public water supplies to 10 ppb from 50 ppb. This decision was made by balancing the understanding of arsenic’s potential health effects against the Best Available Technologies (BATs) for removing the contaminant at that time. Treatment technologies — including adsorption media (AM), i.e., activated alumina (AA), iron-based media (IBS), coagulation/filtration (CF), ion exchange (IX) and reverse osmosis (RO) — were evaluated using a variety of factors including removal capability, ease of operation, cost, waste generation and disposal.

AMS has since developed an expanded list of comparative characteristics (Table 1) that can be used to evaluate arsenic removal treatment processes; shedding light on

overall system effectiveness, operational parameters such as pre-filtering, pre-oxidation, pH adjustment and system inertia and their effect on system performance and cost.

## ASSESSMENT OF ARSENIC TREATMENT SYSTEM OVERALL EFFICIENCY

The removal efficiency or performance of a water treatment system is accessed by its ability to reduce a contaminant from an initial level to targeted lower level. Removal efficiency is a technical characteristic of the treatment process, defined by the nature of the treatment system design. It is also obvious, that removal efficiency is a primary criterion, which allows certain treatment approach to be considered as a treatment option in each specific treatment scenario.

Cost effectiveness is also a highly important consideration in evaluating water treatment solution and related through multiple parameters to treatment approach. Decision making on the water treatment system approach to be chosen always involves critical evaluation of both the removal and cost effectiveness criterion.

In turn, choice of treatment approach depends heavily on treated water composition, which may affect treatment process effectiveness. Initial contaminant level, treatment process goal (MCL) as well as water matrix (pH, alkalinity, interfering compounds, etc.) must be considered.

Comparative effectiveness of different treatment systems (removal and cost) can be understood through following example.

Assuming ground water with the following parameters has to be treated to meet a 5 ppb arsenic level:

- Total As - 25 ppb (both arsenite arsenate present)
- Treatment goal - below 5 ppb
- Water pH - 7.6
- Silica
- Sulfate
- Alkalinity - above average

Performance of conventional treatment systems (AA, IBS, IX, CF, RO) can be significantly challenged by such a water matrix. For instance, generally high-performance IX and RO processes can suffer serious degradation in removal efficiency by treating water with elevated silica or sulfate levels. Damage due to silica, as well as chromatographing peaking due to the sulfates present, can affect overall system performance and reliability.

The robustness and performance of the RO process is affected significantly by both silica and carbonates that cause membrane fouling. Similarly, AA, CF and IBS treatment system performance is affected by the presence of these interferences that weaken removal efficiency. To reduce the negative effects and maintain stable system performance, additional measures must be taken and that oftentimes complicates treatment system design and increases costs.

A comparative review of historical arsenic removal technologies and the new SGH2O arsenic removal treatment process against these expanded parameters is summarized in Table 2.

Every conventional arsenic treatment approach is susceptible to performance degradation from a decline in water quality. Therefore, providing consumers with high quality treated water may be unachievable without a significant increase in treatment cost using conventional methods. The high performance of the innovative adsorption media implemented in the SGH2O treatment approach is less affected by overall water quality parameters.

Because many drinking water treatment systems do not operate continuously and often employ a “stop-and-run” mode with stagnation periods ranging between several hours, weeks or even longer, understanding the treatment system inertia of each arsenic removal technology is imperative.

The development and commercialization of the SGH2O technology is poised to displace traditional systems, given its proven ability to eliminate arsenic and drastically reduce the cost of removing the toxic contaminant.

#### ARSENIC REMOVAL FROM WATER BASED ON TIN DIOXIDES

A number of sorbents for aqueous arsenic removal based on tin oxides have been developed and reported. Tin oxide-based sorbents have greater affinity to the As(III) specie, than to As(V). Stronger affinity of hydrous tin dioxide to

As(III) is highly important because underground aquifers mainly contain arsenic in the As(III) form. Another advantage of tin oxides as an adsorbent for arsenic removal is that they can operate effectively in broad pH ranges which eliminates the need for pH adjustment prior to the removal step. Also, tin oxides demonstrate both high adsorption kinetics and capacity contributing to process simplicity and cost effectiveness.

Multiple methods for the preparation of different tin oxide-based sorbents have been reported for removing arsenic from water. Hydrous synthetic stannic oxide for arsenic removal from groundwater has been reported,<sup>2</sup> the synthesis of iron(III)-tin(IV) mixed oxide has been reported<sup>3</sup> and nano tin ferrous oxide decorated graphene oxide sheets for As(III) removal has been reported.<sup>4</sup> These methods are highly complex, labor- and capital-intensive, costly and difficult to implement, making them impractical for implementation in field-based treatment systems.

#### ELECTROLYTICALLY GENERATED TIN DIOXIDE AS A FILTER MEDIA FOR ARSENIC REMOVAL

A novel arsenic removal approach based on electrolytically produced tin dioxide adsorbent has been developed by AMS. This process is detailed in Figure 1.

An electric current is passed through two electrodes immersed into an electrolyte solution (treated water). The electrodes happen to be food grade specially designed tin shapes. Anodic dissolution of one of the tin electrodes results in generation of stannous ions into the water (1).



