Using the Mexican Cactus as a Natural-Based Separating Agent in a Filter for Removing Contaminants 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 Infrared Spectroscopy. The chemical composition of the drinking water was found through the use of liquid chromatography to determine the anions F^-, Cl^-, NO^{3-}, Br^-, NO^{2-}, $PO4^{2-}$ and $SO4^{2-}$ following the EPA 300 method. The arsenic concentration was analyzed using hydride generation-atomic fluorescence spectrometry. Flocculation studies proved the mucilage to be a much faster flocculating agent when compared to $Al_2(SO_4)_3$ 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.

Introduction

Scientists, governments, the media, and individuals worldwide recognize the benefits of green technology. There is a tremendous push towards developing new green technologies in order to minimize environmental changes. This project is motivated by these environmental requirements as well as the health needs of individuals exposed to contaminated drinking water supplies. 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.

Results

University of South Florida (USF) geologists surveyed water supplies in four separate Mexican communities. Regions were chosen because of suspected water contamination due to their proximities to volcanic or industrial contamination sources (Figure 1). Drinking water samples were taken from wells and storage tanks and analyzed for anion content using liquid chromatography and arsenic content using hydride generation-atomic fluorescence spectrometry. Presence of suspended solids in water supplies was also noted. Table 1 highlights arsenic content and suspended solids found in regions tested along with suspected contamination sources.

Table 1. Arsenic concentrations in communities of interest with suspended solids and suspected source of contamination.

Location	As (ppb)	Suspended Solids	Contamination Source
Hierve el agua	>518	None	Gold Mine
Zimapan	> 221	None	Gold Mine
Region Lagunera	>563	None	Volcanic
Temamatla	> 29	Present	Volcanic
Drinking water stand	< 10	None	

Figure 1. Map of Mexico with communities of interest in red.

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.

These initial findings were used to shape the goals of the project: to not only increase the quality of life for Temamatla residents by reducing concentrations of harmful heavy metals and suspended solids in their drinking water but also to produce a technology that will be applicable to other Mexican communities with similar problems as well as other regions with access to the cactus. The objectives were set to extract a flocculant that is environmentally benign and will have minimal social impact, characterize that flocculant's surface active properties, compare the flocculation efficiency with other chemicals ($Al_2(SO_4)_3$), determine the chemical structure responsible for the flocculation properties, and ultimately design and build a mucilage-based filter for domestic use at minimal cost.

The flocculant source chosen is the *Opuntia ficus-indica* (Figure 2), or nopal cactus commonly known as "prickly pear."

Figure 2. *Opuntia ficus-indica*.

The nopal produces a gum-like substance, cactus mucilage, which shows excellent flocculating abilities and is an economically viable alternative for communities affected by drinking water contamination because:

- ✓ Its extraction is relatively simple
- ✓ It can be stored for a very long time without losing its integrity
- ✓ No external energy is required for operation
- ✓ Cactus plants can be inexpensively harvested in large amounts and in conditions where water supply is critical
- ✓ We have found that cactus mucilage enhances particle settling times compare to aluminum sulfate (a commercially used flocculant)
- ✓ Cactus mucilage can remove heavy metals (such as arsenic, As)

The isolation and purification techniques that we have used to extract mucilage from the cactus pads so far is a modification of the extraction procedure to separate natural gums previously reported in the literature. We have been able to separate three different substances from the mucilage that have significantly different surface-active properties depending on the extraction methodology. A fraction from the solid part of the mucilage produces a gelling extract (GE). The fraction from the liquid part of the mucilage produces a non gelling extract (NE), and the combination of the above species produces a combined substance (CE) (Figure 3).

