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ARSENIC REMOVAL USING SLOW SAND FILTRATION

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ABSTRACT

Arsenic concentrations in potable water supplies available to many small communities throughout Canada, the USA and the world frequently exceed the maximum acceptable concentration of 0.01 mg/L specified in the 2010 Guidelines for Canadian Drinking Water Quality (Similar to World Health Organization (WHO) and the United States Environmental Protection Agency (EPA)). While the provision of safe drinking water is always the first priority, it is very important to recognize that the treatment processes and plants be affordable and therefore sustainable from a community perspective.

There are several treatment processes available to remove arsenic from raw water supplies. They differ widely in complexity, chemical usage, production of wastewater and solids (residuals), capital cost, maintenance costs, energy consumption and other operational costs. The most economical treatment process for the removal of dissolved arsenic involves the addition of coagulants to form metal hydroxides that will adsorb the arsenic and form micro-flocs that are readily removed by direct filtration. The effectiveness and practicality of these processes depend on the use of appropriate microfiltration or polishing filter technology.

The practical use of slow sand filtration as a ‘micro-filter or polishing filter’ is new and only made possible using the recently developed and demonstrated back-washable slow sand filter named the Manz Polishing Sand Filter (MPSF). This technology has been proven very effective for the removal of iron and manganese in water treatment plants in Alberta and Saskatchewan. The process involves oxidizing the dissolved iron and manganese, allow the formation of micro-flocs, followed by filtration. Because the MPSF is cleaned using a backwash process the media bed is shallow and never replaced. Loading rates may be five times that used by traditional slow sand filtration.

Arsenic removal using MPSF based treatment systems requires the filtration of metal hydroxides (naturally occurring or resulting from coagulant additions) that have adsorbed the arsenic. Wastewater can be recycled resulting in zero liquid residuals. The sludge containing all of the solids is considered stable and may be disposed of in sewage lagoons or conditioned for disposal in landfills.

INTRODUCTION

Arsenic is frequently found in groundwater (naturally occurring) considered for potable water supply. It occurs naturally and only rarely a consequence of industrial pollution. The Guidelines for Canadian Drinking Water Quality specify that the maximum concentration of arsenic in drinking water is 0.010 mg/L – reduced from 0.025 mg/L. Treatment of water to reduce arsenic concentrations to these levels can be challenging. Selection of appropriate treatment from the numerous processes available to remove arsenic from water must consider:

1. Variability of the physical, chemical and biological characteristics of raw water.
2. Water demand and demand growth. Is there a need to consider scalability?
3. Treated water quality objectives and how they may change in the future.
4. Residual (waste liquids and solids) management including collection, handling and disposal.
5. Testing and monitoring requirements.
6. Capital cost.
7. Foot print.
8. Operating costs.
9. Energy costs.
10. Maintenance costs.
11. Technical support.
12. Regulatory requirements and restrictions.

Since reducing the maximum contaminant level (MCL) for arsenic in drinking water in 2001, the USEPA in particular put significant effort in providing technical assistance to communities and their advisors/consultants and regulators with respect to the selection of treatment technologies. This work is summarized in an excellent USEPA publication simply titled Treatment Technologies for Arsenic Removal available from the USEPA at the following web site, http://www.epa.gov/nrmrl/pubs/600s05006/600s05006.pdf. This publication provides a good introduction to the technologies that have been available, tested and reviewed by the USEPA in the past ten years and identifies research reports, manuals, handbooks and cost analysis reports. Information on arsenic removal published by the USEPA and other organizations and direction to other water treatment technologies appropriate for small water systems may be found on the U C Davis web site, http://smallwatersystems.ucdavis.edu/Links/links.html.

The Canadian perspective, which relies heavily on USEPA work, may be found on the web site, http://www.hc-sc.gc.ca/ewh-semt/pubs/water-eau/arsenic/treatment-traitement-eng.php.

A very good discussion of arsenic removal technologies may also be found in Edzwald 2011, the Sixth Edition of Water Quality and Treatment, A Handbook on Drinking Water published by the American Water Works Association.