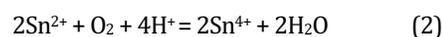
AMS has invested heavily in researching the conditions necessary to produce stannous ions exclusively, which has produced a reliable and robust stannous ion generator.

The anodic dissolution of tin, and thus the quantification of stannous ions, can be understood through the well-studied laws of electrolysis, originally proposed by Michael Faraday in 1834.<sup>5</sup> Faraday's laws of electrolysis established the relationship between the current passed through the electrolyte and the mass of anodic dissolution that occurs. The relationship can be understood through the following equation:

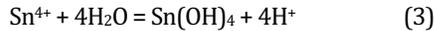
$$m = \left(\frac{Q}{F}\right) \left(\frac{M}{z}\right)$$

Where m is the mass of anodic dissolution, Q is the total electric charge passed through the metal, F = 96,485 C° mol<sup>-1</sup>, known as Faraday's constant, M is the molar mass of the substance and z is the electrons transferred per ion.

Freshly generated and highly reactive stannous ions rapidly react with oxidants present in the water (dissolved oxygen, chlorine) and converted into stannic form (2).



Resulted stannic ions undergo hydrolysis reaction and form insoluble stannic hydroxide (hydrolyzed tin dioxide) according to reaction (3):



#### SAFEGUARD™ H2O INTELLIGENT ARSENIC TREATMENT SYSTEM

The SGH2O arsenic remediation system generates a tin dioxide reagent on demand out of non-toxic, food grade reagent precursor material. The entire generation process is controlled by proprietary software and can be adjusted remotely in real time. Compact and modular design of the treatment system components allows for scalability and the ability to build a treatment system of any size, meeting the needs of water systems small or large.

SGH2O also features AMS' proprietary, continuous, real-time monitoring of contaminant levels at the influent and effluent to ensure optimal treatment and compliance with regulatory and operational targets 24/7/365. Data generated from the onboard arsenic monitoring system help drive a highly accurate remediation process by ensuring reliable reagent dosing control through manipulation of site-specific process parameters.

Unlike traditional treatment systems, which cannot operate unattended, the SGH2O system can be remotely controlled, monitored and optimized in real time so that the presence of personnel on site for supervision is not required, further reducing operating costs.

The SGH2O system is comprised of the following main components (Figure 2):

- Stannous reagent generator (RG)
- Galvanostat and control system
- Contactor vessel
- Arsenic removal composite media filter
- Online MetalGuard™ arsenic analyzer

The stannous reagent generated within a side-stream of the water being treated and reinjected into main water stream. Then treated water passes the contactor in which a stannous ion produced by the electrolytic process rapidly reacts with dissolved oxygen or/and chlorine and undergoes rapid conversion into insoluble hydrated tin dioxide (reactions 2 and 3 above).

Resulted tin dioxide particulates are trapped and retained by the media filter downstream, forming a self-assembled active material for dissolved arsenic remediation. The polisher filter positioned downstream of the media filter serves as a trap for potential tin dioxide breakthrough, which may carry some retained arsenic species providing additional protection to the effluent. The status of the self-sacrificed tin electrode is continuously monitored by the software and upon approaching electrode exhaustion the system automatically switches on the spare generation module.

#### ADVANTAGES AND BENEFITS OF SAFEGUARD™ H2O ARSENIC REMOVAL TREATMENT SYSTEM

The first advantage of SGH2O is its approach to sorbent generation. A tin dioxide active material is generated in situ, on an as-needed basis through a tightly controlled electrolytic process. A stable, non-toxic, food grade and inexpensive tin metal precursor is used and reduces the possibility of wasted reagent and lost capital.

A second advantage of SGH2O is that fresh and highly reactive sorbent efficiently removes both As(III) and As(V) species, avoiding labor and capital intensive As(III) pre-oxidation step.

The third advantage of SGH2O is that it operates effectively in pH range characteristic of typical groundwater conditions, eliminating the costly need for treated water pH adjustment. Although tin dioxide sorbent is not selective toward arsenic species, it demonstrates high tolerances toward treated water composition. Constituents such as silica, sulfates, phosphates, fluorides and many others that may pose significant interferences for conventional treatment approaches have minor to no effect on arsenic removal with SGH2O. Additionally, suspended solids potentially present in the source water can be effectively removed from the water by the composite media filter and do not require pre-filtration.

Finally, the simple, controllable and highly robust treatment system design of SGH2O contributes to high system performance and overall stability.

#### *SafeGuard™ H2O Treatment System Inertia*

SGH2O is an arsenic removal treatment approach that is based arsenic adsorbent generation in-situ, on demand. Minimal treatment process steps are required with SGH2O, and relatively fast arsenic adsorption kinetics contribute to the treatment system's simplicity. The technology requires a low level of process hardware and as such there are less process parameters to control. The technology's online arsenic monitoring capability allows for high treatment process automation, as well as fast process shutdown and restart.

Arsenic species sorption onto an electrogenerated tin oxide adsorbent is fast and stable in a broad range of water parameters. The relatively low dead volume of the vessels in the system configuration allows for ease of media filters backwash, while the biocide properties of the stannous reagent<sup>6</sup> ensure elimination of biological growth inside the treatment system hardware during a stagnation period.

