International Multidisciplinary Efforts in the Development of a Sustainable Green Technology for the Removal of Contaminants in Drinking Water

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Abstract

The objectives of this project are to develop a water purification system based on an economically viable "green technology" and investigate its applicability to a rural community in Mexico. The area of study is the rural community of Temamatla in central Mexico. Its location (25mi/40 km southeast of Mexico City) is critical for this study owing to its proximity to volcanic soils where the concentration of heavy metals such as arsenic, cadmium, and antimony in local water supplies are higher than recommended values. The goals are to produce an economically feasible method of water purification using cactus mucilage and silicate arrays for low-income inhabitants of rural communities that are sensitive to existing economic, social, and cultural patterns. This project transcends disciplinary and national boundaries as it connects the efforts of chemical engineers, geologists, anthropologists, physicists, and policy makers from the United States and Mexico. The expansiveness of this project necessitates a seamless joining of the efforts between investigators from different disciplines at USF, two leading Mexican public universities: UNAM and UAM, and the INE in Mexico. The results of successful collaboration have provided the ability to direct the focus of the project toward goals that are not only achievable but will also have broad implications. A study conducted by USF Anthropolgists concluded that a culturally sensitive solution to purifying water would be an in-home filter. As a result, the goals of the project were reworked to include the design of an in-home filter consisting of cactus mucilage embedded in a silica matrix. Also, USF Geologists completed a broad study of the arsenic content in the drinking water from five different Mexican towns leading to the discovery of levels far above the recommended limit in Temamatla. As such, the focus of the project was narrowed to this town. The success of this intense multidisciplinary, international collaboration will promote mutual opportunities and infrastructure for research, education, training, networking, future partnerships, and most importantly, the proposed technology will improve current water-related issues and problems in areas of extreme need.

Introduction

A need is recognized in low-income, indigenous communities in rural Mexico for a natural flocculant that will perform at efficiencies comparable to existing chemical flocculants and simultaneously remove suspended solids and heavy metals. In addition, the developed technology and implementation must be socially appropriate, producing a minimized effect on the lives of affected individuals while concurrently increasing their quality of life. It was 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 having problems with contaminated water supplies.

University of South Florida (USF) geologists surveyed water supplies in four separate Mexican communities. Their results showed one community in particular that had problems with suspended solids and heavy metal contamination. Temamatla, a community twenty-five miles southeast of Mexico City, was chosen as our test community because it was the only one examined to have current contamination including suspended solids. 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.

Cacti mucilage is a thick substance, comprised of proteins, monosaccharides and polysaccharides. We are particularly interested in studying the tuna (Opuntia ficus indica, (Fig 3) mucilage produced by the flattened pads of this cactus. The nopal plants grow abundantly, and are very inexpensive and edible. It can easily be recognized by its green, thick long pads that are shaped like sports rackets. They grow one linked to the next, and can be considered as both leaves and stalks. They produce blossoms and large pear-shaped edible berries called tunas. There are four major species of Opuntia plants, one with large and wide pads, other with short heart-like pads, one with large spikes that produced red berry fruits and one with green berry fruits. Nopal pads are formed of complex carbohydrates that have the ability to store and retain water, allowing these plants to survive in extremely arid environments. Nopal mucilage is a neutral mixture of approximately 55 high-molecular weight sugar residues composed basically of arabinose, galactose, rhamnose, xylose, and galacturonic acid and has the capacity to interact with metals, cations and biological substances. Cacti mucilage swells but does not dissolve in water. Thus, this special substance has the potential to precipitate ions, bacteria and particles from aqueous solutions. Additionally, natural gums have unique surface active characteristics, which make them ideal candidates for enhancing dispersion properties, creating emulsifications, and for reducing the surface tension of high polarity liquids.

Natural mucilage has been used in Mexico and Latin America since ancient times to reduce turbidity and hardness from natural springs. However, this traditional methodology is primitive and solely based on empirical knowledge. It is unclear how this substance works and why it is so efficient. This project can provide useful information about cactus mucilage and natural products and its potential use in other fields like biomolecular engineering or biochemistry.

<u>Interdisciplinary and International Collaboration</u>

This is an interdisciplinary project that seeks to integrate engineering methodologies, scientific knowledge, educational techniques, economical strategies, and social responses in order to elucidate the complex physical, biological, environmental and socio-economic dynamics of the cactus mucilage material. This is an environmental process that transcends national boundaries and affects the social and economical relations between Mexico and USA; thus it includes collaborations between U.S. investigators and Mexican counterparts. This collaboration offers excellent opportunities for students at USF and Mexican public institutions to gain experience in conducting research in each other's countries.