There are many arsenic removal technologies and various names are given to similar technologies. Technologies of interest include but are not limited to:

1. Enhanced coagulation/ clarification/ filtration.
2. Enhanced lime softening.
3. Activated alumina.
4. Ion exchange.
5. Alternative adsorption media (e. g. iron, titanium and zirconium)
6. Reverse osmosis.
7. Electrodialysis/ Electrodialysis reversal. (ED/ EDR)
8. Oxidation/ filtration.
9. Coagulation assisted direct filtration.
10. Coagulation assisted microfiltration.
11. Point of use/ point of entry. (POU/POE).

Discussions of each of these technologies may be found in the web sites and references previously provided.

Arsenic removal using slow sand filtration includes elements of oxidation/ filtration and coagulation assisted direct filtration or microfiltration. Filtration is provided by a slow sand filter, known as the Manz Polishing Sand Filter or MPSF that can be cleaned using a backwash process. Arsenic removal using slow sand filtration is named oxidation/ coagulation/ slow sand filtration or the OCS process. A comparison of all of the arsenic removal technologies (except for the ED/EDR technology) may be found in Table 1 at the end of this paper. Other references used include; USEPA 2000 and USEPA 2003,

MPSF TECHNOLOGY – PRINCIPLES OF DESIGN OPERATION AND CLEANING

The ability of traditional slow sand filtration (TSSF) to remove iron hydroxide from water has been known since the beginning of the twentieth century, Turneaure and Russell 1902. They report that the media could be coarser than that normally used for sand filtration and with greater surface loading. TSSF is being used in Colombia to remove iron and manganese from well water in combination with pre-treatment using aeration and roughing filters, Sanchez and Burbano 2006. The treatment systems used in Colombia were reported to remove 89% of the manganese and 92% of the iron. The slow sand filters used in Colombia appear to be constructed similar to TSSF, were also used to eliminate bacteria from the groundwater and therefore operated using lower surface loading rates and cleaned using surface scraping. While TSSF is very effective in removing micro-flocs of iron and manganese hydroxide it is not widely used because of the effort required to clean them.

The MPSF technology eliminates the disadvantages of using TSSF as a polishing filter; that is, to treat water with high concentration of suspended solids (high turbidity) and remove micro-flocs of iron and manganese hydroxide. The design of the MPSF satisfies all the criteria for TSSF. The MPSF is cleaned using a backwash wash process and the depth of the filter bed is minimal since scraping and resanding are not required. Roughing filters may not be necessary. Several unique hydraulic features are incorporated to facilitate cleaning using the backwash process including a specially designed underdrain and wastewater removal system. The depth of water on the surface of the media is less than one-half that usually used by TSSSF. The result is a slow sand filter with minimal vertical height and minimal footprint that is simple to operate well and is easily cleaned.

The operation of the MPSF to remove micro-flocs is shown in Figure 1. Surface loading rates may exceed 1 m/h. Note that all the micro-flocs are captured on the surface of the filter media. They are not forced into the media as would be the case in rapid and pressure sand filters and there is no tendency for the micro-flocs to attach to the particles of media. The depth of water above the media, the operating head, is approximately 0.35 m. A maximum of two or three metres of pressure head is required to feed raw water to a filter. Provision is made to insure that the untreated water does not disturb the filter surface when the water level is at its minimum of about 0.05m (5 cm).

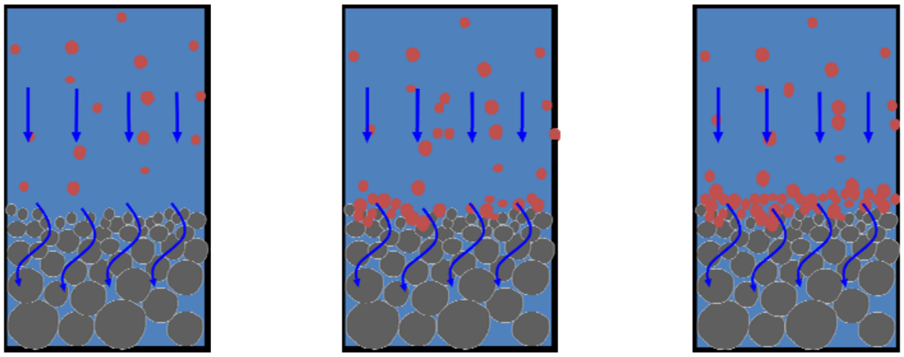

Figure 1. Capture of iron and manganese on media surface.