In fact, the electrolytic stannous reagent generation process is highly dynamic and can be instantly terminated and restarted; ideal for "stop-and-run" operational modes. Therefore, the risks of damage to the treatment system hardware during stagnation period and the stabilization period are minimal. This is a feature unique to the SGH2O technology and not available with other commercially available arsenic removal systems.

## SAFEGUARD™ H2O TREATMENT SYSTEM MAINTENANCE

The SGH2O arsenic removal system is comprised of three main components, which require periodic maintenance:

- Composite media filter
- Stannous reagent generator
- Online MetalGuard™ arsenic monitor

### *Composite Media Filter Maintenance*

During operation, the SGH2O treatment system produces tin dioxide micro particles in-situ which are retained by a sand filter media and serve as an adsorbent material for dissolved arsenic removal.

After some time of operation, solids captured by the filtration media will impede the flow and increase the differential pressure across the filter. To restore hydraulic capacity and re-stratify it, the filter will have to be backwashed. The backwash flow is in the upward direction, which fluidizes the media and washes the accumulated solids out of the filter.

After backwashing, the filter effluent goes to waste (backwash settling tank). The media is allowed to settle, and downward flow is resumed. Backwash step parameters such as frequency, duration, flowrate and more can vary depending on both treated water quality and treatment process parameters (e.g., reagent dose).

### *Treatment Residuals Management and Reuse*

SGH2O backwash water is the only liquid phase residuals produced as a result of the system maintenance. The backwash water contains spent tin dioxide sludge in addition to source water microcontaminants retained by the filter. It should be stressed, that tin is the only component added to the source water during the treatment process and it is not regulated by EPA.

Contamination of the source water by toxic components potentially present in the tin precursor are eliminated by using high purity (food grade) tin metal as an anode for generation of the adsorbent. The tin dioxide adsorbent does not impact major source water characteristics, such pH, color, odor and total dissolved solids (TDS) during the treatment process. Due to the non-selective tin dioxide adsorbent nature, minute amounts of metal ions such as Cr(VI)/Cr(III) can be retained by the media. Schematics of the composite media backwash process and waste handling of SGH2O are shown in Figure 3.

An untreated source water can be used for backwashing both polisher and composite filter. The resultant high turbidity backwash treatment residual is collected in the backwash settling tank for liquid/solid fraction separation. After settling, the sludge is removed from the tank bottom using a sludge pump, dewatered and handled according to Toxicity Characteristic Leaching Procedure (TCLP) regulations.

The handling options for the liquid backwash water fraction are as follows:

- Direct discharge to receiving bodies
- Discharge to publicly owned treatment works (POTW)
- Underground injection
- Land application
- Recycle to facility headworks

The discharge of the liquid treatment process residuals can cause significant water loss from arsenic treatment systems. Backwash water reuse with SGH2O poses a cost-effective alternative to discharge options. Under controlled conditions, the clear fraction of the backwash water can be reused in future backwash procedures without risk of the treatment system contamination. Owing to the high coagulation power of the tin dioxide and its high affinity to retained metals liquid/solid separation proceeds very quickly without the need for the addition of any reagents (i.e., pH adjustment, polymer, etc.).

The online MetalGuard™ arsenic analyzer provides real-time data on the concentration level of total arsenic in the backwash tank and in the tin dioxide sludge. Arsenic values in the clear backwash fraction can be used as an indicator on high water quality for further reuse. In addition, monitoring of total arsenic levels in the sludge controls its potential toxicity in respect of TCLP limits. It should be noted, that stannous ion has a powerful biocidal effect which significantly suppresses risk of potential biological growth in the backwash water tank.

### *Stannous Reagent Generator Maintenance*

The SGH2O system controls the status of tin anodes in the generator based on a direct electric charge/metal dissolution relation. The status of the self-sacrificed tin electrode used for operation is continuously monitored by the software and upon approaching electrode exhaustion the system automatically switches on the spare generation module. With the approach of a critical level of tin metal in the generator, the generator also goes into the maintenance mode. The stannous reagent generator has a modular and flexible design that can be scaled to virtually any size. Depending on the treatment system size, design and specific site requirements the generator can be designed to operate unattended for up to several weeks.

### *Online MetalGuard™ Arsenic Analyzer Maintenance*

The online MetalGuard™ arsenic analyzer is a fully automated instrument designed for unattended operation in the field. The measurement system utilizes self-regenerated robust probe capable of performing thousands of continuous tests.

Also, an automatic, on-board arsenic quantitation technique based of a self-calibration approach eliminates the need for periodic manual system calibration. Additionally, reagents used for analytical procedure are highly stable and economical.

Featuring a simplicity of use unmatched by competitive monitoring technologies, the MetalGuard™ system requires quarterly maintenance involving reagents replenishing, inspection and replacement of few minor parts.

## REVIEW OF HISTORICAL ARSENIC REMOVAL TECHNOLOGIES

Arsenic removal technologies include chemical and physical processes that are often combined for a multi-step treatment approach.

