Point-of-Use Arsenic Treatment Using Activated Alumina

T. Jeffery Cotter

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Point-of Use Arsenic Treatment Using Activated Alumina

by

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A Professional Project Report Submitted in Partial F
the Degree of

Master of Water Res

Water Resources Program
The University of New Mexico
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June, 2001
Committee Approval

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Abstract

Effective and affordable arsenic removal from drinking water has become a significant issue recently. The United States Environmental Protection Agency (EPA) has promulgated a new maximum contaminant level (MCL) for arsenic in drinking water which will take effect in January 2004.

The current arsenic MCL of 50 micrograms per liter (ug/l) was set by the United States Public Health Service in 1943 and has not been reduced in nearly 60 years. Arsenic has been linked to various types of cancers, prompting EPA to change the standard.

Due to the fact many water systems, especially small water utilities serving less than 10,000 people, will be impacted by a reduced standard much research is currently being done to find treatment technologies affordable enough for small water systems to implement and maintain. Many small water utilities lack the financial and technical resources required to construct and maintain centrally located water treatment facilities capable of removing arsenic. For this reason, many small water systems are exploring the option of using point-of-use (POU) systems. POU systems are typically installed under kitchen sinks and provide water from a separate tap to meet daily drinking and cooking needs.

Several types of POU systems are readily available from various retailers. Reverse osmosis POU systems are the most common. There are also several types of POU filtration systems that utilize the adsorption process to remove organic contaminants from drinking water. Most POU filtration systems are designed to remove contaminants associated with taste and odor problems. None are specifically designed to remove arsenic.

This project evaluated a POU filtration/adsorption system utilizing Activated Alumina FS-50 (AA FS-50). The POU system used for this project was fabricated from components of common home water treatment devices. The system was evaluated for performance, affordability, longevity and applicability.

State and federal regulations govern the use of POU water treatment systems. Strict rules must be followed by water systems utilizing POU systems. Possibly, residents of communities employing POU water treatment could perform the necessary maintenance required to keep the systems in compliance. This would reduce maintenance costs, making POU treatment more affordable, but current regulations would need to be changed.

Data gathered during the study indicates effective arsenic removal by the system for 4,000 bed volumes (1 bed volume =1 liter). Under normal operating conditions spent cartridges would only need to be replaced every 6-8 months. Manufacturing, installation and maintenance costs associated with the system may make it an effective and affordable treatment option for some small water systems.
Acknowledgments

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I Introduction

1.0 Introduction

The use of arsenic as a poison has been widely described in detective and mystery stories. Many villains in these stories have poisoned their victims with a large dose of arsenic. Indeed, arsenic has been recognized as hazardous to human health for many centuries. Recently, arsenic has been elevated from the pages of mystery and detective novels onto the front pages of newspapers across the country. A new drinking water standard of 10 micrograms per liter (ug/l) for arsenic was promulgated in January, 2001. Effective and affordable treatment options are needed for small water systems unable to build and operate conventional water treatment facilities. Point-of-use (POU) systems may be an effective affordable alternative for some of these water systems.

This report will provide background information on the arsenic issue and describe and evaluate in detail a point-of-use system using Activated Alumina FS-50 (AA FS-50) to remove arsenic from drinking water by the adsorption process. It will present information on the fabrication, installation and evaluation process. In addition, the longevity, affordability and applicability of the system will be critiqued.

1.1 History of Arsenic Regulation

During the 1800s, scientists began to gain an understanding of the sources and effects of drinking water contamination. By the early 1900s, engineers had developed techniques such as filtration and chlorination to remove pathogenic microorganisms from drinking water supplies. Federal regulation of drinking water began in 1914 when the United States Public Health Service (USPHS) set standards
for disease-causing microbes. Various drinking water standards were revised and modified over the years, and by 1962 all 50 states had adopted the USPHS drinking water standards as either regulations or as guidelines (EPA, 2000 b).

The United States Environmental Protection Agency (EPA) set an interim maximum contaminant level (MCL) for arsenic at 50 micrograms per liter in 1975. This drinking water standard was based on the standard set by the USPHS in 1943 (National Ground Water Association, 2000). The drinking water standard for arsenic remained unchanged for 58 years until January 22, 2001. Finally, after several years of study and debate, the EPA issued a new arsenic standard of 10 ug/l (Code of Federal Regulations, 2001).

1.2 The 10 ug/l Standard

The EPA has a mandate under the Safe Drinking Water Act (SDWA) to protect public health by regulating the nation's public drinking water supplies. The SDWA requires EPA to regulate contaminants that present health risks and are known to occur in public drinking water supplies. For each contaminant requiring regulation, EPA sets an MCL (EPA, 2000 b). Since the SDWA was enacted in 1974, the number of contaminants regulated has quadrupled (EPA, 2000 b). Up to three new MCLs are to be established each year.

Just before leaving office, the Clinton Administration issued a new MCL for arsenic that lowered the arsenic MCL from 50 ug/l to 10 ug/l. The Clinton Administration issued the rule despite the fact that Congress had extended the deadline to set a new arsenic MCL until summer 2001 (Bingaman, 2001). At present, there is considerable debate over the health effects of low levels of arsenic in drinking water and
the cost of removal. The majority of epidemiological studies showing arsenic in drinking water is hazardous to human health have been conducted in foreign countries, especially Taiwan, Argentina and Chile. These countries have extremely high levels of arsenic in their drinking water. In some of these locations, the concentration of arsenic is six times higher than that found in the United States (McKay, 2000).

Recently appointed EPA Administrator, Christie Whitman, issued an order on April 18, 2001 asking the National Academy of Sciences (NAS) to perform an expedited review of a range of 3 to 20 ug/l for the establishment of a new arsenic drinking water standard. This action extends by nine months until February 22, 2002 the current effective date of May 22, 2001 for the 10 ug/l rule set by the Clinton Administration. Compliance dates for the new standard, whatever it may be, will be in 2006 (Code of Federal Regulations, 2001).

Senator Jeff Bingaman of New Mexico said he thinks the EPA's review of the arsenic standard is appropriate. Bingaman said, "I met with EPA officials last year, and frankly their explanation for how they arrived at the 10 ug/l level was not persuasive." Bingaman said, "Clearly, we must set a new arsenic standard, but that standard should be arrived at after adequate studies are conducted in the United States" (Bingaman, 2001).

Although data on the ills of arsenic in drinking water exist, politicians, water experts and water consumers in the United States are not convinced a stricter arsenic standard is necessary. There is a lot of uncertainty over health effects, cost of treatment and the need for a new arsenic standard. The debate over the need for a new standard is sure to continue.
1.3 The Number of Systems Affected

There are approximately 54,000 community water systems in the United States serving over 254 million people (NGWA, 2000). A community water system is classified as a water systems that serves at least 15 locations or 25 residents year-round. All community water systems will be responsible for complying with the new arsenic standard.

An estimated 6,600 water systems nationwide serving approximately 22.5 million people will need to upgrade their water treatment systems to comply with the 10 ug/l MCL (EPA, 2001). Large water systems serving 10,000 people or more will have three years to comply with the new standard. Smaller systems serving less than 10,000 people will have five years to comply. Over 90 percent of the water systems failing to meet the 10 ug/l standard are small systems, most having limited financial and technical resources. Figure 1 shows average arsenic concentrations in areas of the United States affected by the 10 ug/l arsenic standard (USGS, 2000).

In New Mexico, there are 592 community water systems. Of these 592 community systems, 267 are "small" water systems, serving between 24 and 1000 people. The 10 ug/l arsenic standard will affect 114 of the 592 total community water systems (Bitner, 2001). The 114 water systems affected by the new arsenic MCL will need to upgrade or modify their existing treatment systems in order to comply with the regulation. The cost of regulatory compliance for these water systems will be an immense financial burden, especially to the "small" systems. The cost of compliance
with a 10 ug/l in New Mexico is estimated at one billion dollars. Small water systems will be faced with most of the cost burden (Bitner, 2001).

1.4 Arsenic Description

Arsenic is a naturally occurring element in rocks, soils and the waters in contact with them. Arsenic is commonly found in nature as the mineral compound arsenopyrite. Arsenic has more than 200 different organic and inorganic forms, and is sometimes found in food, air and water (Environmental News Network, 1997).

Figure 1: Arsenic Concentrations in Drinking Water Supplies of U.S. (Source: USGS, 2000)

Arsenic is a Group V element, classified as a metalloid, having properties of both metals and non-metals and is odorless and tasteless.

The most common valence states of arsenic in water are arsenic (V), or arsenate, and arsenic (III), arsenite. Arsenite, the more toxic of the two, is generally more mobile
in ground water systems. Arsenate is more readily removed by existing technologies (Breslin, 1998). Arsenate is most common in aerobic surface waters whereas arsenite is most common in anaerobic ground waters (Amy et al., 2000). The molecular configuration of arsenite and arsenate, shown in Figure 2, affects treatment processes. Chlorine will oxidize arsenic (III) to arsenic (IV). The technical evaluation section of this report will provide more details on arsenic treatment technologies.

![Molecular Configuration of Arsenate and Arsenite](image)

**Figure 2: Molecular Configuration of Arsenate and Arsenite**

Over 70% of drinking water in New Mexico comes from ground water sources. In New Mexico, arsenic is associated with volcanic formations as well as sulfide deposits. Therefore, arsenic (III), or arsenite is most prevalent in New Mexico.

### 1.5 Health Concerns

Consumption of food and water are the major sources of arsenic exposure in the United States. People may also be exposed from industrial sources, as arsenic is used in semiconductor manufacturing, petroleum refining, wood preservatives, animal feed additives and herbicides. Natural sources of arsenic include sulfide deposits, and some volcanic minerals. In general, inorganic forms of arsenic are more toxic than organic
forms. While food contains both inorganic and organic forms of arsenicals, inorganic forms are primarily present in water (NGWA, 2000).