The backwash procedure is illustrated in Figure 2. Filtered water is used for the backwash. No wastewater leaves the filter during the backwash process as is the practice with backwashes of rapid and pressure sand filters. Air scour and mechanical agitation of the media surface is not required.

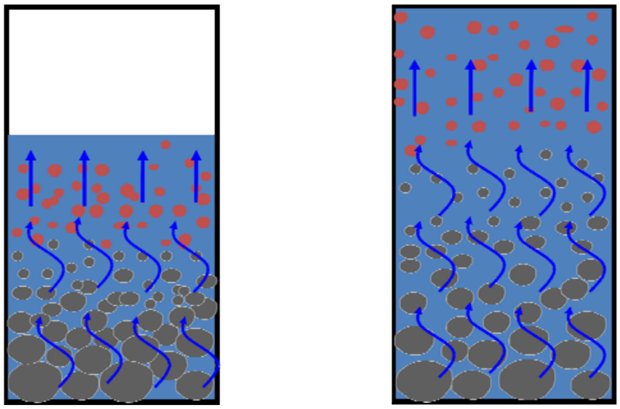

Figure 2. Backwash process.

The backwash will continue until all of the micro-flocs are suspended in the water above the level where the surface of the media would be during filtering operations. The volume of backwash water used is approximately 0.8 to 1.1 m^3/m^2 of filter surface depending on the depth of water in the filter when backwash is initiated. The rate of backwash flow is approximately 1.5 to 2 L/second /m^2 of filter surface under 2 to 3 m of pressure head. This is approximately the same rate of flow at the very beginning of the backwash of a typical rapid sand filter. Once the maximum depth of water and fluidized media has been reached, the backwash flow is abruptly stopped and the media allowed to settle as shown in Figure 3. The wastewater is then decanted. It is not possible for media to be lost during the decant process because it was allowed to settle before the decant started. The entire backwash process including the decant process can take twenty to thirty minutes. Once the decant is complete the filter may be immediately placed back into production without the filter to waste step though this would need to determined on a case-by-case basis.

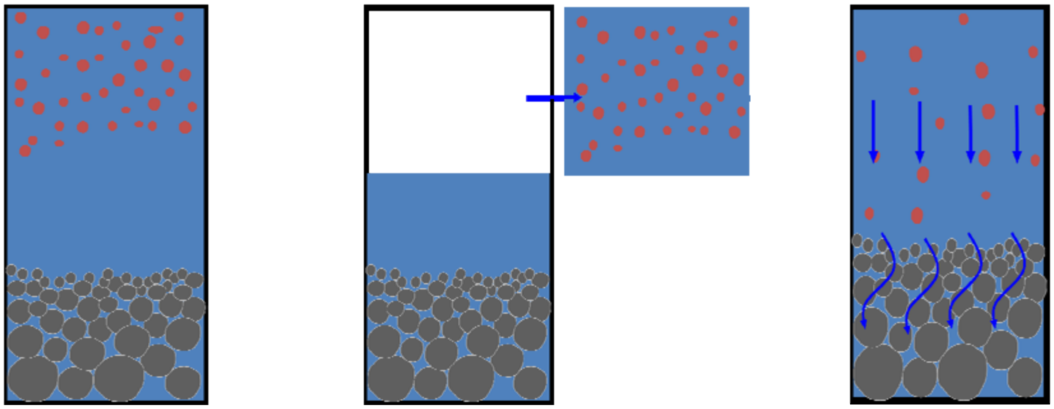

Figure 3. Backwash flow is stopped and media allowed to settle. Wastewater is decanted. The cleaned filter is placed back into production.