We target Mexico for this project because of its unique characteristics: geographically, socially and economically. Mexico's diverse communities are a perfect fit to test and compare our model for water treatment, since 1) their inhabitants are familiar with the nopal plant and its natural mucilage, 2) there is a desperate need for a domestic water treatment solution because of severe contamination with heavy metals (i.e., arsenic, As, thallium, Tl, and cadmium, Cd) in groundwater sources, 3) the nopal is a plant that grows in all regions in Mexico, the geographical and socio-economical conditions of Mexico may be similar to other countries in need of an alternative technology for water treatment such as Bangladesh, China and India, and 4) this project will have a lasting impact in low-income Mexican communities because of lack of funding to implement sophisticated water treatment plants that could benefit them. Consequently, the acceptance of this technology in Mexico will boost votes of confidence to further expand this technology world-wide.

This project involves collaborative efforts between professionals from a public research institution in the United States: the University of South Florida (Universidad del Sur de la Florida, USF); and three main state universities in Mexico: the National Autonomous University of Mexico (Universidad Nacional Autonoma de Mexico, UNAM) the Metropolitan Autonomous University (Universidad Autonoma Metropolitana, UAM), and the Center for Research and Advanced Studies of the National Polytechnic Institute (Centro De Investigación y De Estudios Avanzados, CINVESTAV, del Instituto Politecnico Nacional). We also have the support of the USF Water Institute, the Teaching and Research Unit for Civil Participation (Unidad de Capacitacion e Investigacion Educativa para la participacion) coordinated by Juan Fernando Viveros, and the National Research Center of the Environmental National Institute (Instituto Nacional de Ecologia) in Mexico directed by Victor Gutierrez Avedoy.

This project will have an impact on the growth of interdisciplinary research at USF, which is a relatively young university that has had a rapid and substantial impact on the local and national research environment. The research team from USF is multidisciplinary and it is formed by environmental geochemist, Dr. Thomas Pichler; hydrogeologist, Dr. Mark Stewart; anthropologist, Dr. Karla Davis-Salazar; environmentalist, Dr. Alessandro Anzalone, and chemical engineers, Dr. Babu Joseph and Dr. Norma Alcantar.

<u>Research Team</u>

Dr. Anzalone and Dr. Alcantar have directed the design, study and production of the natural mucilage and its future implementation in the silicate-based mesh. Dr. Pichler's research interests are in the role of water-rock interaction within the system Earth, using chemical, biological, hydrogeological, mineralogical, mathematical, thermodynamic and engineering approaches. He has much experience in international-based research. Dr. Stewart is a hydrologist with expertise in the application of geophysical methods to the solution of geologic and hydrogeologic problems, and investigations of ground-water systems using numerical models. Dr. Joseph has developed models and simulations of the growth of nanostructures that can be used for various applications, sensor materials in particular. Dr. Alcantar and Dr. Joseph will be in charged of developing quantitative modeling and simulations of the interactions between the natural mucilage and the transport phenomena within the complex mesh. Dr. Davis-Salazar's research focuses on social, cultural, and political aspects of drinking water management in Latin America, both in the present and distant past. She is responsible for organizing and overseeing the social component of the proposed project. Specifically, she will work with the communities to facilitate the introduction, use, and maintenance of the water purification prototypes through educational programs and arsenic awareness campaigns, among other techniques. She will also assist with evaluating the success of the project through a socio-cultural impact assessment.

The participation of the three most important research institutions and internationally recognized Mexican institutions of higher learning is necessary to the success of our complex endeavor. UAM is one of the most recognized, and a pioneer public university in Mexico. They will contribute in the engineering, scientific and economic components. Dr. Tomas Viveros and Dr. Michel Picquart are faculty members of UAM that are working on this project. Dr. Viveros' area of expertise is transport phenomena, especially mass transport. He will determine the inertial and viscous variables involved in the separation processes of this project. Dr. Picquart's area of expertise is biophysical-chemistry. He has worked on encapsulating microorganisms within ceramic materials to diminish the nitrogen pollutant levels in waste waters. His contribution to the project is indispensable since he has ample knowledge in water treatment processes and its physical characterization. He also will provide assistance in determining the driving force behind the mucilage's effectiveness. We also have liaisons in the Institute of Geology, one of the leading research institutions in Mexico, and it is affiliated with UNAM, which is a highly renowned research institution and the biggest university in Mexico and the Laboratory of Toxicology of Heavy Metals and Pesticides in the CINVESTAV of the IPN. The importance of having collaborators from the country being studied is a must. Their familiarity with local customs in Mexican communities will help us to gain trust among them. This highly qualified team of researchers are in charge of proving how the key material (cactus mucilage) can be used, ensuring its scientific and engineering development and production, and investigating impact on society and economical patterns.

<u>Using Socio-cultural Impact Assessment to Shape Research Goals</u>

Socio-cultural impact assessment is a necessary component of this project because part of the rationale for this project is that, by using a locally available material, namely the nopal cactus, with which most rural Mexican communities are intimately familiar, we will create an inexpensive, straightforward process that local communities will be able, 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. The socio-cultural component of the proposed arsenic mitigation project is therefore crucial to the project's success.