Exposure to arsenic at high levels poses serious health threats, as arsenic is a known carcinogen. Arsenic is most commonly associated with causing lung, liver, skin and bladder cancers. In addition, arsenic can cause a skin disorder called Blackfoot Disease. There are areas in Bangladesh and India where arsenic poisoning and Blackfoot Disease have reached epidemic proportions. Arsenic has also been linked with the development of diabetes. Amazingly, arsenic was widely used as a medical ingredient in the treatment of certain diseases. In fact, arsenic compounds were the medicine of choice for fighting bacterial infections prior to the invention of antibiotics in the 1940s (NGWA, 2000). Recent research on arsenic suggests the following:

- Humans need a certain amount of arsenic in their diet to survive.
- Arsenic may play a role in the prevention of Parkinson's Disease

Most water experts agree the arsenic standard for drinking water needs to be lowered, but the controversy is by how much.

**II Types of Treatment**

**2.0 Treatment Types**

Beginning in 1996, when the EPA announced it was going to revise the arsenic standard for drinking water, many municipal water systems and private water purveyors began to search for and evaluate different types of technologies to remove arsenic from their water supplies. Arsenic removal technologies generally fall into three major
categories: chemical precipitation, adsorption and membrane separation. Chemical precipitation is the most common of these technologies.

Many treatment technologies have been evaluated and most are very effective at significantly reducing arsenic concentrations in drinking water. Few of these treatment technologies have been developed or incorporated into point-of-use systems. Some of these systems are used in "full-scale" water treatment plants that treat water at a centralized location prior to water entering the distribution system. Other treatment technologies are used onsite, such as at well heads, before water is placed into distribution.

These technologies perform most effectively when treating arsenic in the form of arsenic (V). Arsenic (III) may be oxidized to arsenic (V) by chlorine, potassium permanganate, ozone or hydrogen peroxide. Pre-oxidation with chlorine is possible, but may create undesirable concentrations of disinfection by-products if sufficient organic compounds are present in the water (EPA, 2000a).

The EPA's list of best available technologies (BATs) for removal of arsenic from drinking water include: coagulation/filtration, lime softening, activated alumina, ion exchange, reverse osmosis, electrodialysis reversal and nanofiltration. Several of these treatment technologies and their applicability to point-of-use systems are described below (EPA, 2000a).

2.1 Reverse Osmosis

Reverse Osmosis (RO) is a membrane separation technology that forces water under pressure through a membrane to remove dissolved constituents. RO provides arsenic (V) removal efficiencies of greater than 95 percent (EPA, 2000a). RO point-of-
use systems are common and are fairly simple to operate and maintain. If the pre-filter utilized to prevent bacterial and chlorine damage to the RO membrane is well maintained, membrane life can exceed two years.

On a large scale, an increased need for raw water and brine, or reject water disposal can be a concern. The increased need for raw water and reject water disposal can lead to increased costs for arsenic removal (EPA, 2000a).

2.2 Manganese Greensand Filtration

If arsenic contaminated water also has iron and or manganese present, it is possible to treat the water for both contaminants. The manganese greensand filtration process uses a chemical feed pump to inject potassium permanganate into the water supply prior to the greensand filter. The potassium permanganate turns the water pink prior to the greensand filter, but the pink water does not bleed through the filter. The potassium permanganate oxidizes arsenite to arsenate and it combines with the iron or manganese. The manganese-coated greensand then filters the iron or manganese precipitate which has arsenate attached to it. Backwashing of the filter is necessary to remove accumulated sediments. This arsenic removal process is used in larger scale treatment applications and is not practical for point-of-use treatment (Krudico, 2001).

2.3 Ion Exchange

Ion exchange involves passing water with arsenate anions through a column of resin beads containing an exchangeable anion such as chloride, resulting in a swap that leaves the arsenate in the water column and the chloride in the water. This technology does not work on arsenite because that compound is uncharged.
Arsenic (V) is efficiently removed by chloride anion exchange using conventional strong base resins such as Ionac ASB-2 and Dowex-11. Ion exchange treatment is capable of reducing arsenic below 1 ug/l. Ion exchange works well in the usual pH range of natural waters (6.5-9.2) and the ion exchange resins can be easily regenerated. High sulfate and TDS levels can adversely impact ion exchange arsenic removal. An oxidizer such as chlorine is injected to insure that arsenic is converted to the arsenic (V) state. Since anion resin is not chlorine tolerant, the chlorine must be removed using an activated carbon filter. An advantage to this type of system is that nitrates and nitrites are removed along with the arsenic (Clifford et al., 1997). This process produces arsenic contaminated brine that requires disposal and adds to the cost of arsenic treatment. Studies have shown that ion exchange treatment is 95-97 percent effective (Krudico, 2001).

Ion exchange is common in centralized or onsite treatment applications, but is also used in point-of-use applications for water softening. Waterlink/Barnebey Sutcliffe Corporation of Columbus, Ohio, markets Engelhard-ATS Sorbent Media. ATS™ refers to a class of ceramic ion exchange media with high selectivity for removal of specific ions from water. ATS is a patented product of the Engelhard Corporation. Designed especially for point-of-use and point-of-entry water treatment units, ATS-arsenic is used for arsenic removal (Waterlink, 2001).

2.4 Coagulation/Filtration

Coagulation/filtration is the standard treatment technology for removing arsenic and other contaminants from surface water. Coagulation/filtration most commonly uses ferric chloride, although other coagulants such as alum and ferric sulfate are available.
The coagulant reacts with the arsenic to create a solid that precipitates from the water. The water is then filtered to remove suspended particles. This process is capable of removing arsenic to levels of 2-5 ug/l (Breslin, 1998). Coagulation/filtration treatment produces arsenic-contaminated sludge that must be disposed of. Due to the amount of coagulant needed, the size of flash mixing basins and settling tanks, Coagulation/filtration is not a point-of-use technology.

2.5 Lime Softening
Lime Softening is another arsenic removal technology performed in conventional treatment plants. It begins with the addition of lime (Ca (OH)₂) to raise the pH above 11, then is followed by rapid mixing, flocculation, sedimentation and filtration. If the pH of the water is adjusted to over 11, Lime Softening may be used to remove up to 80 percent of the arsenic in the water supply. Disposal of sludge created in the sedimentation process may be a problem. Due to its many components and size requirements Lime Softening is not applicable as a point-of-use technology.

2.6 Adsorption Processes
The granular ferric hydroxide (GFH) treatment process passes water through a fixed bed reactor where arsenic ions adsorb to the GFH. A contact time of approximately five minutes is required to allow for the adsorption of the arsenic to the GFH. GFH has a high affinity for arsenic and testing has show nearly 100 percent arsenic removals with proper pre-treatment (Driehaus et al., 1998).

In general, GFH treatment is used in centralized water treatment facilities. GFH research has shown promise as an arsenic treatment method in small water facilities. As
was done with AA FS-50 for this project, GFH could be tested in a point-of-use filtration system to determine its effectiveness without pre-treatment.

Activated alumina adsorption is similar to that of GFH adsorption. Water is pumped into activated alumina media columns and flows through to the bottom of the column. Activated alumina columns are sometimes run in series or in parallel. Arsenic removal is best accomplished when feed water pH is adjusted to between 5.5 and 6.0. When pH is adjusted to this range longer run lengths are achievable before arsenic breakthrough occurs. Effluent arsenic concentrations below 2 ug/l have consistently been achieved with activated alumina when a five minute contact time is utilized (Clifford et al., 1997).

Compact activated alumina treatment systems are available and can be used at wellhead locations or other onsite locations. In practice, adsorption processes all involve periodic regeneration of media with a strong base. This process requires the handling of hazardous chemicals and generates sludge with potentially hazardous characteristics.

2.7 Other Arsenic Removal Technologies

The preceding sections discussed the most common arsenic removal technologies, their methodologies, and applicability to point-of-use systems. Some arsenic removal technologies not discussed include Electrodialysis Reversal (EDR) and Nanofiltration (NF). EDR and NF have shown effective results for arsenic removal in testing. Several other arsenic removal technologies, both large and small scale continue to be developed and researched.
2.8 Arsenic Treatment in Bangladesh

Due to extremely high concentrations of arsenic in drinking water supplies in certain regions of Bangladesh, hundreds-of-thousands of people in that country are experiencing arsenic related health problems including, most notably, Blackfoot Disease. Figure 3 shows the location of the arsenic epidemic in Bangladesh.

The extent of the arsenic problem in Bangladesh is without doubt. Currently, the focus is shifting away from identification of the problem and towards finding solutions to the problem. Although there is a tremendous need for long term solutions to the problem, in the meantime, efforts are being made to find short-term solutions that will provide residents in the affected areas with safe drinking water.

Figure 3: Arsenic Epidemic Area in Bangladesh

In December 2000, a study was conducted by the Bangladesh Arsenic Mitigation Water Supply Project (BAMWSP), Water Aid and several other international agencies to evaluate the performance and acceptability of nine point-of-use or "household level" arsenic removal technologies. The evaluations were primarily concerned with technical
performance, ease of use, environmental impact, and affordability (BAMWSP, 2000). Table 1 briefly describes these technologies. Although these technologies were developed to remove arsenic from water supplies in areas with little or no public water distribution, it is interesting to note these point-of-use systems and their performance capabilities.

The technologies used in Bangladesh are relatively simple systems that show promising results. The concentrations of arsenic in the water supplies of Bangladesh are some of the highest in the world. For more information on these technologies and the arsenic crisis in Bangladesh visit [www.bamwsp.org](http://www.bamwsp.org) or [www.wateraid.org.uk](http://www.wateraid.org.uk) on the Internet.