Considering filter operation and cleaning, free board requirements and the objective to meet minimum filter media depth for slow sand filtration the vertical height of a MPSF cell will vary between 1.25 and 2 metres. The underdrain and backwash water supply piping should be covered with at least 5 cm of coarse aggregate, itself covered at least two more layers (5 cm thick) of successively finer aggregate before reaching the filtering media which would be less than 0.4 m in depth.

It is possible for the raw water to contain gases that are released within the filter media. The effect is to plug the filter media with gas bubbles. These are easily removed by providing a short reverse flow (short backwash flow) without decanting any water. This process takes only a few minutes to perform.

Wastewater generated during the backwash process, residuals, may be recycled resulting in virtually zero liquid discharge and production of minimal volumes of sludge. The concentration of metal hydroxides in the wastewater is very high and is readily clarified. It may be important that the residuals not leave the treatment plant to avoid any opportunity for pathogen contamination.

If the groundwater is considered to be under direct influence of surface water, the surface loading rate may be reduced to that recommended for TSSF.

DESCRIPTION OF THE TREATMENT PROCESS FOR REMOVAL OF ARSENIC USING SLOW SAND FILTRATION

The process flow diagram illustrating the treatment process for removal of arsenic using the OCS process and the MPSF technology is shown in Figure 4.

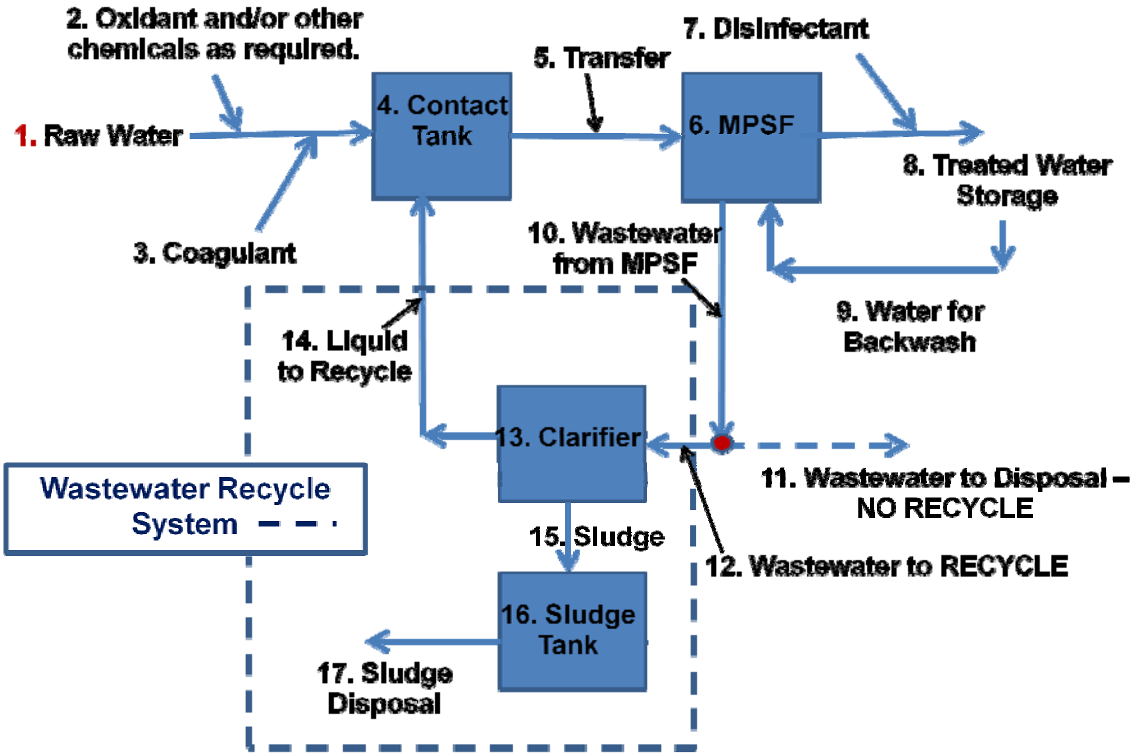

Figure 4. Process flow diagram illustrating removal of arsenic using OCS process.