Historical arsenic removal technologies:

- Adsorption media (i.e., AA, IBS)
- Coagulation/filtration
- Ion exchange
- Reverse osmosis membrane treatment

### *Adsorption Media Treatment Technologies (AM)*

The adsorption media (AM) treatment technology is a relatively simple, fixed-bed process where arsenic is adsorbed onto a packed bed of media. Of the commercially available adsorbents, iron and aluminum-based materials have received the most attention and evaluation for their effectiveness in removing arsenic from drinking water. Despite AM's ability to remove dissolved arsenic from groundwater, this approach suffers from significant limitations and drawbacks.

#### Activated Alumina (AA)

Activated alumina (AA) is a sorption process that uses porous, granular aluminum-based material. In drinking water treatment, packed-bed AA adsorption is used for removal of natural organic matter and fluoride. The removal of As(V) by adsorption can be accomplished by continuously passing water under pressure through one or more beds. A typical process flow diagram for the AA process is detailed in Figure 4.

The selectivity of AA toward As(III) is poor, therefore, pre-oxidation of As(III) to As(V) is critical. The effectiveness of the AA bed under acidic pH conditions is much higher than under neutral or basic pH levels, so that pH adjustment is necessary. The presence of suspended solids in the feed water can gradually clog the media, thereby increasing head-loss. Pre-filtration is recommended for sources where the turbidity exceeds 0.3 Nephelometric Turbidity Units (NTU).<sup>7</sup>

Because of the high pH of the regeneration process, roughly 2% of the AA media dissolves during each regeneration sequence. Therefore, the waste solution typically contains high levels of TDS, aluminum and soluble arsenic. In most cases, this arsenic level will exceed the 5.0 mg/L toxicity characteristic (TC), and the waste stream will be classified as a hazardous liquid waste.

Backwashing may also be necessary to prevent cementation of the media, which can occur as a result of dissolution caused by chemical addition during regeneration. For these

reasons, regeneration of AA is likely to be an infeasible option for most small water systems.

The efficiency and economics of the system are contingent upon factors such as water quality characteristics, pre-oxidation of As(III) to As(V) and the presence of suspended solids. Although AA has a long history as an adsorptive media for arsenic removal, it is rarely used because the emerging media, including modified AA, treat much higher bed volumes of water without the need to adjust pH.

Several constituents of water can interfere with the arsenic removal process by competing for adsorption sites or clogging the media with particulates. These interferences include chlorine, fluorine, iridium, manganese, silica, sulfate, TDS, dissolved organic carbon and more. With the presence of these interferences, multiple process steps are required, and potentially hazardous waste is generated. This results in technical limitations and high operation costs that significantly limit applicability and practicality of the approach for ground water arsenic removal.<sup>7</sup>

#### Iron-Based Sorbents (IBS)

Several iron-based media products have been introduced in the drinking water treatment market during since 2006. Two of the more commonly used products are granular ferric hydroxide, GFH®, (GFH) and granular ferric oxide Bayoxide® E33 (E33).

The few studies conducted with IBS have revealed that the affinity of this media for arsenic is strong under natural pH conditions, relative to AA. This feature allows IBS to treat much higher bed volumes without the need for pH adjustment. However, similar to AA, optimal IBS performance is obtained at lower pH values, so that treated water pH adjustment is recommended. As with the AA treatment process, an As(III) pre-oxidation step is required to increase treatment system performance.

Phosphate and silica have been shown to compete aggressively with As(V) for adsorption sites on the iron media. Each 0.5 mg/L increase in phosphate above 0.2 mg/L will reduce adsorption capacity by roughly 30%.<sup>7</sup>

When adsorptive media no longer has the ability to retain the arsenic to less than the MCL, the common practice is to remove and replace the exhausted media with new virgin media. The exhausted media that normally passes the federal TCLP (EPA, 1992) can be disposed in a sanitary landfill. However, if the media exceeds toxicity levels, it is treated as a hazardous waste which significantly increases system operation, equipment and maintenance costs.

In California, a waste extraction test (WET) (California Code of Regulations, 1985) is required for media disposal. Frequently, the exhausted media products will fail the California WET test even though they passed the federal TCLP test.<sup>8</sup> When an exhausted media fails the WET procedure, the State of California requires that the media be disposed at a California hazardous waste designated landfill.

The operation and maintenance cost elements of the adsorptive media process includes media replacement, chemicals, electricity and labor.<sup>9</sup> In the EPA Arsenic Demonstration Program (ADP), where capital and operating (O&M) costs were collected on 15 AM systems having to undergo media replacement, the cost of media replacement (that included exhausted media disposal) averaged around 80% of the total O&M cost.<sup>10</sup> In only two cases the media replacement cost was less than 50% of the total O&M cost. Some systems had to replace the media within only a few months resulting in an O&M cost as high as \$20/1,000 gallons of treated water.<sup>10</sup>

#### Adsorption Media (AM) Treatment System Inertia

Biological growth in adsorptive iron media arsenic filters may occur during stagnation periods especially if an oxidizer is not used during water pre-treatment. High pH and water temperature may significantly accelerate biofilm formation. Biofilm impacted media cannot remove arsenic from ground water effectively and it impacts general water quality. In order to reduce risk of biofilm formation, the iron media filter has to be treated prior to system shutdown. If biological growth is present, the treatment system has to undergo extensive treatment prior to system restart. Such a treatment may involve backwashes, treatment with strong oxidizers (sanitizing) and multiple rinses. These measures significantly increase treatment system inertia during “stop-and-run” mode, increasing operational expenses and reducing automation.