The application of these types of arsenic removal technologies in the United States is unlikely due to the nearly complete presence of indoor household water distribution systems and advanced water supply infrastructure. Point-of-use treatment systems such as these could be useful however, in remote areas lacking indoor plumbing or in emergency situations.
Table 1: Arsenic Removal Technologies used in Bangladesh (Source: BAMSWP, 2000)

<table>
<thead>
<tr>
<th>Technology</th>
<th>Process</th>
<th>Operating Procedure</th>
<th>Effectiveness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alcan</td>
<td>Sedimentation, filtration,</td>
<td>Usually attached to well head and pump directly into filter</td>
<td>Studies by Department of Chemistry, Dhaka University, show a removal rate of 100 %</td>
</tr>
<tr>
<td>Activated Alumina Filter</td>
<td>activated alumina (AAFS-50)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ardasha</td>
<td>Filtration</td>
<td>Pour water into tray within bucket. Use tap to get treated water from bottom of bucket</td>
<td>Thought to reduce arsenic below 50 ug/l. Unknown as to why.</td>
</tr>
<tr>
<td>BUET</td>
<td>Oxidation, sedimentation,</td>
<td>Fill top bucket and add chemicals. Stir vigorously and leave for one hour. Turn tap to allow water into</td>
<td>100 % arsenic removal after treatment with initial levels of 120-1000 ug/l. Arsenic removal below 50</td>
</tr>
<tr>
<td>Activated Alumina Filter</td>
<td>filtration, activated alumina</td>
<td>the activated alumina column. Retrieve water from bottom of column.</td>
<td>ug/l with initial levels 116-201 ug/l.</td>
</tr>
<tr>
<td>DPHE/DANIDA Bucket Treatment</td>
<td>Oxidation/coagulation/flocculation/filtration</td>
<td>Pour water into the top bucket. Add mixture of aluminum sulfate and potassium permanganate and stir</td>
<td></td>
</tr>
<tr>
<td>Treatment Unit</td>
<td></td>
<td>vigorously 20 times. Leave to settle for 2 hours. Turn tap to send water to, lower bucket where it passes</td>
<td></td>
</tr>
<tr>
<td>Garnet Filter</td>
<td>Coagulation, adsorption and</td>
<td>Water frequently topped up in top bucket. Flow regulated to second bucket-regular checking required.</td>
<td>Removal efficiencies of 70-100% depending on presence of As and Fe in feed water.</td>
</tr>
<tr>
<td>Passive sedimentation</td>
<td>filtration</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SONO3-Kolshi Filter</td>
<td>Coagulation, adsorption,</td>
<td>Pour water into top kolshi. Use water from bottom kolshi</td>
<td>Arsenic removal below 50 ug/l.</td>
</tr>
<tr>
<td>Passive sedimentation</td>
<td>filtration</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tetrahedron</td>
<td>Ion exchange resin</td>
<td>Fill first container with feed water (over chlorine tablet), water enters second container and turning</td>
<td>Complete arsenic removal in water with initial concentrations of 100-1700 ug/l.</td>
</tr>
<tr>
<td>Stevens Institute of Technology</td>
<td>Coagulation and filtration</td>
<td>the tap at the second container releases the water. Water supply is almost instant.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
III Point-of-Use Systems

3.0 Point-of-Use Systems

Point-of-use water treatment systems have gained wide popularity in the past decade. The Water Quality Society has conducted several surveys indicating a lack of confidence in municipal or private well water quality in the United States (WQS, 1999). Some of the survey's key findings include:

- 60% of adults believe the quality of their drinking water affects their health.
- 75% of adults have some concern regarding the quality of their household water.
- 50% of adults are concerned about possible health-related contaminants.
- 33% believes his or her water is not as safe as it should be.
- 20% are dissatisfied with the quality of his or her household water.

The percentage of adults who reported using a household water treatment device jumped to 38% in 1999 from 32% in 1997, a 28% increase from 1995. In the same four-year period, the percentage of consumers who report using a home water treatment device or bottled water rose to 62% from 53% (WQS, 1999). The use of household water treatment units has caught up with the use of bottled drinking water. One out of ten adults who do not report use of a water filtration unit now plan to purchase one within a year. Forty-seven percent of survey respondents say that if they were in the market for a new home, they would more likely purchase one with a home water treatment device (WQS, 1999). Fear by consumers of contaminated water, stricter water regulations and the adoption of healthier lifestyles has promoted the increased use of household water treatment devices.
Point-of-use water treatment systems are the most common household water treatment devices next to pour-through water pitchers. Point-of-use systems, typically installed under a sink, can remove many contaminants. Filtration, ion-exchange, reverse osmosis, and distillation are all used in point-of-use systems.

Point-of-use reverse osmosis units are capable of removing a diverse list of contaminants including nitrates, sodium, other dissolved inorganics and organic compounds.

Point-of-use filtration systems typically use sediment and activated carbon filters, which adsorb organic contaminants and constituents that cause taste and odor problems. Activated carbon will remove most organic contaminants including chlorination by-products, cleaning solvents and pesticides. Activated carbon filters will not remove metals such as lead and copper.

Ion exchange based water softeners will remove calcium, magnesium, radium and barium from water. Ion exchange units require periodic regeneration of the exchange media with salt.

Point-of-use distillation units boil water and condense the resulting steam to create distilled water. One problem with distillation systems is that vaporized organic contaminants can condense back into the product water reducing the removal of organics.

Point-of-use systems are now being designed and tested to remove arsenic from water. Paul Friot, of Friot's Water Treatment Company in Ayer, Massachusetts, is currently seeking a patent on a point-of-use system to remove arsenic from water. Due to patent pending restrictions, details on the technology of this system are not available. The system is currently in use in a variety of homes and lab testing confirms removal of
arsenic to below 10 ug/l and in most cases to below detection level of 0.5 ug/l (Friot, 1999).

Arsenic Remediation Technology, dubbed AsRT by its developers is being developed into point-of-use systems. AsRT technology involves pumping arsenic-contaminated water through a bed of sand and iron filings. As the water passes through the iron filter, arsenic is removed from the solution through an as-yet-unidentified mechanism. The arsenic may be removed as part of the iron precipitation or co-precipitation, or may attach to the iron filings that have corroded, or finally, may attach to the iron oxides that coat the sand (Nikolaidis et al., 2000). Further studies are underway to determine the exact removal mechanism of this technology. AsRT is very effective in removing arsenate, but also shows impressive results for removing arsenite. Arsenic levels of less than 1 ug/l have been achieved in testing (Breslin, 1998). A patent is pending on AsRT. The developers hope to scale down the AsRT technology for use in treating wells in areas such as Bangladesh or incorporate it into point-of-use units. For more information on AsRT arsenic removal technology visit www.eng2.uconn.edu/~nikos/asrt-brochure.html.

Figure 4: Arsenic Remediation Technology (AsRT) System.
In an interesting side note on the issue of point-of-use arsenic removal technologies, EPA Administrator, Christie Whitman, suggested in a recent radio interview that a lack of residential treatment technology is partly to blame for the difficulty of lowering the drinking water arsenic standard. Whitman said "Unfortunately, there's no technology at the moment that allows you to remove arsenic at the tap and at home." She also said those with contaminated private wells could not be expected to treat their water because "there is no at-the-tap ability to take the arsenic out." In the Federal Register notice of a new arsenic rule issued by the Clinton Administration, reverse osmosis point-of-use is listed as an approved technology for arsenic removal (Water Tech Online, 2001 b). Wisconsin and other states have already begun pilot tests of point-of-use devices for arsenic reduction. At their annual conference in March 2001, the WQA held workshops on affordable point-of-use treatment for arsenic. Several EPA employees attended these workshops.

3.1 Advantages of Point-of-Use Treatment

Point-of-use arsenic removal systems can remediate arsenic levels in drinking water well below the 10 ug/l standard. Advantages to point-of-use arsenic removal include (WQS, 2001):

- Point-of-use reverse osmosis treatment offers an affordable compliance option for small systems and individual homeowners.
- Systems are capable of removing more contaminants than just arsenic.
- Systems provide an adequate supply of water on a daily basis.
• Treatment systems are small, easily fitting under most sinks or faucets.

• Units can be located in many different areas.

### 3.2 Disadvantages of Point-of-Use Treatment

Although point-of-use water treatment technologies have proven to be very effective they can have some disadvantages. Disadvantages to point-of-use treatment include (WQS, 2001):

• Units require regular maintenance to insure proper operation.

• If units are not properly maintained, contaminants may accumulate and actually make water worse.

• Systems treat water at a single tap only.

• Systems require special regulations regarding customer responsibilities, water utility responsibilities and the requirement of installation of the devices in each home obtaining water from the utility.

• Point-of-use systems must be managed by the water utility, which requires entry into each residence.

• Systems require more recordkeeping to monitor individual devices than does central treatment

• Reverse osmosis systems waste a lot of water

• Systems must be installed in each house.

### 3.3 Point-of-Use/Point-of-Entry Treatment versus Centralized Treatment

There are two major treatment strategies available for arsenic treatment. They are centralized treatment and point-of-use/point-of-entry (POU/POE) treatment.
Centralized water treatment is performed at a single facility where all drinking water for distribution is treated. Centralized treatment facilities are large and operated by state-certified operators. One advantage to centralized treatment is that all treatment equipment is centrally located and readily accessible. Personnel at these facilities are usually highly qualified and experienced. Centralized treatment facilities can employ many different treatment technologies and are capable of providing a community with high quality drinking water free of contamination.