Oxidants may be added to convert As(III) to As(V), the form that is readily adsorbed to ferric and aluminum hydroxides, to oxidize any iron or manganese that may be in the water or to destroy any organic complexation of naturally occurring hydroxides of iron or manganese that would inhibit the formation of micro-flocs. If the raw water does not contain sufficient metal hydroxides, small amounts of coagulants such as ferric sulphate, ferric chloride or alum, may be added to form sufficient ferric and aluminum hydroxides to adsorb As(V). Coagulant dosage will vary with water chemistry but may be as low as 1 mg/L. The contact tank provides the opportunity for the formation micro-flocs and for the As(V) to be adsorbed to the iron and aluminum hydroxides. Water containing the micro-flocs is transferred to the MPSFs. The MPSFs remove the micro-flocs and water containing very low concentration of arsenic, iron, manganese and aluminum is transferred to treated water storage. If the oxidant used is sodium hydroxide, sufficient quantity is added to ensure there is adequate chlorine residual in the filtered water. Backwash uses chlorinated filtered water. Wastewater resulting from the backwash process may be disposed of in a local sewage lagoon. The wastewater may be recycled by sending the wastewater to a clarifier. Liquid residual is returned to the transfer tank. Sludge is sent to a sludge tank from which it may be periodically removed and disposed in landfills (See USEPA Treatment Technologies for Arsenic Removal.)

The efficacy of the OCS process that uses a form of household slow sand filtration, known as BioSand Water Filtration, that is very similar to the MPSF technology, is reported by Pokral et al 2005. This study evaluated several technologies as to their ability to remove arsenic and iron from well water. The OCS process included aeration and a contact tank but did not include addition of coagulants. The OCS process removed 96% of the arsenic and 99.8% of the iron.

IRON AND MANGANESE REMOVAL USING THE OCS PROCESS

The treatment process for the removal of arsenic is very similar to that used for the removal of iron and manganese. It is not uncommon for iron, manganese and arsenic to be found in the same groundwater. If the iron and manganese can be made to form micro-flocs and the arsenic is in a suitable form it may not be necessary to add coagulants. The basic treatment for iron and manganese removal is as follows:

1. Oxidation of iron and manganese (preferably using aeration, sodium hypochlorite or chlorine dioxide). Bench scale testing is used to guide the selection of the pre-treatment process.
2. Formation of micro-flocs in contact tanks.
3. Filtration using MPSF.
4. Chlorination if not using sodium hypochlorite for oxidation.
5. Storage and distribution.

Iron may be oxidized by simple aeration if not naturally sequestered (e.g. organically complexed). Manganese cannot be oxidized efficiently by aeration unless the pH is at least 9.0. The pH of the water can be increased and subsequently decreased but this is not a practical solution. If sequestration is evident, manganese must be removed or there is a need to accelerate the oxidation process, the water may be chlorinated using sodium hypochlorite or chlorine dioxide prior to filtration and storage. Contact tanks are used for the development of micro-flocs prior to filtration. Water is transferred from the contact tanks by pumps to the filter cells.

If sodium hypochlorite is used to oxidize the iron or manganese the dosages used are large enough to insure that the water leaving the filter has sufficient chlorine residual that additional chlorine is not required prior to storage.

If chlorine dioxide is used it is necessary to chlorinate the water using sodium hypochlorite or chlorine gas prior to storage. Excess chlorite residual is not a problem since it is consumed during the oxidation of the iron and manganese.

It is important to preserve an oxidation environment in the filter to prevent the manganese from going back into solution. This is simply controlled by ensuring that the water leaving the filter has a chlorine residual. With time the manganese will coat the media particles and filters will become more efficient in both iron and manganese removal.

Iron will form micro-flocs very quickly after oxidation while oxidized manganese may require up to one hour to form micro-flocs that can be removed efficiently by the filters. Contact tanks are used to allow formation of adequately sized micro-flocs.