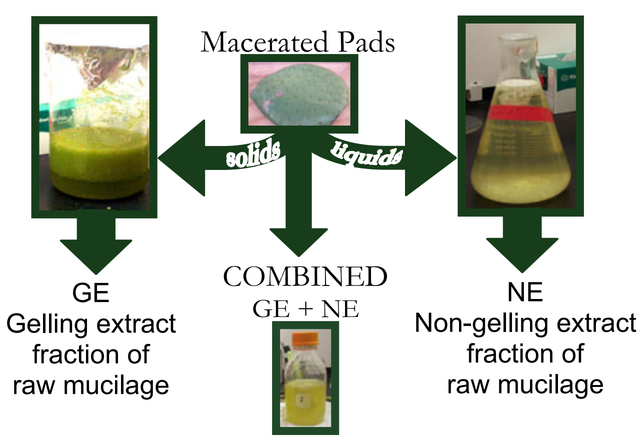

Figure 3. Extraction fractions of mucilage. Gelling (GE), non-gelling (NE) and Combined (CE) extracts.

Raman IR analysis of GE, NE, and CE, extracts highlighted the differences and similarities between the three cactus derivatives. Curiously, the spectrum for the CE matched exactly with the NE. The real differences were found to be between GE and NE. 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}). There 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 bounding. Both show nitrile peaks around 2200 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 amide and amine functionality to which the mucilage owes its water treating properties.

The cylinder tests performed for flocculation studies revealed the gelling extract to be the fastest at coagulating suspended solids. 5 g/L concentrations of kaolin in 100 mL graduated cylinders (control) were treated with doses of mucilage extract and aluminum sulfate in order to measure the fall of solid/liquid interface height with respect to time. High concentrations of kaolin were chosen since they mimic mud conditions and make the interface visible. It was found that the GE provided settling rates much faster than aluminum sulfate. That is, it takes about 3.6 min to obtained a settling height of 6 cm with a solution containing 3 ppm GE, where as it takes 10 min to achieve the same height if the solution contains the same concentration of aluminum sulfate (Figure 4).

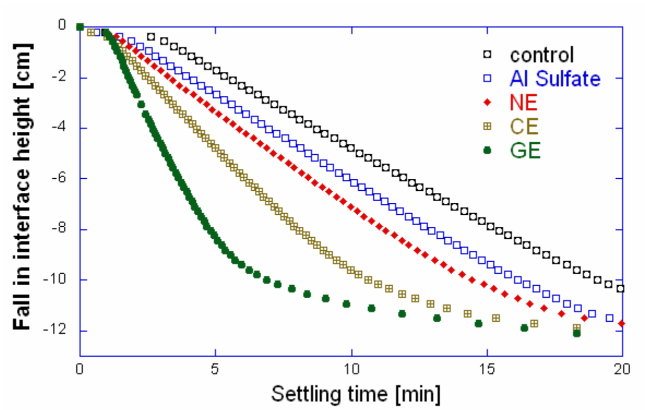

Figure 4. Flocculation rate determined by cylinder test (5 g/L kaolin solution & 3 ppm flocculant dosage)

Additionally, a complete dosage study was performed using GE and it was found that it was faster than aluminum sulfate even at very low concentrations (10 ppb).

To assess the capacity of the mucilage to reduce As from water we performed a test in which a 70 ppm As solution was treated with 3 ppm of GE, since this extraction fraction provided to be more efficient at separating particulates in shorter times (Figure 4). After addition of the mucilage, samples at different position on the solution were taken. The As rich fraction goes to the air-water interface, where as the bulk of the solution had lower As concentration after 30 minutes compared to the original concentration (15% removal). If the solution is left for 36 hours, the removal rate is shown to be 50%. We have found that pH influences the removal process significantly. In the case of As, pH solutions around 8 proved to be more efficient. This process can also be optimized to obtain higher removal rates by driven the equilibrium reaction as the As supernatant is removed continuously from the air-water interface of the solution. Also, if a solution contains around 20 ppb of As, 50% removal is effective to bring the As concentration close to standard values.

Discussion and Conclusions

We have proven 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.

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