Some communities may require multiple treatment facilities due to the geography of the area. Communities which rely upon widely dispersed wells require elaborate distribution systems, thus centralized treatment may not be an option. Centralized treatment facilities are expensive to build and operate making them impractical for many smaller communities. The availability of property on which to locate the treatment facility can sometimes also be a problem for many communities. Centralized treatment can especially be a problem for communities utilizing ground water because it is very difficult, if not impossible, to import all ground water to a central location for treatment. Albuquerque is a prime example of this dilemma.

Centralized treatment facilities are commonly surface water facilities that employ treatment technologies such as coagulation/filtration, ion exchange, and lime softening to remove arsenic. Examples of centralized treatment facilities include the Franklin Canal Water Treatment Plant in El Paso, Texas, and the Sangre de Cristo Water Treatment Plant in Santa Fe, New Mexico.
Point-of-entry and point-of-use treatment technologies are similar. POE treatment devices are installed where the water line enters the house. POU treatment devices can be installed in various places throughout the home, including on the countertop, at the faucet itself, or under the sink. POU/POE treatment technologies include reverse osmosis, distillation, ion exchange, and filtration.

**IV Study Objectives**

**4.0 Study Objectives**

The main objective of this point-of-use study was to determine if a POU system using Activated Alumina FS-50 could meet a 10 µg/l drinking water standard for arsenic. Other objectives include determining the longevity, affordability and applicability of point-of-use Activated Alumina FS-50 adsorption. Affordability is measured by determining the cost of producing and maintaining the units. The cost of manufacturing and maintaining the Activated Alumina FS-50 adsorption cartridges will
be estimated. The applicability of these units for meeting the arsenic rule when utilized by small water systems will be evaluated. The final objective is to develop a routine operation and maintenance protocol for the system.

V Description of Prototype

5.0 Description of Prototype

The arsenic removal system designed for this project was fabricated from a typical undersink drinking water filtration system. This system is based on the design of point-of-use filtration and reverse osmosis systems already in existence. Activated Alumina FS-50 was the adsorbent used in this study. Activated Alumina FS-50 was chosen because of its known affinity for arsenic and its affordability. This POU system uses adsorption to remove arsenic. Adsorption processes are relatively slow. For this reason, sufficient contact time must be allowed for the water to be in contact with the adsorbent. Previous research has shown a contact time of between five and ten minutes is sufficient for arsenic adsorption by activated alumina media (Clifford et al., 1997). In order to provide sufficient contact time a flow restrictor was incorporated into the design.

A dual undersink filtration system was modified into a triple cartridge system by adding a single filter cartridge housing to a dual housing filtering unit. This modification allowed an Activated Alumina FS-50 filter cartridge to be placed between a sediment pre-filter and sediment post-filter. Figure 6 shows a schematic of the system. Section 5.1 describes each component of the filtration system in detail.
5.1 System Components

*Saddle Valve*- A saddle valve was used to puncture a 1/8" hole in the copper waterline from the household cold water supply. The saddle valve allows water flow from the household cold water supply into the filtration system via 3/8" outside diameter (O.D.) polyethylene tubing connected to the saddle valve using a 3/8" tubing insert.

*Filter Housing*- Water flows through the tubing into the filter housing. The filter housing consists of three heavy-duty plastic containment canisters in series. The canisters contain filter cartridges.

![Diagram of Point-of-use System Schematic](image)

*Figure 6: Point-of-use System Schematic*

Each housing canister is coarsely threaded at the top and can be screwed off and on for easy replacement of filter cartridges. A rubber O-ring located at the top of each canister seals the canister and prevents water leakage. The filter housing is shown in Figure 7.
**Sediment Pre-filter:** The first canister contains a 5-micron synthetic fiber sediment cartridge (pre-filter). The sediment pre-filter removes sand, silt, clay, dirt, and other sediments from the influent water. The pre-filter is extremely important due to the particulate nature of the AA FS-50 media. The influent water must be filtered to prevent accumulation of solids which would plug of the adsorption media. The sediment pre-filter is shown in Figure 8.

![Filter Housing Containment Compartments](image)

*Figure 7: Filter Housing Containment Compartments*
Activated Alumina Cartridge-The second housing canister contains the AA FS-50 adsorption media cartridge. The AA FS-50 cartridge is a 3" diameter by 10" long hollow plastic cylinder filled with approximately 540 grams of 28 x 48 mesh (0.3 to 0.6-mm-diameter) Activated Alumina FS-50. The cartridge has an inlet port at the top and outlet port at the bottom through which water enters and exits the cartridge. A one-inch diameter rubber O-ring seals the outlet port against the housing canister. The AA FS-50 adsorption media cartridge is unique to this system. It was fabricated by emptying an activated carbon cartridge of its contents and filling it with arsenic removal grade AA FS-50 and resealing the cartridge inlet port. The activated alumina cartridge is pictured in Figure 9. Note the rubber O-ring surrounding the outlet port.

Sediment Post-filter- The final housing canister contains a sediment post filter. The post-filter is constructed of synthetic fiber and is identical to the sediment pre-filter. Due to the particulate nature of the AA FS-50 adsorption media, a post-filter is necessary to prevent clogging of the flow restrictor by any particulate that may have escaped the AA FS-50 cartridge.
Flow Restrictor- After exiting the filtration components of the treatment system, water moves through 3/8" O.D. polyethylene tubing which is reduced to 1/4" O.D. tubing using reducer couplings and flows through a specially designed flow restrictor. The polyethylene flow restrictor has a 0.4-millimeter internal diameter orifice. The flow restrictor produces a flow rate of 100 milliliters per minute. The flow restrictor facilitates a minimum ten-minute empty bed contact time needed for proper arsenic adsorption by the AA FS-50 media. Figure 10 shows the flow restrictor and 1/4" O.D. polyethylene tubing.

Pressurized Storage Tank- A pressurized 3.2-gallon storage tank containing a membrane bladder is connected following the flow restrictor to provide adequate storage and flow of treated drinking water to the dispenser. A tee connection directs the flow to either the dispenser or the storage tank. When the pressure in the bladder of the tank is less than line pressure, water will flow into the bladder. When pressure in the bladder is greater than or equal to line pressure, equilibrium is achieved and water flow stops. The pressurized storage tank is shown in Figure 11.
Dispenser: A chrome lever-activated dispenser installed next to the kitchen faucet and connected to the storage tank via 3/8" O.D. tubing and connection adaptors provides treated drinking water. The dispenser has a 1/2" diameter orifice capable of providing adequate flow when water in storage tank is under pressure. When the storage tank is not pressurized the dispenser provides water at a steady rate of 100 milliliters per minute. The lever-activated dispenser can be placed in a locked open position to dispense water for relatively long periods of operation or held open by hand for short periods of operation. Figure 12 shows the dispenser and its operating positions.

Flow Meter: A low volume flow meter was installed to monitor gallons per day of water produced by the system. However, due to the extremely low flow rate, the water meter never functioned properly during the evaluation period. The flow meter can be seen in the background of Figure 13.
Tapping the household water line with a saddle valve as described earlier is necessary to provide water flow to the system. In addition, it may be necessary to drill a hole in the counter top to facilitate installation of the dispenser. It may possible to install the dispenser in an existing sprayer hose orifice if available. Figure 13 shows the point-of-use system installed in an undersink location.

5.2 System Specifications

The point-of-use AA FS-50 adsorption system described above incorporates a unique flow restrictor into the design to facilitate a contact time allowing for arsenic adsorption. The AA FS-50 media cartridge has a nominal volume of one liter. At a flow rate of 100 milliliters per minute, the system will produce 144 liters per day (38 gallons) of drinking water. The 3.2-gallon (11.7-liter) storage tank will fill to capacity in about 2 hours.
A study done by Natural Solutions Environmental, Inc. indicates that the average family of four uses between 600-800 gallons of water per year from a point-of-use system (Natural Solutions, 2001). This equates to approximately 2-4 gallons per day. The POU system described for this study provides sufficient water for daily drinking and cooking needs.

The other unique feature of this POU system is the use of Activated Alumina FS-50 as the adsorption media. Activated alumina is an aluminum oxide which is highly porous and exhibits large surface area. AA FS-50 is resistant to thermal shock and abrasion and will not shrink, swell, soften nor disintegrate when immersed in water (Alcan, 2001). AA FS-50 exhibits a great affinity for arsenic adsorption and with 540 grams of AA FS-50 contained within the cartridge many bed volumes of arsenic remediated water can be produced. A bed volume is equal to the size of the AA FS-50 adsorption cartridge, in this case one-liter. The system produces 144 bed volumes per day. Previous studies have shown an optimum pH of 5.5 to 6 for arsenic adsorption onto activated alumina (Clifford et al., 1997). No pH adjustments were performed in this study. The feed water pH ranges between 7.4 and 7.8. More rapid exhaustion of the AA FS-50 adsorption media, quicker arsenic breakthrough and fewer bed volumes produced can be expected with pH in this range.

Large centralized treatment systems employing activated alumina adsorption regenerate AA media using a strong base such as sodium hydroxide (NaOH) and strong acid such as sulfuric acid (H₂SO₄). Due to the small size of the AA FS-50 cartridge and its relatively low cost, regeneration is probably not practical for this POU system. In addition, NaOH and H₂SO₄ used in the regeneration process create hazardous wastes.
Zone 15, in which the study was conducted, has an average arsenic concentration of 19 ug/l according to City data.