The chemicals, their dosage and time required to form adequate micro-flocs are determined using bench and pilot scale evaluations. It is preferred not to use potassium permanganate for oxidation because of the control complexities that can inadvertently be introduced resulting in higher level operator certification requirements. Chlorine gas or ozone cannot be used for oxidation purposes because of off-gassing in the filters. As well, water treatment plants that use either chlorine gas or ozone will require their operators to have higher levels of operator certification.

EXPERIENCE USING THE OCS PROCESS

Two water treatment plants to remove iron, manganese, hydrogen sulfide and sulfur reducing bacteria are operating in Alberta and another is under construction in Saskatchewan. The basic technology for arsenic removal has been proved at the proto-type level.

The OCS process has successfully reduced arsenic to below World Health Organization (and Canadian) maximum concentrations in groundwater in Bangladesh where up to 80,000,000 people drink water with arsenic concentrations well above the 0.01 mg/L concentration and are experiencing significant arsenic poisoning. The extent of the arsenic contamination of groundwater in Bangladesh is reported in Kinniburgh and Smedley 2001. Not only does the groundwater contain elevated concentrations of arsenic but it may be seriously contaminated by pathogens. The OCS technique, while successful at the household level, needed to be modified to use oxidants other than sodium hypochlorite to avoid excessive total and residual chlorine in the treated water. This problem has been resolved. Community scale water treatment plants that use the OCA process for purposes of arsenic removal in developing countries such as Bangladesh or West Bengal in India have been designed.

At the time of writing two water treatment plants for purposes of arsenic removal using the OCS process are in the initial phase of design. Bench scale testing has proven that the OCS approach would be successful and appropriate.

SUMMARY AND CONCLUSIONS

The use of slow sand filtration, in particular the MPSF technology as part of the OCS treatment process, provides an effective, low cost method for removal of arsenic from groundwater that may or may not be considered under direct influence of surface water or is otherwise microbiologically compromised. Specific advantages include:

1. Effective in removing arsenic.
2. Simplicity – which allows employment of trained local staff.

3. Minimum use of chemicals.
4. Minimum energy consumption.
5. Minimum maintenance.
6. Minimum production of wastewater.
7. Opportunity to recycle wastewater resulting in:
    a. Zero liquid residuals.
    b. Sludge residual that is stable and easily disposed of.
8. Appropriate for isolated communities.
9. Low capital cost.
10. Low operating cost.
11. Low maintenance cost.
12. Can be adapted to remove arsenic from all surface and ground waters.
13. Can be used to treat water for very small to very large communities (scalable).

A possible disadvantage is the larger footprint required by the OCS process.

It is very important to realize that there are several factors which may complicate the OCS arsenic removal process including pH, presence of natural occurring organic materials, phosphates and silicates and other factors. The design of the treatment process is determined using bench and pilot scale testing.

The OCS process is not limited to municipal applications. With appropriate evaluation, including bench and pilot scale testing, and the inclusion of necessary pre-treatment, it is possible to remove arsenic from a variety of industrial wastewater and mining operations

REFERENCES

Kinniburgh, D. G. and Smedley, P. L., editors 2001. Arsenic contamination of groundwater in Bangladesh, BGS Technical Report WC/00/19, Volumes 1, 2, 3 and 4, February 2001.

Edzwald, James K. ed. 2011. Water Quality & Treatment, A Handbook on Drinking Water published by the American Water Works Association.

Pokhrel, Damodar, Viraraghavan, Thiruvenkatachari and Braul, Larry 2005. Evaluation of Treatment Systems for the Removal of Arsenic from Groundwater, Practice Periodical of Hazardous, Toxic and Radioactive Waste Management, ASCE July 2005, pp 152 – 157.

Sanchez, L. D. and Burbano, L. M. 2006. Iron and manganese removal by multi-stage filtration (MSF) in Recent Progress in Slow Sand and Alternative Biofiltration Processes edited by Rolf Gimbel, Nigel J. D. Graham and M. Robin Collins published by the International Water Association.