#### *Coagulation/Filtration (CF)*

A cost-effective approach for arsenic removal is coagulation and precipitation (chemical processes) followed by filtration (a physical process). Common coagulants used for arsenic are iron salts and aluminum sulfate. Aluminum coagulation is generally less efficient than iron coagulation, so alum should only be used in systems with low arsenic concentrations. Typical iron salts used are ferric chloride and ferric sulfate. Following coagulation, a process such as multimedia filtration with automated backwashing is typically used to remove precipitated arsenic. CF systems are provided by companies such as Pureflow Filtration, Kinetico and Tonka.

CF processes can be optimized to remove dissolved inorganic As(V) from water. The mechanism involves the adsorption of As(V) to an aluminum or ferric hydroxide precipitate. As(III) is not effectively removed, therefore, pre-oxidation is recommended.

The efficiency and economics of the system are contingent upon several factors, including the type and dosage of coagulant, mixing intensity and pH. However, optimized CF systems are capable of achieving over 90% removal of As(V) and producing water with less than 5 ppb of As(V).<sup>7</sup>

The optimal pH ranges for coagulation with aluminum and ferric salts are 5 to 7 and 5 to 8, respectively. At pH values above 7, the removal performance of aluminum-based coagulants drops markedly. Feed water pH should be adjusted to the appropriate range prior to coagulant

addition. Post-filtration pH adjustment may be necessary to optimize corrosion control and comply with other regulatory requirements. Several batch studies have demonstrated that As(V) removal is positively related to coagulant dosage. However, specific dose requirements needed to meet As(V) removal objectives were contingent upon the source water quality and pH. Effective coagulant dosage ranges were 5-25 mg/L of ferric chloride and as much as 40 mg/L of alum.

Water intended for indirect discharge will be subject to technically based local limits (TBLLs) for TDS and arsenic. Dewatering can be accomplished by gravity thickening, followed by other mechanical or nonmechanical techniques. Settling basins can be used to allow settleable solids to drop out of solution via gravity, while the supernatant can be decanted and recycled to the process head following monitoring and analysis.<sup>7</sup>

#### CF Treatment System Inertia

Treatment system inertia of CF is associated with multiple treatment steps and multiple parameters that must be tightly controlled to achieve remediation goals. The treatment process steps are arsenite pre-oxidation, pre- and post-treatment pH adjustments and coagulant addition. Some of these processes are relatively slow and lengthy, and some require reaction or mixing vessels with large footprints. Based on the relatively high dead volume of CF process equipment and the multiple parameters that need to be controlled and stabilized, CF systems are difficult to operate in “stop-and-run” manner.

#### *Ion Exchange (IX)*

Ion exchange (IX) is a physical-chemical process in which ions are exchanged between a liquid phase and solid (resin) phase. Arsenic removal is accomplished by continuously passing water under pressure through one or more columns packed with exchange resin. The affinity of As(III) and As(V) to IX resin is different: The As(V) specie is retained better than the As(III) form.

In a vast majority of groundwaters, dissolved inorganic arsenic exists as As(III). As a result, a pre-oxidation step is required before the IX removal system to convert As(III) to As(V) and achieve effective arsenic remediation.

A typical process flow diagram for the IX process is detailed in Figure 5.

Efficiency of the IX process for As(V) removal depends strongly on the treated water composition, especially on TDS content and the presence of sulfates. Additionally, small amounts of iron may form a soluble complex with arsenic and carry it out of the column.<sup>7</sup>

Another concern related to IX treatment is the phenomenon known as chromatographic peaking, which can cause As(V) levels in the effluent to exceed those in the influent stream. This can occur if sulfates are present in the raw water and the resin bed is operated past exhaustion. Because sulfate is preferentially exchanged, incoming sulfate anions may

displace previously adsorbed As(V). In most groundwaters, sulfates are present in concentrations that are orders of magnitude greater than As(V).

A significant drawback of the IX arsenic removal approach is that the presence of suspended solids in the feed water, could gradually plug the media, thereby increasing headloss and necessitating more frequent backwashing. Therefore, pre-filtration is recommended if the source water turbidity exceeds 0.3 NTU.<sup>7</sup>

Another concern with IX systems is resin fouling, which occurs when mica or a mineral scale coats the resin, or when ions bond with the active sites and are not removable by the standard regeneration methods. This can have a significant effect on the IX resin's capacity as the media ages. Eventually, the IX regeneration waste may contain extremely high levels of arsenic that require its handling and disposal as a hazardous waste.<sup>7</sup>

#### IX Treatment System Inertia

When an IX treatment system is inactive and the water is stagnant for relatively long time periods, unwanted and potentially dangerous processes may occur, such as scaling, biological growth, resin swelling or shrinking and more.

