The Mucilage of Opuntia Ficus Indica: A Natural, Sustainable, and Viable Water Treatment Technology for Use in Rural Mexico for Reducing Turbidity and Arsenic Contamination in Drinking Water

by

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A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Chemical Engineering Department of Chemical Engineering College of Engineering University of South Florida

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Dedication

The dedications of a thousand theses would not suffice as a thank you to my loving parents, Mr. Jeffery B. Young and Mrs. Nancy S. Young, for their sacrifice, hard work, understanding and support for my goals. The successes I have experienced would not have been possible without them selflessly adopting my personal goals as their own. For that, I am eternally grateful.

This work is also dedicated to the memories of those lives lost from arsenic poisoning due to contaminated drinking water.
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The Mucilage of *Opuntia Ficus Indica*: A Natural, Sustainable, and Viable Water Treatment Technology for Use in Rural Mexico for Reducing Turbidity and Arsenic Contamination in Drinking Water

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ABSTRACT

The use of natural environmentally benign agents in the treatment of drinking water is rapidly gaining interest due to their inherently renewable character and low toxicity. We show that the common Mexican cactus produces a gum-like substance, cactus mucilage, which shows excellent flocculating abilities and is an economically viable alternative for low-income communities. Cactus mucilage is a neutral mixture of approximately 55 high-molecular weight sugar residues composed basically of arabinose, galactose, rhamnose, xylose, and galacturonic acid. We show how this natural product was characterized for its use as a flocculating agent. Our results show the mucilage efficiency for reducing arsenic and particulates from drinking water as determined by light scattering, Atomic Absorption and Hydride Generation-Atomic Fluorescence Spectroscopy. Flocculation studies proved the mucilage to be a much faster flocculating agent when compared to $\text{Al}_2(\text{SO}_4)_3$ with the efficiency increasing with mucilage concentration. Jar tests revealed that lower concentrations of mucilage provided the optimal effectiveness for supernatant clarity, an important factor in
determining the potability of water. Initial filter results with the mucilage embedded in a silica matrix prove the feasibility of applying this technology as a method for heavy metal removal. This project provides fundamental, quantitative insights into the necessary and minimum requirements for natural flocculating agents that are innovative, environmentally benign, and cost-effective.
Chapter One

Introduction

1.1. Thesis Structure

This document will serve as an introduction to a possible water treatment method for turbidity reduction and arsenic remediation using Opuntia ficus-indica (OFI) mucilage as a natural material. Chapter One serves as an overall introduction to the project. Chapter Two outlines current accepted turbidity reduction and arsenic removal technologies and analyzes remediation technologies implemented in Bangladesh, West Bengal, India and Mexico. Chapter Three introduces the four Mexican communities surveyed for water contamination and describes the results of socio-cultural impact assessment in Temamatla, Mexico that helped to shape the goals of this project. Chapter Four is an introduction to natural methods of water treatment and to the natural treatment method analyzed in this study, OFI mucilage. Analytical and experimental methods are detailed in Chapters Five and Six while results are discussed in Chapter Seven. Chapter Eight serves as conclusions and recommendations for future work.
1.2. Introduction

Water is a resource essential for life, and water quality commands much attention from the world community. Access to clean water varies with geography, economics, politics, and culture; however, the worldwide community agrees that all of Earth’s citizens deserve access to the planet’s most essential resource. Many people are still affected by contaminated, unhygienic drinking water, especially in developing countries. There are about 1.1 billion people in the world without access to clean water. It has been suggested that household water treatment will be the critical path toward improved health due to the relatively slow process of designing, installing, and delivering piped water to communities [1].

The source of contaminants in drinking water can run the gamut from chemical to biological to geological in such forms as man-made pollution, stagnation or bacterial contamination, or natural sources of harmful minerals. There are a myriad of guidelines outlining requirements for drinking water contaminant concentrations but only two will be addressed in this thesis: turbidity (particle removal) and arsenic.

1.3. Turbidity and Arsenic Poisoning

Drinking water turbidity, or cloudiness, affects a community’s opinion on the safety of certain water sources. The visual aspect of cloudy water is enough to discourage any consumer from drinking water from a faucet, well, spring, or any other source. Turbidities less than 5 NTU (nephelometer turbidity units) are
considered to be “safe” by most consumers, but the World Health Organization (WHO) unofficially considers 0.1 NTU to be the maximum turbidity allowed for disinfection [2].

The turbidity in any water source is due to solids suspended in the water column. These solids result from a variety of sources including resuspended sediments, inadequate filtration, inorganic particles, or biological sources. All sources of turbidity will decrease the effectiveness of the disinfection process because particles promote the growth of microorganisms and protect them from the disinfecting agents. Microbial contamination in drinking water can cause many hygiene-related illnesses such as diarrhea and infectious diseases [3]. Turbidity reduction can vastly improve the effectiveness of disinfection methods [2]. Although WHO unofficially considers 0.1 NTU as a maximum turbidity allowance, they currently have no guidelines on drinking water turbidity [2].

The prevalence of arsenic in drinking water is variable, depending on water source and location. Arsenic can be found in rainwater, surface waters, and groundwaters [4]. The latter poses the greatest health risk to humans due to direct ingestion of arsenic-contaminated well waters [4]. The WHO recognized the risks of ingesting arsenic-contaminated ground water in 1958 and, therefore, in 1993 they reduced the recommended guidelines from 0.05 mg L$^{-1}$ (50 µg L$^{-1}$) to 0.01 mg L$^{-1}$ (10 µg L$^{-1}$). The WHO based this guideline on current detection limits due to equipment diagnostic abilities [5].

Natural arsenic sources include minerals, rocks, soils, sediments, and the atmosphere where arsenic is transported due to industrial effluents, fossil-fuel
combustion products, and natural volcanic emissions. Arsenic is not considered a natural constituent of water, so when it is found it is due to several mobilization mechanisms such as physical, chemical, or biological interactions. Mineral-water interactions are often enough to mobilize arsenic through a solid-solution interaction like precipitation-dissolution, adsorption-desorption, or coprecipitation interactions [4].

Adsorption-desorption is the primary arsenic mobilizing interaction in many environments. The As adsorption-desorption potential is a function of many different variables including pH, redox potential, As concentration, the concentration of competing and complexing ions, aquifer mineralogy, reaction kinetics, and biological activity [6]. The mechanism relies upon a surface adsorption phenomenon, implying the presence of suspended solids in the groundwater source. Adsorption-desorption contributing aquifer solids include iron oxides, aluminum oxides, oxyhydroxides, manganese oxides, silica oxides, aluminosilicate clay minerals, carbonate minerals, aquifer solids covered with an adsorbed layer of humic acids, and soil and sediment particles [6]. This dependence upon the presence of solids in groundwater for the occurrence of adsorption-desorption arsenic mobilization supports a need for the simultaneous reduction of turbidity and mobilized arsenic.

Health effects resulting from exposure to inorganic arsenic depend on the exposure amount and exposure duration. Months of exposure to arsenic concentrations of 0.04 mg kg\(^{-1}\) day\(^{-1}\) (considered high) can result in health effects that are usually reversible including diarrhea and cramping, anemia, leukopenia,
and peripheral neuropathy; chronic exposure to high doses for 0.5 to 3 years can result in skin effects like hyperpigmentation. Hyperpigmentation can also be found in those exposed to long durations of low doses (5-15 years). Many other detrimental effects to health are linked to chronic arsenic ingestion including vascular diseases, cardiovascular diseases such as hypertension, diabetes mellitus, immune system disease, respiratory diseases, developmental and reproductive effects, neurological effects, and hepatotoxic effects [7]. The occurrence of some skin, bladder, and lung cancers have also been linked to arsenicosis [8], or the exposure to arsenic over a long period of time [9].

1.4. Introduction to this Study

The overall project is a complex interdisciplinary, international research project merging engineering principles, scientific explorations, and socio-cultural investigations. As such, a network of researchers from different disciplines and countries was assembled to efficiently elucidate a solution for this complex problem of drinking water quality facing Mexican communities. Relationships were formed between investigators in the U.S. and collaborators in Mexico, as well as across the engineering, geology, physical chemistry, and anthropology disciplines. Chemical engineers, geologists and hydrologists, and anthropologists from the University of South Florida in Tampa have combined with counterparts at Mexico's three most important and internationally recognized research institutions to create a successful team of collaborators.
The study represented by this thesis is a contribution to the overall goals of the project. It includes culturally sensitive engineering and scientific investigations into the flocculation and arsenic removal properties of the mucilage of the cactus OFI. It also includes insights gathered with respect to the success of interdisciplinary collaborations.

1.5. Significance of this Study

The WHO recognizes a need for investigations into new low-cost physical and physical-chemical techniques to remove turbidity from household water [10]. This study seeks to uncover an innovative new technology that can be implemented for turbidity reduction and arsenic removal in areas of contamination where citizens are economically unable to invest in the established, accepted, and costly methods of drinking water treatment. In doing so, individuals exposed to arsenic contamination through ingested groundwater will benefit from an inexpensive, easy to implement, and natural technology that will be a socially, culturally, environmentally, and scientifically appropriate way to improve their quality of life and health. In the process, a scientific explanation of a naturally observed phenomenon will be provided: the ability of the cactus OFI to reduce turbidity when added to cloudy waters. Also, investigations into the ability of OFI extracts to remove heavy metals from water will uncover new scientific pathways for research into natural arsenic removal methods.

WHO recognizes the social applicability of drinking water treatment methods as an essential component in their effectiveness [3]. By adhering to
recommended guidelines for social applicability of water remediation projects, this research will also provide a case study in the use of socio-cultural impact assessment for the shaping of project methods and goals.

1.6. Research Goals

1.6.1. Goal One: Turbidity Removal

This project seeks to determine the scientific basis for the use of OFI as a natural flocculant in reducing drinking water turbidity. Specifically, the mucilage of the OFI will be investigated as the primary source of the flocculation process.

1.6.2. Goal Two: Arsenic Removal

It is suspected that the mucilage of the OFI will not only be active in reducing turbidity, but also in removing arsenic from contaminated waters. This project will determine the effectiveness of the mucilage in the reduction of arsenic concentration, which will be a contribution to the final project goal of assessing mucilage effectiveness in the removal of heavy metals including arsenic, selenium, cadmium, as well as other harmful metals.

1.6.3. Goal Three: Chemical Characterization

The third goal of this project is to determine the composition of the mucilage in order to determine the source of its flocculation ability. Also, to determine the mechanism by which the mucilage removes suspended solids and arsenic.
1.6.3. Goal Four: Cultural Sensitivity

The third goal of this project is the overreaching umbrella of cultural sensitivity. The turbidity reduction and arsenic removal technology developed must be implementable, acceptable, and useful in the houses or towns of low-income communities.

1.6.4. Goal Five: Insights into Interdisciplinary Collaboration

The final goal of this project is to extract useful information in the form of protocols and suggestions for success applicable to interdisciplinary collaborations in related studies.

1.7. Delimitations and Limitations of this Study

It has been suggested that technologies developed for implementation in low-income, indigenous communities should be simple and easy to produce, inexpensive, employ native or easily accessible materials, and have a rural focus [11]. These guidelines are the design boundaries for this project. This study also seeks to determine the efficiency of the mucilage of OFI in water treatment in order to determine the least work-intensive, most culturally sensitive way to implement *Opuntia* as a natural method for water treatment in Mexican communities.

The mucilage can be separated into different concentrations of sugars. Depending on the chemical composition, it is easy to extract three substances that can be tested to treat water. As a result, only these three extracted chemicals were utilized in the water treatment analyses described herein.
Chapter Two

Flocculation, Arsenic Removal, and the Socio-Cultural Aspects of Water Quality

2.1. Water Treatment: Turbidity

The World Health Organization (WHO) considers treating biological contamination of turbid water in the home a challenge due to the effect of turbidity in decreasing access to microbes by inactivation mechanisms such as UV radiation from lamps or sunlight [10]. The WHO maintains that,

“There is a need to investigate, characterize and implement physical and physical-chemical technologies for practical and low cost pre-treatment of treatment of household water prior to chlorination, solar disinfection with UV plus heat and UV disinfection with lamps [1].”

The WHO currently recognizes four different categories of turbidity-reduction mechanisms (listed below) as potential areas for investigation [1].

- Settling or plain sedimentation
- Filtering with fibers, cloth, or membranes
- Filtering with granular media
- Slow sand and Biosand filters
Plain Sedimentation

Settling, or plain sedimentation, is simply allowing cloudy water sit for a period of time and letting gravity settle the particulates present. Decanting or ladling out the supernatant leaves the sediment behind. This can be done with any size of water vessel and has been practiced since ancient times [1]. This process has the advantage of being a low-cost way to reduce suspended solids and some microbes, and is generally recommended as pre-treatment before disinfection. Unfortunately, sedimentation will not remove clays and smaller solid particles, nor will it remove smaller microbes [1]. Also, the settling length for some solids can be as long as two days [1].

Membrane Filter

Filtration is another technology that has been in use since ancient times. The WHO recognizes three types of filtering: membranous, granular media, and slow sand and Biosand filters. Membrane filters include filters made of compressed or cast fibers like cellulose papers or synthetic polymer filters, spun threads or woven fabrics. Generally, filters are placed over a water source and are used widely for point-of-use water supply systems. Funnels are also used to pass water through the filters on which solids are collected; a variation of this is the use of porous cartridges. These membrane filters do not always remove all suspended solids or all microbial contamination [1].

Granular Media

The use of sand filters, or other porous granular media filters are the most widely used physical water treatment technology on the community
level. Different technologies have been produced that include the use of different granular media such as sand, anthracite, crushed sandstone, other soft rock, and charcoal. These filters are designed to be used at the household level and include bucket filters, drum filters, barrel filters, roughing filters (one or more basins), and above or below grade cistern filters. Table 1 compares the different granular media filters [1].

Table 1: Granular Media Filter Advantages and Disadvantages.

<table>
<thead>
<tr>
<th>Filter Design</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bucket filter</td>
<td>• Use on a small scale at household level</td>
<td>• May require fabrication by user</td>
</tr>
<tr>
<td></td>
<td>• Simple</td>
<td>• Initial education and training in fabrication and use needed</td>
</tr>
<tr>
<td></td>
<td>• Can use local, low cost media and buckets</td>
<td>• Requires user maintenance</td>
</tr>
<tr>
<td></td>
<td>• Simple to operate manually</td>
<td></td>
</tr>
<tr>
<td>Barrel or drum filter</td>
<td>• Use on a small scale at household or community level</td>
<td>• Requires some technical knowledge for fabrication and use</td>
</tr>
<tr>
<td></td>
<td>• Relatively simple</td>
<td>• Initial education and training needed</td>
</tr>
<tr>
<td></td>
<td>• Can use local and low cost media and barrels or drums</td>
<td></td>
</tr>
<tr>
<td>Roughing filter</td>
<td>• Use on a small scale at community level</td>
<td>• Less amenable to individual household use because of scaling</td>
</tr>
<tr>
<td></td>
<td>• Relatively simple</td>
<td>• Requires some technical knowledge for construction and use</td>
</tr>
<tr>
<td></td>
<td>• Can use local, low cost construction material and media</td>
<td></td>
</tr>
</tbody>
</table>
Bucket filters consist of two buckets - one as a filter and the other as a cistern. The filter bucket has holes drilled in the bottom and a layer several centimeters thick of gravel, on top of which is placed an even thicker bed of sand (0.1 to 1mm grain size). Water is poured through the filter bucket and collected in the cistern bucket. The collected water has a low turbidity, but the sand must be replaced often to avoid the buildup of biological contaminants. Bucket filters are commercially available [1].

Drum or barrel filters are generally configured in a down-flow or up-flow design. A 55-gallon drum is set up much like the filtering bucket in bucket filters. Water is poured through the drum and a pipe at the bottom collects the clean water. For the up-flow design, water is forced up through the bottom of the filter bucket and discharged near the top. Different granular media can be used, even combinations of sand and charcoal [1].

Roughing filters consist of a rectangular-shaped basin of different compartments of granular media with decreasing particle size in the direction of water flow. Water moves through the filter until non-turbid product is collected at the end. This set-up requires frequent backwashing, requiring a certain amount of skill or proper operation [1].

Everything from sponges to charcoal has been employed in the reduction of turbidity for the apparent cleansing of drinking water. Biomass has also been used as a filter medium. Filters have also been made of cotton, wool, linen, pulverized glass, burnt rice hulls, and fresh coconut fibers [1]. Table 2 serves as a comparison of the different types of filter media [1].
Table 2: A Comparison of Filter Types for the Reduction of Turbidity in Drinking Water.

<table>
<thead>
<tr>
<th>Type of Filtration</th>
<th>Media</th>
<th>Ease of Use</th>
<th>Effectiveness (comments)</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Granular media, rapid rate depth filters</td>
<td>Sand, gravel, diatomaceous earth, coal, other minerals</td>
<td>Easy to moderate</td>
<td>Moderate* (depends on microbe size and pre-treatment)</td>
<td>Low to moderate</td>
</tr>
<tr>
<td>Slow sand filters</td>
<td>Sand</td>
<td>Easy to moderate (community use)</td>
<td>High** in principle but often low in practice</td>
<td>Low to moderate</td>
</tr>
<tr>
<td>Vegetable and animal derived depth filters</td>
<td>Coal, sponge, charcoal, cotton, etc.</td>
<td>Moderate to difficult</td>
<td>Moderate*</td>
<td>Low to moderate</td>
</tr>
<tr>
<td>Fabric, paper, membrane, canvas, etc. filters</td>
<td>Cloth, other woven fabric, synthetic polymers, wick siphons</td>
<td>Easy to moderate</td>
<td>Varies from high to low (with pore size and composition)</td>
<td>Varies: low for natural; high for synthetics</td>
</tr>
</tbody>
</table>

* Moderate typically means 90-99% reductions of larger pathogens (Helminth ova and larger protozoans) and solids-associated pathogens, but low (<90%) reductions of viruses and free bacteria, assuming no pre-treatment. With pre-treatment (typically coagulation), pathogen reductions are typically >99% (high). **High pathogen reduction means >99%.

2.2. Water Treatment: Arsenic Removal

The US Environmental Protection Agency (USEPA) recognizes eight different categories for arsenic treatment technologies applicable to groundwater in their report, Arsenic Treatment Technologies for Soil, Waste, and Water [12]. They are as follows:
Precipitation/Coprecipitation

This is the most frequently used method for arsenic remediation in groundwater for both drinking water and wastewater. This method has reduced levels below the current USEPA guideline of 0.01 mg L\(^{-1}\). Also, it has the potential to reduce other contaminants that hinder the quality of drinking water, including turbidity, iron, phosphate, manganese, fluoride, color, and odor [13]. Precipitation/coprecipitation technologies include the use of a chemical treatment leading to the precipitation or coprecipitation of a solid and the subsequent separation of the solid from the water source. Chemicals used to precipitate a solid include ferric chemicals such as salts and sulfates; sulfate chemicals like ammonium, copper, and manganese sulfate; aluminum hydroxide, lime, and a form of pH adjustment [12]. An example of a precipitation/coprecipitation process is illustrated in Figure 1 [12].
Membrane Filtration This is a process used less frequently than precipitation/coprecipitation processes although their solids removal efficiencies are comparable. They are also associated with having higher operating costs. Membrane filtration is a technology used mostly to treat groundwaters and is characterized by processes including any one of the following: microfiltration, ultrafiltration, nanofiltration, or reverse osmosis. Figure 2 illustrates the pore sizes of different membrane technologies [13]. The applicability of this process depends upon the quality of the feed stream. Suspended solids or any dissolved solid with high molecular weight can potentially foul the membrane [12]. Depending upon feedwater quality, different pretreatment options must be employed. Also, to increase arsenic removal efficiencies, prior treatment must be performed to convert As(III) to As(V) since the As(V) tends to have a larger ionic radius [12].
Adsorption Adsorption methods are also used less frequently than precipitation/coprecipitation although they also have similar removal efficiencies. This technology includes any process where adsorption is the primary mechanism employed for removal. Adsorption processes can use a combination of precipitation/coprecipitation, ion exchange, and filtration technologies. Generally, they involve a column with a bed of sorbent media through which feedwater is passed. A variety of sorbents can be used including activated alumina, activated carbon, copper-zinc granules; ferric-hydroxide or ferric-hydroxide newspaper pulp; iron oxide coated sand or iron filings in sand, KMnO4 coated glauconite, surfactant-modified zeolite, and others [12, 13]. Adsorption methods generally include regenerating the sorbent through a backwashing
method [12]. Pretreatment is also required for adsorption methods due to the same factors affecting fouling in membrane methods [14, 15]. Figure 3 illustrates a typical adsorption process [12].

![Adsorption Column with Sorbent](image)

**Ion Exchange** Treatments employing ion exchange for arsenic removal are very similar to the adsorption technique with respect to process configuration. The difference is in the replacement of a sorbent with an ion exchange resin [12]. An ion exchange media is used consisting of either a strong or weak acid or base in order to regenerate the resin after it is fouled with removed arsenic [16]. This technology can provide effective arsenic removal in the range of $<0.05$ mg L$^{-1}$ to $<0.01$ mg L$^{-1}$, but is used less frequently than precipitation/coprecipitation due to the same process sensitivities effecting membrane filtration and adsorption processes: tedious, skillful regeneration and high cost [12].
Permeable Reactive Barrier A permeable reactive barrier (PRB) treatment system is placed underground in the direction of groundwater flow, creating an *in situ* arsenic treatment method. This is not a popular treatment technology but has been used as a way to treat contaminated plumes of groundwater. It consists of an underground wall, inside of which is a media that is reactive with arsenic. Water passes through the wall and arsenic is immobilized. PRBs are not effective in aquifers with high hydraulic conductivities or aquifers deeper than 70 feet. Also, PRB plugging with loose rock and sediments can hinder PRB effectiveness. Figure 4 illustrates a generic PRB set-up [12].

![Figure 4: Model of a PRB.](image)

Electrokinetic The USEPA classifies electrokinetic arsenic treatment methods as an emerging technology. This is a method applicable to not only groundwater but also to soils. Essentially, electrodes are placed in soil or water and a current is passed through the media to be treated. Metals in the form of
ions are attracted by the electric field to the electrodes where they are removed [12]. Arsenic species present would have to be in ionic forms for this process to be applicable. This technology is also only suitable to acid-soluble polar compounds [12].

Phytoremediation, or the use of plants (specifically plant roots), to remove contaminants and biological treatments will be addressed in Chapter 4 of this thesis, Section 4.1.

2.3. Investigated Modes of Arsenic Remediation

Arsenic contamination can be reduced with several different remediation methods falling under the categories described in section 2.2. In this section, an introduction to the multitude of remediation techniques tested in Bangladesh and West Bengal, India is followed by a review of removal strategies implemented in the contaminated regions of Mexico. Each remediation technique is described and evaluated with respect to cultural sensitivity, acceptability, and sustainability.