Turneaure, F. E. and Russell, H. L. 1902. Public Water-Supplies, Requirements, Resources, and Construction of Works, John Wiley & Sons, New York.

USEPA 2000. Technologies and Costs for Removal of Arsenic from Drinking Water prepared by International Consultants, Inc., Malcolm Pirnie, Inc. and The Cadmus Group, Inc., December 2000.

USEPA 2003. Arsenic Treatment Technology Evaluation Handbook for Small Systems, Office of water (4606M), EPA 816-4-03-014, July 2003.

Table 1. Comparison of Selected Arsenic Removal Technologies

Characteristic	**Oxidation/ Coagulation/ SSF** **Using MPSF Technology**	**Ion Exchange**	**Activated Alumina**	**Alternative Adsorption Media (e.g. iron, titanium, and zirconium)**	**Reverse Osmosis**	**Enhanced Lime Softening**	**Enhanced Coagulation/ Clarification/ Filtration**	**Coagulation-Assisted Micro-Filtration**	**Coagulation Assisted Direct Filtration**	**Oxidation Filtration**
Removal Process	Coagulants (usually iron or aluminum salts) with polishing filtration provided by the BSF or LHPF that removes all particulates, including those that have adsorbed As.	Removal of As as part of ion exchange process using synthetic resins. Media usually regenerated on site.	Adsorption of As on particles of activated alumina Regeneration on site is possible	Adsorption of As on fixed media that is not usually regenerated on site	Membrane filtration process that removes almost all dissolved solids including As.	Enhanced lime softening usually followed by filtration	Coagulation – clarification - filtration. As removal achieved by removal of all flocculated particles that will have adsorbed As attached.	Coagulants (usually iron or aluminum salts) with micro-filtration that removes all particulates, including those that have adsorbed As.	Coagulants (usually iron or aluminum salts) with conventional filtration that removes all particulates, including those that have adsorbed As.	There are usually iron salts that are or can be oxidized to form micro-flocs that can be removed by conventional or micro-filtration
Removal Efficiency	Up to 99%	As(V) 95% As(III) 0%	95%	Up to 98%	More than 95%	90%	95%(w/ $FeCl_3$) Less than 90% (w/ Alum)	90%	90%	50-90%
Central System Size (pop. served)	25 and greater	25-10,000	25-10,000	25-10,000	501-10,000	25 and greater	25 and greater	25 and greater	25 and greater	25 and greater
Optimal Water Quality Conditions for Tech. to Perform	pH 5.5-8.5	pH 6.5-9 <5 mg/L NO_3^- <50 mg/L SO_4^{2-} <500 mg/L TDS < 0.3 mg/L NTU turbidity	pH 5.5-6 pH 6-8.3 <250 mg/L CL^- <2 mg/L F^- <360 mg/L SO_4^{2-} <30 mg/L Silica <0.5 mg/L Fe^{-3} <0.05 mg/l Mn^{-2} <1000 mg/L TDS <4 mg/L TOC <0.3 NTU Turbidity	pH 6-8.5 <1 mg/L PO_4^3 <0.3 NTU Turbidity	No Particulates	pH 10.5-11 >5mg/L Fe^{3+}	pH 5.5-8.5	pH 5.5-8.5	pH 5.5-8.5	pH 5.5-8.5 >0.3mg/l Fe Fe:As Ratio > 20:1
Chemical Requirements (Pre and Post Treatment)	May require pre-oxidation. May require addition of ferric chloride, ferric sulphate or alum.	Requires pre-oxidation and pre-filtration. May require pre and post pH adjustment Media regeneration	Requires pre-oxidation May require pre-filtration May require media regeneration chemicals	Requires pre-oxidation May require pre-filtration and removal of TOC May require media	Requires pre-filtration (polishing) May require pre-oxidation, removal of TOC and other chemical	Requires pre-oxidation Uses lime and treated water will require pH adjustment and filtration	Requires pre-oxidation Uses conventional iron and aluminum coagulants and various polymers as required.	Requires pre-oxidation Uses conventional iron and aluminum coagulants and various polymers as required.	Requires pre-oxidation Uses conventional iron and aluminum coagulants and various polymers as required.	Pre-oxidation