Biological growth problems are caused by inactivity of the IX resin during extended storage in the vessel under neutral pH conditions. In order to minimize the potential for biofouling, inactive IX systems should be stored in a biostatic solution.

The procedure applied before treatment system shut down typically involves a thorough backwash to remove suspended impurities by applying a special preservation solution to the bed and filling the vessel so that no air is present.

In cases where biological growth has occurred, costly and timely measures may potentially restore the resin to a usable condition. However, if those procedures are not successful, resin replacement should be considered. All of the above significantly complicates IX treatment system restart after a stagnation period, increasing operational costs and labor, while reducing system automation.

The drawbacks mentioned above significantly limit the applicability of an IX arsenic removal approach for operations that are in a "stop-and-run" manner.

#### Membrane Treatment Technologies

Membrane separation technologies are attractive arsenic treatment processes for small water systems. Reverse Osmosis (RO) units can be used as stand-alone arsenic

treatment systems under most water quality conditions. Figure 6 provides a block flow diagram for a typical RO membrane process.

RO is a pressure-driven membrane separation capable of achieving over 97% removal of As(V) and 92% removal of As(III) in a single pass (NSF, 2001a; NSF 2001b). The treatment process is relatively insensitive to pH. Water recovery is typically 60-80%, depending on the desired purity of the treated water. Multiple RO units can be applied in series to improve the overall arsenic removal efficiency.

Figure 6 illustrates a RO treatment process flow. Membrane fouling can occur in the presence of natural organic matter (NOM) and various inorganic ions, most notably calcium, magnesium, silica, sulfate, chloride and carbonate. These ions can be concentrated (in the retentate) to concentrations an order of magnitude higher than in raw water. This can lead to the formation of scale on the membrane surface, which in turn can cause a decline in arsenic rejection and water recovery.

Further, the membrane surface can act as a substrate for biological growth. Membrane cleaning can restore treatment performance; however, the cleaning process is difficult and costly.<sup>7</sup>

The rate of membrane fouling depends on the configuration of the module and feed water quality. Most RO modules are designed for crossflow filtration, which allows water to permeate the membrane while the retentate flow sweeps rejected salts away from the membrane surface.

In many cases, pre-filtration (commonly through sand or granular activated carbon) is worthwhile. This minimizes the loading of salt precipitates and suspended solids on the membrane surface, thereby extending run length, improving system hydraulics, and reducing O&M requirements.

Some membranes, particularly those composed of polyamides, are sensitive to chlorine. Feed water should be dechlorinated (if applicable) in these instances. Another potential concern associated with RO treatment is the removal of alkalinity from water, which in turn could affect corrosion control within the distribution system.

If feasible, this problem can usually be avoided by conducting a side stream treatment for arsenic removal. Indirect discharge to a public wastewater treatment plant or direct discharge to an onsite sewerage system (for point-of-use (POU) systems) are considered the most viable residuals disposal option. For those systems considering indirect discharge, the retentate must meet local TBLs for arsenic.

SUMMARY

The 2001 EPA decision to set the final arsenic standard for drinking water at 10 ppb was made by balancing the current understanding of arsenic’s potential health effects against the cost of removing the contaminant with BATs. Historically, arsenic treatment technologies have struggled to economically treat at the 10 ppb standard.

The innovation of the SGH2O system, which employs a revolutionary way to harness the power of tin dioxide, virtually eliminates the presence of arsenic at a very

economic cost compared to the alternative treatment technologies.

There are no arguments technically and economically now not to set a new more stringent arsenic regulatory limit that is well below where it is today and even as low as 3 ppb.

The AMS SGH2O technology is proven, validated and commercially available to safeguard the public from this carcinogenic contaminant.

TABLES AND FIGURES

Parameter	
<b>Removal Efficiency (Performance)</b>	Ability of the treatment system to reduce a contaminant from an initial level to a targeted lower level.
<b>Water Loss (%)</b>	Both raw or/and treated water loss during treatment system operation and maintenance.
<b>Pre-Oxidation</b>	If the selectivity of the arsenic removal treatment technology toward As(III) is poor, pre-oxidation of As(III) to As(V) is critical when both valence states of the contaminant are present.
<b>Pre-Filtering</b>	If suspended solids affect arsenic removal treatment technology performance, as a result, pre-filtration is recommended for water sources where the turbidity exceeds 0.3 NTU.
<b>pH Adjustment</b>	pH adjustment is used to ensure that an arsenic removal treatment technology is working with water that is within an optimal pH range for operational performance. pH adjustment may also be necessary to optimize corrosion control and comply with other regulatory requirements.
<b>Waste Generated</b>	Volume of waste generated by the arsenic removal process to include all liquid and solid waste.
<b>Operator Skill</b>	Skill sets required to operate the arsenic removal technology.
<b>System Inertia</b>	Characterized as a system’s ability to reach steady operational conditions and high arsenic removal efficiency after shut-down. The shorter the time period required for treatment process stabilization, the lower the system inertia.
<b>Capital/O&amp;M</b>	Initial investment and ongoing operating and maintenance costs to remove arsenic to <5ppb.