2.3.1. Bangladesh and West Bengal, India

Bangladesh and West Bengal, India solved problems associated with access to drinking water by installing shallow tubewells in flood plain aquifers. In solving one health problem, another was created – arsenic poisoning due to ingestion from contaminated tubewell water. Water in the shallow aquifers is routinely contaminated with mobilized arsenic above recommended limits, putting millions at risk for arsenic poisoning. Many different scaled-down technologies have been introduced to the region and evaluated for their effectiveness. These
methods fall under well-known arsenic removal categories outlined in section 2.2., paragraph one and include [17]:

- Oxidation
- Co-precipitation/adsorption
- Sorptive filtration
- Ion exchange
- Membranes

**Oxidation** Due to arsenic speciation in groundwater, many technologies take advantage of the easier-to-remove pentavalent form of As(V) by oxidizing the trivalent form As(III), converting it to pentavalent arsenic. This can be done using oxygen, ozone, free chlorine, hypochlorite, permanganate, hydrogen peroxide, and Fenton’s reagent; but the most frequently used are atmospheric oxygen, hypochlorite, and permanganate. However, the use of atmospheric oxygen can take weeks to convert all trivalent species to pentavalent arsenic [18]. The chemical reactions for these three oxidation methods are as follows [17]:

\[
\begin{align*}
H_3AsO_3 + \frac{1}{2}O_2 & \rightarrow H_2AsO_4^- + H^+ \\
H_3AsO_3 + HClO & \rightarrow HAsO_4^{2-} + 3H^+ + Cl^- \\
3H_3AsO_3 + 2KMnO_4 & \rightarrow 3HAsO_4^{2-} + 2MnO_2^{2+} + 2K^+ + 4H^+ + H_2O
\end{align*}
\]

Processes taking advantage of oxidation are passive sedimentation, *in situ* oxidation, and solar oxidation [17].

Passive sedimentation has been discussed in section 1.1.1 as a method for turbidity reduction, but it can also apply in the reduction of arsenic by
oxidation. Drinking water is exposed to atmospheric oxygen during the gathering and storing process and, as a result, this process has been studied to determine if arsenic concentration is reduced. Fifty percent removal was obtained using passive sedimentation of drinking water with 380-480 mg L\(^{-1}\) of CaCO\(_3\) for alkalinity and 8-12 mg L\(^{-1}\) of iron, but most studies only showed a 25% reduction which is not enough in most of Bangladesh and India [19].

In situ oxidation was performed under the DPHE (Department of Public Health Engineering) - Danida Arsenic Mitigation Pilot Project where a tubewell was aerated by the injection of aerated water into the well. As a result, the atmospheric oxygen converts As(III) to the less mobile pentavalent form and ferrous iron present in the aquifer is converted to ferric iron. This combination of conversion results in a coprecipitation/adsorption process, reducing mobilized arsenic in the well water by the following equations (surface sites are denoted with an italicized S) [17]:

\[
\begin{align*}
\text{Fe(OH)}_3 + \text{H}_3\text{AsO}_4 & \rightarrow \text{FeAsO}_4\cdot2\text{H}_2\text{O} + \text{H}_2\text{O} \quad (4) \\
\text{SFeOH}^0 + \text{AsO}_4^{3-} + 3\text{H}^+ & \rightarrow \text{SFeH}_2\text{AsO}_4 + \text{H}_2\text{O} \quad (5) \\
\text{SFeOH}^0 + \text{AsO}_4^{3-} + 2\text{H}^+ & \rightarrow \text{SFeHAsO}_4^{-} + \text{H}_2\text{O}[20] \quad (6)
\end{align*}
\]

This technology reduces arsenic content by about 50% [21].

Solar oxidation takes advantage of both solar ultraviolet (UV) radiation and atmospheric oxygen [22]. It was found that UV radiation can catalyze the oxidation process with atmospheric oxygen, resulting in a 66% removal rate, on average [17].
Co-precipitation and Adsorption  Co-precipitation processes were discussed in section 1.1.2. paragraph two as a method for reducing turbidity in drinking water, but coprecipitation coupled with adsorption can also remove mobilized arsenic. Seven different coprecipitation/adsorption technologies have been implemented and evaluated in Bangladesh and India, these include:

- bucket treatment units (BTU)
- Stevens Institute Technology (SIT)
- Bangladesh Council of Scientific and Industrial Research Filter Unit (BCSIR)
- fill and draw units
- arsenic removal units attached to tubewells
- naturally occurring iron

Different coagulants/flocculants can be employed in this process, some of which are aluminum alum (Al₂(SO₄)₃·18H₂O, also known as aluminum sulfate), ferric chloride (FeCl₃), and ferric sulfate (Fe₂(SO₄)₃·7H₂O). The co-precipitation/adsorption process is typical of other flocculation methods. A dose of the flocculant is added to water, agitated for a few minutes while aggregated flocs form, slowly stirred for a few minutes to allow for the flocs to gain in size and begin to settle, and then let sit to allow all of the flocs to settle. Arsenic is adsorbed onto these flocs, and, thus, removed by sedimentation. Again, for this technology to be efficient, trivalent arsenic must first be oxidized to its charged pentavalent form [17] but this can easily be performed using atmospheric oxygen or the combination of oxygen and UV radiation [22]. Proposed chemical
reactions for the formation of and coprecipitation/adsorption of the aluminum-
arsenic complex using alum are as follows. Chemical reactions involving ferric
salts are the same as equations 4 through 6 and also require pretreatment to
oxidize As(III) to As(V) [17].

Alum dissolution:

\[
\text{Al}_2(\text{SO}_4)_3 \cdot 18\text{H}_2\text{O} \rightarrow 2\text{Al}^{3+} + 3\text{SO}_4^{2-} + 18\text{H}_2\text{O}
\] (7)

Aluminum precipitation (acidic):

\[
2\text{Al}^{3+} + 6\text{H}_2\text{O} \rightarrow 2\text{Al}(	ext{OH})_3 + 6\text{H}^+
\] (8)

Co-precipitation:

\[
\text{H}_2\text{AsO}_4^- + \text{Al}(	ext{OH})_3 \rightarrow \text{Al-As} + \text{Other Products}
\] (9)

The DPHE-Danida Project developed the BTU technology introduced in
Bangladesh. It requires the use of two buckets (20 L); one to perform
flocculation/coagulation and sedimentation and the other consists of a sand filter
to remove resulting contaminants. Next, 200 mg L\(^{-1}\) and 2 mg L\(^{-1}\) doses of a
chemical flocculant, alum, are added to the flocculation bucket and stirred rapidly
for one to two minutes. Then, the contents are allowed to settle. A valve in a
hose connected just above the bottom of the bucket is then opened, allowing the
supernatant to flow into the second bucket (sand filter) [17]. Thousands of these
units were distributed in Bangladesh and a rapid preliminary study by BAMWSP
(Bangladesh Arsenic Mitigation Water Supply Project, BDFID (British Department
for International Development) and WaterAid in 2001, reported mixed results.
They were found to be inefficient in reducing arsenic content below the
Bangladesh limit of 50 µg L\(^{-1}\) under rural use. The inefficiencies were blamed on
poor mixing conditions and varying pH of water supplies [19]. The BTU technology falls under most of the requirements for socio-cultural acceptability discussed in the introduction to this chapter, but fails to use indigenous materials for remediation. Specifically, the flocculant is not a material known to community members.

The SIT configuration is analogous to the BTU setup. It also consists of two buckets, one for mixing and flocculation, and the other as a secondary sand filter. The difference in the SIT technology is the flocculant used, the location of sedimentation, and the configuration of the sand filter bucket. The SIT uses iron sulphate and calcium hypochloride as flocculants. These chemicals are mixed in the first bucket. Then, the bucket contents are poured into the second bucket that consists of a smaller bucket with perforations inserted on top of a sand filter. Sedimentation takes place in this second bucket, and water is drawn from underneath the sand filter by a hose [17]. Figure 5 shows the general configuration of the SIT.
Rapid assessment of the SIT showed arsenic reduction to levels below the 50 µg L⁻¹ requirements in 80 – 95% of cases. However, the sand filter was found to clog frequently due to sedimentation in the second bucket [19]. This method fails under the requirements for cultural sensitivity for the same reasons as the BTU method. It uses foreign chemical flocculants and requires skillful operation.

The BCSIR filter unit is similar to both the BTU and SIT methods with the differences again in the flocculant chemicals and the sand filter treatment [17, 23]. The flocculant is a mixture of iron oxide, alum, activated charcoal and calcium carbonate. The flocs formed settle and the entire bucket of water is passed through a sand filter that contains iron-bearing minerals of various grain sizes. Drawbacks of this technology are the requirement of the flocculant dose on level of contamination [23] and the lack of dependence on indigenous materials (the use of chemicals as a flocculant). The BCSIR claims that arsenic contaminated drinking water can be reduced to levels below the 50 µg L⁻¹
standard for waters containing up to 2.7 mg L\(^{-1}\) As [23]. However, the BCSIR did not take part in the rapid assessment program [17].

The fill and draw unit initiated by DPHE-Danida Arsenic Mitigation Pilot Project is essentially a larger version of the aforementioned methods, aimed at community-based use instead of individual household use. Flocculation takes place in a large (600 L) tank with a mixer of flat-blade impellers and is operated by hand. Chemical oxidants and flocculants are added, mixed, and allowed to settle. The resulting supernatant is withdrawn from a few inches above the sludge line near the bottom of the tank and passed through a sand filter, finally collected at the end for drinking purposes. These units performed better because the mixing and flocculation are better controlled, resulting in higher removal efficiencies. These units are still serving communities and some educational institutions in the form illustrated in Figure 6 [17].

![Figure 6: Schematic of the DPHE-Danida Arsenic Mitigation Pilot Project Fill and Draw Units.](image)
Arsenic removal units attached to tubewells have been implemented in West Bengal, India and are designed and built to be attached directly to a tubewell outlet. This employs the use of sodium hypochlorite and alum for coagulation, followed by sedimentation and subsequent filtration through an upflow filter unit. This technology is designed to be used for an entire village and has been shown to remove 90% of arsenic from the contaminated source with an initial concentration of 0.3 mg L\(^{-1}\) [17]. A schematic of this design is presented in Figure 7.

![Figure 7: Schematic of Arsenic Removal Units Attached to a Tubewell in West Bengal, India.](image)

It was found that most drinking water sources with low amounts of iron precipitates (<1 mg L\(^{-1}\)) also had low arsenic values (<50 µg L\(^{-1}\)), and those with iron precipitates between 1 and 5 mg L\(^{-1}\) only satisfied the 50 µg L\(^{-1}\) limit 50% of the time, and those with >5 mg L\(^{-1}\) only satisfied the limit 25% of the time. It has also been found that only aeration and subsequent sedimentation of drinking water with high iron content suitably removes arsenic. From this data and data showing that Iron Removal Plants (IRP) which use the same methods of aeration
and sedimentation with subsequent filtration, also removed arsenic without any added chemicals, medium scale IRPs were installed in district towns. These IRPs suitably remove arsenic with the only disadvantage of the technology’s high use being treated water for backwashing the filters [17].

**Sorptive Filtration**  Sorptive filtration requires the use of a sorptive media, and all proposed media have one universal drawback: saturation, meaning the media is spent and can no longer remove arsenic without regeneration [17]. The different media types employed fall under two broad categories: foreign (usually chemical-based), and indigenous (usually natural-based). Some sorptive media investigated for arsenic removal are as follows [17]:

**Foreign:**

- activated alumina
- activated carbon
- iron coated sand
- iron and manganese coated sand
- kaolinite clay
- hydrated ferric oxide
- activated bauxite
- titanium oxide
- silicon oxide

**Indigenous:**

- oxidized iron-rich soil
Both the foreign material-based filters and indigenous filters are generally effective at removing arsenic but must be frequently regenerated and most suffer the effects of fouling [17]. The use of indigenous materials is well advised in devising a sustainable arsenic removal technology, but these technologies suffer the same two drawbacks as the foreign materials: labor-intensive regeneration and problems with fouling.

**Ion Exchange** This process is similar to sorptive filtration except that the sorptive media is replaced with a synthetic ion exchange resin designed for optimized removal. This technology also requires regeneration when the resin is spent. An example of the chemical process is outlined below (where italicized $R$ denotes resin).

**Arsenic Removal**

$$2R-\text{Cl} + \text{HAsO}_4^{2-} \rightarrow R\text{2HAsO}_4 + 2\text{Cl}^- \quad (10)$$

**Regeneration**

$$R\text{2HAsO}_4 + 2\text{N}^+ +2\text{Cl}^- \rightarrow 2R-\text{Cl} + \text{HAsO}_4^{2-} + 2\text{Na}^+ [17] \quad (11)$$

The ion exchange process efficiency, like most others, depends on an oxidation pretreatment step [17]. The use of a foreign ion exchange resin in community
households does not fit the requirement that materials be familiar to community members. Also, regeneration with other chemicals is labor-intensive and adds another step with a foreign material. Although this technology is promising for arsenic removal, it is not an ideal technology from the sustainability standpoint.

Membranes The membrane technologies proposed and tested for use in Bangladesh and India are similar to and fall under the same category as the membrane technologies discussed previously in section 2.2. The MRT-1000 and Reid System Ltd. technologies relied upon reverse osmosis on the household level to remove arsenic and found that both effectively removed arsenic, but the technologies are too costly for wide implementation [17].

J.I. Oh et al., 2000, at the University of Tokyo, developed one interesting technology [24]. It employed the use of a bicycle pump to feed contaminated drinking water at low pressure to a filtration system. This technology was developed for use in regions without access to electricity. Nanofiltration and reverse osmosis were both tested, and the reverse osmosis system removed the most arsenic at a pressure of 4 MPa. However, the nanofiltration unit was highly efficient at removing arsenate (As(V)), showing a 99% removal, but less efficient at removing arsenite (As(III)), with 55% removal. Oxidative pretreatment to convert arsenite to arsenate will help the total arsenic removal efficiency [24]. The reverse osmosis system adequately removes arsenic to below the 50 µg L⁻¹ standard, but the technology, like the other reverse osmosis method, is costly.
and is not comprised of indigenous materials, leading to the conclusion that it, too, is unsuitable for sustainability cultural sensitivity.

In summary, none of the techniques for arsenic removal tested in Bangladesh or India fit the requirements for sustainability with respect to cultural sensitivity laid forth by Shaban et al., 2005, that provide the boundaries for our project. The requirements that technologies developed for implementation in low-income, rural communities should be simple, easy to produce, inexpensive, employ indigenous or easily accessible materials, and have a rural focus [11], are not considered in existing technologies. The coprecipitation/adsorption technologies such as the BTUs and Sits are easy to produce, inexpensive, and have a rural focus, but they do not employ indigenous or easily accessible materials due to their dependence on chemical flocculants. Sorptive filtration units also tend to employ chemicals for the regeneration of sorptive medias, as does ion exchange technologies and both produce waste materials. Also, neither sorptive filtration nor ion exchange has a rural focus, both relying on labor-intensive regeneration processes. The nanofiltration and reverse osmosis membrane technologies are promising with regards to arsenic removal but fail when held up to the standards of sustainability due to their high capital and operation costs.

The technology with the most room for improvement with respect to sustainability is the coprecipitation/adsorption processes like the BTUs and SITs. If their dependence upon chemical flocculants can be alleviated, they will fit well within the guidelines for sustainable arsenic removal technologies in low-income,
indigenous communities. This project seeks to develop a similar filtration unit that employs flocculation, precipitation, and filtration but uses only indigenous, easily accessible materials.

2.3.2. Mexico

Due to the minimal success of in-home filters and other remedies in Bangladesh and West Bengal, India, there is a growing demand for natural flocculants that will perform at efficiencies comparable to existing chemical flocculants and simultaneously remove suspended solids, as well as heavy metals [25]. To ensure a sustainable impact, the natural technology must also be socially appropriate, producing a minimized effect on the lives of affected individuals while simultaneously increasing their quality of life. It is this need that motivated the initiation of a project to investigate the scientific basis, feasibility, and product development of a natural filter for use in Mexican communities experiencing problems with contaminated water supplies.

Mexico’s geographic, social, and economical characteristics make it the ideal location for this water treatment project. Severe heavy metal contamination in water supplies has created a desperate need for a treatment solution and the current economic conditions provide a comparable situation with other areas suffering contamination: Bangladesh, China, and India. Also, the Mexican people are extremely familiar with our chosen flocculant source, the nopal cactus (commonly called “prickly pear”), due to its amazing abundance in the arid
climates of the country. The need for a functional, inexpensive, and accessible flocculant source is also dire due to a lack of funding for the construction and implementation of beneficial water treatment facilities in affected Mexican communities.

Many of the aforementioned arsenic removal technologies have been investigated for use in affected communities in Mexico. Those investigated fall into four separate categories: adsorption on iron-based adsorbents, adsorption on other adsorbents, precipitation/coprecipitation, and emerging technologies. All of the technologies described in this section have been studied for use in other countries and have found varying success. As a result of knowledge gained from previous implementation, most of the Mexican trials were scientifically successful. However, their social applicability varies and are described below.

**Iron-based Adsorption** Hematite and natural minerals present in Mexican aquifers have been tested for their efficiency in adsorbing mobilized arsenic. Simeonova, 2000, selected natural Hematite for an *in situ* pilot study of removal from an underground water source in Mexico [26]. Water obtained from the treated water source was consistently below the Mexican drinking water standard of 50 μg L⁻¹ [26]. Carrillo and Drever, 1998, found similar results in their study of the possibility of using natural aquifer minerals for *in situ* removal. They found that removal was, at maximum, 80% when the natural minerals contained from 10-12% Fe. It was determined that the partial removal was based on selectivity
for arsenate over the difficult-to-remove arsenite. Quartz, feldspar, calcite, chlorite, illite, and magnetite/hematite were all present in their adsorbent sample [27].

The social acceptability of these iron-based adsorption methods is high based on the use of natural, indigenous materials. However, there is a lack of a rural focus to these methodologies. There is a limited ability for residents in rural communities to inject adsorbents into aquifers for \textit{in situ} treatment. Also, due to the possible presence of a governmental distrust amongst community members, the prospect of injecting anything into an aquifer may cause suspicion.

\textit{Adsorption} The adsorption techniques studied include the use of natural, indigenous non-ferric minerals and natural zeolites. A naturally occurring, clay-rich limestone material called Soyatal Formation was analyzed for its ability to adsorb arsenic and was found to be an outstanding performer. Contaminated water samples of $600 \mu g \text{ L}^{-1}$ were cleaned to below $30 \mu g \text{ L}^{-1}$ As. It was found that a weight ratio of 1:10 rock-to-water is the proper dosage to reduce arsenic levels from $500 \mu g \text{ L}^{-1}$ to below $30 \mu g \text{ L}^{-1}$ [28]. It would follow that lower doses would be required for contaminated water with lower levels of arsenic. The Soyatol Formation owes its abilities to its composition; it contains kaolinite and illite, which are both known arsenic adsorbers [28].

Natural zeolites of the clinoptilolite variety formed in Mexico were also investigated for their adsorption efficiency and were found to reduce
contaminated water with 200 $\mu$g L$^{-1}$ As to 10 $\mu$g L$^{-1}$, the WHO recommended limit. The presence of anions and cations did not effect the arsenic removal [29].

Both of these natural minerals are excellent arsenic absorbers and also fit the requirements for social acceptability. If implemented in such a way that individual households could have control of their water treatment, this method would also have a rural focus. The limiting factor with these methods is sustainability. While both minerals are formed in Mexico, mining of the minerals could affect the cost of such a treatment.

Precipitation/Coprecipitation Combination treatments consisting of alum and a polymeric anion flocculant (PAF), as well as ferric sulfate flocculation have been determined to be efficient modes of remediation. The combination flocculant removed 99% of arsenic at an NaOH-adjusted pH of 7.1 and the PAF played no part in As removal [30]. The ferric sulfate removal process investigated consisted of a tank outfitted with a manual agitator. Ferric sulfate salts were added by individual households (10 families) and the tanks were agitated and left to settle for three hours. The clean water was then decanted. Removal was total in seven of the ten systems and $>93\%$ in the other three [31].

Both flocculation methods are scientifically solid, but socially unacceptable. The use of unindigenous chemicals to treat contaminated water is a source of instability with respect to sustainability due to distrust in unfamiliar materials. Also, the use of chemicals adversely affects the cost of the treatment process.
Emerging Technologies  Electro-remediation was discussed in section 2.2 of this thesis. A form of electro-remediation, electrocoagulation, was performed in the Comarca Lagunera region of Mexico for treating contaminated well water. Electrocoagulation is a technique unlike those discussed above. It does not require chemicals, nor does it require labor-intensive and cost sensitive regeneration, as do most filters and ion exchange technologies. Results of the pilot study show removal of more than 99% of arsenic due to the mutualistic effect of the presence of magnetite particles and amorphous iron oxyhydroxides [32]. Electrodialysis was also investigated by Clifford and Lin who found it most effective at removing arsenic in waters with low levels of arsenite (73% removal). Elevated arsenite concentration reduced removal to only 28% [33].

Phytoremediation was also investigated in Mexico, specifically in the mine sites and hot springs of Chihuahua. An investigation into arsenic-bearing plants of the region identified a native plant, Eleocharis sp. with great potential for arsenic removal [34].

Emerging technologies are exciting due to their ability to be both scientifically and socially acceptable. Electro-remediation does not have a rural focus; however, due to the fact that many rural families in under-developed countries do not have access to electricity. Phytoremediation, however, is an ideal technology from the social acceptability and sustainability standpoints. Plants are easily reproduced and are an indigenous, natural resource trusted by communities. The technique outlined in this thesis can potentially be considered
as a combination of the scientific acceptability of precipitation/coprecipitation with the social and sustainability sensibilities of phytoremediation.
Chapter Three

Water Contamination in Four Mexican Communities

Just as arsenic contaminated drinking water is quickly becoming a globally recognized problem in areas such as Bangladesh and India where millions of residents are potentially exposed to arsenic contamination [17], the same problem is also being uncovered in low-income, indigenous communities in rural Mexico. Razo, et al., 2004, studied the Villa de la Paz-Matehuala region to determine the effect of mining in the area on sands, sediments, and surface waters, and found arsenic levels in Carbonera and Cerrito Blanco well systems to be greater than 6,000 µg L⁻¹, or more than 120 times the Mexican water quality guidelines at that time (<50 µg L⁻¹) [35]. Sediment samples from the wells were not studied, but sediments from nearby channels were found to be as much as 20 times the Mexican guidelines [35]. Another Mexican region similar to the Villa de la Paz-Matehuala area is the mining district of Zimapán. Previously reported figures for groundwater arsenic contamination in Zimapán show levels greater than 300 µg L⁻¹ [36]. Mejia et al. [37] studied urine samples from children in Villa de la Paz and found arsenic levels greater than 100 µg g⁻¹ in 28% of children tested, proving a need for a technological solution.

The first action taken under the project was a survey of drinking water supplies of Mexican towns chosen because of known or suspected drinking
water contamination, due to their proximity to either geologic or industrial sources of arsenic contamination. University of South Florida (USF) geologists examined water samples from four different communities, Region Lagunera, Zimapán, Híerve el Agua, and Temamatla, illustrated in Figure 8, for arsenic concentration using hydride generation-atomic fluorescence spectrometry. They also noted suspended solid presence in the samples. The results are summarized in Table 3 along with suspected sources of arsenic contamination. The test community for this project was chosen based on the presence of arsenic contamination above WHO recommended guidelines and the presence of suspended solids.

Figure 8: Mexican Communities Surveyed for Contaminated Water.
Table 3: Contamination in Four Mexican Communities.

<table>
<thead>
<tr>
<th>Location</th>
<th>As (μg L⁻¹)</th>
<th>Suspended Contamination Solids</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hierve el Agua</td>
<td>&gt;518</td>
<td>None</td>
<td>Geologic</td>
</tr>
<tr>
<td>Zimapán</td>
<td>&gt; 221</td>
<td>None</td>
<td>Industrial</td>
</tr>
<tr>
<td>Region Lagunera</td>
<td>&gt;563</td>
<td>None</td>
<td>Industrial</td>
</tr>
<tr>
<td>Temamatla</td>
<td>&gt; 29</td>
<td>Present</td>
<td>Geologic</td>
</tr>
<tr>
<td>Drinking water standard</td>
<td>&lt; 50</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3.1. Zimapán

USF engineers and geologists found an average arsenic concentration in drinking water samples taken from Zimapán, Mexico to be greater than 221 μg L⁻¹, more than four times the Mexican standard and more than 22 times the recommended WHO guidelines.