These data provided a baseline against which arsenic removal efficiencies were gauged. Arsenic data for treated samples, untreated samples and pH analyses are located in the appendix. Table 2 shows Zone 15 data for major water contaminants as reported by the City's water quality division. These data were compiled from well and tap samples taken by the City during the year 2000 (CABQ, 2001).
Table 2: Water Quality Data for Zone 15 City of Albuquerque (Source: CABQ, 2001)

<table>
<thead>
<tr>
<th>Contaminant (metals)</th>
<th>MCL</th>
<th>City Average</th>
<th>Zone 15 Minimum</th>
<th>Zone 15 Average</th>
<th>Zone 15 Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arsenic</td>
<td>50 ug/l</td>
<td>12 ug/l</td>
<td>14 ug/l</td>
<td>19 ug/l</td>
<td>22 ug/l</td>
</tr>
<tr>
<td>Barium</td>
<td>2 ppm</td>
<td>0.09 ppm</td>
<td>0.10 ppm</td>
<td>0.14 ppm</td>
<td>0.17 ppm</td>
</tr>
<tr>
<td>Boron</td>
<td>-</td>
<td>0.13 ppm</td>
<td>0.05 ppm</td>
<td>0.08 ppm</td>
<td>0.10 ppm</td>
</tr>
<tr>
<td>Cadmium</td>
<td>0.005 ppm</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>Chromium</td>
<td>100 ug/l</td>
<td>2 ug/l</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>Copper</td>
<td>1.3 ppm</td>
<td>0.016 ppm</td>
<td>0.017 ppm</td>
<td>0.021 ppm</td>
<td>0.025 ppm</td>
</tr>
<tr>
<td>Iron</td>
<td>0.3 ppm</td>
<td>0.012 ppm</td>
<td>ND</td>
<td>0.004 ppm</td>
<td>0.021 ppm</td>
</tr>
<tr>
<td>Lead</td>
<td>15 ug/l</td>
<td>1.0 ug/l</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>Manganese</td>
<td>0.05 ppm</td>
<td>0.002 ppm</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>Nickel</td>
<td>-</td>
<td>7.0 ug/l</td>
<td>ND</td>
<td>26 ug/l</td>
<td>82 ug/l</td>
</tr>
<tr>
<td>Selenium</td>
<td>50 ug/l</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>Zinc (Minerals)</td>
<td>5 ppm</td>
<td>0.039 ppm</td>
<td>ND</td>
<td>0.025 ppm</td>
<td>0.056 ppm</td>
</tr>
<tr>
<td>Fluoride</td>
<td>4.0 ppm</td>
<td>1.1 ppm</td>
<td>1.0 ppm</td>
<td>1.2 ppm</td>
<td>1.4 ppm</td>
</tr>
<tr>
<td>(Nutrients) Nitrate+Nitrite</td>
<td>10 ppm as N</td>
<td>0.5 ppm as N</td>
<td>0.2 ppm as N</td>
<td>0.2 ppm as N</td>
<td>0.2 ppm as N</td>
</tr>
</tbody>
</table>

General Chemistry

| Alkalinity           | -       | 121 ppm as CaCO₃ | 101 ppm as CaCO₃ | 113 ppm as CaCO₃ | 119 ppm as CaCO₃ |
| Bicarbonate          | -       | 119 ppm as CaCO₃ | 100 ppm as CaCO₃ | 112 ppm as CaCO₃ | 118 ppm as CaCO₃ |
| Calcium              | -       | 34 ppm as CaCO₃ | 47 ppm as CaCO₃ | 49 ppm as CaCO₃ | 53 ppm as CaCO₃ |
| Chloride             | 250 ppm | 25 ppm         | 60 ppm          | 71 ppm          | 76 ppm          |
| Hardness             | -       | 6.6 grs/gal    | 8.0 grs/gal     | 8.5 grs/gal     | 8.9 grs/gal     |
| Magnesium            | -       | 5 ppm          | 2 ppm           | 2 ppm           | 3 ppm           |
| Potassium            | -       | 5 ppm          | 2 ppm           | 3 ppm           | 4 ppm           |
| Silica               | -       | 55 ppm as SiO₂ | 32 ppm as SiO₂ | 35 ppm as SiO₂ | 40 ppm as SiO₂ |
| Sodium               | -       | 47 ppm         | 38 ppm          | 44 ppm          | 49 ppm          |
| Sulfate              | 250 ppm | 51 ppm         | 24 ppm          | 27 ppm          | 29 ppm          |
| Total Dissolved Solids| 500 ppm | 296 ppm       | 274 ppm        | 309 ppm        | 334 ppm        |
| Free Chlorine Residual | -   | 0.7 ppm       | 0.4 ppm        | 0.7 ppm        | 1.1 ppm        |
| Conductance          | -       | 421 m/cm       | 427 m/cm       | 503 m/cm       | 538 m/cm       |
| pH                   | 6.5-8.5 su | 7.8 su       | 7.4 su         | 7.5 su         | 7.8 su         |
| Temperature          | -       | 68°F           | 65°F           | 72°F           | 80°F           |
| Total THMs           | 100 ug/l | 5.1 ug/l      | ND             | 0.61 ug/l      | 1.1 ug/l       |
6.2 Monitoring Process

Sample collection to evaluate the performance of the POU system commenced three hours after the unit was installed. The first sample was collected at 23:18 on March 30, 2001. Samples were collected in 20-milliliter glass vials, preserved with 0.5 milliliters of nitric acid (HNO₃), and refrigerated until time of analysis. Sampling protocol the first week of evaluation consisted of collecting three samples per day. One sample was collected approximately every eight hours. One sample per day was collected the second week. Sampling was conducted on an every-other-day basis starting the third week and continued until the study was terminated. Samples were collected at the dispenser at approximately the same time each day. Sample vials were thoroughly cleaned and rinsed with distilled water and rinsed again with treated sample water before final samples were collected.

Samples were analyzed for arsenic concentration by graphite furnace atomic adsorption spectroscopy at the Department of Civil Engineering Laboratory on the campus of the University of New Mexico. Arsenic standards of 10, 20 and 30 ug/l were used to calibrate the atomic adsorption unit and testing procedures were in accordance with approved EPA methodology.

The system's flow rate was checked weekly by measuring the volume of flow from the dispenser into a graduated cylinder over a one-minute time interval. This check helped assure the proper contact time for the adsorption process was maintained. pH tests were also conducted each week. pH was measured using a hand-held pH meter and all samples were collected at the POU system's tap. pH test results are located in the appendix.
An operations schedule alternating between filling the system's storage tank and letting the treated water free flow from the tap was initiated to help achieve exhaustion of the AA FS-50 adsorption media more rapidly. The system was alternated every forty-eight hours for the first three weeks of the study and then allowed to flow freely for the remainder of the study. The operations schedule log is located in the appendix.

**VII Maintenance Procedures**

**7.0 Maintenance Procedure**

Point-of-use water treatment devices have demonstrated the capability of providing suitable treatment for a number of contaminants. Reverse osmosis POU systems have been utilized for many years in San Ysidro, New Mexico. Documentation shows POU systems must be well maintained if they are to perform properly. The Village of San Ysidro, New Mexico was provided an EPA grant in 1987 to install POU reverse osmosis units to remediate high levels of arsenic in the public drinking water supply. The units were maintained and evaluated by an EPA contractor for two years following installation. During the two year study period the units attained 86 percent arsenic removal (Rogers, 1990). Maintenance and inspection duties were turned over to the Village at the conclusion of the study period. Unfortunately, the POU devices have not been well maintained and removal efficiencies have dropped dramatically (O'Grady and Thomson, 1998).

This section describes the necessary maintenance procedures for the POU system evaluated in this study.
7.1 Major Component Maintenance

Pre-filter- The sediment pre-filter lengthens the life of the AA FS-50 filtration cartridge by removing sediment particles capable of clogging the adsorption media and severely shortening its life expectancy. According to the manufacturer, average sediment filter life is about six months (Sears, 1999). A good indication as to when the sediment pre-filter needs to be replaced is when the pressure to the dispenser drops. Replacing the sediment pre-filter on a 6-8 month interval will help extend the lifecycle of the adsorption media and aid its effectiveness.

Activated Alumina Adsorption Cartridges- The AA FS-50 adsorption cartridges is the most important part of the system. Effective arsenic removal cannot be achieved without regular replacement of exhausted cartridges. This study has shown that the AA FS-50 cartridges must be replaced every 6-8 months to assure effective arsenic removal. Following the correct replacement schedule for the AA FS-50 cartridges will assure effective arsenic removal from drinking water.

Post-Filter- The sediment post filter protects the flow restrictor from becoming plugged with adsorption media that may have escaped its containment cartridge. If the flow restrictor were to become clogged with AA FS-50 particles, water would cease to flow through the system. The sediment post-filter should be replaced on the same 6-8 month interval has the sediment pre-filter to ensure effective performance.

Flow Restrictor- The polyethylene flow restrictor should be inspected for leaks and blockages on a monthly basis. The performance of the flow restrictor is critical. If the flow restrictor fails to function properly by becoming clogged water is unable to flow
through the system. Leaks will prevent proper contact time and effective arsenic removal will not be achieved. Inspecting the flow restrictor monthly will assure its performance.

7.2 Minor Component Maintenance

Although it is critical for the major components of the POU system to receive regular maintenance and inspection, it is also important for the minor components as well. Minor components including tubing, tubing connectors, pressurized storage tank, dispenser and filter housing canisters should be checked regularly. At a minimum, tubing and tubing connectors should be inspected when cartridges and filters are replaced. It is advisable they be inspected monthly for leaks that may prevent the units from operating properly. The pressurized storage tank should be assessed for leaks or other damage monthly. After prolonged use (3-5 years), it may be necessary to replace the storage tank. The bladder may eventually wear and fail to hold water (PAMIC, 2000). The dispenser should be kept clean and leak-free in order to prevent damage to countertops and carpentry beneath the sink. Housing canisters should be scrubbed with soap and water and rinsed with each cartridge or filter change. It is important to inspect housing canisters monthly and make sure they are tightened securely to prevent leaks (Sears, 1999).