Table 1: List of comparative characteristics developed by AMS to evaluate arsenic removal treatment technologies

Parameter	Treatment Process					
	SAFEGUARD H2O™	IX	AA	IBS	CF	RO
Performance	High	Med-Low	Low	Low	Low	Med-Low
Water Loss	Low	Low	Low	Low	Med	High
Pre-Oxidation	No	Yes	Yes	Yes	Yes	Likely
Pre-Filtering	No	Yes	Yes	Likely	Likely	Yes
pH Adjustment	No	Likely	Likely	No	Likely	No
Waste Generated	Low	High	Med/High	Med/High	High	High
Operator Skill	Low	High	Low	Low	Med	Med
System Inertia	Low	High	High	High	Med	High
Capital/O&M	\$/ \$	\$\$\$/\$\$	\$\$/\$\$\$	\$\$/\$\$\$	\$\$/\$\$\$	\$\$\$/\$\$\$

Table 2: Comparative characteristics and a review of arsenic removal treatment processes

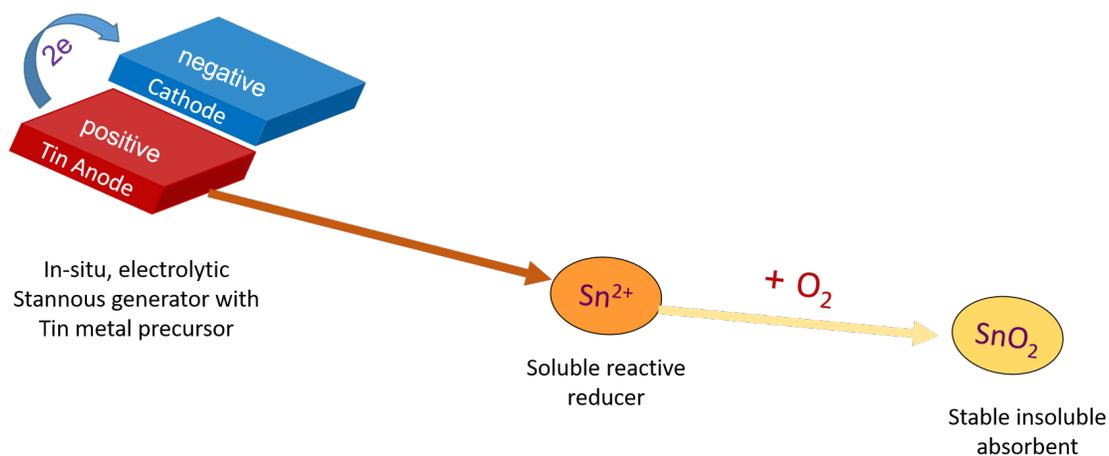


Figure 1. Electrogeneration of soluble stannous ion and its conversion into tin dioxide adsorbent