Zimapán is mainly a mining district where Ag, Zn, and Pb ores are processed. Also, smelters operated in the district until the 1940’s. Wastes from these industries have collected in areas along the Toliman River. It is these industrial sources, as well as arsenic-bearing minerals, contaminating the drinking water of Zimapán[38, 39]. Arsenic was initially found in shallow wells of the Zimapán basin in 1992 as part of a study detecting cholera. Residents of this region obtain drinking water from these shallow wells due to the lack of groundwater supplies in the semi-arid landscape [39].

While arsenic contamination in this region is well above arsenic standard guidelines, the residents of Zimapán were not experiencing contamination due to suspended solids, so this study did not adopt Zimapán as a test community.
3.2. Region Lagunera

Arsenic contamination in Region Lagunera is attributed mainly to mining sources, and the population drinking contaminated water show As-related skin disorders [40]. Pineda-Zavaleta *et al* studied children from three primary schools in the region and found that 92% had urinary arsenic levels above 50 μg L⁻¹, indicating widespread exposure [41]. USF researchers found data to corroborate previous studies: arsenic levels greater than 550 μg L⁻¹. However, once again, this region did not have contamination due to suspended solids so it was not adopted as a test community.

3.3. Hierve el Agua

Hierve el Agua is a region well known for its mineral-rich waters. There are canals and terraces built in Oaxaca, Mexico of unknown purpose but the waters’ riches lead prognosticators to two separate hypotheses: either the region was used agricultural purposes or for salt production [42]. If either of these hypotheses is true, the creators of the irrigation features could not have known the mineral-laden waters bore high levels of arsenic.

We found As levels greater than 500 μg L⁻¹ in Hierve el Agua, mainly due to geologic sources. The name “Hierve el Agua” translates to “Boiling Water” and is an appropriate moniker for the region, which owes its popularity to the prevalence of hot springs. Unfortunately, the belief that natural spring water from hot springs is healthier than piped water leads many to drink copious amounts of the arsenic-laden “health” water. Mothers even lead small children to sip from
the springs. Due to the staunch belief that these waters are beneficial and the absence of a problem with suspended solids, Hierve el Agua was not considered as a test community.

### 3.4. Temamatla

Temamatla was the community chosen for study due to its dual contamination of arsenic and suspended solids from volcanic sources and a suspected collapsed well, respectively. Temamatla lies 25 miles southeast of Mexico City, providing fairly easy travel to the study site by collaborators in Mexico City and their Tampa counterparts. Most community members obtain their drinking water from a centralized well due to limited water resources. City workers deliver water to households on a regular basis where it is stored in 55 gallon water barrels and used for all of the households’ water needs (Figure 9).
3.5. Socio-Cultural Impact Assessment in Temamatla

USF Anthropologist, Dr. Davis-Salazar, directed the second step crucial to our success: socio-cultural impact assessment. This is a necessary component of this project because part of the motivation for this project is the use of a locally available material, namely the nopal cactus with which most rural Mexican communities are intimately familiar. We will create an inexpensive, straightforward process with this material that local communities will be able to use, and will want to use. However, in developing countries non-locally designed
water systems have had minor success in terms of performance and sustainability due to limited community participation, and, more specifically, a failure to integrate local knowledge, customs, and beliefs in system design and implementation, particularly in rural areas of Latin America. In other parts of the world, most notably Bangladesh, arsenic mitigation projects, specifically, have identified important social and cultural factors that affect the degree of success of such projects. These factors include the value placed on water quality by the local community, the community’s level of knowledge concerning the health consequences of arsenic-contaminated water, the degree of compatibility between the organizational requirements of the water technology and the social and political structures of the local community, and gender and age-based differences in household water use and exposure to arsenic-contaminated water. Anthropology, defined by its holistic approach to the study of the human experience, is in a unique position to integrate local knowledge and experience with empirical data to develop socially informed and culturally sensitive water supply and treatment programs.

In Temamatla, the site of our pilot study, our water tests indicate arsenic levels above normal. Residents, however, remain very concerned about their water quality and, therefore, are very receptive to our efforts. Interestingly, a comment made by the mayor of the town indicates that any remediation efforts in Temamatla should be readily apparent - that is, visible to the local residents because they will want “proof” that action has been taken to solve the problem. This indicates that the water treatment process we design for Temamatla must
be somewhat physically conspicuous. USF anthropologists determined that Temamatla citizens preferred a domestic filter for use by individual households out of convenience due to existing drinking water infrastructure and a certain amount of distrust of community officials. It was also determined that a filter based on a Mexican cactus that grows abundantly in the community and across the country would be more readily accepted than a chemical-based filter design. We were able to interview the locals and speak with the mayor of the city. We obtained very positive responses to our project because there is a collective awareness about water quality. Additionally, the people responded exceptionally well to the project socially because we explained that we would be utilizing the nopal plant to remediate their problem. They know the plant; they use it regularly in their diet and know its availability in the region. As a final phase of the planning grant, we will design a filter-kit for the main well. This is something that is feasible since the line is centralized and it is already maintained by two state workers from 5am to 10pm daily. Economically, this is a better solution than implementing the filter-kits domestically since we will have to train only the two workers and because the water flow is relatively small (20 L s⁻¹). We expect that each community for this project will design specific solutions according to their needs.

3.6. Implications for This Project

The results of the socio-cultural assessment provided more design boundaries for this project. In summary, a culturally accepted water treatment
method would be one in an in-home filter form with technology based on native Mexican cactus. Also, a centralized treatment system placed at the drinking water source would be an acceptable, economic application with respect to the culture of Temamatla. Most importantly, to maintain community trust and interest in the project, visibility is key.
Chapter Four

The Mexican Cactus as a Natural Technology for Water Treatment

4.1. Current Options: Natural Technologies

USEPA-recognized natural technologies for water treatment are all considered emerging technologies by the agency. They acknowledge two very different biological treatment options: phytoremediation and microbiological removal processes. Phytoremediation exploits some plants’ natural ability to remove heavy metals through root uptake, and microbial processes use microbes that can aid in the precipitation/coprecipitation of arsenic either by producing conditions supporting precipitation or by converting arsenic to species that are easier to remove [12].

Phytoremediation is a viable technology for small-scale water sources serving communities of less than 10,000 people. Elless et al., 2005, demonstrated this technology in New Mexico, employing Pteris vittata ferns with root systems submerged in contaminated water. ‘Throughputs as high as 1944 L \text{day}^{-1} \text{ were treated and resulting arsenic levels were lower than the detection limit of } 2 \, \mu \text{g L}^{-1}. \text{ However, the initial contamination never exceeded } 14 \, \mu \text{g L}^{-1} \text{ [43]. This technology would have to be evaluated further in order to treat sources with higher levels of arsenic contamination.}
Other plants investigated for use in phytoremediation are poplar, cottonwood, sunflower, Indian mustard, and corn [12]. This is a technology highly dependent upon agricultural factors such as temperature, sunlight, seasons, etc. These variables can be controlled by treating the water in a greenhouse environment with a controlled environment [12].

Microbiological removal processes exploit sulfate-reducing and arsenic-reducing bacteria to create improved conditions for precipitation/coprecipitation. A simple schematic of a typical biological treatment process is shown in Figure 10 [12]. Katsoyiannis et al., 2004, used bacteria native to iron-rich groundwaters in an upflow packed-media filter to remove iron and arsenic from drinking water [44]. The two most prevalent bacteria were Gallionella ferruginea and Leptothrix ochracea. The two most important factors in their biological treatment were redox potential and dissolved oxygen concentration. A redox potential of 320 mV was optimal for the removal of As, specifically in the trivalent form. Residual As values were always below 5 μg L⁻¹ at this redox potential. This is due to oxidation of As(III) to its pentavalent form at this redox potential [44].
4.2. Proposed Source of Natural Flocculant: *Opuntia ficus-indica*

The genus *Opuntia* is the largest under the *Cactaceae* family. Varieties of *Opuntia* can be found from Western Canada south to the tip of South America. The *Opuntia* species chosen as a flocculant source for this project, *Opuntia ficus indica*, also known as nopal or prickly pear, is commonly found and cultivated in Mexico where it grows in tree-like proportions (Figure 11). The nopal cactus was
chosen as a flocculant source based on its ubiquity in Mexico and due to the Mexican people’s familiarity with the nontoxic cactus. There is also previous empirical knowledge of the nopal being used since ancient times in Latin America to reduce turbidity and hardness in natural spring waters [45].

Figure 11: An Example of *Opuntia* Growing as a Tree in Mexico.

### 4.2.1. Current Uses

*Opuntia ficus-indica* is widely used for its nutritional value. It is used as a fruit crop and a vegetable crop for human consumption [46, 47], and as a forage crop for livestock in drought conditions [46]. The fruit of the *Opuntia* is commonly referred to as tunas, their Spanish name [48]. Typically, the fruit is dried for use during the winter, but sometimes a sauce is made from boiled, unripe fruits. They are also used for their skins, (food coloring), their syrup (tuna honey), fermented and nonfermented beverages, and in the dried form as tuna cheese [49]. The seeds of the tuna have also been ground and used as a meal by some American Indians. The fruits have been shown to be a source of sugars (15%
sugars and 85% water) and even a source of small amounts of Vitamin C. They typically have a pH around 6.5 and are rich in calcium and phosphorous [46]. The advantage of using Opuntia as a fruit crop is the ability to grow cactus in otherwise unfertile, rocky soil. Crop concentrations of 20,000 kg of fruit hectare$^{-1}$ have been produced, which equates to about 2,800 kg of sugar [48].

The use of Opuntia as a vegetable crop is less popular. Typically, only the young joints of the cactus (nopalitos) are used as a vegetable in Hispanic households [50]. They are typically cooked as a green vegetable or marinated as part of a salad [46]. The cactus skin and thorns can be easily removed, leaving the edible insides of the cactus pad [51]. Opuntia pads have been shown to be made up of 87% water, 1% protein, 0.1% fat, 1.3% ash, 1.1% crude fiber, and 5.4% carbohydrates [50].

In drought conditions, when grasses and other forage crops are no longer edible, the Opuntia cactus remains green and is used as an emergency feed crop for ranging livestock in both the southwestern United States and Mexico [51]. The spines are burned off, soaked in water, or washed with soda to eliminate their harmful effects on the livestock. Sheep have lived for up to 8 months eating entirely Opuntia [46].

Opuntia is not used exclusively as a food source. They are popular as ornamental and hedge plants and the stem of the cactus is used in producing decorative elements [46].
4.3. The Mucilage of *Opuntia ficus-indica*

The mucilage of *Opuntia ficus-indica* is a thick, gummy substance and is what provides the cacti’s natural ability to store large amounts of water. When in water, the mucilage swells, producing unique surface-active properties seen in many natural gums, giving the mucilage a suspected ability to precipitate particles and ions from aqueous solutions. The mucilage is extracted from the pads of the cactus. Diced nopal cladodes have been used for centuries in Latin America as a primitive technology for the rapid flocculation of turbid natural spring waters, but a scientific baseline has never been provided for this observed phenomenon [45].

4.3.1. Chemical Composition

The mucilage of *Opuntia ficus-indica* is composed of 55 sugar residues including arabinose, rhamnose, galactose, and xylose, and some, specifically Burbank’s cv Spineless, show fractions of glucans and glycoproteins [52]. The mucilage of *Opuntia ficus-indica* has been a source of some confusion amongst investigators [45].

The molecular weight of the mucilage has been reported as different values, probably also due to differences in extraction techniques and the possibility of contaminants [45]. In 1981, Trachtenberg and Mayer reported a molecular weight of \(4.3 \cdot 10^6\) g mol\(^{-1}\) [53], but a study by Cárdenas et al. in 1997, reported a value of \(3 \cdot 10^6\) g mol\(^{-1}\) [54], and in 2000, Medina-Torres et al. reported \(2.3 \cdot 10^6\) g mol\(^{-1}\) [53-55].
In 2001, Madjoub et al isolated two separate mucilage fractions, calling one the “high weight sample” (HWS) with a molecular weight of $13 \cdot 10^6$ g mol$^{-1}$ and the other the “low weight sample” (LWS) with a molecular weight of $3.9 \cdot 10^3$ g mol$^{-1}$ [56]. The HWS was determined to make up about 10% of the total mucilage content and was devoid of proteins. It contained about 20% charged sugar [56], leading to the possibility of its potential to interact with divalent cations [45]. The sugars detected in the HWS were the same as reported previously in the literature and in this thesis.

Madjoub’s LWS was determined to be composed mostly (~80%) of protein with a nitrogen composition of 2.2% [56], helping to confirm the presence of glycoproteins in mucilage. Table 4 summarizes research results on the chemical constituents of *Opuntia* mucilage.

Table 4: Differences in Detected Mucilage Properties: Molecular Weight and Sugar Content.

<table>
<thead>
<tr>
<th>Author</th>
<th>MW (g mol$^{-1}$)</th>
<th>Galactose</th>
<th>Rhamnose</th>
<th>Arabinose</th>
<th>Xylose</th>
<th>Uronic acid</th>
<th>Galactose/Arabinose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cárdenas et al (1997) [54]</td>
<td>$3 \times 10^6$</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trachtenberg &amp; Mayer (1282) [57]</td>
<td>$1.56 \times 10^6$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>McGarvie and Parolis (1981) [58]</td>
<td></td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>McGarvie and Parolis (1981) [59]</td>
<td></td>
<td>+</td>
<td>+</td>
<td>+</td>
<td></td>
<td></td>
<td>1.5/3</td>
</tr>
<tr>
<td>Trachtenberg &amp; Mayer (1981) [53]</td>
<td>$4.3 \times 10^6$</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td></td>
<td>4.9/3</td>
</tr>
<tr>
<td>McGarvie and Parolis (1979) [60]</td>
<td></td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td></td>
<td>1.3/3</td>
</tr>
<tr>
<td>Paulsen and Lund (1979) [61]</td>
<td></td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td></td>
<td>2.3/3</td>
</tr>
<tr>
<td>Saag et al. (1975) [62]</td>
<td></td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td></td>
<td>3.5/3</td>
</tr>
</tbody>
</table>
McGarvie and Parolis studied the chemical structure of the mucilage and proposed the structure represented in Figure 12, with R indicating the presence of different arabinose and xylose forms, D-Gal indicating D-galacturonic acid, Gal indicating galactose, and Rha indicating Rhamnose [45, 58, 59].

\[
\left( D - Gal \ A - \alpha(1 \rightarrow 2) - L - Rha - \beta (1 \rightarrow 4) \right)_n
\]

\[
\beta \\
Gal 3 \rightarrow R \\
6 \\
1 \\
\beta \\
R \rightarrow 4 Gal 3 \rightarrow R \\
6 \\
1 \\
\beta \\
1 \\
Gal 3 \rightarrow R \\
4 \\
1 \\
R
\]

R = arabinose or xylose

Figure 12: McGarvie and Parolis's Proposed Mucilage Structure, Taken from Sáenz, 2004.

4.3.2. Extraction Techniques

The mucilage was extracted prior to the inception of the portion of the project described by this thesis. What follows is an overview of the techniques used to extract the mucilage used in the flocculation and arsenic removal project. The cactus pads used for the gelling extract (GE) and the nongelling extract (NE) were cut from plants obtained from Living Stones Nursery, Tucson, Arizona and pads used for the combined extract (CE) were obtained from Blue Diamond Nursery, Las Vegas, Nevada. They were then potted and allowed to acclimate in direct sunlight before the mucilage was extracted.
In total, three types of mucilage were extracted. A modified method detailed by Goycoolea and Cárdenas was used to obtain GE and NE [63], and CE, consisting of GE & NE, was obtained using the method outlined by Medina-Torres et al. [55]. All mucilage types extracted were stored dry and at room temperature.

Gelling and Nongelling Extracts The Goycoolea and Cárdenas method was used as a guideline in extracting the GE and NE used in the flocculation and arsenic experiments. However, changes were made in order to maximize mucilage extraction. The actual procedure implemented is outlined in Figure 13 with boxes highlighting the modified steps.
The Medina-Torres et al., 2000, method [55] is a modified version of a method used by McGarvie and Parolis in 1979 [55, 60]. Two nopal pads were macerated in a blender and the resulting solids and liquid supernatant were separated in a centrifuge at 4000 rpm. The resulting supernatant was collected and mucilage was precipitated with a 1:2 ratio of pulp to acetone. The acetone was decanted and the precipitate was washed with a 1:1 volume ratio of precipitate to isopropanol. The resulting precipitate was air dried on a watch glass.
4.3.3. Current Applications

*Opuntia* mucilage has been extracted and evaluated for uses including dietary fiber [64], medicinal [65-69], digestive [70, 71], lime mortar additive [72], and emulsifying agents [73]. The *Opuntia* is used as a food source by many Latin Americans and the mucilage component of *Opuntia* contributes to the dietary fiber component of the cactus [64]. The mucilage has also been investigated for its use in controlling blood glucose levels in diabetics and cholesterol in guinea pigs fed a high-cholesterol diet. It significantly reduced both blood glucose and cholesterol levels [66-68, 74]. It has also been studied for its wound-healing abilities and was found to significantly effect healing in rats when administered topically [75].

Other non-medical uses of *Opuntia* mucilage have been investigated. In Mexico, nopal juice is sometimes added to lime mortar to reduce cracking and water penetration. However, in investigating nopal mucilage’s role in the strength of the mortar, Cárdenas *et al.*, found that, while it may decrease water penetration and cracking, it also reduces the mechanical strength of the lime mortar [72]. The mucilage has also been suggested for use in food industries due to its efficiency in stabilizing oil-water emulsions [73].
Chapter Five

Physical and Chemical Analytical Methods

5.1. Mucilage Characterization: Raman Spectroscopy

Raman Spectroscopy (RS) is adept at determining functionalization of chemical structures, especially those of organic compounds, from their vibrational spectra. Samples analyzed with RS can exist in either the solid, liquid, or gas states [76]. The samples of GE, NE, and CE analyzed were in the solid phase (powder form), a condition that RS is particularly suited for since conventional Infrared Spectroscopy (IR) provides water band interference [76]. The mucilage samples were loaded in a capillary tube, inserted in the Raman Spectrometer, and their vibrational spectra were analyzed. The system was purged with nitrogen to reduce interference from ambient contaminants.

5.2. Turbidity

5.2.1. Cylinder Tests

The abilities of the three mucilages (GE, NE, and CE) and aluminum sulfate to settle suspended solids were tested with standard cylinder tests [77-86]. The tests were performed with 50 g L\(^{-1}\) concentrations of kaolin in 100 mL graduated cylinders (control). They were treated with varying doses of mucilage extract and aluminum sulfate, and the fall of solid/liquid interface height with respect to time
was recorded. High concentrations of kaolin were chosen since they mimic mud conditions and make the interface visible.

5.2.2. Jar Tests

The residual turbidity of the resulting supernatant after the suspended solids have been settled is another benchmark with which to measure the flocculation effectiveness of the three mucilages (GE, NE, and CE). Residual turbidity tests were carried out according to standard jar test procedures [77, 84, 87-96]. They were performed with 0.5 g L\(^{-1}\) kaolin suspensions in a standard jar test apparatus (ECE MLM4, ECE Engineering, Canada) consisting of four identical 500 mL compartments.

5.2.3. Light Scattering

A turbidimeter (Micro 100, HF Scientific, North Andover, Massachusetts) was used to measure the turbidity of jar test supernatant in Nephelometer Turbidity Units (NTU), the accepted unit of turbidity [97]. A sodium lamp was utilized. Indexed cuvettes were filled with supernatant and inserted in the optical well. The highest measurement was recorded as the turbidity of the supernatant.

5.3. Arsenic Removal

5.3.1. Hydride Generation – Atomic Fluorescence Spectroscopy

Arsenic concentrations for the single-dose methods were determined by hydride generation-atomic fluorescence spectrometry (HG-AFS) in the Center for Water and Environmental Analysis at the University of South Florida. A
PSAnalytical 10.055 Millennium Excalibur instrument was used to determine the total arsenic content of treated samples. Then, 10 mL of each 20 mL sample was added to 15 mL of concentrated hydrochloric acid, used in HG-AFS in order to produce excess H\(^+\), and 1 mL of saturated potassium iodide to convert arsenic species to arsenite for analysis. Then, 24 mL of deionized water were added to make the final volume 50 mL [98]. Tetraborohydride is then added in order to form arsenic hydride (AsH\(_3\)), which is then atomized in a hydrogen flame. Fluorescence spectrometry is then utilized to establish the arsenic concentration in the sample. Arsenic calibration curves are determined through the use of standards prepared with arsenic reference solutions. HG-AFS is a particularly useful technique due to the minimal presence of interference from matrix interactions [99].

**5.3.2. Atomic Absorption (AA) Spectroscopy**

Atomic absorption spectrometry was used to analyze total arsenic content in water samples. The graphite furnace (GF) technique was chosen for use in a Varian Zeeman 240Z Atomic Absorption Spectrometer (AAS). The GF technique is the most widely used and, as a result, the most well understood. In a graphite tube atomizer, there is the combination of an atmosphere of inert gas and reducing conditions produced by incandescent graphite that makes this technique perfect for analyzing pure analytes. Also, GF technique provides a longer residence time (two to three times greater than flame atomic absorption spectroscopy), leading to less interferences [100].
Acidified arsenic samples (0.4% HNO$_3$) were diluted by 5 with 5% Nitric Acid in order to fit within the analyzable limits of the AAS (10 – 60 µg L$^{-1}$ As). Then, 1000 mg L$^{-1}$ As standard was diluted to 10, 20, and 30 µg L$^{-1}$ standards and used to form the calibration curve, using the New Rational method for fitting. Finally, 20 µl samples consisting of 15 µl of diluted As samples and 5 µl of a Nickel Nitrate modifier were injected into the graphite furnace of the AAS. The contents were atomized and analyzed with the concentrations taken from absorption peak height.
Chapter Six

Experimental Procedures

6.1. Turbidity Experiments

6.1.1 Materials

The reagents, equipment, and instruments used in the flocculation experiments performed are listed in Table 5 and Table 6.

Table 5: Reagents Used in Flocculation Experiments.

<table>
<thead>
<tr>
<th>Name</th>
<th>Short Name</th>
<th>Manufacturer</th>
<th>Serial/Catalog No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum Silicate (hydrated)</td>
<td>Kaolin</td>
<td>Fisher Scientific</td>
<td>S71954</td>
</tr>
<tr>
<td>Sodium Hydroxide</td>
<td>NaOH</td>
<td>Acros Organics</td>
<td>206060010</td>
</tr>
<tr>
<td>Aluminum Sulfate</td>
<td>Al$_2$(SO$_4$)$_3$·18H$_2$O</td>
<td>Fisher Scientific</td>
<td>S70495</td>
</tr>
<tr>
<td>Gelling Extract</td>
<td>GE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nongelling Extract</td>
<td>NE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Combined Extract</td>
<td>CE</td>
<td>Extracted according to procedures outlined in section 5.1, this thesis.</td>
<td></td>
</tr>
<tr>
<td>Name</td>
<td>Manufacturer</td>
<td>Serial/ Catalog No.</td>
<td>Model No.</td>
</tr>
<tr>
<td>-------------------------------------------</td>
<td>----------------------</td>
<td>---------------------</td>
<td>-----------</td>
</tr>
<tr>
<td>Minimix Laboratory Mixer/Jar Test Apparatus</td>
<td>ECE Engineering</td>
<td>M443</td>
<td>ECE MLM4</td>
</tr>
<tr>
<td>AccuSeries II © Analytical Balances</td>
<td>Fisher Scientific</td>
<td>13-265-220</td>
<td>Accu-124</td>
</tr>
<tr>
<td>Accumet 1003 pH Meter</td>
<td>Fisher Scientific</td>
<td>1003</td>
<td></td>
</tr>
<tr>
<td>pH Probe</td>
<td>Accumet</td>
<td>13-620-111</td>
<td></td>
</tr>
<tr>
<td>Micro 100 Turbidimeter</td>
<td>HF Scientific</td>
<td>40228/20001</td>
<td>Micro 100</td>
</tr>
</tbody>
</table>

### 6.1.2. Cylinder Test Procedure

The procedure was uniform throughout each cylinder test performed according to the following step-by-step explanation.