Regular maintenance and inspection will help assure the POU system functions properly. Failure to replace filters and cartridges as recommended may result in improperly treated drinking water and a shortened system lifecycle.
VIII Arsenic Chemistry and System Performance

8.0 Arsenic Chemistry

Adsorption by activated alumina is a water treatment process in which arsenic is adsorbed onto the activated alumina surface. This is accomplished in a packed bed of activated alumina granules. Source water is continually passed through the bed until the adsorbent is exhausted, as evidenced by the breakthrough of the unwanted contaminant at an unacceptable concentration in the effluent (Clifford, 1999). Activated Alumina FS-50 is an excellent adsorbent in this regard, as it has the following characteristics (ALCAN, 2001):

- High Surface Area
- High Porosity
- Broad pore size distribution
- High crush strength
- Low pore blockage
- High adsorption rate
- Low cost

Activated alumina processes are sensitive to pH, and anions are best adsorbed below pH 8.2, a typical zero point of charge (ZPC), below which the alumina surface has a net positive charge, and excess protons are available to fuel the adsorption reaction. Above the ZPC, alumina is predominantly a cation exchanger (Clifford, 1999). Because activated alumina has a higher pH (ZPC) than most oxide minerals, it has an affinity for anions such as arsenic, especially arsenic V (arsenate) in water. The removal process exchanges hydroxide ions for the contaminant (arsenic). For this reason, contaminants
removed by AA FS-50 adsorption must be negatively charged (anionic) and the pH of the water must be sufficiently low so that the surface of the AA FS-50 is positively charged (cationic). The chemical reaction is as follows:

\[ \text{Al-OH} + \text{H}^+ + \text{H}_2\text{AsO}_4^- \Rightarrow \text{Al-H}_2\text{AsO}_4^- + \text{HOH} \]

The optimum pH for arsenic adsorption on to activated alumina is 5.5 to 6.0 (Clifford, 1999). This process requires the addition of a strong acid such as sulfuric or hydrochloric acid to lower the pH. Increased TDS levels shorten the life expectancy of the sediment filters, media cartridges and the addition of acid creates hazardous waste. pH adjustment for point-of-use systems is impractical and therefore AA FS-50 cartridges are exhausted more quickly than would be if a pH adjustment were made.

Arsenic contamination is almost exclusively a ground water problem. The primary arsenate species found in ground water in the pH range of 6 to 9 are monovalent \( \text{H}_2\text{AsO}_4^- \) and divalent \( \text{HAsO}_2^- \). pH level is important to arsenic removal from ground water using activated alumina (Clifford, 1999). Theoretically arsenite is not removed by activated alumina adsorption, but arsenate is readily removed. This is true because arsenate is negatively charged and thus adsorbs more readily onto the activated alumina.

To achieve effective removal of arsenic from ground water by activated alumina adsorption, arsenite must be oxidized to arsenate. The oxidation process is easily accomplished through the addition of chlorine. In a laboratory study greater than 95 percent oxidation of arsenite to arsenate was observed in the presence of 1 ppm free chlorine in the 6 to 10 pH range in less than five seconds (Clifford, 1999). Activated alumina adsorption of arsenate is highly dependent on pH: at alkaline pHs where
hydroxide competition is significant, arsenate adsorption is poor. As the pH is lowered arsenate adsorption increases dramatically until about pH 5.

Particle size and empty-bed contact time can significantly influence arsenic removal by AA FS-50. Research shows that finer particles have a higher arsenic adsorption capacity, lower leakage and longer life expectancy than larger particles. Also, studies indicate an empty-bed contact time of 3-12 minutes is necessary for effective adsorption (Clifford, 1999).

**8.1 Activated Alumina FS-50 System Performance**

Treated water samples were analyzed by graphite furnace atomic adsorption spectroscopy using a Varian SpectrAA-64OZ graphite furnace atomic adsorption spectrophotometer in accordance with Standard Methods 3113B. Sample analyses results are located the appendix. The detection limit of the atomic adsorption unit is 2 ug/l. Figure 16 shows the results of the analyses in graphic form, from which, the performance of the system can be determined. Sample values below detection limit are plotted as 1 ug/l.

Arsenic removal by adsorption onto Activated Alumina FS-50 was extremely effective during the first 4,000 bed volumes (1 bed volume = 1 liter) treated. Arsenic was reduced from an average source water concentration of 24 ug/l to non-detectable levels.

At a near continuous flow rate of 100 milliliters per minute, it took about one month for arsenic breakthrough to occur. The first sign of significant breakthrough occurred after 4,000 bed volumes when an arsenic result of 4.2 ug/l was recorded. As previous discussion indicated, the final arsenic standard for drinking water is still in debate. A standard in the 10-20 ug/l range could increase significantly the number of bed volumes capable of being effectively treated by this system.
After the first three weeks, the system was operated continuously for this study. Under normal residential operating conditions arsenic breakthrough would not occur until after approximately 250 days (see Section 9.4). Exhausted cartridges would therefore need to be replaced every 6-8 months.

Under normal operating conditions, the system would not be running continuously, as in this study. Operation of the system would be intermittent. Intermittent operation would significantly prolong the lifecycle of the adsorption cartridge, due to the fact that when water is not flowing through the adsorption media it
remains within the cartridge. Water retained within the adsorption cartridge already has arsenic removed from it, and is not exhausting adsorption sites on the media as water would if it were flowing through the system continuously. Testing of the POU system under intermittent use is needed to determine exactly how many additional bed volumes could be treated before arsenic breakthrough occurs.

pH adjustment will improve the arsenic adsorption capacity of the media. pH adjustment was not incorporated into this system. The average source water pH for this study was 7.5, significantly higher than the optimum range of 5.5 to 6.0 for arsenic adsorption onto activated alumina. Higher source water pH reduces the number of bed volumes that can be treated effectively by the AA FS-50 system before breakthrough occurs. This is due to the fact that the surface of the AA FS-50 media becomes less positively charged in the presence of higher alkaline source water. Water of alkaline pH contains an excess of hydroxide ions that are negatively charged, causing electrostatic repulsion, thus reducing the adsorption capacity of the media. AA FS-50 shows promise for use in POU systems under normal operating conditions without pH adjustment.

IX Cost Evaluation

9.0 Cost Evaluation

An integral part of this project was to determine the cost of manufacturing, installing and maintaining the point-of-use system. Although it was not practical to determine actual costs of building the system because it was fabricated by modifying an existing system, it was possible to determine the additional costs of the system. Additional costs include fabricating the activated alumina adsorption cartridge, adding an
additional housing canister to the existing system, constructing the flow restrictor and maintaining the system.

According to the National Sanitation Foundation (NSF) there are currently 21 manufacturers of point-of-use drinking water treatment units. Companies including: General Electric, Culligan, Ecowater, Sears, U.S. Filter, Apyron and Pure Water all manufacture and distribute point-of-use drinking water treatment devices (National Sanitation Foundation, 2000a). Many of these units have arsenic removal capabilities. In fact, Apyron has designed the Aqua-Bind MP Arsenic (V) removal cartridge. Aqua-Bind MP is a specially designed granular chemical media for removing arsenic from water. The media has been certified by the National Sanitation Foundation and the standard size cartridges are designed for use in a number of currently available POU systems (Apyron Technologies, Inc., 2001).

POU drinking water treatment units are readily available at numerous retail outlets including Lowe's, Home Depot, Sears and Home Base. Units typically range in cost from $30 to $300. Treatment units employing filtration are less expensive, usually less than $100, while units utilizing more sophisticated technologies such as reverse osmosis retail for about $150-$250. Reverse osmosis units are capable of removing arsenic whereas conventional filtration systems will not. None of the aforementioned 21 manufacturers utilize AA FS-50 media in their systems.

9.1 Added Cost of Manufacture

The significant difference between systems currently available and the system fabricated for this study is the adsorption media. There are several types of activated alumina commercially available. Activated Alumina FS-50, manufactured by ALCAN,
was used for this project. Activated Alumina FS-50 sells for $1,800/metric ton or about 88 cents per pound (Azizian, 2001). Approximately one pound or 454 grams of AA FS-50 is used per cartridge. The plastic cartridge used for containing the media needs to be added to the cost of the activated alumina. Assuming the cartridges are produced in mass quantities, the cost would be less than two dollar per cartridge. Considering the low cost of the absorbent media and cartridges, the AA FS-50 adsorption cartridges should cost $3-$5 per cartridge. Flowmatic, Inc. sells POU activated alumina cartridges similar to AA FS-50 for $3. Activated Alumina FS-50 cartridges would sell for about the same or less.

Activated carbon cartridges for use in current POU filtration systems retail for about $12 each (Flowmatic, 2001). The cost of producing the flow restrictor must also be considered. Due to the low cost of material, (polyethylene) used to construct the flow restrictor and the fact restrictors would be produced in mass quantities, no appreciable cost would be added to the unit.

The POU system modified for this study was a Sears Kenmore Undersink Water Filter System. It utilizes two housing canisters, in which, different filter cartridges can be placed. The system retails for $80. As described previously, an additional housing canister was added to the dual system. The cost of the additional housing canister was $20. Sediment filters retail for about $4 each. The cost of the system not including the storage tank was $111. Locating the flow restrictor ahead of the housing canisters eliminates the need for a post-filter. Employing this design eliminates the need for an additional housing canister and thus reduces the cost of the system by $20, from $111 to $91.
Pressurized water storage tanks with a capacity of 3.2 gallons, range in price from $25 for slightly damaged tanks to $60 for new tanks (PurePro USA, Inc., 2001). The average cost for a storage tank among three distributors surveyed was $50. The total cost of the system was approximately $161, including the water storage tank, filters, cartridges, Activated Alumina FS-50 and connectors. Table 3 summarizes the cost of the system. Assuming the same manufacturing processes used to produce currently available POU systems can also be used in manufacturing an AA FS-50 POU system the total retail cost would be approximately $160-$170.