		chemicals		regeneration chemicals	conditioning	Other chemicals may be used to assist in clarification of water	May require pre- and post-treatment pH adjustment	May require pre- and post- treatment pH adjustment	May require pre- and post- treatment pH adjustment	
Complexity of Bench and Pilot Scale Testing	Low	High	High	High	High	Medium to High	Medium	High	Medium	Medium
Liquid Waste Generated Type	Backwash water that is recycled	Backwash water and Potentially hazardous brine waste	Backwash water and Potentially hazardous brine waste	Backwash water and Potentially hazardous brine waste	Reject water that has high TDS and As concentration	Backwash water that can be recycled	Backwash water that can be recycled	Backwash water that can be recycled	Backwash water that can be recycled	Backwash water that can be recycled
Liquid Waste Generated Volume	0 Backwash water can be recycled.	1-2%	1-2%	1-2%	15-75%	0	0	5%	1-2%	1-2%
Relative Cost of Liquid Waste Disposal	0	High	High	High	Medium	Low	Low	Low	Low	Low
Solid Waste Generated Type	Dewatered coagulant containing As Very stable	Spent resin.	Spent media	Spent media	Solids from pre-filter if used	Sludge that is usually very stable	Sludge that is usually very stable	Sludge that is usually very stable	Sludge that is usually very stable	Sludge that is usually very stable
Solid Waste Generated Volume	Very Low to Low	Low	Low	Low	Very low	High	High	Medium	Medium	Very Low
Relative Cost for Solid Waste Disposal	Very Low to Low	High	High	High	Very low	Medium	Medium	Medium	Medium	Very Low
Relative Size of Footprint of Treatment System Incorporating Technology	Very large	Very small.	Very small.	Very small.	Small	Very large	Very Large	Medium	Large	Medium
Complexity of Treatment Technology	Simple	Very complex	Somewhat complex (can be very complex if includes media regeneration)	Complex	Very complex	Complex	Complex	Complex	Somewhat complex	Somewhat complex

Operator Skill Required	Low	High	Medium (High if there is site regeneration of media)	Medium (Depends on operator involvement in maintenance)	Medium to High	High	High	High	High	Medium
Relative Capital Cost of Centralized System	Low	Medium	Medium	Medium	High	Low	Low	High	Medium	Medium
Energy Requirements	Very Low	Medium	Medium	Medium	Very High	Low	Low	Medium	Medium	Medium
Testing and Monitoring Requirements	Low	Medium	Medium	Medium	High	High	High	High	Medium	Medium
Technical Support	Low	Medium	Medium	Medium	Very High	Medium	Medium	High	Low	Medium
Relative Capital Cost of POU/POE System	Low	High	Low	High	Low	N/A	N/A	N/A	N/A	N/A
Relative Operating Cost	Low	High	High	High	Very High	Low	Low	Medium	Medium	Medium
Relative Maintenance Cost	Low	High	High	High	Very High	Low	Low	Medium	Low	Low
Risks	May be difficult to dispose of sludge.	Difficulty in managing regeneration chemicals and process and the handling and disposing of brine waste	Difficulty in managing regeneration chemicals and process and the handling and disposing of brine waste. May be difficulties in disposing of media if media replacement strategy used.	Media may be very expensive, have a short life and be difficult to dispose.	Reject water may be very difficult to dispose of. May be complex if pre- and post-treatment become excessive. Expensive to operate.	Sludge volumes are large and may represent a disposal problem.	Sludge volumes are large and may represent a disposal problem.	Micro-filtration technologies can be sophisticated and their maintenance can be complex. May be difficult to dispose of sludge.	Most conventional filtration technologies require development of well developed flocs or filtration will be inadequate. May be difficult to dispose of sludge.	Simple oxidation may not be sufficient to capture As or flocs that are formed will not be easily removed by filtration process. May be difficult to dispose of sludge.