Initially, a 50 g L⁻¹ kaolin suspension was produced by diluting 5 g of powdered kaolin in 100 mL of Milli-Q water in a 100 mL glass volumetric flask fitted with a glass stopper. The volumetric flask was then stoppered and fully inverted 10 times in order to ensure the presence of a well-mixed suspension. The suspension was then allowed to sit for 24 hours before use.

After a 24 h period, the cylinder tests were performed. The suspension was mixed well by inverting the flask 10 times. Then, the pH of the suspension was adjusted to 7 by adding the required amount of NaOH. The neutral
suspension was then mixed again by inversion and added to a 100 mL graduated cylinder fitted with a glass stopper. Using the appropriate micropipette and micropipette tip, the desired dose of flocculant (either Al₂(SO₄)₃, GE, NE, or CE) was added. An example of the dosage scheme is outlined in Appendix A. The cylinder was then capped and inverted 10 times to ensure the suspension and flocculant were well mixed. The cylinder was placed on a level surface and flocs immediately began to form and settle. The height of the visible solid/liquid interface was then recorded with time until the flocs were fully settled\(^1\).

6.1.3. Jar Test Procedure

The procedure followed for all jar tests performed was as is detailed in this section. There were four steps to performing the residual turbidity tests: suspension preparation, cuvette indexing, the jar tests, and the final light scattering measurements.

**Suspension Preparation** Initially, a 0.5 g L\(^{-1}\) kaolin suspension was produced by diluting 0.5 g of powdered kaolin in 1 L of Milli-Q water in a 1 L glass volumetric flask with a glass stopper. This dilution was repeated once in order to prepare another liter of suspension. Each flask was inverted 10 times to ensure that the suspensions were well mixed. Then, the suspensions were allowed to sit for 24 hours before use.

---

\(^1\) The solid/liquid interface was measured against the tic marks on the graduated cylinder. Time was recorded exactly as the interface passed a tic mark (1 cm\(^3\)). The distance between the tic marks was then measured and the measured height was calculated based on this interval.
Cuvette Indexing Since light scattering was employed to determine the residual turbidity, it was imperative that turbidimeter cuvettes be indexed. To do this, the turbidimeter cuvette compartment was capped; the turbidimeter was turned on, and allowed to warm up for about 5 minutes. Four clean, capped turbidimeter cuvettes were chosen and the outsides were wiped to remove fingerprints and dust. The empty cuvette was inserted into the turbidimeter compartment. The cuvette was rotated fractions of a turn, stopping to allow the reading to stabilize until the lowest NTU reading was determined. Finally, this position was marked on the cuvette cap and this procedure was repeated for the other four cuvettes.

Jar Tests Initially, the paddle header was removed from the apparatus jars. Then, a two-step procedure was used to fill the jars. First, one flask containing the previously prepared kaolin suspension was inverted 10 times to resuspend the kaolin. The stopper was removed and the flask was inverted over the jars, quickly filling each compartment equally\(^2\). This was done again for the second flask. Any volume difference was corrected by quickly transferring suspension from over-filled compartments to under-filled compartments. The mixing paddle header was replaced on the jars and mixing was started at 100 rpm. The desired flocculant dose (GE, CE, or Al\(_2\)(SO\(_4\))\(_3\)) was then added to the jars. An example of dosage schemes is presented in Appendix A. Stirring continued for 2 minutes at 100 rpm. The speed was reduced to 20 rpm for 5 minutes. Stirring was then

\(^2\) It is imperative that the filling of the jars be performed as quickly as possible to ensure the suspension in each jar test apparatus compartment is equally mixed.
stopped and the flocs formed were allowed to settle for 30 minutes. Samples of the supernatant were collected from each compartment by opening the valve set ~3 cm above the bottom of the jars and filling a turbidimeter cuvette. The cuvettes were then inserted into the turbidimeter and aligned with the previously marked indexed alignment. The highest measurement was then recorded as the supernatant turbidity.

6.2. Arsenic Removal Experiments

6.2.1. Materials

The reagents, equipment, and instruments used in the arsenic experiments are listed in Table 7 and Table 8.

Table 7: Reagents Used in Arsenic Removal Experiments.

<table>
<thead>
<tr>
<th>Name</th>
<th>Short Name</th>
<th>Manufacturer</th>
<th>Serial/Catalog No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arsenic (III) Solid</td>
<td>Arsenic (III) Oxide</td>
<td>Acros Organics</td>
<td>R45 28 34 50/53</td>
</tr>
<tr>
<td>Arsenic (V) Solid</td>
<td>Arsenic (V) Oxide</td>
<td>Acros Organics</td>
<td>R45 23/25 50/53</td>
</tr>
<tr>
<td>Arsenic Standard</td>
<td>As₂O₃·18H₂O</td>
<td>Hach Company</td>
<td>14571-42</td>
</tr>
<tr>
<td>Sodium Hydroxide</td>
<td>NaOH</td>
<td>Acros Organics</td>
<td>106060010</td>
</tr>
<tr>
<td>Aluminum Sulfate</td>
<td>Al₂(SO₄)₃</td>
<td>Fisher Scientific</td>
<td>S70495</td>
</tr>
<tr>
<td>Nickel Nitrate</td>
<td>Ni(NO₃)·6H₂O</td>
<td>Fisher Scientific</td>
<td>N62-500</td>
</tr>
<tr>
<td>Gelling Extract</td>
<td>GE</td>
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<td>Nongelling Extract</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Combined Extract</td>
<td>CE</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Mucilage was extracted according to procedures outlined in section 5.1, this thesis.

Table 8: Equipment and Instruments Used in Arsenic Removal Experiments.

<table>
<thead>
<tr>
<th>Name</th>
<th>Manufacturer</th>
<th>Serial/ Catalog No.</th>
<th>Model No.</th>
<th>Range</th>
<th>Description</th>
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<td>Screw-top Glass Vials</td>
<td>Fisher Scientific</td>
<td>0333921J</td>
<td>FS60957C-4</td>
<td>5 mL</td>
<td>Screw thread with PC lined cap, made from Type I, Class B borosilicate glass</td>
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Table 8: Cont’d.

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<th>Material</th>
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<th>Part No. 2</th>
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<tr>
<td>Polystyrene Round Bottom Tubes</td>
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<td>352027</td>
<td>8 mL</td>
<td>Graduated with screw cap</td>
</tr>
<tr>
<td>Syringe</td>
<td>Becton Dickinson</td>
<td>309603</td>
<td>4120416</td>
<td>5 mL Luer-LokTM tip, latex free, single use, disposable, 1/5mL graduation</td>
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<tr>
<td>Syringe Filter</td>
<td>Fisher Scientific</td>
<td>09-719-A</td>
<td>R4DN26317</td>
<td>25 mm 0.22 μm pore size Mixed Cellulose Ester (MCE), sterile, 50/package</td>
</tr>
<tr>
<td>Centrifuge Tubes</td>
<td>Fisher Scientific</td>
<td>05-539-7</td>
<td>11197003</td>
<td>50 mL Sterile, polypropylene, plug seal cap</td>
</tr>
<tr>
<td>AccuSeries II ® Analytical Balances</td>
<td>Fisher Scientific</td>
<td>13-265-220</td>
<td>Accu-124</td>
<td>Max: 120 grams Readability: 0.1 mg, taring, repeatability: 0.1 mg, linearity: ±0.2 mg</td>
</tr>
<tr>
<td>Accumet 1003 pH Meter</td>
<td>Fisher Scientific</td>
<td>1003</td>
<td>-6 to 20 pH</td>
<td>Resolution: 0.1, 0.01</td>
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<tr>
<td>pH Probe</td>
<td>Accumet</td>
<td>13-620-111</td>
<td>0 to 14 pH</td>
<td>Accuracy: &lt;±0.05 pH at 25 ºC</td>
</tr>
<tr>
<td>Atomic Absorption Spectrometer</td>
<td>Varian, Inc.</td>
<td>Zeeman 240Z</td>
<td>10 – 100 µg L⁻¹</td>
<td>Detection limit: 10 µg L⁻¹</td>
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</tbody>
</table>

6.2.2. Single Dose Method Procedure

The arsenic tests were carried out using GE due to its convincing effectiveness as a flocculent of suspended solids. Initial tests were performed by preparing a standard arsenic solution from solid As(III) and As(V) stock in a 50 mL centrifuge vial, removing 20 mL before sample, dosing with 0.10, 1.0, and 10 mg L⁻¹ GE, inverting 10 times, and removing a 20 mL after sample from the top of the vial (the air-water interface) after 1 h. The samples were examined using hydride generation-atomic fluorescence spectrometry for total As content.

In light of the data obtained, new experiments were designed with a taller water column (300 mL of As standard prepared from a 1000 mg L⁻¹ stock diluted...
to ~80 μg L\(^{-1}\) in a 1000 mL graduated cylinder) in order to determine more precisely the As concentrations at the air-water interface. Three columns were dosed with 5 mg L\(^{-1}\) GE and inverted 10 times. Then, 5 mL samples were taken from the top of the column after one hour and filtered with 0.22 micron mixed cellulose ester syringe filters, acidified with 0.4 % HNO\(_3\), and tested for total As content using atomic absorption spectroscopy. This series of experiments was performed at three different mucilage pHs held constant: 7, 8, and 9.

Experiments were also performed in order to elicit the arsenic distribution in the water column. A 500 mL beaker containing a port at the bottom was outfitted with a 2mm nylon tube at the 250 mL level so samples could be taken from the bottom and the middle of the system. The system was dosed with 5 mg L\(^{-1}\) GE and stirred for 10 s. The system was then placed on a level surface. Samples were taken at 0.5 h intervals and examined with AAS.

Finally, an experiment was performed with concentrated arsenic (10.34 mg L\(^{-1}\)) and a high dosage concentration of GE (187.5 mg L\(^{-1}\)) in a 50 mL centrifuge tube. A 20 mL sample of the arsenic solution was reserved as a before sample and 40 mL was added to the centrifuge tube. A 15 mL dose of 0.5 g L\(^{-1}\) GE was added to the centrifuge tube, inverted 10 times, and a 20 mL after sample was taken from the top. These samples were examined with HG-AFS.

### 6.2.3. Optimization Procedure

New arsenic tests were performed using a make-up method designed to replace spent mucilage removed from the top of the column. A mucilage pH of 8
was chosen due to its apparent superior performance in creating the arsenic concentration differential. The same 300 mL water column set-up was used with identical As stock solution and GE dosage. The column was initially dosed with 2.5 mg L\(^{-1}\) GE and inverted 10 times. A 5 mL sample was taken at the air-water interface after 0.5 h and treated the same as the previous test. The 5 mL sample was then replaced with 5 mL of GE at a concentration of 2.5 mg L\(^{-1}\) at the top of the column. This procedure was performed at 0.5 h intervals for four hours. The samples were examined using atomic absorption spectroscopy.

Based on the performance of GE in removing As, a simple filter was designed consisting of 400 mL of sand in a beaker containing a port level at the bottom. The filter was initially rinsed with 50 mL of distilled water, allowing all of the water to drain. Then, it was dosed with 50 mL of GE at 1 mg L\(^{-1}\), allowing the solution to completely run through the filter and discarding the filtrate. A 50 mL volume of a 5 mg L\(^{-1}\) solution prepared from As(V) solid was then poured into the filter and collected from the bottom port. The samples were then analyzed with Hydride Generation-Atomic Fluorescence Spectrometry.
Chapter Seven

Results and Discussion

Experimental results are presented and discussed in this chapter. A presentation and discussion of the chemical composition of the mucilage is followed by the results of the turbidity and arsenic study. An evaluation of the cultural sensitivity of the project is then followed by an evaluation of the interdisciplinary work involved in this study.

7.1. Comparison of Extracts: Chemical Composition

Raman IR analysis of GE, NE, and CE extracts highlighted their differences and similarities. Curiously, the spectrum for the CE matched exactly with the NE, as can be seen in Figure 22.
The real differences were found to be between GE and NE (Figure 15). The NE spectrum shows a broad peak in the isolated OH region (3600-3200 cm\(^{-1}\)) and peaks in the region suggesting liberation mode of residual water molecules (~800 cm\(^{-1}\)). These are both split in the GE spectrum, suggesting two types of O-H stretching, isolated OH species and residual water molecules attached to the complex structure of the mucilage with is a combination of polyethers. However, the real differences occur in areas relating to nitrogen bonding (Figure 15). Both show nitrile peaks between 2200 cm\(^{-1}\) and 2400 cm\(^{-1}\), but NE shows a much stronger peak. GE shows a peak in a region generally attributed to C-NH\(_2\) bonds (~1100 cm\(^{-1}\)). We believe it is this to which the mucilage owes its water treating properties.
The structures of GE and NE/CE have similar properties of polymers that show the same functionality. Poly(ethyl cyanoacrylate), in Figure 16, shows similar structural composition to NE/CE, is known as a bonding agent, and has been investigated as a colloidal carrier of drugs. Figure 16 also shows poly(ethyl acrylamide), a polymer with similar structure to GE. It also exhibits similar properties as GE, such as its ability to form a gel, its use as a thickening agent, and its ability to flocculate colloidal systems [101].

Figure 15: The Spectral Differences Between GE and NE.

Figure 16: Poly(ethyl cyanoacrylate) and Poly(ethyl acrylamide).
7.2. A Comparison of Extracts: Flocculation

7.2.1. Settling Rate

The gelling extract was found to be the best performer with respect to suspended solids removal as determined by standard cylinder tests. It out performed NE, CE, and Al$_2$(SO$_4$)$_3$, a widely used chemical flocculant and benchmark for this study, whose usage could cause contamination and an extra separation step in drinking water treatment. The fall in liquid-solid interface was recorded with time, and rates were measured from the linear decay portion of settling. The pH was a constant value of 7 during these experiments. The GE performed at rates 3.3 times faster than that of Al$_2$(SO$_4$)$_3$ at flocculant doses of 3 mg L$^{-1}$ (2.20 cm min$^{-1}$ for GE versus 0.67 cm min$^{-1}$ for Al$_2$(SO$_4$)$_3$ in Figure 1). The control (no flocculant dose) settled at a rate of 0.56 cm min$^{-1}$. As can be seen in Figure 18, at a GE dose of 0.01 gm L$^{-1}$, the mucilage performed at a rate equivalent to Al$_2$(SO$_4$)$_3$ dosed at 300 times that concentration (3 mg L$^{-1}$), proving that the GE is a more effective flocculent than the popular Al$_2$(SO$_4$)$_3$ with respect to settling rate and requiring the use of less material to obtain the same results.
Figure 17: Flocculation Rates Comparison.

Figure 18: GE Compared to Al$_2$(SO$_4$)$_3$. 
The flocculation effectiveness of all three types of mucilage with respect to settling rate increases when dosage concentration is increased. The effect of dose concentration is illustrated in Figure 19.

Figure 19: The Effect of Dose on the Settling Rates of GE, CE, and NE.

The effectiveness of the flocculants in this study is directly related to the size of the flocs formed. Larger flocs fall faster under the influence of gravity, leading to a faster settling rate. Larger flocs require more restructuring of the settled solids in the graduated cylinders, leading to a shorter linear settling portion. As the large flocs pile up they begin to rearrange, leading to an earlier removal from the linear settling scheme. Examining the data in Figure 20, it is obvious that GE performs as a faster flocculant due to its ability to form larger
flocs than NE, CE, and Al$_2$(SO$_4$)$_3$, as is evidenced by its relatively early departure from the linear scheme (5 min in comparison to the control’s 21 min).

![Figure 20: A Comparison Showing the Differences in the Linear Portion of Settling.](image)

The cylinder test results suggest that the ability of GE to form a gel, much like polyacrylamide, provides it with excellent floc-forming properties. The ability of GE to perform at the same efficiencies of Al$_2$(SO$_4$)$_3$, at doses 300 times smaller is a testament to its attractiveness as a flocculant alternative when settling rate is a critical variable. Adding this to the fact that it is derived from a renewable resource and is a green technology supports GE, CE, or NE as viable flocculant alternatives.
7.2.2. Residual Turbidity

Residual turbidity is a critical aspect to the evaluation of the efficiency of a flocculant. Results of jar tests performed with GE, CE, and Al$_2$(SO$_4$)$_3$ show that while higher mucilage doses improve settling rate, they degenerate residual turbidity (Figure 21). These results suggest that GE, CE, and NE are extremely efficient at quickly flocculating systems, but do not completely rid the system of suspended solids. However, as is illustrated in Figure 22, at extremely low doses (approximately 1 \( \mu \)g L$^{-1}$ and below), the mucilage provides residual turbidities comparable to Al$_2$(SO$_4$)$_3$.

![Figure 21: Residual Turbidity of the Mucilages GE and CE.](image_url)
These tests were performed with solutions of very high turbidity not indicative of the turbidities found in Temamatla. Also, the suspended solids in the well water were observed to be of larger particle size than the kaolin used in this study. As a result, GE, NE, or CE would all be applicable in Temamatla. However, in areas with high turbidities, residual turbidity can be reduced by inexpensive secondary filtration, possibly built into the filter design that is the final goal of the overall project.
7.3. Gelling Extract: Arsenic Removal Efficiency

7.3.1. Single Dose Method

The data from the initial single dose experiments (Figure 31) showed a variety of effects. The GE mucilage was definitely transporting the As in the 30 mL water column. Different concentrations showed increases of mucilage at the bottom of the column (0.1 and 37.5 mg L\(^{-1}\)) while the others exhibited decreasing arsenic concentrations. It was concluded that GE was either entrapping the As and transporting it to the air-water interface or to the bottom of the column, as it did with suspended solids.

![Single-Dose Arsenic Tests](image)

Figure 23: Results of the Single Dose Arsenic Tests.
Single dose experiments with CE showed little or no removal, so this extract was abandoned for the rest of the arsenic study. The focus shifted to eliciting the mechanism and performance of GE in removing As.

Experiments designed to determine the arsenic concentration at the top of the water column, when dosed at different GE pH, revealed the action of the mucilage-As complex in the water column and exposed the optimal pH for GE As removal efficiency. The results are illustrated in Figure 33 and Figure 34. At pH of 7 and 9, the GE caused a minimal average increase of As at the top of the water column. However, at a pH of 8, the top As concentration was increased by 11 µg L⁻¹. This does not agree with the action the GE distributed in flocculating suspended solids.
Figure 24: Single Dose Experiments to Elicit the Effect of pH on As Removal.
To adequately determine the action of the GE, a tri-level experiment was designed, the results of which are presented in Figure 35. It is important to note that in this experiment, the samples were filtered in order to remove the entire mucilage-As complex. As a result of this procedural difference, a decrease in arsenic concentration represents the samples containing mucilage-As complexes. The data suggests that GE does, in fact, transport the As to the top of the water column. At 1.5 h, the top concentration is at 57 μg L$^{-1}$, reflecting a 33% removal. After 1.5 h, the data reflects a restructuring of the As concentration profile, probably due to an event occurring during the sampling at 1.5 h. The system experienced perturbation. However, at 3 h, the top concentration is 63.5 μg L$^{-1}$, or 26% removal.
Figure 26: Results of the Tri-level Arsenic Distribution Experiment.

The results of a concentrated test performed with 10.4 mg L\(^{-1}\) As and 65 mg L\(^{-1}\) GE dose seem to contradict the hypothesis that the mucilage transports As to the top of the water column. A removal of 41% As was found at the top with this experiment, using HG-AFS, keeping in mind that an increase in As at the top of the column would have translated to As removal since these samples were not filtered. It seems that at high concentrations, the mucilage-As system reaches a critical concentration, changing conformation and actually sinks to the bottom of the water column. This is corroborated by visual inspection in a reproduction of this test performed in a graduated cylinder. Shiny, solid particles can be seen entrapped in the mesh of the GE and sinking to the bottom (Figure 27). These solid particles could be As or simply small air bubbles trapped in the
sinking mucilage, each demonstrating the action of the mucilage at high concentrations.

![Image of solid particles observed in high concentration As and GE systems.](image)

Figure 27: Solid Particles Observed in High Concentration As and GE Systems.

The results of preliminary filter tests are presented in Figure 36. This demonstrates the ability of GE to be used in a filter form with a silica matrix. This quick, crude experiment exhibited an As removal of 3%. The results from the single-dose tests suggest that as much as 41% removal could be obtained if the filter design and mucilage dosage are optimized.

7.3.2. Optimization

The optimization data in Figure 37 confirms what was found in the tri-level experiment of Figure 35. The data shows a lag time of 1.5 h before a decrease in As concentration. As removal of 35% was reached after 3 h, compared with 33% in the tri-level experiment. This lag time is a result of the GE-As complex diffusing to the air-water interface. This lag time will depend on water column height. As was seen in the tri-level experiment, perturbing the water column
disturbs the As concentration profile. For the optimization experiments performed where they were shaken each time after they were dosed there was no lag or removal exhibited due to the inability of the GE to distribute in the water column.

![Graph of Arsenic Removal Optimization Methods](image)

Figure 28: Results of the Optimization Experiments Illustrating the Importance of Settling Time.

### 7.4. Cultural Sensitivity

The delimitations of this study were laid out in section 1.5 of this thesis. They consisted of guidelines aimed at keeping the project in the realm of cultural sensitivity. To summarize, in order to be culturally sensitive with respect to low-income, indigenous communities, the project must provide a technology that is simple, easily produced, and inexpensive, employ indigenous or easily
accessible materials, and have a rural focus. The results of keeping within these guidelines are listed below.

Simplicity The extraction techniques for GE mucilage are extensive and difficult. However, now that the Opuntia mucilage has been identified as a flocculant, simple extraction techniques can be explored if extraction is to be done by communities. If the mucilage is extracted by a third party and provided to the community members, the actual treatment techniques consisting of simple dosing and decanting techniques are simple and universally known.

Reproducibility This technology is extremely reproducible. The GE is derived from a renewable resource, the Opuntia ficus-indica that grows abundantly in arid and semi-arid regions. The project has at no point departed from the Opuntia cactus as a flocculant source, for the very reason that it is a renewable resource.

Cost Expensive treatment techniques have never been introduced into this study. The most cost-intensive step of the procedure exists in extraction. However, it remains to be determined if macerated Opuntia cladodes can be used for As removal and to what extent. If that were the case, no expensive extraction step would be required.

Materials All materials employed in this proposed technology are familiar to community members in our target community and any other community in an arid or semi-arid region.

Rural Focus The focus of this study has always been the community members of the rural town of Temamatla, Mexico. Using GE for water treatment
is an easy method not requiring any hard labor or materials unavailable to rural individuals.