Table 3: Summary of Costs for AA FS-50 POU System

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<th>Component</th>
<th>Number</th>
<th>Cost</th>
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<tr>
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<td>$8</td>
</tr>
<tr>
<td>AA FS-50 Cartridges</td>
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<td>$3</td>
<td>$3</td>
</tr>
<tr>
<td>Filtration system (with tubing and connectors)</td>
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<td>$80</td>
<td>$80</td>
</tr>
<tr>
<td>Housing canister</td>
<td>1</td>
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<tr>
<td>Water storage tank</td>
<td>1</td>
<td>$50</td>
<td>$50</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td><strong>$161</strong></td>
</tr>
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</table>

One change to the manufacturing process would include substituting activated alumina for activated carbon or other adsorption media during the cartridge production phase. This change would be easy to accommodate given the similarity of particle size between the different media.

The cost of producing an AA FS-50 system therefore would be competitive with the cost of producing many currently available POU systems. The price range for an AA FS-50 system can be estimated by using the costs described above at $160-$170. The
same price range as many currently available POU filtration systems not capable of removing arsenic. The availability of numerous types of activated alumina could increase or decrease the cost slightly depending on the cost and type of activated alumina used. Variations to the design of the unit have the potential for altering the manufacturing cost slightly as well. Design variations are discussed in a subsequent section. The additional cost of manufacture estimate is based upon costs associated with fabricating the POU system prototype evaluated in this study. Determining the actual costs of producing the AA FS-50 cartridges and flow restrictor would provide a more accurate estimate of the total cost of the system.

9.2 Installation Costs

Installation costs include the cost of equipment, materials and labor necessary to place the POU system in service. The cost of equipment and materials needed to install the system are virtually non-existent considering water utilities choosing to utilize POU systems are most likely in possession of the tools required to perform installations. Materials necessary to install the system, such as, tubing and some tubing connectors are included with the unit. Reducing connectors for changes in tubing size are additional and retail for about $3 each. Depending on the size of the tubing used for the flow restrictor, reducing connectors may or may not be needed.

Common hand tools such as wrenches, pliers and screwdrivers are needed to install the system. The only power tool that may be required is an electric drill to make a hole in the counter top to facilitate installation of the dispenser. The cost of drills and drill bits would be included in the installation costs, if the water utility were not in possession of this equipment.
The only significant cost of system installation is labor cost. Water system installers employed by Culligan, Inc. of Albuquerque are paid $12 per hour on the average (Culligan, 2001). Small water utilities electing to employ point-of-use treatment for arsenic removal would most likely employ certified operators or trained laborers to install systems. Small water systems serving less than 10,000 people are required to employ State Certified Level I or Level II Water System Operators. The pay range for a Level II Operator in Truth or Consequences, New Mexico (T or C) is $10-$14 per hour. T or C has a population of less than 10,000 people and employs Level II Operators (Truth or Consequences, 2001). For the purpose of calculating installation costs, a value of $20 per hour for labor was used. This hourly wage represents the average of the pay ranges described above plus the cost of benefits. It represents an educated estimate of per hour labor costs water systems may incur when installing POU systems.

According to Culligan, Inc. (2001), POU systems can be installed in about 1 hour. It took slightly over one hour to install the system used for this project. At a rate of $20 per hour labor cost and using one hour as the average installation time required, POU systems like the one used in this study can be installed for an estimated $20-$25 per unit. This figure takes into consideration labor and installation equipment costs. Total cost of installation per unit, including the cost of the POU system, is about $181. Labor cost to install the system is relatively insignificant compared to the initial cost of the system.

In some cases, public water systems may contract with a plumbing company to install the POU systems. If a plumbing contractor is used, labor costs could be as much as $50 per hour, increasing the cost of installing the units to over $200 each.
9.3 Maintenance Costs

In order to perform effectively systems must be well maintained. Regularly scheduled inspections are vital. Routine maintenance procedures include inspecting the unit for leaks or other problems and replacing filters and cartridges. POU systems should be inspected on a quarterly basis according to literature supplied by most manufacturers. Using the $20 per hour rate described in the previous section, the following calculation can be made. One hour, maximum, is the estimated time needed to inspect, repair and replace filters, cartridges or other components during routine maintenance inspections. This takes into account estimated costs of $3 per AA FS-50 cartridge and $4 per sediment filter. The AA FS-50 POU system has an estimated life expectancy of five years. Replacement costs for the system must also be included. Maintenance costs per POU system are calculated as follows:

System life = 5 years

Replacement cost = $161 (cost of system)/5 years = ~$32/year

Labor = 2 hours/year @ $20/hr = $40

Sediment filter replacement 4 @ $4 = $16/year

AA FS-50 cartridge replacement 2 @ $3 = $6/year

Total = $94 per unit/year or ~$8 per month

The Village of San Ysidro, New Mexico, is a good example of a small water system employing point-of-use systems. It serves as a good example to further illustrate maintenance costs. The San Ysidro water system includes 90 POU systems used to treat drinking water for its residents (Rogers, 1990). The calculation above can be expanded to estimate the yearly maintenance costs for a small water utility utilizing POU activated alumina adsorption.
1 hour X 2 inspections/year X 90 units = 180 inspection hours/year

$20/hour (labor) X 180 hours = $3,600/year (labor cost)

$20/unit (supplies) X 90 units X 2 inspections/year = $3,600/year (supplies)

$3,600 (labor) + $3,600 (supplies) = $7,200/year (Maintenance cost for entire system)

 Depending on the performance of the AA FS-50 cartridges used and the quality of water treated by the systems, replacement of the filters and cartridges may be required more or less frequently. Performance of Activated Alumina FS-50 cartridges used in this study is discussed in a subsequent section. The calculation above is based on replacing both AA FS-50 cartridge and sediment filters every six months.

 POU systems maintenance costs for the San Ysidro water system described above is applicable to many small water systems. Small water systems needing to provide arsenic treatment and lacking the financial resources to implement centralized water treatment may benefit from point-of-use systems. The $7,200/year maintenance cost coupled with initial installation costs is less expensive in most cases than building and maintaining centralized treatment facilities.

9.4 Maintenance of AA FS-50 System

Data collected during the evaluation of the Activated Alumina FS-50 system for this project suggests the following maintenance requirements. Special emphasis is given to replacing exhausted AA FS-50 cartridges. Regular replacement of exhausted cartridges is critical in order to achieve effective arsenic removal. Performance data collected during this study indicates cartridges need to be replaced after about 4,000 bed volumes.
treatment facility added to the cost of maintaining the treatment plant and employing qualified operators precludes many small systems from utilizing conventional systems. Often small water systems are located in rural areas and have difficulty attracting and retaining qualified employees.

Problems such as those described above make POU treatment a viable option for small water systems. A minimal staff can maintain POU treatment devices. Using regularly scheduled maintenance appointments one operator or maintenance technician can perform maintenance on several units daily. Quarterly inspections are typically required and costs associated with POU systems are much less than those of conventional systems. In many instances, residents themselves are capable of maintaining their own POU system.

Small water systems such as San Ysidro and Columbus, New Mexico, have exceptionally high arsenic concentrations in their drinking water supplies. These communities have only a few hundred residents and could benefit greatly from a point-of-use arsenic removal system like the one evaluated for this project. The effectiveness of the units would rely on proper regular maintenance. A few simple procedures that can be followed by the residents would ensure a long system life expectancy and effective arsenic removal.

10.1 Residential Maintenance

The effective removal of arsenic by the AA FS-50 POU system depends on replacing exhausted media cartridges. Based on the performance measured in this study, AA FS-50 cartridges should be replaced every 6-8 months. A program could be established requiring each resident utilizing a POU system to bring in their exhausted
cartridge every six months in order to receive a fresh one. At this time, the resident would be given their water bill. Failure to exchange the exhausted cartridge would lead to a service charge being added to the customer's water bill. Incentives for exchanging exhausted cartridges such as a discount on the following month's water bill could be offered. Small systems usually have only a couple hundred customers or less and requiring biannual exchange of exhausted cartridges could be easily accomplished.

Prior to installation, the filter housings (see Figure 7) could be color coded in order to facilitate easier filter and cartridge replacement. For example, the AA FS-50 cartridge housing could be painted red or a clear housing could be used. This would make it easier for the customer to identify which housing compartment they need to remove and replace the cartridge from. No tools are needed to perform this task and it takes only a few minutes.

In some instances, customers will be unable to come in and exchange exhausted cartridges at the water utility office. In these cases, they can phone in and make arrangements for a utility employee to come to their home and make the exchange, deliver their water bill and switch out the spent cartridge if need be. It is advisable to have POU systems serviced once a year by water utility employees in order to replace sediment filters and inspect for damage, but this is not a hard rule. If need be, customers themselves could replace their own sediment filters and conduct their own inspections.

There are some variations to this residential maintenance program that can be used as well. For instance, having a meter reader leave a new cartridge every six months during his/her rounds and requiring the customer to bring the exhausted cartridge to the water utility office in order receive their water bill. Cartridges could be mailed out twice
a year and a couple of days could be set aside to allow for water utility employees to make rounds and collect used cartridges. Utilizing any number of methods would make residential maintenance practical and eliminate many maintenance costs incurred by a water utility utilizing AA FS-50 POU systems.

10.2 Regulatory Considerations

POU systems have demonstrated the ability to effectively remove many types of water contaminants depending on the type of POU system used. State and federal regulations govern the use of POU systems. The National Sanitation Foundation (NSF) and the American National Standards Institute (ANSI) set certification standards for POU systems as part of the regulatory effort as well. This section describes state, federal and NSF/ANSI regulations affecting POU systems.