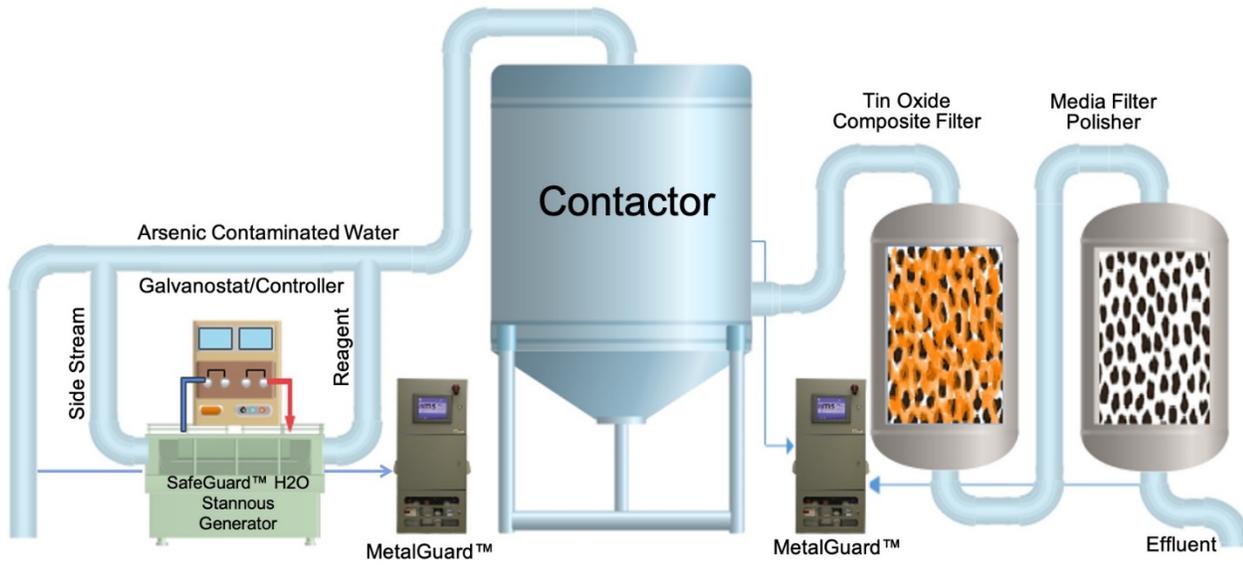


Figure 2. SafeGuard™ H2O treatment process schematic

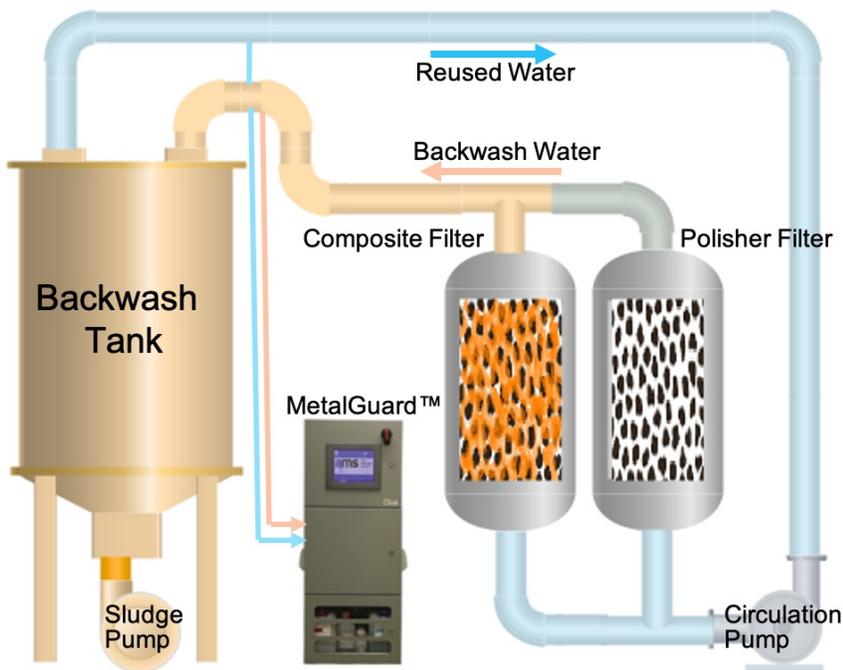


Figure 3. SafeGuard™ H2O treatment system backwash process schematic

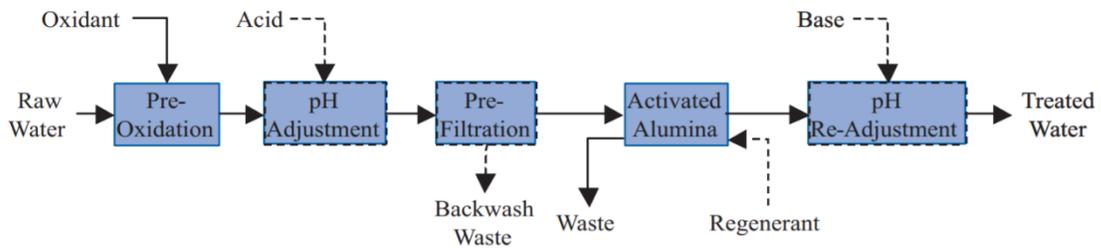


Figure 4. Activated alumina treatment process flow diagram

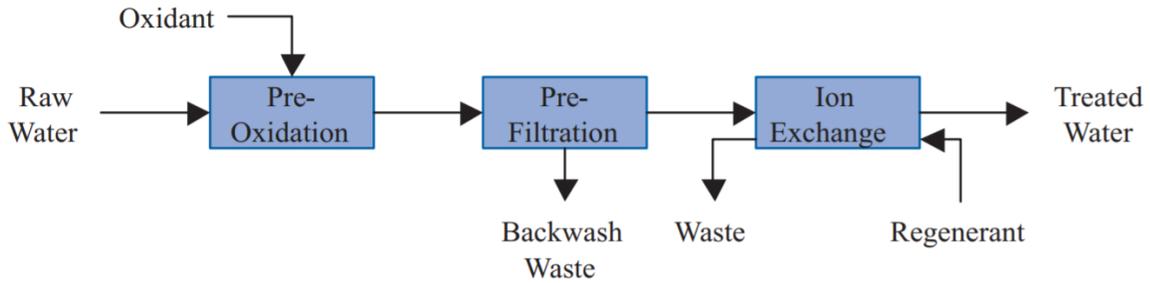


Figure 5. Ion exchange process flow diagram

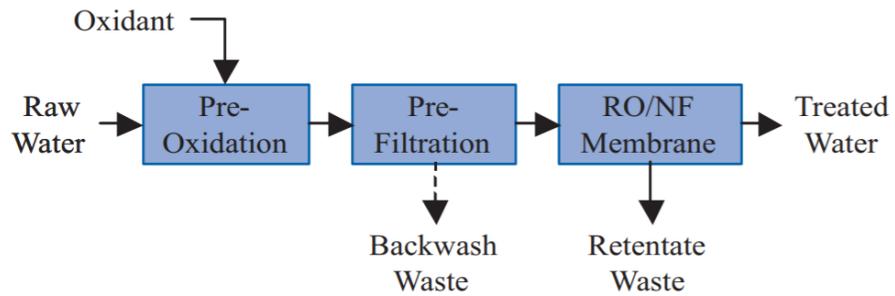


Figure 6. RO membrane process flow diagram

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