7.5. **Interdisciplinary Collaboration**

This extensive project has successfully overcome challenges found in both multidisciplinary and international collaborations. We found the five major challenges to the project were not only due to the complexities of the international aspect of the problem, as might be expected, but also arose due to some unexpected difficulties in dealing between the disciplines of engineering, anthropology, and geology. They are as follows:

- Building, maintaining, and improving *rapport* between all parties involved
- Creating project *legitimacy* in the eyes of all disciplines involved.
- Making and sustaining valuable *relationships* amongst departmental, cultural, and intellectual differences
- *Cultural sensitivity*, including discipline-specific vernacular, viewpoints, research methods, and principles
- Sustaining *future involvement* after each aspect of the project is complete

Re-imagining borders between the disciplines can break down these hurdles in the way of success. In this section, suggestions and observations, more adequately described as lessons learned are offered for the improvement of current and future interdisciplinary, international projects.
It may seem obvious that a positive rapport must be achieved for success when interacting with communities in different countries, but it can be taken for granted that a rapport must be established and maintained amongst the research group members. This relationship can be established through group meetings and maintained through constant communication. Email list serves can facilitate communication of ideas, concerns, and information. Make sure to include every team member in important communications and meetings.

When dealing with community members in any setting, one must instill a feeling of urgency or legitimacy in order to gain support from the community. This same attitude should be applied to interdisciplinary relationships. In our project we are chemical engineers working with anthropologists who are helping to focus our research toward meeting a community’s technological need. The engineering discipline is traditionally steeped in quantitative data and eschews or simply does not understand the benefits of qualitative data that anthropological expertise can provide. It becomes the data owner’s responsibility to relay the legitimacy of their data with respect to the goals of the project. In asking an anthropologist to describe their interactions with engineers one can expect a multitude of responses both positive and negative. These difficulties in communicating legitimacy between disciplines can easily be overcome.

Start with choosing individuals from other disciplines that have experience working with your discipline. Often, those with experience have developed personal ways to overcome these difficulties. In our case, we chose an anthropologist specialized in applied anthropology in the area of water quality.
She is adept at collecting useful qualitative data and especially adept at relaying that data in a manner that communicates its legitimacy and subsequent applicability to engineering principles.

Also, make an effort to understand the diverse disciplines involved in the project. Start by reading publications from the other disciplines. If possible, find articles pertaining to the research subject. This can give a good idea of what can be expected out of the research team members. Strides in the direction of legitimacy and rapport can be made by producing a small amount of high-impact reading material on the research subject from your field of interest to the team members from other disciplines.

From the engineering perspective, difficulties can arise when attempting to explain the importance of numerical data to those who are not on the same mathematical or scientific level. Patience is key in overcoming this hurdle. In presenting data, eliminate supporting data that does not directly support the research findings. Also, detailing experimental procedures when dealing with nonscientists can be tedious and tiresome for your audience. In this case, simplification is key in facilitating the legitimacy of your data and suggestions for further work.

Cultural differences abound in both international and interdisciplinary relationships. Cultural sensitivity can provide a way to re-imagine and bridge these boundaries. Languages are not only different from one nation to the next but also between disciplines. Vernacular from one engineering subject to the next differs, as well as from engineering to science and social sciences. Reading
publications from other disciplines can also help familiarity. Be prepared to answer questions about the meaning of terms used and do not be shy answering questions.

Sustaining involvement of all research team members can be a problem in every endeavor. However, in interdisciplinary work, this problem is exacerbated by all the aforementioned inherent difficulties. Taking steps to improve rapport, legitimacy, team relations, and cultural sensitivity can be valuable in sustaining involvement.
Chapter Eight

Conclusions and Future Work

8.1. Summary of Findings

- The three mucilage fractions (GE, CE, and NE) of Opuntia ficus-indica are efficient flocculants with respect to settling rate when compared to the flocculating abilities of the widely used chemical flocculant $\text{Al}_2(\text{SO}_4)_3$.

- The GE fraction of the mucilage provides the fastest settling rate of suspended solids.
  - In comparison to $\text{Al}_2(\text{SO}_4)_3$, GE flocculates at a rate 3.3 times faster when both are dosed at 3 mg $\text{L}^{-1}$ in a 5 g $\text{L}^{-1}$ kaolin slurry.
  - GE provides a comparable settling rate to $\text{Al}_2(\text{SO}_4)_3$ when dosed at a concentration 300 times less than the required amount of $\text{Al}_2(\text{SO}_4)_3$.

- The efficiency of the three extracts is directly related to their flocc-forming abilities. GE is a better flocculant because it produces the largest flocs.

- Settling rates increase with increasing mucilage dose concentrations.
• Residual turbidity increases with increasing mucilage dose concentrations.
• Mucilage doses less than 1 μg L-1 provide comparable residual turbidities with Al₂(SO₄)₃.
• The GE fraction of *Opuntia ficus-indica* mucilage is a promising arsenic removal agent.
• When added to arsenic-contaminated water, GE forms a complex with the As and floats to the air-water interface.
• Arsenic removals of 33% and 35% were found for systems containing between 80 and 90 μg L-1 As and dosed with 5 mg L⁻¹ GE.
• 41% removal was found from a system containing high levels of arsenic (~10 mg L⁻¹) and dosed with high concentrations of GE (~65 mg L⁻¹).
  • In this system, the GE-As complex appeared to sink to the bottom of the water column, suggesting that high levels of As and high levels of GE perform more closely with the action of GE and suspended solids.
• Preliminary results suggest the mucilage of *Opuntia ficus-indica* can be utilized in filter form as a promising technology for arsenic removal.
• The abilities of *Opuntia ficus-indica* to flocculate and remove arsenic are due to the chemical composition of the three fractions.
• The compositions of NE and CE are very similar and show similar functionality to poly(ethyl cyanoacrylate). It is suggested that the possible nitrile functionality contributes to the flocculation abilities.

• The composition of GE is different from that of NE and CE, and show similar functionality and properties of poly(ethyl acrylamide). It is suggested that the aliphatic amine functionality contributes to its abilities in flocculation and arsenic removal.

• The cultural sensitivity of low income, indigenous communities was preserved during this study.

• Suggestions for further interdisciplinary endeavors were extracted from the experiences of this study in the following forms:
  • Build rapport
  • Create and preserve project legitimacy
  • Sustain relationships
  • Respect interdiscipline cultural differences
  • Sustain future involvement

8.2. Future Work

8.2.1. Mucilage Extraction

Efforts must be implemented in the direction of simplifying the mucilage extraction procedures. In order for the overall project to succeed in its goals of
cultural sensitivity and low socio-cultural impact, the extraction procedure should be simple enough to be performed in a low-income household.

8.2.2. Flocculation

Optimal dosage schemes must be determined for the combined goals of fast settling rate and low residual turbidity. Also, different slurry components should be used to determine the versatility of the mucilage. One of the slurry components should be sediment from the Temamatla well water.

8.2.3. Arsenic Removal

An intense arsenic removal investigation should be undertaken to elicit the effects of the following variables on the ability of mucilage to remove arsenic from contaminated water:

- Arsenic concentration
- Mucilage dose
- System pH
- Mucilage fraction (GE, NE, CE, or simply macerated and filtered cladodes)
- Temperature
- Conductivity
- Arsenic speciation
8.2.4. Filter Design

An engineering study is required to determine the appropriate filter design for combined arsenic and suspended solids removal using Opuntia mucilage. Some of the design parameters requiring investigation are as follows:

- Filter type
- Filter matrix
- Required throughput
- Required mucilage concentration
- Appropriate regeneration scheme

8.2.5. Temamatla Implementation

The resulting implementable technology will be introduced to the people of Temamatla and a socio-cultural impact assessment will be performed to determine the applicability of the technology, as well as the feasibility of the technology having a sustained impact. Also, the performance of the technology must be evaluated in a real-world setting.

8.3. Final Remarks

Opuntia ficus-indica mucilage is a promising actor in the field of emerging technologies for arsenic removal. The implications of this project are exciting. The possibility of introducing an indigenous material as an improver of quality of life and health to concerned residents is attractive from a cultural sensitivity and sustainability standpoint.
References


Appendices
**Appendix A: Cylinder and Jar Tests Sample Dosage Schemes**

Table 9: Flocculant Doses for 100 ml Graduated Cylinder Tests from Prepared 1 g L\(^{-1}\) Stock Solutions of Flocculants.

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<th>Appropriate Dose Volume Into the</th>
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</tr>
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<td>5</td>
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<td>10</td>
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</table>

Table 10: Flocculant Doses for Each 0.5 L Jar Test Compartment from Prepared 1 g L\(^{-1}\) Stock Solutions of Flocculants.

<table>
<thead>
<tr>
<th>Desired Final Flocculant Concentration [mg L(^{-1})]</th>
<th>Appropriate Dose Volume [ml]</th>
</tr>
</thead>
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<tr>
<td>0.01</td>
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<td>0.1</td>
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Appendix B: Material Safety Data Sheets

B.1. Aluminum Sulfate

ALUMINUM SULFATE

1. Product Identification
   **Synonyms:** Sulfuric acid, aluminum salt (3:2), octadeca hydrate; Cake alum; Patent alum
   **CAS No.:** 10043-01-3 (Anhydrous) 7784-31-8 (Octadecahydrate)
   **Molecular Weight:** 666.44
   **Chemical Formula:** Al₂(SO₄)₃·18H₂O
   **Product Codes:**
   - J.T. Baker: 0564
   - Mallinckrodt: 3208

2. Composition/Information on Ingredients

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<tbody>
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</tr>
</tbody>
</table>

3. Hazards Identification

   **Emergency Overview**

   **WARNING! HARMFUL IF SWALLOWED OR INHALED. CAUSES IRRITATION TO SKIN, EYES AND RESPIRATORY TRACT.**

   **SAF-T-DATA**(tm) Ratings (Provided here for your convenience)

   - Health Rating: 2 - Moderate
   - Flammability Rating: 0 - None
   - Reactivity Rating: 1 - Slight
   - Contact Rating: 2 - Moderate
   - Lab Protective Equip: GOGGLES; LAB COAT; VENT HOOD; PROPER GLOVES
   - Storage Color Code: Green (General Storage)
Potential Health Effects

This material hydrolyzes in water to form sulfuric acid, which is responsible for the irritating effects given below.

**Inhalation:**
Causes irritation to the respiratory tract. Symptoms may include coughing, shortness of breath.

**Ingestion:**
Causes irritation to the gastrointestinal tract. Symptoms may include nausea, vomiting and diarrhea. There have been two cases of fatal human poisonings from ingestion of 30 grams of alum.

**Skin Contact:**
Causes irritation to skin. Symptoms include redness, itching, and pain.

**Eye Contact:**
Causes irritation, redness, and pain.

**Chronic Exposure:**
No information found.

**Aggravation of Pre-existing Conditions:**
No information found.

4. First Aid Measures

**Inhalation:**
Remove to fresh air. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. Get medical attention.

**Ingestion:**
If swallowed, DO NOT INDUCE VOMITING. Give large quantities of water. Never give anything by mouth to an unconscious person. Get medical attention immediately.

**Skin Contact:**
Wipe off excess material from skin then immediately flush skin with plenty of water for at least 15 minutes. Remove contaminated clothing and shoes. Get medical attention. Wash clothing before reuse. Thoroughly clean shoes before reuse.

**Eye Contact:**
Immediately flush eyes with plenty of water for at least 15 minutes, lifting upper and lower eyelids occasionally. Get medical attention.

5. Fire Fighting Measures

**Fire:**
Not considered to be a fire hazard.
Appendix B (Continued)

**Explosion:**
Not considered to be an explosion hazard.

**Fire Extinguishing Media:**
Keep in mind that addition of water can cause the formation of sulfuric acid.

**Special Information:**
In the event of a fire, wear full protective clothing and NIOSH-approved self-contained breathing apparatus with full facepiece operated in the pressure demand or other positive pressure mode.

---

6. Accidental Release Measures
Ventilate area of leak or spill. Keep unnecessary and unprotected people away from area of spill. Wear appropriate personal protective equipment as specified in Section 8. Spills: Pick up and place in a suitable container for reclamation or disposal, using a method that does not generate dust. Cover spill with sodium bicarbonate or soda ash and mix. US Regulations (CERCLA) require reporting spills and releases to soil, water and air in excess of reportable quantities. The toll free number for the US Coast Guard National Response Center is (800) 424-8802.

7. Handling and Storage
Keep in a tightly closed container, stored in a cool, dry, ventilated area. Protect against physical damage. Isolate from incompatible substances. Aluminum sulfate absorbs moisture and becomes a safety hazard when spilled because it absorbs moisture and becomes slippery. Containers of this material may be hazardous when empty since they retain product residues (dust, solids); observe all warnings and precautions listed for the product.

8. Exposure Controls/Personal Protection

**Airborne Exposure Limits:**
- OSHA Permissible Exposure Limit (PEL):
  2 mg/m³ (TWA) soluble salts as Al
- ACGIH Threshold Limit Value (TLV):
  2 mg/m³ (TWA) soluble salts as Al

**Ventilation System:**
A system of local and/or general exhaust is recommended to keep employee exposures below the Airborne Exposure Limits. Local exhaust ventilation is generally preferred because it can control the emissions of the contaminant at its source, preventing dispersion of it into the general work area. Please refer to the ACGIH document, *Industrial Ventilation, A Manual of Recommended Practices*, most recent edition, for details.
Appendix B (Continued)

**Personal Respirators (NIOSH Approved):**
If the exposure limit is exceeded and engineering controls are not feasible, a half facepiece particulate respirator (NIOSH type N95 or better filters) may be worn for up to ten times the exposure limit or the maximum use concentration specified by the appropriate regulatory agency or respirator supplier, whichever is lowest. A full-face piece particulate respirator (NIOSH type N100 filters) may be worn up to 50 times the exposure limit, or the maximum use concentration specified by the appropriate regulatory agency, or respirator supplier, whichever is lowest. If oil particles (e.g. lubricants, cutting fluids, glycerine, etc.) are present, use a NIOSH type R or P filter. For emergencies or instances where the exposure levels are not known, use a full-facepiece positive-pressure, air-supplied respirator. **WARNING:** Air-purifying respirators do not protect workers in oxygen-deficient atmospheres.

**Skin Protection:**
Wear impervious protective clothing, including boots, gloves, lab coat, apron or coveralls, as appropriate, to prevent skin contact.

**Eye Protection:**
Use chemical safety goggles and/or full face shield where dusting or splashing of solutions is possible. Maintain eye wash fountain and quick-drench facilities in work area.

9. Physical and Chemical Properties

**Appearance:**
Colorless crystals.

**Odor:**
Odorless.

**Solubility:**
87 g/100 cc water @ 0C (32F).

**Specific Gravity:**
1.69 @ 17C/4C

**pH:**
No information found.

**% Volatiles by volume @ 21C (70F):**
0

**Boiling Point:**
No information found.

**Melting Point:**
87C (189F) Decomposes.
Appendix B (Continued)

**Vapor Density (Air=1):**
No information found.

**Vapor Pressure (mm Hg):**
No information found.

**Evaporation Rate (BuAc=1):**
No information found.

10. Stability and Reactivity

**Stability:**
Stable under ordinary conditions of use and storage.

**Hazardous Decomposition Products:**
Hydrolyzes to form dilute sulfuric acid. Toxic and corrosive oxides of sulfur may be formed when heated to decomposition.

**Hazardous Polymerization:**
Will not occur.

**Incompatibilities:**
Corrosive to metals in the presence of water.

**Conditions to Avoid:**
Moisture and incompatibles.

11. Toxicological Information

Anhydrous Material: Oral mouse LD50: 6207 mg/kg; Irritation eyes rabbit: 10 mg/24H severe; investigated as a mutagen and reproductive effector.

18-Hydrate: Oral mouse LD50: > 9 gm/kg; investigated as a mutagen.

--------\Cancer Lists\\-------------------------------------

---NTP Carcinogen---

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<tr>
<th>Ingredient</th>
<th>Known</th>
<th>Anticipated</th>
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<tr>
<td>Aluminum Sulfate (10043-01-3)</td>
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<td>No</td>
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</tbody>
</table>

12. Ecological Information

**Environmental Fate:**
No information found.

**Environmental Toxicity:**
No information found.
13. Disposal Considerations
Whatever cannot be saved for recovery or recycling should be managed in an appropriate and approved waste disposal facility. Processing, use or contamination of this product may change the waste management options. State and local disposal regulations may differ from federal disposal regulations. Dispose of container and unused contents in accordance with federal, state and local requirements.

14. Transport Information
Not regulated.

15. Regulatory Information

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<thead>
<tr>
<th>Ingredient</th>
<th>TSCA</th>
<th>EC</th>
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<thead>
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<th>CERCLA</th>
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<th>8(d)</th>
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<td>Aluminum Sulfate (10043-01-3)</td>
<td>5000</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>

Chemical Weapons Convention: No   TSCA 12(b): No   CDTA: No
SARA 311/312: Acute: Yes   Chronic: No   Fire: No   Pressure: No
Reactivity: No   (Mixture / Solid)

**Australian Hazchem Code**: None allocated.
**Poison Schedule**: None allocated.
Appendix B (Continued)

WHMIS:
This MSDS has been prepared according to the hazard criteria of the Controlled Products Regulations (CPR) and the MSDS contains all of the information required by the CPR.

16. Other Information

NFPA Ratings: Health: 2 Flammability: 0 Reactivity: 0

Label Hazard Warning:
WARNING! HARMFUL IF SWALLOWED OR INHALED. CAUSES IRRITATION TO SKIN, EYES AND RESPIRATORY TRACT.

Label Precautions:
Avoid breathing dust.
Keep container closed.
Use only with adequate ventilation.
Wash thoroughly after handling.
Avoid contact with eyes, skin and clothing.

Label First Aid:
If swallowed, DO NOT INDUCE VOMITING. Give large quantities of water. Never give anything by mouth to an unconscious person. If inhaled, remove to fresh air. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. In case of contact, wipe off excess material from skin then immediately flush eyes or skin with plenty of water for at least 15 minutes. Remove contaminated clothing and shoes. Wash clothing before reuse. In all cases, get medical attention.

Product Use:
Laboratory Reagent.

Revision Information:
No Information Found.

Disclaimer:
********************************************************************************************
****
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Appendix B (Continued)

RESPONSIBLE FOR DAMAGES RESULTING FROM USE OF OR RELIANCE UPON THIS INFORMATION.
********************************************************************************************
****
Prepared by: Environmental Health & Safety
Phone Number: (314) 654-1600 (U.S.A.)
Appendix B (Continued)

B.2. Arsenic(III) Oxide

Material Safety Data Sheet
Arsenic (III) Oxide, 99.999%
ACC# 99309

Section 1 - Chemical Product and Company Identification

MSDS Name: Arsenic (III) Oxide, 99.999%
Catalog Numbers: AC192490000, AC192490050
Synonyms: Arsenic oxide; Arsenic sesquioxide; Arsenous oxide; Arsenous acid anhydride; Arsenous acid.
Company Identification:
Acros Organics N.V.
One Reagent Lane
Fair Lawn, NJ 07410
For information in North America, call: 800-ACROS-01
For emergencies in the US, call CHEMTREC: 800-424-9300

Section 2 - Composition, Information on Ingredients

<table>
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<tr>
<th>CAS#</th>
<th>Chemical Name</th>
<th>Percent</th>
<th>EINECS/ELINCS</th>
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<td>1327-53-3</td>
<td>Arsenic trioxide</td>
<td>99.999</td>
<td>215-481-4</td>
</tr>
</tbody>
</table>

Section 3 - Hazards Identification

EMERGENCY OVERVIEW
Appearance: white solid.
Danger! May be fatal if swallowed. Cancer hazard. Poison! Contains inorganic arsenic. Harmful if inhaled. Causes eye and skin irritation. May cause severe respiratory and digestive tract irritation with possible burns. May cause central nervous system effects. May cause blood abnormalities. May cause lung damage. May cause cardiac disturbances. May cause liver and kidney damage. This substance has caused adverse reproductive and fetal effects in animals.
Target Organs: Kidneys, central nervous system, liver, lungs, cardiovascular system, red blood cells, skin.
Appendix B (Continued)

Potential Health Effects
Eye: Contact produces irritation, tearing, and burning pain. May cause conjunctivitis.

Skin: Causes irritation with burning pain, itching, and redness. May cause dermatitis. Exposure to arsenic compounds may produce hyperpigmentation of the skin and hyperkeratoses of plantar and palmar surfaces as well as both primary irritation and sensitization types. Ingestion: May be fatal if swallowed. Causes severe digestive tract burns with abdominal pain, vomiting, and possible death. May cause hemorrhaging of the digestive tract. Ingestion of arsenical compounds may cause burning of the lips, throat constriction, swallowing difficulties, severe abdominal pain, severe nausea, projectile vomiting, and profuse diarrhea. Ingestion of arsenic compounds can produce convulsions, coma, and possibly death within 24 hours. Inhalation: May cause severe irritation of the respiratory tract with sore throat, coughing, shortness of

breath and delayed lung edema. Inhalation of arsenic compounds may lead to irritation of the respiratory tract and to possible nasal perforation. Long-term exposure to arsenic compounds may produce impairment of peripheral circulation. Chronic: May cause liver and kidney damage. Chronic inhalation may cause nasal septum ulceration and perforation. May cause anemia and other blood cell abnormalities. Chronic skin effects include: cracking, thickening, pigmentation, and drying of the skin. Arsenic trioxide can cause cancer in humans. Other long term effects include: anemia, liver and kidney damage. Chronic exposure to arsenical dust may cause shortness of breath, nausea, chest pains, and garlic odor.

Section 4 - First Aid Measures

Eyes: Flush eyes with plenty of water for at least 15 minutes, occasionally lifting the upper and lower eyelids. Get medical aid.
Skin: Get medical aid. Flush skin with plenty of water for at least 15 minutes while removing contaminated clothing and shoes. Wash clothing before reuse. Ingestion: Call a poison control center. If swallowed, do not induce vomiting unless directed to do so by medical personnel. Never give anything by mouth to an unconscious person. Get medical aid.
Appendix B (Continued)

**Inhalation:** Remove from exposure and move to fresh air immediately. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. Get medical aid. Do NOT use mouth-to-mouth resuscitation.  
**Notes to Physician:** Treat symptomatically and supportively.

---

### Section 5 - Fire Fighting Measures

**General Information:** As in any fire, wear a self-contained breathing apparatus in pressure-demand, MSHA/NIOSH (approved or equivalent), and full protective gear. During a fire, irritating and highly toxic gases may be generated by thermal decomposition or combustion. Use extinguishing media appropriate to the surrounding fire. Substance is noncombustible.  
**Extinguishing Media:** Substance is noncombustible; use agent most appropriate to extinguish surrounding fire. Do NOT get water inside containers.  
**Flash Point:** Not applicable.  
**Autoignition Temperature:** Not applicable.  
**Explosion Limits, Lower:** Not available.  
**Upper:** Not available.  
**NFPA Rating:** (estimated) Health: 3; Flammability: 0; Instability: 0

---

### Section 6 - Accidental Release Measures

**General Information:** Use proper personal protective equipment as indicated in Section 8.  
**Spills/Leaks:** Vacuum or sweep up material and place into a suitable disposal container. Avoid runoff into storm sewers and ditches which lead to waterways. Clean up spills immediately, observing precautions in the Protective Equipment section. Avoid generating dusty conditions. Provide ventilation. Do not get water inside containers.

---

### Section 7 - Handling and Storage

**Handling:** Wash thoroughly after handling. Remove contaminated clothing and wash before reuse. Minimize dust generation and accumulation. Avoid contact with eyes, skin, and clothing. Avoid ingestion and inhalation. Do not allow contact with water. Use only with adequate ventilation or respiratory protection.  
**Storage:** Store in a tightly closed container. Store in a cool, dry, well-ventilated area away from incompatible substances. Do not store in metal containers.
Section 8 - Exposure Controls, Personal Protection

**Engineering Controls:** Use adequate general or local exhaust ventilation to keep airborne concentrations below the permissible exposure limits. See 29CFR 1910.1018 for regulatory requirements pertaining to all occupational exposures to inorganic arsenic.