The Safe Drinking Water Act

The Safe Drinking Water Act (SDWA) is the major federal legislation affecting the use POU drinking water treatment systems. Currently, only reverse osmosis POU systems are acceptable for treating arsenic in public drinking water under SDWA (EPA, 2000a). The Safe Drinking Water Act contains strict regulations for operating and maintaining POU systems. These regulations affect the general use of POU systems, and how a residential maintenance program might be operated for an activated alumina POU adsorption system.

Implementing a residential maintenance program such as the one described in section 10.1 would require amending Safe Drinking Water Act regulations governing the use of POU systems. Section 1412 (b) (4) (E) (ii) of the Safe Drinking Water Act requires the following from public water systems utilizing POU systems:
• The systems must be maintained, controlled and owned by the water utility and not the water customer.

• The systems must be certified by NSF/ANSI where standards exist.

• The systems must be equipped with a mechanical warning device to alert customers when the system is out of compliance.

Although these requirements are important for insuring effective treatment of drinking water by POU systems, perhaps the regulations could be changed to allow for residential maintenance programs. A rules change would decrease maintenance costs incurred by small water systems utilizing POU systems and make arsenic treatment more affordable. Expanding the list of acceptable POU systems to include systems not utilizing reverse osmosis, may also help some water systems find affordable arsenic treatment technologies.

State of New Mexico Regulations

In New Mexico, public water supply systems can obtain a variance or an exemption from any MCL or water treatment technique from the New Mexico Environment Department (NMED). Under section 74-1-8 of the New Mexico Statutory Authority, POU systems in New Mexico must meet the following requirements (New Mexico Statutory Authority, 1978):

• The public water supply system must operate and maintain the POU treatment systems.

• Before POU systems are installed, the public water systems must obtain approval of a monitoring plan from NMED which ensures that the devices provide health protection equivalent to that of central water treatment.
• The POU systems must be operated under a plan approved by NMED. The microbiological safety of the water must be maintained at all times.

• NMED requires certification of performance, field testing, and a rigorous design review of the POU systems.

• The design and application of the POU systems must consider the risk for increasing concentrations of heterotrophic bacteria in water treated with activated carbon. Measures must be taken to ensure the microbiological safety of the water.

• NMED must be assured that buildings connected to the systems have sufficient POU devices that are properly installed, maintained and monitored such that all consumers will be protected.

• NMED must be assured that as a condition for granting approval for use of a POU system that the use of the device will not cause increased corrosion of lead and copper bearing materials located between the device and the tap that could increase contaminant levels at the tap.

San Ysidro, New Mexico, is currently operating under a drinking water treatment variance. It is possible, NMED might grant a variance for use of an activated alumina POU adsorption system for arsenic removal as long as the above requirements are complied with.

NSF/ANSI Certification of POU Systems

The NSF and ANSI have been involved in evaluating the design and performance capabilities of drinking water treatment devices for over three decades. The EPA asked NSF and ANSI to develop consensus standards and certify contaminant reduction claims
for these products. Each drinking water treatment device standard requires (NSF, 2001 b):

- Verification of contaminant reduction
- Structural integrity testing of the product
- Toxicological assessment and acceptance of all materials used in the fabrication of the product
- Extraction testing and health effects assessments of all materials in contact with the water to assure the product is not adding any substance of toxicological significance.
- Review and acceptance of all labeling and sales literature used with the product

There are currently six NSF/ANSI standards relating to water filtration and treatment devices, each one designed for a specific type of product (NSF, 2001 b). NSF/ANSI Standard 53 applies to POU treatment systems that are plumbed-in. This type of system is usually installed under the kitchen sink and requires permanent connection to an existing water pipe. Standard 53 applies to adsorption style units and covers contaminants that can harm human health if present in quantities which exceed recommended levels. Adsorption style units include carbon and granular activated charcoal filters. Although not approved for use by EPA, NSF/ANSI has certified several POU adsorption systems capable of removing arsenic. The activated alumina system evaluated in this report would fall under NSF/ANSI Standard 53 (NSF, 2001 b).

As shown in the cost evaluation section of this report, point-of-use treatment is far more affordable for many small water systems than operating and maintaining conventional treatment facilities. A POU treatment system program can be maintained for thousands of dollars per year whereas conventional treatment can cost hundreds-of-

thousands of dollars or more per year. Many small water systems in New Mexico and elsewhere would be wise to investigate POU drinking water treatment, especially for arsenic removal.

**XI Recommendations**

11.0 Recommendations

Performance results obtained during this study show exhausted AA FS-50 cartridges need to be replaced every 6-8 months in order to maintain effective arsenic removal without lowering source water pH. Exchange of spent cartridges 1-2 times per year suggests a POU activated alumina adsorption system utilizing AA FS-50 may be economically feasible for small water systems. Improvements made to the system may improve its performance and increase its affordability even more.

In the area of increasing the affordability of the system, one change that could be incorporated into the design would be to relocate the flow restrictor. Moving the flow restrictor to a location prior to water entering the cartridge housing would eliminate the need for an additional housing canister (See Figure 6). The need for a post-filter would be eliminated due to the fact the flow restrictor would now be located in advance of the AA FS-50 cartridge and concern over escaped particles plugging the flow restrictor's tiny orifice would be eliminated. This modification would reduce the cost of the system by $20-$25.

In the area of improving the system’s performance, most of the changes that could be made involve modifying the media cartridges in some fashion. One option is to design a larger filter cartridge capable of holding more adsorption media. Figure 17 shows what
larger cartridge housings might look like. The actual media cartridges would be only slightly smaller than the housing. This modification would allow for more AA FS-50 to be contained within the cartridge and thus lengthen the amount of time before arsenic breakthrough occurs. About twice as much adsorption media could be contained within a larger cartridge, therefore doubling cartridge exhaustion time. This modification cuts maintenance cost in half, making such a system even more affordable. One drawback is larger cartridges and housings require more room under sinks and this may reduce the number of locations in some homes where these systems can be installed. Many POU systems utilizing larger sized cartridges are already on the market, making this type of alteration to the system easy to accomplish.

Figure 17: Large Housing Canisters (Source: PurePro, 2001).

A system utilizing two media cartridges run in series may also increase the performance of the system with regards to increasing the length of time before arsenic breakthrough is achieved. Not only could this alteration increase the system's arsenic removal effectiveness, it may also eliminate the need for a flow restrictor. The increased amount of time required for water to pass through the system may be enough to provide the contact time necessary for effective arsenic adsorption. Furthermore, it may be
possible to design an oversized "stand alone" AA FS-50 filter capable of remediating arsenic as the only component of a POU system. If the filter design were large enough, long run lengths could be achieved and maintenance costs reduced. Designing an AA FS-50 filter resembling the water storage tank used in this study might be achievable. The affordability of AA FS-50 makes many designs possible. In order to comply with Safe Drinking Water Act requirements the AA FS-50 POU system also needs to be equipped with a mechanical warning device to alert customers when the unit is out of compliance. This could be accomplished in a number of ways including attaching a total dissolved solids (TDS) meter with a warning light to the unit. When the TDS concentration reaches a pre-set level the warning light would illuminate indicating to the customer that the AA FS-50 cartridge needs to be replaced.

This study evaluated Activated Alumina FS-50 as an arsenic adsorbent. There are several other types of adsorption media capable of effectively removing arsenic. Granular ferric hydroxide, iron oxide, magnesium oxide and others are included in this group. Evaluating the performance of other types of media using the same POU system would have been beneficial to this project. Perhaps another type of media would have achieved longer run lengths without pH adjustment and proven to be more affordable. It is difficult to determine the exact lifecycle of AA FS-50 cartridges without knowing what the final arsenic standard will be.

Evaluating POU systems incorporating the design modifications discussed above would have also been beneficial to this project. Alterations to the design of the POU system used in this study may have proven better performing and more affordable.
XII Conclusions

12.0 Conclusions

This report has investigated and determined the performance, affordability and applicability of a point-of-use drinking water treatment unit utilizing Activated Alumina FS-50 as an adsorbent. The chemistry of arsenic adsorption includes many factors. Most notable is the role pH plays in arsenic adsorption. Research has shown optimal arsenic removal for conventional activated alumina occurs in pH range 5.5-6.0 (Clifford, 1999). The settings in which POU systems are applicable make pH adjustment of source water impractical. For this reason, pH of source water was not adjusted for this study. In any case, arsenic removal was significant during the first 4,000 bed volumes treated by the AA FS-50 system. It is difficult to estimate the number of bed volumes that can be effectively treated for arsenic without knowing what the final drinking water standard for arsenic will be. Even so, the AA FS-50 system evaluated here proved effective and affordable. Proper pH adjustment would have increased run lengths achievable by this system even more. Longer run lengths equate with reduced maintenance costs and increased affordability. This study suggests that under typical operating conditions a POU treatment system using AA FS-50 may be practical for many small water systems. Data indicate spent cartridges need to be switched out every 6-8 months. Alterations to the design of the system evaluated here have the potential for improving the system's performance and further increasing its affordability and applicability. Further investigation is needed to make such a determination however.

Nationwide, many small water systems, often serving less than a few hundred residents, will need to implement some type of arsenic treatment soon. Point-of-use
systems offer an economical alternative to expensive central treatment facilities. Within a few months time, a new drinking water standard for arsenic should be promulgated and many small water systems will have to accelerate their search for practicable and affordable treatment options. The AA FS-50 Point-of-Use system evaluated in this report may provide some of these systems with a viable arsenic removal option.
References


Appendix

Treated Arsenic Samples
Untreated Arsenic Samples
pH Analyses
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