Preliminary information gathered during site visits to three of the four proposed study areas in Mexico highlights the importance of integrating local knowledge, needs, desires, and beliefs into the design and implementation of water treatment systems. For example, at Hierve el Agua, Oaxaca, our initial water tests of two hot springs indicate very high levels of arsenic (>520 mg/L). Unfortunately, due to local belief that "natural water" issuing from the earth has curative powers, people frequently bath in the hot springs and drink the water as a form of therapy. As an example, a mother was observed urging her child to drink from one of the sampled hot springs in order to cure his cough. The perception that water from hot springs is good for one's health is so pervasive and embedded in the local belief system that numerous spas, hotels, and other tourist activities have developed in recent years centered on the use of these springs. This indicates that any remediation efforts in Hierve el Agua will need to address local perceptions of water quality. Specifically, we will need to convince residents of the presence of arsenic in the hot springs and inform them of the adverse health effects caused by arsenic. We will likely encounter resistance given that the arsenic-contaminated hot springs are an important source of revenue, but the extremely high arsenic levels detected demand that the issue be addressed.

In contrast, at Zimapan, Hidalgo, residents have been aware of the high arsenic content of their water supply since at least the mid nineties. As a result, an aqueduct was constructed by the Mexican government to bring arsenic-free water to the community from farther north. However, our water tests suggest that some older parts of the city may not be connected to the new water system since arsenic was detected in one of our samples. We also found that the residents of Zimapan seemed accustomed to outsiders taking water samples and, in fact, required our project staff to obtain authorization from a local official before taking any samples. This suggests that Zimapan residents are somewhat inured to the arsenic problem. This also indicates that, in Zimapan, we will need to direct much of our efforts at building rapport and trust with the community. One way to accomplish this is to maintain frequent contact with the community and to keep them informed of our progress.

Finally, in Temamatla, just outside of Mexico City and the site of our pilot study, our water tests indicate arsenic levels just above normal. Residents, however, remain very concerned about their water quality and therefore are very receptive to our efforts. Interestingly here, 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.

The preliminary data highlighting the social dimensions of the proposed mitigation project also carry three broader implications. First, significantly more, pertinent socio-cultural information that will directly affect the success of the proposed project needs to be gathered. The above information is based on just a few hours of observation and conversation, and yet important issues that need to be addressed already have been identified. Second, the preliminary data indicate that each of the study areas is unique and that remediation efforts must be tailored to fit individual community needs and wants. For example, while all three of the study sites visited have arsenic in their drinking water, the degree of interest and concern regarding this knowledge varies from site to site. Importantly, the degree of interest does not correspond to the levels of arsenic indicated by our water tests. For example, while Temamatla had very little arsenic in its water supply compared to Zimapan, the residents of Temamatla expressed much more interest and concern in arsenic mitigation than the residents of Zimapan. Third, our preliminary data support findings of mitigation studies elsewhere, which identified social and cultural factors affecting the success of remediation projects. Factors, such as knowledge and value placed on water quality as well as compatibility between community needs and system design, indicate that community participation in design and implementation aspects of the proposed project is essential.

We have studied in detail the groundwater sources of Temamatla. This is a community near the active volcano of Popocatepetl in the State of Mexico. We have also performed *in-vitro* experiments to prove the efficiency of the nopal as a flocculating agent with water from this source, and we have analyzed the socio-economical impacts of a project like the one we are proposing here. This community had complained of fine particulates in their drinking water. We were able to test and analyze water from the well that feeds the three towns in the county. Our findings show that the levels of arsenic in their drinking water are just above recommended maximum levels, but they also show the presence of other metals. 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 will 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 we can do in this case, since the line is centralized and it is already maintained by a state two 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 (20L/s). We expect that each community for this project will have specific solutions according to their needs.

Research Results

The mucilage was found to be an excellent flocculant of suspended solids when compared to $Al_2(SO_4)_3$. Cylinder tests showed that in 3.6 minutes, the same dosage of mucilage settled the same amount as $Al_2(SO_4)_3$ did in 10 minutes. Also, it was found that small dosages of mucilage still provided faster settling rates and the clearest supernatant. The mucilage was also found to reduce arsenic concentrations by 50% after 36 hours at low dosages.

Discussion and Conclusions

Due to the successful efforts of all collaborators, we have proven that mucilage from the nopal cactus is efficient at flocculating suspended solids and is effective in removing arsenic. The development of this technology into a useable domestic filter will provide a large impact not only on the lives of low-income individuals in Mexico but the possibility that a natural-based, culturally appropriate flocculating agent can be extracted from an indigenous, edible plant has the potential to provide an impact around the world. It will establish a systematic, natural method for water purification that can then be expanded to other regions, communities of underdeveloped countries and developed countries. This is an ambitious, interesting project with potentially profound effects on industry, individuals, and green technology overall

We found it necessary to include an international, multidisciplinary team of researchers in order to ensure success in this ongoing project. A tremendous help has been the presence of a lead researcher native to the country of interest, researchers already experienced in international research, researchers knowledgeable of the socio-cultural state of the communities of interest, and contacts in universities and government institutions in the country of interest. Without these key players, the task at hand would be insurmountable.

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