**Exposure Limits**

<table>
<thead>
<tr>
<th>Chemical Name</th>
<th>ACGIH</th>
<th>NIOSH</th>
<th>OSHA - Final PELs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arsenic trioxide</td>
<td>0.01 mg/m3 TWA (listed under Arsenic)</td>
<td>5 mg/m3 IDLH (listed under Arsenic).5 mg/m3 IDLH (as As) (listed under Arsenic, inorganic compounds).</td>
<td>0.5 mg/m3 TWA (listed under Arsenic).5 æg/m3 Action Level (as As); 10 æg/m3 PEL (as As. Cancer hazard - see 29 CFR 1 910.1018. Arsine excepted) (listed under Arsenic, inorganic compounds).</td>
</tr>
</tbody>
</table>

**OSHA Vacated PELs:** Arsenic trioxide: No OSHA Vacated PELs are listed for this chemical.

**Personal Protective Equipment**

**Eyes:** Wear appropriate protective eyeglasses or chemical safety goggles as described by OSHA’s eye and face protection regulations in 29 CFR 1910.133 or European Standard EN166.

**Skin:** Wear appropriate gloves to prevent skin exposure.

**Clothing:** Wear appropriate protective clothing to prevent skin exposure.

**Respirators:** Follow the OSHA respirator regulations found in 29 CFR 1910.134 or European Standard EN 149. Use a NIOSH/MSHA or European Standard EN 149 approved respirator if exposure limits are exceeded or if irritation or other symptoms are experienced.
Appendix B (Continued)

Section 9 - Physical and Chemical Properties

**Physical State:** Solid
**Appearance:** white
**Odor:** odorless
**pH:** Not available.
**Vapor Pressure:** 66 mm Hg @ 312C
**Vapor Density:** Not available.
**Evaporation Rate:** Negligible.
**Viscosity:** Not available.
**Boiling Point:** 465 deg C
**Freezing/Melting Point:** 312 deg C
**Decomposition Temperature:** Not available.
**Solubility:** 3.7% in water.
**Specific Gravity/Density:** 3.738
**Molecular Formula:** As2O3
**Molecular Weight:** 197.84

Section 10 - Stability and Reactivity

**Chemical Stability:** Stable under normal temperatures and pressures.
**Conditions to Avoid:** Dust generation, moisture, metals, excess heat.
**Incompatibilities with Other Materials:** Incompatible with chlorine trifluoride, fluorine, hydrogen fluoride, oxygen difluoride, and sodium chlorate. Can generate arsine, which is an extremely poisonous gas, when arsenic compounds contact acid, alkalis, or water in the presence of an active metal (zinc, aluminum, magnesium, manganese, sodium, iron, etc).
**Hazardous Decomposition Products:** Irritating and toxic fumes and gases, oxides of arsenic, arsine.
**Hazardous Polymerization:** Has not been reported.
Appendix B (Continued)

Section 11 - Toxicological Information

RTECS#:
CAS# 1327-53-3: CG3325000
LD50/LC50:
CAS# 1327-53-3:
   Oral, mouse: LD50 = 20 mg/kg;
   Oral, rabbit: LD50 = 20190 ug/kg;
   Oral, rat: LD50 = 10 mg/kg;

.Carcinogenicity:
CAS# 1327-53-3:
ACGIH: A1 - Confirmed Human Carcinogen (listed as 'Arsenic').
California: carcinogen, initial date 2/27/87 (listed as Arsenic, inorganic compounds).
NTP: Known carcinogen (listed as Arsenic, inorganic compounds).
IARC: Group 1 carcinogen (listed as Arsenic).

Epidemiology: In a large number of studies, exposure to inorganic arsenic compounds in drugs, food, and water as well as in an occupational setting have been causally associated with the developmental of cancer, primarily of the skin and lungs.

Teratogenicity: Teratogenic effects, including exencephaly, skeletal defects, and genitourinary system defects, of arsenic compounds administered intravenously or intraperitoneally at high doses have been demonstrated in hamsters, rats and mice.

Reproductive Effects: May cause reproductive effects.
Mutagenicity: No information available.
Neurotoxicity: No information available.
Other Studies:

Section 12 - Ecological Information

Ecotoxicity: Water flea Daphnia: LC50 = 0.038 mg/L; 24 Hr.;
UnspecifiedBacteria: Phyto bacterium phosphoreum: EC50 = 31.43-73.73 mg/L;
5,15,30 minutes; Microtox test No data available.

Environmental: Terrestrial: Half-life in soil 6.5 years. Aquatic: Tends to bioaccumulate. Will biodegrade to arsine and will bioconcentrate.

Physical: No information available.
Other: No information available.
Appendix B (Continued)

Section 13 - Disposal Considerations

Chemical waste generators must determine whether a discarded chemical is classified as a hazardous waste. US EPA guidelines for the classification determination are listed in 40 CFR Parts 261.3. Additionally, waste generators must consult state and local hazardous waste regulations to ensure complete and accurate classification.

**RCRA P-Series:** CAS# 1327-53-3: waste number P012.
**RCRA U-Series:** None listed.

Section 14 - Transport Information

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<th>Shipping Name:</th>
<th>US DOT</th>
<th>Canada TDG</th>
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<tbody>
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<td>DOT regulated - small quantity provisions apply (see 49CFR173.4)</td>
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<table>
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<th>Packing Group:</th>
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<tbody>
<tr>
<td></td>
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Section 15 - Regulatory Information

**US FEDERAL**

**TSCA**
CAS# 1327-53-3 is listed on the TSCA inventory.

**Health & Safety Reporting List**
None of the chemicals are on the Health & Safety Reporting List.

**Chemical Test Rules**
None of the chemicals in this product are under a Chemical Test Rule.

**Section 12b**
None of the chemicals are listed under TSCA Section 12b.

**TSCA Significant New Use Rule**
None of the chemicals in this material have a SNUR under TSCA.

**CERCLA Hazardous Substances and corresponding RQs**
CAS# 1327-53-3: 1 lb final RQ; 0.454 kg final RQ
Appendix B (Continued)

SARA Section 302 Extremely Hazardous Substances
CAS# 1327-53-3: 100 lb TPQ (lower threshold); 10000 lb TPQ (upper threshold)

SARA Codes
CAS # 1327-53-3: immediate, delayed.

Section 313
This material contains Arsenic trioxide (listed as Arsenic), 99.999%, (CAS# 1327-53-3) which is subject to the reporting requirements of Section 313 of SARA Title III and 40 CFR Part 373.

Clean Air Act:
CAS# 1327-53-3 (listed as Arsenic, inorganic compounds) is listed as a hazardous air pollutant (HAP).
This material does not contain any Class 1 Ozone depletors.
This material does not contain any Class 2 Ozone depletors.

Clean Water Act:
CAS# 1327-53-3 is listed as a Hazardous Substance under the CWA. CAS# 1327-53-3 is listed as a Priority Pollutant under the Clean Water Act. CAS# 1327-53-3 is listed as a Toxic Pollutant under the Clean Water Act.

OSHA:
None of the chemicals in this product are considered highly hazardous by OSHA.

STATE
CAS# 1327-53-3 can be found on the following state right to know lists:
California, New Jersey, Pennsylvania, Minnesota, (listed as Arsenic), Minnesota, (listed as Arsenic, inorganic compounds), Massachusetts.

California Prop 65
The following statement(s) is(are) made in order to comply with the California Safe Drinking Water Act:
WARNING: This product contains Arsenic trioxide, listed as `Arsenic, inorganic compounds', a chemical known to the state of California to cause cancer.
WARNING: This product contains Arsenic trioxide, listed as `Arsenic (inorganic oxides)', a chemical known to the state of California to cause developmental reproductive toxicity.
California No Significant Risk Level: CAS# 1327-53-3: 0.06 æg/day NSRL (inhalation); 10 æg/day NSRL (except inhalation) (listed under Arsenic)

European/International Regulations
European Labeling in Accordance with EC Directives
Hazard Symbols:
T+ N
Appendix B (Continued)

Risk Phrases:
R 28 Very toxic if swallowed.
R 34 Causes burns.
R 45 May cause cancer.
R 50/53 Very toxic to aquatic organisms, may cause long-term adverse effects in the aquatic environment.

Safety Phrases:
S 45 In case of accident or if you feel unwell, seek medical advice immediately (show the label where possible).
S 53 Avoid exposure - obtain special instructions before use.
S 60 This material and its container must be disposed of as hazardous waste.
S 61 Avoid release to the environment. Refer to special instructions /safety data sheets.

WGK (Water Danger/Protection)
CAS# 1327-53-3: 3

Canada - DSL/NDSL
CAS# 1327-53-3 is listed on Canada's DSL List.

Canada - WHMIS
not available.

This product has been classified in accordance with the hazard criteria of the Controlled Products Regulations and the MSDS contains all of the information required by those regulations.

Canadian Ingredient Disclosure List
CAS# 1327-53-3 is listed on the Canadian Ingredient Disclosure List.

Section 16 - Additional Information

MSDS Creation Date: 6/21/1999
Revision #5 Date: 10/03/2005

The information above is believed to be accurate and represents the best information currently available to us. However, we make no warranty of merchantability or any other warranty, express or implied, with respect to such information, and we assume no liability resulting from its use. Users should make their own investigations to determine the suitability of the information for their particular purposes. In no event shall Fisher be liable for any claims, losses, or damages of any third party or for lost profits or any special, indirect, incidental, consequential or exemplary damages, howsoever arising, even if Fisher has been advised of the possibility of such damages.
Appendix B (Continued)

B.3. Arsenic (V) Oxide

Material Safety Data Sheet
Arsenic(V) oxide
ACC# 02088

Section 1 - Chemical Product and Company Identification

**MSDS Name:** Arsenic(V) oxide

**Catalog Numbers:** AC192500000, AC192500250, AC366310000, AC366310050, AC366310250

**Synonyms:** Arsenic pentoxide; Diarsenic pentaoxide; Arsenic acid anhydride; Arsenic anhydride.

**Company Identification:**
Acros Organics N.V.
One Reagent Lane
Fair Lawn, NJ 07410

For information in North America, call: 800-ACROS-01
For emergencies in the US, call CHEMTREC: 800-424-9300

Section 2 - Composition, Information on Ingredients

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<tr>
<th>CAS#</th>
<th>Chemical Name</th>
<th>Percent</th>
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<td>Arsenic(V) oxide</td>
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Section 3 - Hazards Identification

**EMERGENCY OVERVIEW**
Appearance: white solid.

**Danger!** May be fatal if swallowed. Cancer hazard. Contains inorganic arsenic. Harmful if inhaled. Causes eye, skin, and respiratory tract irritation. May cause nervous system effects. May cause fetal effects.

**Target Organs:** Liver, lungs, nervous system, skin.

**Potential Health Effects**

**Eye:** May cause eye irritation. May result in corneal injury.

**Skin:** May cause skin irritation. May cause skin sensitization, an allergic reaction, which becomes evident upon re-exposure to this material.
Appendix B (Continued)

**Ingestion:** May cause liver damage. Can cause nervous system damage. Ingestion of arsenical compounds may cause burning of the lips, throat constriction, swallowing difficulties, severe abdominal pain, severe nausea, projectile vomiting, and profuse diarrhea. All soluble arsenic (As) compounds are considered to be poisonous to humans. Inorganic arsenic is more toxic than organic arsenic. Organic arsenic is excreted more rapidly than inorganic arsenic. Arsenic 5+ is excreted more rapidly than arsenic 3+. Arsenic inhibits enzymes required for cellular respiration and also competes with phosphorus for incorporation into ATP, depleting cellular energy stores and leading to cell death.

**Inhalation:** Causes respiratory tract irritation. May cause effects similar to those described for ingestion. Inhalation of arsenic compounds may lead to irritation of the respiratory tract and to possible nasal perforation.

**Chronic:** Chronic ingestion is characterized by weakness, anorexia, gastrointestinal disturbances, impairment of cognitive function, peripheral neuropathy, and skin disorders. Chronic ingestion may cause fetal effects. Inorganic arsenic compounds may cause skin and lung cancers in humans. Based on a case report of one family with chronic exposure, the spectrum of toxic effects from arsenic pentoxide may include skin rashes, nosebleeds, easy bruising, hair loss, headaches, malaise, and grand mal seizures. Because of mixed exposures, these effects cannot be attributed solely to arsenic pentoxide.

### Section 4 - First Aid Measures

**Eyes:** Flush eyes with plenty of water for at least 15 minutes, occasionally lifting the upper and lower eyelids. Get medical aid immediately.

**Skin:** Flush skin with plenty of water for at least 15 minutes while removing contaminated clothing and shoes. Get medical aid if irritation develops or persists.

**Ingestion:** Call a poison control center. If swallowed, do not induce vomiting unless directed to do so by medical personnel. Never give anything by mouth to an unconscious person. Get medical aid.

**Inhalation:** Get medical aid immediately. Remove from exposure and move to fresh air immediately. If not breathing, give artificial respiration. If breathing is difficult, give oxygen.

**Notes to Physician:** Treat symptomatically and supportively.
Appendix B (Continued))

Section 5 - Fire Fighting Measures

**General Information:** As in any fire, wear a self-contained breathing apparatus in pressure-demand, MSHA/NIOSH (approved or equivalent), and full protective gear.

**Extinguishing Media:** Use water spray to cool fire-exposed containers.

**Flash Point:** Not available.

**Autoignition Temperature:** Not available.

**Explosion Limits, Lower:** Not available.

**Upper:** Not available.

**NFPA Rating:** (estimated) Health: 3; Flammability: 0; Instability: 0

Section 6 - Accidental Release Measures

**General Information:** Use proper personal protective equipment as indicated in Section 8.

**Spills/Leaks:** Vacuum or sweep up material and place into a suitable disposal container. Avoid generating dusty conditions. Provide ventilation.

Section 7 - Handling and Storage

**Handling:** Wash thoroughly after handling. Remove contaminated clothing and wash before reuse. Do not get in eyes, on skin, or on clothing. Do not ingest or inhale. Use only with adequate ventilation or respiratory protection.

**Storage:** Poison room locked.

Section 8 - Exposure Controls, Personal Protection

**Engineering Controls:** Use adequate general or local exhaust ventilation to keep airborne concentrations below the permissible exposure limits. See 29CFR 1910.1018 for regulatory requirements pertaining to all occupational exposures to inorganic arsenic.
Appendix B (Continued)

Exposure Limits

<table>
<thead>
<tr>
<th>Chemical Name</th>
<th>ACGIH</th>
<th>NIOSH</th>
<th>OSHA - Final PELs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arsenic(V) oxide</td>
<td>0.01 mg/m3 TWA (as As) (listed under Arsenic, inorganic compounds).</td>
<td>5 mg/m3 IDLH (as As) (listed under Arsenic, inorganic compounds).</td>
<td>5 æg/m3 Action Level (as As); 10 æg/m3 PEL (as As. Cancer hazard - see 29 CFR 1910.1018. Arsine excepted) (listed under Arsenic, inorganic compounds).</td>
</tr>
</tbody>
</table>

**OSHA Vacated PELs:** Arsenic(V) oxide: No OSHA Vacated PELs are listed for this chemical.

**Personal Protective Equipment**

**Eyes:** Wear appropriate protective eyeglasses or chemical safety goggles as described by OSHA's eye and face protection regulations in 29 CFR 1910.133 or European Standard EN166.

**Skin:** Wear appropriate protective gloves to prevent skin exposure.

**Clothing:** Wear appropriate protective clothing to prevent skin exposure.

**Respirators:** Follow the OSHA respirator regulations found in 29 CFR 1910.134 or European Standard EN 149. Use a NIOSH/MSHA or European Standard EN 149 approved respirator if exposure limits are exceeded or if irritation or other symptoms are experienced.

Section 9 - Physical and Chemical Properties

**Physical State:** Solid

**Appearance:** white

**Odor:** odorless

**pH:** acidic in soln

**Vapor Pressure:** Not available.

**Vapor Density:** Not available.

**Evaporation Rate:** Not available.

**Viscosity:** Not available.

**Boiling Point:** Not available.

**Freezing/Melting Point:** 315 deg C (dec)

**Decomposition Temperature:** 315 deg C

**Solubility:** Soluble.
Appendix B (Continued)

Specific Gravity/Density: Not available.
Molecular Formula: As2O5
Molecular Weight: 229.84

Section 10 - Stability and Reactivity

Chemical Stability: Stable under normal temperatures and pressures.
Conditions to Avoid: Excess heat, moist air.
Incompatibilities with Other Materials: Acids, aluminum, halogens, zinc, rubidium carbide.
Hazardous Decomposition Products: Oxides of arsenic.
Hazardous Polymerization: Has not been reported.

Section 11 - Toxicological Information

RTECS#: 
CAS# 1303-28-2: CG2275000
LD50/LC50:
CAS# 1303-28-2:
  Oral, mouse: LD50 = 55 mg/kg;
  Oral, rat: LD50 = 8 mg/kg;
.

Carcinogenicity:
CAS# 1303-28-2:
ACGIH: A1 - Confirmed Human Carcinogen (listed as 'Arsenic, inorganic compounds').
California: carcinogen, initial date 2/27/87 (listed as Arsenic, inorganic compounds).
NTP: Known carcinogen (listed as Arsenic, inorganic compounds).
IARC: Group 1 carcinogen (listed as Arsenic compounds, n.o.s.).

Epidemiology: No data available.
Teratogenicity: No data available.
Reproductive Effects: No data available.
Mutagenicity: No data available.
Neurotoxicity: No data available.
Appendix B (Continued)

Other Studies:

Section 12 - Ecological Information

Ecotoxicity: No data available. No information available.
Environmental: No information available.
Physical: No information available.
Other: Used in wood preservatives, weed control, and as fungicide.

Section 13 - Disposal Considerations

Chemical waste generators must determine whether a discarded chemical is classified as a hazardous waste. US EPA guidelines for the classification determination are listed in 40 CFR Parts 261.3. Additionally, waste generators must consult state and local hazardous waste regulations to ensure complete and accurate classification.

**RCRA P-Series:** CAS# 1303-28-2: waste number P011.
**RCRA U-Series:** None listed.

Section 14 - Transport Information

<table>
<thead>
<tr>
<th></th>
<th>US DOT</th>
<th>Canada TDG</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Shipping Name:</strong></td>
<td>DOT regulated - small quantity provisions apply (see 49CFR173.4)</td>
<td>ARSENIC PENTOXIDE</td>
</tr>
<tr>
<td><strong>Hazard Class:</strong></td>
<td></td>
<td>6.1</td>
</tr>
<tr>
<td><strong>UN Number:</strong></td>
<td></td>
<td>UN1559</td>
</tr>
<tr>
<td><strong>Packing Group:</strong></td>
<td></td>
<td>II</td>
</tr>
</tbody>
</table>

Section 15 - Regulatory Information

**US FEDERAL**

**TSCA**
CAS# 1303-28-2 is listed on the TSCA inventory.

**Health & Safety Reporting List**
None of the chemicals are on the Health & Safety Reporting List.
Appendix B (Continued)

Chemical Test Rules
None of the chemicals in this product are under a Chemical Test Rule.

Section 12b
None of the chemicals are listed under TSCA Section 12b.

TSCA Significant New Use Rule
None of the chemicals in this material have a SNUR under TSCA.

CERCLA Hazardous Substances and corresponding RQs
CAS# 1303-28-2: 1 lb final RQ; 0.454 kg final RQ

SARA Section 302 Extremely Hazardous Substances
CAS# 1303-28-2: 100 lb TPQ (lower threshold); 10000 lb TPQ (upper threshold)

Section 313
This material contains Arsenic(V) oxide (listed as Arsenic, inorganic compounds), >99.9%, (CAS# 1303-28-2) which is subject to the reporting requirements of Section 313 of SARA Title III and 40 CFR Part 373.

Clean Air Act:
CAS# 1303-28-2 (listed as Arsenic, inorganic compounds) is listed as a hazardous air pollutant (HAP).
This material does not contain any Class 1 Ozone depletors.
This material does not contain any Class 2 Ozone depletors.

Clean Water Act:
CAS# 1303-28-2 is listed as a Hazardous Substance under the CWA.
None of the chemicals in this product are listed as Priority Pollutants under the CWA. CAS# 1303-28-2 is listed as a Toxic Pollutant under the Clean Water Act.

OSHA:
None of the chemicals in this product are considered highly hazardous by OSHA.

STATE
CAS# 1303-28-2 can be found on the following state right to know lists:
California, New Jersey, Pennsylvania, Minnesota, (listed as Arsenic, inorganic compounds), Massachusetts.

California Prop 65
The following statement(s) is(are) made in order to comply with the California Safe Drinking Water Act:
WARNING: This product contains Arsenic(V) oxide, listed as `Arsenic, inorganic compounds', a chemical known to the state of California to cause cancer.
WARNING: This product contains Arsenic(V) oxide, listed as `Arsenic (inorganic oxides)', a chemical known to the state of California to cause developmental reproductive toxicity.
Appendix B (Continued)

California No Significant Risk Level: None of the chemicals in this product are listed.

**European/International Regulations**

**European Labeling in Accordance with EC Directives**

**Hazard Symbols:**

T N

**Risk Phrases:**

R 23/25 Toxic by inhalation and if swallowed.
R 45 May cause cancer.
R 50/53 Very toxic to aquatic organisms, may cause long-term adverse effects in the aquatic environment.

**Safety Phrases:**

S 45 In case of accident or if you feel unwell, seek medical advice immediately (show the label where possible).
S 53 Avoid exposure - obtain special instructions before use.
S 60 This material and its container must be disposed of as hazardous waste.
S 61 Avoid release to the environment. Refer to special instructions /safety data sheets.

**WGK (Water Danger/Protection)**

CAS# 1303-28-2: 3

**Canada - DSL/NDSSL**

CAS# 1303-28-2 is listed on Canada's DSL List.

**Canada - WHMIS**

This product has a WHMIS classification of D2A, D1A. This product has been classified in accordance with the hazard criteria of the Controlled Products Regulations and the MSDS contains all of the information required by those regulations.

**Canadian Ingredient Disclosure List**

CAS# 1303-28-2 is listed on the Canadian Ingredient Disclosure List.
Appendix B (Continued)

Section 16 - Additional Information

**MSDS Creation Date:** 9/02/1997  
**Revision #4 Date:** 6/01/2005

The information above is believed to be accurate and represents the best information currently available to us. However, we make no warranty of merchantability or any other warranty, express or implied, with respect to such information, and we assume no liability resulting from its use. Users should make their own investigations to determine the suitability of the information for their particular purposes. In no event shall Fisher be liable for any claims, losses, or damages of any third party or for lost profits or any special, indirect, incidental, consequential or exemplary damages, howsoever arising, even if Fisher has been advised of the possibility of such damages.
Appendix B (Continued)

B.4. Arsenic Standard Solution

MATERIAL SAFETY DATA SHEET

1. CHEMICAL PRODUCT AND COMPANY IDENTIFICATION
Product Name: Arsenic Reference Standard Solution 1000 ± 10 mg/l as As+3
Catalog Number: 1457142
Hach Company Emergency Telephone Numbers:
P.O.Box 389 (Medical and Transportation)
Loveland, CO USA 80539 (303) 623-5716 24 Hour Service
(970) 669-3050 (515)232-2533 8am - 4pm CST
MSDS Number: M00697
Chemical Name: Not applicable
CAS No.: Not applicable
Chemical Formula: Not applicable
Chemical Family: Not applicable
Hazard: Carcinogen. Harmful if swallowed
Date of MSDS Preparation:
Day: 23
Month: 09
Year: 2004

2. COMPOSITION / INFORMATION ON INGREDIENTS
Sodium Hydroxide
CAS No.: 1310-73-2
TSCA CAS Number: 1310-73-2
Percent Range: < 0.1
Percent Range Units: weight / volume
LD50: Oral rat LDLo = 500 mg/kg.
LC50: None reported
TLV: 2 mg/m³
PEL: 2 mg/m³
Hazard: Causes severe burns. Toxic.
Demineralized Water
CAS No.: 7732-18-5
TSCA CAS Number: 7732-18-5
Percent Range: > 99.0
Percent Range Units: volume / volume
LD50: None reported
LC50: None reported
TLV: Not established
PEL: Not established
Appendix B (Continued)

Hazard: No effects anticipated.
Arsenic Trioxide
CAS No.: 1327-53-3
TSCA CAS Number: 1327-53-3
Percent Range: < 0.5
Percent Range Units: weight / volume
LD50: Oral rat LD50 = 15.1 mg/kg; Oral human LDLo = 29 mg/kg
LC50: None reported
TLV: 0.2 mg/m3 as As
PEL: 0.01 mg/m3 as As

3. HAZARDS IDENTIFICATION
Emergency Overview:
Appearance: Clear, colorless liquid
Odor: None
HARMFUL IF SWALLOWED
CANCER HAZARD CONTAINS MATERIAL WHICH CAN CAUSE CANCER
HMIS:
Health: 4
Flammability: 0
Reactivity: 0
Protective Equipment: X - See protective equipment, Section 8.
NFPA:
Health: 2
Flammability: 0
Reactivity: 0
Symbol: Not applicable
Potential Health Effects:
Eye Contact: May cause irritation
Skin Contact: No effects are anticipated
Skin Absorption: Will be absorbed through the skin. Effects similar to those of ingestion
Target Organs: Blood Liver Kidneys Central nervous system
Ingestion: Can cause: nausea vomiting gastrointestinal irritation convulsions death
Target Organs: Blood Liver Kidneys Central nervous system
Inhalation: No data reported.
Target Organs: None reported
Medical Conditions Aggravated: Pre-existing: Liver conditions Kidney conditions blood disorders
Appendix B (Continued)

Chronic Effects: Chronic overexposure may cause central nervous system effects gastrointestinal disturbances kidney damage liver damage muscle aches death
Cancer / Reproductive Toxicity Information:
An ingredient of this product is an OSHA listed carcinogen.
Inorganic Arsenic
An ingredient of this mixture is: IARC Group 1: Recognized Carcinogen
Inorganic Arsenic
An ingredient of this mixture is: NTP Listed Group 1: Recognized Carcinogen
Inorganic Arsenic
Additional Cancer / Reproductive Toxicity Information: Contains: an experimental mutagen. an experimental teratogen.
Toxicologically Synergistic Products: None reported

4. FIRST AID
Eye Contact: Immediately flush eyes with water for 15 minutes. Call physician.
Skin Contact (First Aid): Wash skin with plenty of water. Call physician if irritation develops.
Ingestion (First Aid): Induce vomiting using syrup of ipecac or by sticking finger down throat. Never give anything by mouth to an unconscious person. Call physician immediately.
Inhalation: None required.

5. FIRE FIGHTING MEASURES
Flammable Properties: Material will not burn.
Flash Point: Not applicable
Method: Not applicable
Flammability Limits:
Lower Explosion Limits: Not applicable
Upper Explosion Limits: Not applicable
Autoignition Temperature: Not applicable
Hazardous Combustion Products: Not applicable
Fire / Explosion Hazards: None reported
Static Discharge: None reported.
Mechanical Impact: None reported
Extinguishing Media: Use media appropriate to surrounding fire conditions
Fire Fighting Instruction: As in any fire, wear self-contained breathing apparatus pressure-demand and full protective gear.
6. ACCIDENTAL RELEASE MEASURES
Spill Response Notice:
Only persons properly qualified to respond to an emergency involving hazardous substances may respond to a spill according to federal regulations (OSHA 29 CFR 1910.120(a)(v)) and per your company's emergency response plan and guidelines/procedures. See Section 13, Special Instructions for disposal assistance.
Containment Technique: Releases of this material may contaminate the environment. Absorb spilled liquid with nonreactive sorbent material. Stop spilled material from being released to the environment. Dike the spill to contain material for later disposal.
Clean-up Technique: Avoid contact with spilled material. Absorb spilled liquid with non-reactive sorbent material. Sweep up material. Dispose of material in an E.P.A. approved hazardous waste facility. Decontaminate the area of the spill with a soap solution.
Evacuation Procedure: Evacuate general area (50 foot radius or as directed by your facility's emergency response plan) when: any quantity is spilled. If conditions warrant, increase the size of the evacuation.
Special Instructions (for accidental release): Mixture contains a component which is regulated as a water pollutant.
Mixture contains a component which is regulated as a hazardous air pollutant.
304 EHS RQ (40 CFR 355): Arsenic Trioxide - RQ 1 lbs
D.O.T. Emergency Response Guide Number: None

7. HANDLING / STORAGE
Handling: Avoid contact with eyes skin Do not breathe mist or vapors. Wash thoroughly after handling. Maintain general industrial hygiene practices when using this product.
Storage: Keep container tightly closed when not in use.
Flammability Class: Not applicable

8. EXPOSURE CONTROLS / PROTECTIVE EQUIPMENT
Engineering Controls: Have an eyewash station nearby. Maintain general industrial hygiene practices when using this product.
Personal Protective Equipment:
Appendix B (Continued)

Eye Protection: safety glasses with top and side shields
Skin Protection: lab coat disposable latex gloves
Inhalation Protection: adequate ventilation
Precautionary Measures: Avoid contact with: eyes skin Do not breathe: mist/vapor Wash thoroughly after handling.
TLV: Not established
PEL: Not established

9. PHYSICAL / CHEMICAL PROPERTIES
Appearance: Clear, colorless liquid
Physical State: Liquid
Molecular Weight: Not applicable
Odor: None
pH: 5-7
Vapor Pressure: Not determined
Vapor Density (air = 1): Not determined
Boiling Point: 100°C
Melting Point: Not determined
Specific Gravity (water = 1): 0.997
Evaporation Rate (water = 1): 1.053
Volatile Organic Compounds Content: Not applicable
Partition Coefficient (n-octanol / water): Not applicable
Solubility:
Water: Soluble
Acid: Soluble
Other: Not determined
Metal Corrosivity:
Steel: Not determined
Aluminum: Not determined

10. STABILITY / REACTIVITY
Chemical Stability: Stable when stored under proper conditions.
Conditions to Avoid: Heating to decomposition. Extreme temperatures Evaporation
Reactivity / Incompatibility: None reported

11. TOXICOLOGICAL INFORMATION
Product Toxicological Data:
LD50: None reported
LC50: None reported
Appendix B (Continued)

Dermal Toxicity Data: None reported
Skin and Eye Irritation Data: None reported
Mutation Data: Arsenic Trioxide: Human lung - Unscheduled DNA synthesis -
1µmol/l; Human lymphocyte - sister
chromatid exchange - 2µg/cm3
Reproductive Effects Data: Oral Mouse TDLo = 3636 mg/kg : Reproductive -
Fertility - abortion
Ingredient Toxicological Data: Arsenic Trioxide: Oral rat LD50 = 15.1 mg/kg; Oral
human LDLo = 29 mg/kg

12. ECOLOGICAL INFORMATION
Product Ecological Information: --
No ecological data available for this product.
Ingredient Ecological Information: --
No ecological data available for the ingredients of this product.

13. DISPOSAL CONSIDERATIONS
EPA Waste ID Number: D004
Special Instructions (Disposal): Dispose of material in an E.P.A. approved
hazardous waste facility.
Empty Containers: Rinse three times with an appropriate solvent. Dispose of
empty container as normal trash.
NOTICE (Disposal): These disposal guidelines are based on federal regulations
and may be superseded by more stringent
state or local requirements. Please consult your local environmental regulators
for more information.

14. TRANSPORT INFORMATION
D.O.T.: 
D.O.T. Proper Shipping Name: Not Currently Regulated
--
DOT Hazard Class: NA
DOT Subsidiary Risk: NA
DOT ID Number: NA
DOT Packing Group: NA
I.C.A.O.: 
I.C.A.O. Proper Shipping Name: Not Currently Regulated
--
ICAO Hazard Class: NA
ICAO Subsidiary Risk: NA
ICAO ID Number: NA
ICAO Packing Group: NA
I.M.O.: 

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Appendix B (Continued)

I.M.O. Proper Shipping Name: Not Currently Regulated

I.M.O. Hazard Class: NA
I.M.O. Subsidiary Risk: NA
I.M.O. ID Number: NA
I.M.O. Packing Group: NA

Additional Information: This product may be shipped as part of a chemical kit composed of various compatible dangerous goods for analytical or testing purposes. This kit would have the following classification: Proper Shipping Name: Chemical Kit Hazard Class: 9 UN Number 3316

15. REGULATORY INFORMATION

U.S. Federal Regulations:
O.S.H.A.: This product contains Inorganic arsenic and is regulated under 29CFR Subpart Z 1910.1018.
E.P.A.:
S.A.R.A. Title III Section 311/312 Categorization (40 CFR 370): Immediate (Acute) Health Hazard Delayed (Chronic) Health Hazard
S.A.R.A. Title III Section 313 (40 CFR 372): This product contains a chemical(s) subject to the reporting requirements of Section 313 of Title III of SARA.
Arsenic Trioxide
302 (EHS) TPQ (40 CFR 355): Arsenic Trioxide 100 lbs.
304 CERCLA RQ (40 CFR 302.4): Arsenic Trioxide 1 lb.
304 EHS RQ (40 CFR 355): Arsenic Trioxide - RQ 1 lbs
RCRA: Contains RCRA regulated substances. See Section 13, EPA Waste ID Number.
C.P.S.C.: Not applicable

State Regulations:
California Prop. 65: WARNING - This product contains a chemical known to the State of California to cause cancer.
Identification of Prop. 65 Ingredient(s): Arsenic (inorganic compounds)
Trade Secret Registry: Not applicable

National Inventories:
U.S. Inventory Status: All ingredients in this product are listed on the TSCA 8(b) Inventory (40 CFR 710).
TSCA CAS Number: Not applicable
16. OTHER INFORMATION
Intended Use: Standard solution
Values and Biological Exposure Indices for
Technical Judgment. IARC Monographs
on the Evaluation of the Carcinogenic Risks to Humans. World Health
Organization (Volumes 1-42) Supplement 7.
Materials, 10th Ed. Quincy, MA: National Fire
(67/548) - Classification, Packaging and
Revision Summary: Updates in Section(s) 14,

Legend: NA - Not Applicable w/w - weight/weight
ND - Not Determined w/v - weight/volume
NV - Not Available v/v - volume/volume
USER RESPONSIBILITY: Each user should read and understand this
information and incorporate it in individual site safety
programs in accordance with applicable hazard communication standards and
regulations.
THE INFORMATION CONTAINED HEREIN IS BASED ON DATA
CONSIDERED TO BE ACCURATE.
HOWEVER, NO WARRANTY IS EXPRESSED OR IMPLIED REGARDING THE
ACCURACY OF THESE DATA
OR THE RESULTS TO BE OBTAINED FROM THE USE THEREOF.
HACH COMPANY ©2004
Appendix B (Continued)

B.5. Kaolin

Material Safety Data Sheet
Kaolin, acid washed powder, USP
ACC# 12325

Section 1 - Chemical Product and Company Identification

**MSDS Name:** Kaolin, acid washed powder, USP  
**Catalog Numbers:** K2-500, K2-500LOT001  
**Synonyms:** Aluminum silicate (hydrated); Bolus Alba; China clay; Porcelain clay; White Bole.  
**Company Identification:**  
Fisher Scientific  
1 Reagent Lane  
Fair Lawn, NJ 07410  
For information, call: 201-796-7100  
**Emergency Number:** 201-796-7100  
For CHEMTREC assistance, call: 800-424-9300  
For International CHEMTREC assistance, call: 703-527-3887

Section 2 - Composition, Information on Ingredients

<table>
<thead>
<tr>
<th>CAS#</th>
<th>Chemical Name</th>
<th>Percent</th>
<th>EINECS/ELINCS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1332-58-7</td>
<td>Kaolin</td>
<td>100</td>
<td>unlisted</td>
</tr>
</tbody>
</table>

Section 3 - Hazards Identification

**EMERGENCY OVERVIEW**  
Appearance: white to yellow solid.  
**Caution!** May cause eye, skin, and respiratory tract irritation. This is expected to be a low hazard for usual industrial handling.  
**Target Organs:** None.

**Potential Health Effects**  
**Eye:** Dust may cause mechanical irritation.  
**Skin:** Dust may cause mechanical irritation.  
**Ingestion:** Ingestion of large amounts may cause gastrointestinal irritation. Low hazard for usual industrial handling.  
**Inhalation:** May cause respiratory tract irritation. Low hazard for usual industrial
Appendix B (Continued)

handling. When inhaled as a dust or fume, may cause benign pneumoconiosis. **Chronic:** Chronic inhalation can cause pneumoconiosis.

**Section 4 - First Aid Measures**

**Eyes:** Flush eyes with plenty of water for at least 15 minutes, occasionally lifting the upper and lower eyelids. If irritation develops, get medical aid.

**Skin:** Flush skin with plenty of water for at least 15 minutes while removing contaminated clothing and shoes. Get medical aid if irritation develops or persists. Wash clothing before reuse.

**Ingestion:** Never give anything by mouth to an unconscious person. Do NOT induce vomiting. If conscious and alert, rinse mouth and drink 2-4 cupfuls of milk or water. Wash mouth out with water. Get medical aid if irritation or symptoms occur.

**Inhalation:** Remove from exposure and move to fresh air immediately. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. Get medical aid if cough or other symptoms appear.

**Notes to Physician:** Treat symptomatically and supportively.

**Section 5 - Fire Fighting Measures**

**General Information:** As in any fire, wear a self-contained breathing apparatus in pressure-demand, MSHA/NIOSH (approved or equivalent), and full protective gear. Substance is noncombustible.

**Extinguishing Media:** Use extinguishing media most appropriate for the surrounding fire.

**Flash Point:** Not applicable.

**Autoignition Temperature:** Not applicable.

**Explosion Limits, Lower:** Not available.

**Upper:** Not available.

**NFPA Rating:** (estimated) Health: 1; Flammability: 0; Instability: 0

**Section 6 - Accidental Release Measures**

**General Information:** Use proper personal protective equipment as indicated in Section 8.

**Spills/Leaks:** Vacuum or sweep up material and place into a suitable disposal container. Clean up spills immediately, observing precautions in the Protective Equipment section. Avoid generating dusty conditions. Provide ventilation.
Appendix B (Continued)

Section 7 - Handling and Storage

Handling: Wash thoroughly after handling. Wash hands before eating. Use with adequate ventilation. Minimize dust generation and accumulation. Avoid contact with eyes, skin, and clothing. Keep container tightly closed. Avoid breathing dust.

Storage: Store in a tightly closed container. Store in a cool, dry, well-ventilated area away from incompatible substances. No special precautions indicated.

Section 8 - Exposure Controls, Personal Protection

Engineering Controls: Use adequate general or local exhaust ventilation to keep airborne concentrations below the permissible exposure limits.

Exposure Limits

<table>
<thead>
<tr>
<th>Chemical Name</th>
<th>ACGIH</th>
<th>NIOSH</th>
<th>OSHA - Final PELs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kaolin</td>
<td>2 mg/m3 TWA (respirable fraction, particulate matter containing no asbestos and &lt; 1% crystalline silica)</td>
<td>10 mg/m3 TWA (total dust); 5 mg/m3 TWA (respirable dust)3000 mg/m3 IDLH (listed under Silica, amorphous).</td>
<td>15 mg/m3 TWA (total dust); 5 mg/m3 TWA (respirable fraction)</td>
</tr>
</tbody>
</table>

OSHA Vacated PELs: Kaolin: 10 mg/m3 TWA (total dust); 5 mg/m3 TWA (respirable fraction)

Personal Protective Equipment

Eyes: Wear appropriate protective eyeglasses or chemical safety goggles as described by OSHA's eye and face protection regulations in 29 CFR 1910.133 or European Standard EN166.

Skin: Wear appropriate protective gloves to prevent skin exposure.

Clothing: Wear appropriate protective clothing to minimize contact with skin.

Respirators: Follow the OSHA respirator regulations found in 29 CFR 1910.134 or European Standard EN 149. Use a NIOSH/MSHA or European Standard EN 149 approved respirator if exposure limits are exceeded or if irritation or other symptoms are experienced.
Appendix B (Continued)

Section 9 - Physical and Chemical Properties

Physical State: Solid
Appearance: white to yellow
Odor: none reported
pH: Not available.
Vapor Pressure: Negligible.
Vapor Density: Not available.
Evaporation Rate: Not applicable.
Viscosity: Not available.
Boiling Point: Not available.
Freezing/Melting Point: 3200 deg F
Decomposition Temperature: Not available.
Solubility: Insoluble in water.
Specific Gravity/Density: 1.8 to 2.6
Molecular Formula: H2Al2Si2O8-H2O
Molecular Weight: 258.2

Section 10 - Stability and Reactivity

Chemical Stability: Stable under normal temperatures and pressures.
Conditions to Avoid: Dust generation, excess heat.
Incompatibilities with Other Materials: Strong acids, strong bases.
Hazardous Decomposition Products: Silicon dioxide, aluminum oxide.
Hazardous Polymerization: Has not been reported.

Section 11 - Toxicological Information

RTECS#: 
CAS# 1332-58-7: GF1670500
LD50/LC50:
Not available.

Carcinogenicity:
CAS# 1332-58-7: Not listed by ACGIH, IARC, NTP, or CA Prop 65.

Epidemiology: No information available.
Teratogenicity: No information available.
Reproductive Effects: No information available.
Appendix B (Continued)

**Mutagenicity:** No information available.

**Neurotoxicity:** No information available.

**Other Studies:**

Section 12 - Ecological Information

No information available.

Section 13 - Disposal Considerations

Chemical waste generators must determine whether a discarded chemical is classified as a hazardous waste. US EPA guidelines for the classification determination are listed in 40 CFR Parts 261.3. Additionally, waste generators must consult state and local hazardous waste regulations to ensure complete and accurate classification.

**RCRA P-Series:** None listed.

**RCRA U-Series:** None listed.

Section 14 - Transport Information

<table>
<thead>
<tr>
<th></th>
<th>US DOT</th>
<th>Canada TDG</th>
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<tr>
<td><strong>Shipping Name:</strong></td>
<td>Not regulated as a hazardous material</td>
<td>No information available.</td>
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<tr>
<td><strong>Hazard Class:</strong></td>
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<td><strong>UN Number:</strong></td>
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<td></td>
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<td><strong>Packing Group:</strong></td>
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</table>

Section 15 - Regulatory Information

**US FEDERAL**

**TSCA**

CAS# 1332-58-7 is listed on the TSCA inventory.

**Health & Safety Reporting List**

None of the chemicals are on the Health & Safety Reporting List.

**Chemical Test Rules**

None of the chemicals in this product are under a Chemical Test Rule.

**Section 12b**

None of the chemicals are listed under TSCA Section 12b.
Appendix B (Continued)

TSCA Significant New Use Rule
None of the chemicals in this material have a SNUR under TSCA.

CERCLA Hazardous Substances and corresponding RQs
None of the chemicals in this material have an RQ.

SARA Section 302 Extremely Hazardous Substances
None of the chemicals in this product have a TPQ.

Section 313 No chemicals are reportable under Section 313.

Clean Air Act:
This material does not contain any hazardous air pollutants.
This material does not contain any Class 1 Ozone depletors.
This material does not contain any Class 2 Ozone depletors.

Clean Water Act:
None of the chemicals in this product are listed as Hazardous Substances under the CWA.
None of the chemicals in this product are listed as Priority Pollutants under the CWA.
None of the chemicals in this product are listed as Toxic Pollutants under the CWA.

OSHA:
None of the chemicals in this product are considered highly hazardous by OSHA.

STATE
CAS# 1332-58-7 can be found on the following state right to know lists:
California, (listed as Silica, amorphous), New Jersey, (listed as Silica, amorphous), Pennsylvania, Minnesota, Massachusetts.

California Prop 65
California No Significant Risk Level: None of the chemicals in this product are listed.

European/International Regulations
European Labeling in Accordance with EC Directives

Hazard Symbols:
Not available.

Risk Phrases:
Appendix B (Continued)

Safety Phrases:
- S 24/25 Avoid contact with skin and eyes.
- S 37 Wear suitable gloves.
- S 45 In case of accident or if you feel unwell, seek medical advice immediately (show the label where possible).
- S 28A After contact with skin, wash immediately with plenty of water

WGK (Water Danger/Protection)
- CAS# 1332-58-7: 0

Canada - DSL/NDSL
- CAS# 1332-58-7 is listed on Canada's DSL List.

Canada - WHMIS
- This product has a WHMIS classification of Not controlled.
- This product has been classified in accordance with the hazard criteria of the Controlled Products Regulations and the MSDS contains all of the information required by those regulations.

Canadian Ingredient Disclosure List
- CAS# 1332-58-7 (listed as Silica, amorphous) is listed on the Canadian Ingredient Disclosure List.

Section 16 - Additional Information

MSDS Creation Date: 2/16/1999
Revision #4 Date: 10/03/2005

The information above is believed to be accurate and represents the best information currently available to us. However, we make no warranty of merchantability or any other warranty, express or implied, with respect to such information, and we assume no liability resulting from its use. Users should make their own investigations to determine the suitability of the information for their particular purposes. In no event shall Fisher be liable for any claims, losses, or damages of any third party or for lost profits or any special, indirect, incidental, consequential or exemplary damages.
B.6. Nickel Nitrate

NICKEL NITRATE

1. Product Identification
   **Synonyms:** Nickel (II) nitrate, hexahydrate (1:2:6); nickelous nitrate; nitric acid, nickel (2+) salt, hexahydrate; Nickelous nitrate, 6-Hydrate
   **CAS No.:** 13138-45-9 Anhydrous; (13478-00-7 Hexahydrate)
   **Molecular Weight:** 290.83
   **Chemical Formula:** Ni(NO₃)₂ 6H₂O
   **Product Codes:**
   J.T. Baker: 2784
   Mallinckrodt: 6384

2. Composition/Information on Ingredients

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<th>Ingredient</th>
<th>CAS No</th>
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<td>13138-45-9</td>
<td>90 - 100%</td>
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</table>

3. Hazards Identification
   **Emergency Overview**

   DANGER! STRONG OXIDIZER. CONTACT WITH OTHER MATERIAL MAY CAUSE FIRE. HARMFUL IF SWALLOWED OR INHALED. CAUSES IRRITATION TO SKIN, EYES AND RESPIRATORY TRACT. MAY CAUSE ALLERGIC SKIN OR RESPIRATORY REACTION. CANCER HAZARD. CAN CAUSE CANCER. Risk of cancer depends on duration and level of exposure. Very toxic to aquatic organisms; may cause long term adverse effects in the aquatic environment.

   **SAF-T-DATA** (Provided here for your convenience)

   Health Rating: 3 - Severe (Cancer Causing)
   Flammability Rating: 0 - None
   Reactivity Rating: 3 - Severe (Oxidizer)
   Contact Rating: 3 - Severe (Life)
   Lab Protective Equip: GOGGLES & SHIELD; LAB COAT & APRON; VENT

   150
Appendix B (Continued)

HOOD; PROPER GLOVES

Storage Color Code: Yellow (Reactive)

Potential Health Effects

**Inhalation:**
Causes irritation to the respiratory tract. Symptoms may include coughing, sore throat, and shortness of breath. Lung damage may result from a single high exposure or lower repeated exposures. Lung allergy occasionally occurs, with asthma type symptoms.

**Ingestion:**
Toxic. Symptoms may include abdominal pain, diarrhea, nausea, and vomiting. Absorption is poor, but should it occur, symptoms may include giddiness, capillary damage, myocardial weakness, central nervous system depression, and kidney and liver damage.

**Skin Contact:**
Causes irritation. May cause skin allergy with itching, redness or rash. Some individuals may become sensitized to the substance and suffer "nickel itch", a form of dermatitis.

**Eye Contact:**
Causes irritation, redness, and pain.

**Chronic Exposure:**
Prolonged or repeated exposure to excessive concentrations may affect lungs, liver and kidneys. Chronic exposure to nickel and nickel compounds is associated with cancer.

**Aggravation of Pre-existing Conditions:**
Persons with pre-existing skin disorders, impaired respiratory or pulmonary function, or with a history of asthma, allergies, or sensitization to nickel compounds may be at an increased risk upon exposure to this substance.

4. First Aid Measures

**Inhalation:**
Remove to fresh air. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. Get medical attention.

**Ingestion:**
Induce vomiting immediately as directed by medical personnel. Never give anything by mouth to an unconscious person. Get medical attention.
Appendix B (Continued)

Skin Contact:
Wipe off excess material from skin then immediately flush skin with plenty of water for at least 15 minutes. Remove contaminated clothing and shoes. Get medical attention. Wash clothing before reuse. Thoroughly clean shoes.

Eye Contact:
Immediately flush eyes with plenty of water for at least 15 minutes, lifting lower and upper eyelids occasionally. Get medical attention immediately.

5. Fire Fighting Measures
   Fire:
   Not combustible, but substance is a strong oxidizer and its heat of reaction with reducing agents or combustibles may cause ignition. Increases the flammability of any combustible material.
   Explosion:
   Contact with oxidizable substances may cause extremely violent combustion. Strong oxidants may explode when shocked, or if exposed to heat, flame, or friction. Also may act as initiation source for dust or vapor explosions.
   Fire Extinguishing Media:
   Water or water spray in early stages of fire. Foam or dry chemical may also be used.
   Special Information:
   Wear full protective clothing and breathing equipment for high-intensity fire or potential explosion conditions.

6. Accidental Release Measures
   Remove all sources of ignition. Ventilate area of leak or spill. Wear appropriate personal protective equipment as specified in Section 8. Spills: Clean up spills in a manner that does not disperse dust into the air. Use non-sparking tools and equipment. Reduce airborne dust and prevent scattering by moistening with water. Pick up spill for recovery or disposal and place in a closed container.

7. Handling and Storage
   Keep in a tightly closed container, stored in a cool, dry, ventilated area. Protect against physical damage and moisture. Isolate from any source of heat or ignition. Avoid storage on wood floors. Separate from incompatibles, combustibles, organic or other readily oxidizable materials. Areas in which exposure to nickel metal or soluble nickel compounds may occur should be identified by signs or appropriate means, and access to the area should be limited to authorized persons. Containers of this material may be hazardous when empty since they retain product residues (dust, solids); observe all warnings and precautions listed for the product.
Appendix B (Continued)

8. Exposure Controls/Personal Protection

**Airborne Exposure Limits:**
- OSHA Permissible Exposure Limit (PEL):
  soluble Nickel compounds as Ni: 1 mg/m³ (TWA)
- ACGIH Threshold Limit Value (TLV):
  soluble Nickel compounds as Ni: 0.1 mg/m³ (TWA), A4 - Not classifiable as a human carcinogen

**Ventilation System:**
A system of local and/or general exhaust is recommended to keep employee exposures below the Airborne Exposure Limits. Local exhaust ventilation is generally preferred because it can control the emissions of the contaminant at its source, preventing dispersion of it into the general work area. Please refer to the ACGIH document, *Industrial Ventilation, A Manual of Recommended Practices*, most recent edition, for details.

**Personal Respirators (NIOSH Approved):**
If the exposure limit is exceeded and engineering controls are not feasible, a full facepiece particulate respirator (NIOSH type N100 filters) may be worn for up to 50 times the exposure limit or the maximum use concentration specified by the appropriate regulatory agency or respirator supplier, whichever is lowest. If oil particles (e.g. lubricants, cutting fluids, glycerine, etc.) are present, use a NIOSH type R or P filter. For emergencies or instances where the exposure levels are not known, use a full-facepiece positive-pressure, air-supplied respirator.

**WARNING:** Air-purifying respirators do not protect workers in oxygen-deficient atmospheres.

**Skin Protection:**
Rubber or neoprene gloves and additional protection including impervious boots, apron, or coveralls, as needed in areas of unusual exposure.

**Eye Protection:**
Use chemical safety goggles and/or full face shield where dusting or splashing of solutions is possible. Maintain eye wash fountain and quick-drench facilities in work area.

**Other Control Measures:**
Eating, drinking, and smoking should not be permitted in areas where solids or liquids containing soluble nickel compounds are handled, processed, or stored. NIOSH recommends pre-placement and periodic medical exams, with maintaining of records for all employees exposed to nickel in the workplace.

9. Physical and Chemical Properties

**Appearance:**
Green, transparent crystals.

**Odor:**
Odorless.
Appendix B (Continued)

Solubility:
238.5g/100cc water @ 0C
Specific Gravity:
2.05
pH:
3.5 - 5.5 (5% solution @ 25C (77F).
% Volatiles by volume @ 21C (70F):
0
Boiling Point:
137C (279F)
Melting Point:
56.7C (135F)
Vapor Density (Air=1):
No information found.
Vapor Pressure (mm Hg):
0 @ 20C (68F)
Evaporation Rate (BuAc=1):
No information found.

10. Stability and Reactivity
Stability:
Stable under ordinary conditions of use and storage. Substance has both oxidant and reducing characteristics, and is unstable when heated or shocked.
Hazardous Decomposition Products:
Emits toxic fumes of nickel and nitrogen oxides when heated to decomposition.
Hazardous Polymerization:
Will not occur.
Incompatibilities:
Aluminum, boron phosphide, cyanides, esters, combustible material, phospham, phosphorus, sodium hypophosphite, stannous chloride, thiocyanates, strong reducing agents, and organic materials.
Conditions to Avoid:
Heat, shock, friction, incompatibles.
Appendix B (Continued)

11. Toxicological Information

Nickelous Nitrate Hexahydrate; Oral rat LD50: 1620 mg/kg. Investigated as a tumorigen.

---\Cancer Lists\---

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<thead>
<tr>
<th>Ingredient</th>
<th>Known</th>
<th>Anticipated</th>
<th>IARC Category</th>
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12. Ecological Information

**Environmental Fate:**
When released into water, this material is not expected to evaporate significantly. This material is not expected to significantly bioaccumulate.

**Environmental Toxicity:**
Dangerous to the environment. Very toxic to aquatic organisms; may cause long term adverse effects in the aquatic environment.

13. Disposal Considerations

Whatever cannot be saved for recovery or recycling should be handled as hazardous waste and sent to a RCRA approved waste facility. Processing, use or contamination of this product may change the waste management options. State and local disposal regulations may differ from federal disposal regulations. Dispose of container and unused contents in accordance with federal, state and local requirements.

14. Transport Information

**Domestic (Land, D.O.T.)**

---

**Proper Shipping Name:** NICKEL NITRATE
**Hazard Class:** 5.1
**UN/NA:** UN2725
**Packing Group:** III
**Information reported for product/size:** 4X25LB

**International (Water, I.M.O.)**

---

**Proper Shipping Name:** NICKEL NITRATE
**Hazard Class:** 5.1
**UN/NA:** UN2725
**Packing Group:** III
**Information reported for product/size:** 4X25LB
## Appendix B (Continued)

15. Regulatory Information

### Chemical Inventory Status - Part 1

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<th>EC</th>
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### Chemical Inventory Status - Part 2

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### Federal, State & International Regulations - Part 1

-SARA 302-  -----SARA 313-----

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<th>TPQ</th>
<th>List</th>
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<td>Nickel cmpd/</td>
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### Federal, State & International Regulations - Part 2

-RCRA- -TSCA-

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<th>CERCLA</th>
<th>261.33</th>
<th>8(d)</th>
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<td>Nickel Nitrate (13138-45-9)</td>
<td>No</td>
<td>No</td>
<td>No</td>
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</table>


**WARNING:**

THIS PRODUCT CONTAINS A CHEMICAL(S) KNOWN TO THE STATE OF CALIFORNIA TO CAUSE CANCER.

**Australian Hazchem Code:** 1Y  
**Poison Schedule:** None allocated.  
**WHMIS:**

This MSDS has been prepared according to the hazard criteria of the Controlled Products Regulations (CPR) and the MSDS contains all of the information required by the CPR.
Appendix B (Continued)

16. Other Information

**NFPA Ratings:** Health: 1 Flammability: 0 Reactivity: 0 Other: Oxidizer

**Label Hazard Warning:**
DANGER! STRONG OXIDIZER. CONTACT WITH OTHER MATERIAL MAY CAUSE FIRE. HARMFUL IF SWALLOWED OR INHALED. CAUSES IRRITATION TO SKIN, EYES AND RESPIRATORY TRACT. MAY CAUSE ALLERGIC SKIN OR RESPIRATORY REACTION. CANCER HAZARD. CAN CAUSE CANCER. Risk of cancer depends on duration and level of exposure. Very toxic to aquatic organisms; may cause long term adverse effects in the aquatic environment.

**Label Precautions:**
- Do not store near combustible materials.
- Do not get in eyes, on skin, or on clothing.
- Remove and wash contaminated clothing promptly.
- Wash thoroughly after handling.
- Do not breathe dust.
- Keep container closed.
- Use only with adequate ventilation.
- Avoid release to the environment.

**Label First Aid:**
- If swallowed, induce vomiting immediately as directed by medical personnel. Never give anything by mouth to an unconscious person. If inhaled, remove to fresh air. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. In case of contact, wipe off excess material from skin then immediately flush eyes or skin with plenty of water for at least 15 minutes. Remove contaminated clothing and shoes. Wash clothing before reuse. In all cases, get medical attention.

**Product Use:**
Laboratory Reagent.

**Revision Information:**
MSDS Section(s) changed since last revision of document include: 3, 11, 12, 16.
Appendix B (Continued)

B.7. Nitric Acid

General
Synonyms: azotic acid, aqua fortis
Molecular formula: HNO\textsubscript{3}
CAS No: 7697-37-2
EC No: 231-714-2
Physical data
Appearance: colourless liquid with a choking odour
Melting point: -42°C
Boiling point: 121°C (69% boils at ca. 86°C)
Specific gravity: 1.41
Vapour pressure: 62 mm Hg at 20°C (68%)
Flash point:
Explosion limits:
Autoignition temperature:
Stability
Stable. Strong oxidizer. Substances to be avoided include strong bases, strong reducing agents, alkalis, most common metals, organic materials, alcohols, carbides. Corrodes steel. Light-sensitive.
Toxicology
May be fatal if swallowed or inhaled. Extremely corrosive. Contact with skin or eyes may cause severe burns and permanent damage. TLV 2 ppm. OES long-term 5 mg/m\textsuperscript{3}
Toxicity data
(The meaning of any abbreviations which appear in this section is given here.)
IHL-RAT LC\textsubscript{50} 244 ppm (NO\textsubscript{2})/30m
ORL-HMN LDLO 430 mg kg\textsuperscript{-1}
Risk phrases
(The meaning of any risk phrases which appear in this section is given here.)
R8 R23 R24 R25 R34 R41.
Transport information
(The meaning of any UN hazard codes which appear in this section is given here.)
UN No 2031. Packing group II. Hazard class 8.0. Transport category 2.
Personal protection
Safety glasses or face mask, gloves. Fume cupboard.
Safety phrases
(The meaning of any safety phrases which appear in this section is given here.)
S23 S26 S36 S37 S39 S45.
Appendix B (Continued)

B.8. Sodium Hydroxide

SODIUM HYDROXIDE
MSDS Number: S4034 --- Effective Date: 03/05/97

1. Product Identification
Synonyms: Caustic soda; lye; sodium hydroxide solid; sodium hydrate
CAS No.: 1310-73-2
Molecular Weight: 40.00
Chemical Formula: NaOH
Product Codes: J.T. Baker: 3718, 3721, 3722, 3723, 3728, 3729, 3734, 3736, 5045, 5565 Mallinckrodt: 7001, 7680, 7708, 7712, 7772, 7798

2. Composition/Information on Ingredients

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<th>Ingredient</th>
<th>CAS No</th>
<th>Percent</th>
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<td>Sodium Hydroxide</td>
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</table>

3. Hazards Identification

Emergency Overview

POISON! DANGER! CORROSIVE. MAY BE FATAL IF SWALLOWED. HARMFUL IF INHALED. CAUSES BURNS TO ANY AREA OF CONTACT. REACTS WITH WATER, ACIDS AND OTHER MATERIALS.

J.T. Baker SAF-T-DATA™ Ratings (Provided here for your convenience)

Health Rating: 3 - Severe (Poison)
Flammability Rating: 0 - None
Reactivity Rating: 2 - Moderate
Contact Rating: 4 - Extreme (Corrosive)
Lab Protective Equip: GOGGLES; LAB COAT; VENT HOOD; PROPER GLOVES
Storage Color Code: White Stripe (Store Separately)
Appendix B (Continued)

Potential Health Effects
----------------------------------

**Inhalation:**
Severe irritant. Effects from inhalation of dust or mist vary from mild irritation to serious damage of the upper respiratory tract, depending on severity of exposure. Symptoms may include sneezing, sore throat or runny nose. Severe pneumonitis may occur.

**Ingestion:**
Corrosive! Swallowing may cause severe burns of mouth, throat, and stomach. Severe scarring of tissue and death may result. Symptoms may include bleeding, vomiting, diarrhea, fall in blood pressure. Damage may appear days after exposure.

**Skin Contact:**
Corrosive! Contact with skin can cause irritation or severe burns and scarring with greater exposures.

**Eye Contact:**
Corrosive! Causes irritation of eyes, and with greater exposures it can cause burns that may result in permanent impairment of vision, even blindness.

**Chronic Exposure:**
Prolonged contact with dilute solutions or dust has a destructive effect upon tissue.

**Aggravation of Pre-existing Conditions:**
Persons with pre-existing skin disorders or eye problems or impaired respiratory function may be more susceptible to the effects of the substance.

---

4. First Aid Measures

**Inhalation:**
Remove to fresh air. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. Call a physician.

**Ingestion:**
DO NOT INDUCE VOMITING! Give large quantities of water or milk if available. Never give anything by mouth to an unconscious person. Get medical attention immediately.
Appendix B (Continued)

Skin Contact:
Immediately flush skin with plenty of water for at least 15 minutes while removing contaminated clothing and shoes. Call a physician, immediately. Wash clothing before reuse.

Eye Contact:
Immediately flush eyes with plenty of water for at least 15 minutes, lifting lower and upper eyelids occasionally. Get medical attention immediately.

Note to Physician:
Perform endoscopy in all cases of suspected sodium hydroxide ingestion. In cases of severe esophageal corrosion, the use of therapeutic doses of steroids should be considered. General supportive measures with continual monitoring of gas exchange, acid-base balance, electrolytes, and fluid intake are also required.

5. Fire Fighting Measures

Fire:
Not considered to be a fire hazard. Hot or molten material can react violently with water. Can react with certain metals, such as aluminum, to generate flammable hydrogen gas.

Explosion:
Not considered to be an explosion hazard.

Fire Extinguishing Media:
Use any means suitable for extinguishing surrounding fire. Adding water to caustic solution generates large amounts of heat.

Special Information:
In the event of a fire, wear full protective clothing and NIOSH-approved self-contained breathing apparatus with full facepiece operated in the pressure demand or other positive pressure mode.
Appendix B (Continued)

6. Accidental Release Measures
Ventilate area of leak or spill. Keep unnecessary and unprotected people away from area of spill. Wear appropriate personal protective equipment as specified in Section 8. Spills: Pick up and place in a suitable container for reclamation or disposal, using a method that does not generate dust. Do not flush caustic residues to the sewer. Residues from spills can be diluted with water, neutralized with dilute acid such as acetic, hydrochloric or sulfuric. Absorb neutralized caustic residue on clay, vermiculite or other inert substance and package in a suitable container for disposal. US Regulations (CERCLA) require reporting spills and releases to soil, water and air in excess of reportable quantities. The toll free number for the US Coast Guard National Response Center is (800) 424-8802.

7. Handling and Storage
Keep in a tightly closed container. Protect from physical damage. Store in a cool, dry, ventilated area away from sources of heat, moisture and incompatibilities. Always add the caustic to water while stirring; never the reverse. Containers of this material may be hazardous when empty since they retain product residues (dust, solids); observe all warnings and precautions listed for the product. Do not store with aluminum or magnesium. Do not mix with acids or organic materials.

8. Exposure Controls/Personal Protection

Airborne Exposure Limits:
- OSHA Permissible Exposure Limit (PEL): 2 mg/m3 Ceiling - ACGIH Threshold Limit Value (TLV): 2 mg/m3 Ceiling

Ventilation System:
A system of local and/or general exhaust is recommended to keep employee exposures below the Airborne Exposure Limits. Local exhaust ventilation is generally preferred because it can control the emissions of the contaminant at its source, preventing dispersion of it into the general work area. Please refer to the ACGIH document, Industrial Ventilation, A Manual of Recommended Practices, most recent edition, for details.
Appendix B (Continued)

Personal Respirators (NIOSH Approved):
If the exposure limit is exceeded, a half-face dust/mist respirator may be worn for up to ten times the exposure limit or the maximum use concentration specified by the appropriate regulatory agency or respirator supplier, whichever is lowest. A full-face piece dust/mist respirator may be worn up to 50 times the exposure limit, or the maximum use concentration specified by the appropriate regulatory agency, or respirator supplier, whichever is lowest. For emergencies or instances where the exposure levels are not known, use a full-facepiece positive-pressure, air-supplied respirator. WARNING: Air-purifying respirators do not protect workers in oxygen-deficient atmospheres.

Skin Protection:
Wear impervious protective clothing, including boots, gloves, lab coat, apron or coveralls, as appropriate, to prevent skin contact.

Eye Protection:
Use chemical safety goggles and/or a full face shield where splashing is possible. Maintain eye wash fountain and quick-drench facilities in work area.

9. Physical and Chemical Properties

**Appearance:**
White, deliquescent pellets.

**Odor:**
Odorless.

**Solubility:**
111 g/100 g of water.

**Specific Gravity:**
2.13

**pH:**
13 - 14 (0.5% soln.)

**% Volatiles by volume @ 21C (70F):**
0

**Boiling Point:**
1390C (2534F)
Appendix B (Continued)

Melting Point:
318°C (604°F)

Vapor Density (Air=1):
> 1.0

Vapor Pressure (mm Hg):
Negligible.

Evaporation Rate (BuAc=1):
No information found.

10. Stability and Reactivity

Stability:
Stable under ordinary conditions of use and storage. Very hygroscopic. Can slowly pick up moisture from air and react with carbon dioxide from air to form sodium carbonate.

Hazardous Decomposition Products:
Sodium oxide. Decomposition by reaction with certain metals releases flammable and explosive hydrogen gas.

Hazardous Polymerization:
Will not occur.

Incompatibilities:
Contact with water, acids, flammable liquids, and organic halogen compounds, especially trichloroethylene, may cause fire or explosion. Contact with nitromethane and other similar nitro compounds causes formation of shock-sensitive salts. Contact with metals such as aluminum, tin, and zinc causes formation of flammable hydrogen gas.

Conditions to Avoid:
Moisture, dusting and incompatibles.
Appendix B (Continued)

11. Toxicological Information

Irritation data: skin, rabbit: 500 mg/24H severe; eye rabbit: 50 ug/24H severe; investigated as a mutagen.

---\Cancer Lists\---

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Known</th>
<th>Anticipated</th>
<th>IARC Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sodium Hydroxide (1310-73-2)</td>
<td>No</td>
<td>No</td>
<td>None</td>
</tr>
</tbody>
</table>

12. Ecological Information

**Environmental Fate:**
No information found.

**Environmental Toxicity:**
No information found.

13. Disposal Considerations

Whatever cannot be saved for recovery or recycling should be handled as hazardous waste and sent to a RCRA approved waste facility. Processing, use or contamination of this product may change the waste management options. State and local disposal regulations may differ from federal disposal regulations. Dispose of container and unused contents in accordance with federal, state and local requirements.

14. Transport Information

**Domestic (Land, D.O.T.)**

Proper Shipping Name: SODIUM HYDROXIDE, SOLID
Hazard Class: 8
UN/NA: UN1823
Packing Group: II
Information reported for product/size: 300LB

**International (Water, I.M.O.)**

Proper Shipping Name: SODIUM HYDROXIDE, SOLID
Hazard Class: 8
UN/NA: UN1823
Packing Group: II
Information reported for product/size: 300LB
Appendix B (Continued)

15. Regulatory Information

---\Chemical Inventory Status - Part 1\---------------------------------
Ingredient TSCA EC Japan Australia
----------------------------------------------- ---- -- ----- --------
Sodium Hydroxide (1310-73-2) Yes Yes Yes Yes

---\Chemical Inventory Status - Part 2\---------------------------------
--Canada--
Ingredient Korea DSL NDSL Phil.
----------------------------------------------- ----- --- ---- -----
Sodium Hydroxide (1310-73-2) Yes Yes No Yes

---\Federal, State & International Regulations - Part 1\----------------
-SARA 302- -----SARA 313-----
Ingredient RQ TPQ List Chemical Catg.
----------------------------------------- --- ----- ---- --------------
Sodium Hydroxide (1310-73-2) No No Yes No

---\Federal, State & International Regulations - Part 2\----------------
-RCRA- -TSCA-
Ingredient CERCLA 261.33 8(d)
----------------------------------------- ----- ----- ------
Sodium Hydroxide (1310-73-2) 1000 No No

Chemical Weapons Convention: No TSCA 12(b): No CDTA: No SARA 311/312: Acute: Yes Chronic: No Fire: No Pressure: No Reactivity: Yes (Pure / Solid)

**Australian Hazchem Code:** 2R **Poison Schedule:** S6

**WHMIS:**
This MSDS has been prepared according to the hazard criteria of the Controlled Products Regulations (CPR) and the MSDS contains all of the information required by the CPR.
Appendix B (Continued)

16. Other Information

**NFPA Ratings:**
- **Health:** 3
- **Flammability:** 0
- **Reactivity:** 1

**Label Hazard Warning:**
POISON! DANGER! CORROSIVE. MAY BE FATAL IF SWALLOWED. HARMFUL IF INHALED. CAUSES BURNS TO ANY AREA OF CONTACT. REACTS WITH WATER, ACIDS AND OTHER MATERIALS.

**Label Precautions:**
Do not get in eyes, on skin, or on clothing. Do not breathe dust. Keep container closed. Use only with adequate ventilation. Wash thoroughly after handling.

**Label First Aid:**
If swallowed, DO NOT INDUCE VOMITING. Give large quantities of water. Never give anything by mouth to an unconscious person. In case of contact, immediately flush eyes or skin with plenty of water for at least 15 minutes while removing contaminated clothing and shoes. Wash clothing before reuse. If inhaled, remove to fresh air. If not breathing give artificial respiration. If breathing is difficult, give oxygen. In all cases get medical attention immediately.

**Product Use:**
Laboratory Reagent.

**Revision Information:**
Pure. New 16 section MSDS format, all sections have been revised.