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Design, Characterization, and Economic Analysis of a Low Cost Water Purification System for Mexico

Dr. Nasrin R. Khalili, Ph.D.
Associate Professor and Academic Director, Environmental Management Program, Illinois Institute of Technology565 W. Adams Street, Chicago, IL 60661,tel: 312-906-6546 fax:312-906-6549, email: khalili@iit.edu
Dr. Joaquín Acevedo M.
Director - Departamento de Ingeniería Química, División de Ingeniería y Arquitectura, Tec de Monterrey - Campus Monterrey, Tel: (81) 81582034; (81) 81581400 Ext 5436, Fax: (81) 83284250, email: Joaquin Acevedo <jacevedo@itesm.mx>
Dr. Enrique Ortiz Nadal
Director de Carrera, Ingeniero Químico de Sistemas, Campus Monterrey, Tecnológico de Monterrey, Tel.: 52 (81) 8358-2000 Ext. 5490 , email: eortiz@itesm.mx.

Abstract

Numerous reports by the United Nations and the World Health Organization have indicated a significant worldwide problem with water pollution and accessibility to potable drinking water exists. Due to technological and economical barriers, the problem with water pollution is particularly more serious for under-developed and developing countries. Current water purification systems including sand filters, bio-filters, chlorination units, solar-based systems, and clay-based filters are branded globally as a means to address this problem. However, these systems have presented considerable limitations with their applications including high cost and lack of availability in rural areas. In conjunction with continuing and intensive worldwide efforts to address water pollution problems and accessibility to potable drinking water, researchers at Illinois Institute of Technology and Tecnológico de Monterrey have developed a low-cost, clay-based water purification system called Klaraqua for developing countries and sensitive areas in need of clean water. Focusing on sustainable development, Klaraqua's mission is to promote health, hygiene, and economic prosperity. Klaraqua was developed taking into consideration local water usage issues, cultural factors, and social economics. Engineering and economic feasibility of Klaraqua were evaluated during initial study in rural communities of Monterrey in Mexico. Results have indicated simplicity of design, potentiality for local material use, and ease of production, empower inhabitants to build, commercialize and use this system locally. The system can be easily modified to extend its reach beyond Mexico to provide other developing regions of the world with potable drinking water.

Keywords: Klaraqua, Clay Filter, Health and Economic Development, Water Pollution.

Introduction

Research studies published in 2000 by the United Nations and the World Health Organization underscored the continued significant, worldwide problem with water pollution and mortality due to waterborne diseases. Numerous epidemiological studies have demonstrated that improvements in water supply and sanitation reduce the incidence of water-borne diseases. The problem with water pollution is more pronounced in under-developed and developing countries due to economical factors, awareness, hygiene, and lack of access to appropriate technologies. On the order of 1.1 billion people in these countries lack access to safe drinking water, and 2.4 billion people do not have access to basic sanitation (WHO/UNICEF 2000). Poor access to safe drinking water is a major cause of diarrhea-related, the second leading killer of children under five in most developing and under developed countries. Improved water supply and appropriate sanitation systems could significantly contribute to the reduction of diarrhea mortalities and improved health outcomes. According to the latest WHO reports less than 10 to 20 percent of the world's population has access to clean water. The development of an efficient, stable, low cost and easy to use water purification system is, therefore, essential for many regions and countries currently suffering from health problems and increasing mortality due to water pollution.

This paper outlines two design modifications to the existing ceramic filters. The main goal of the project has been to make these types of filters more effective for treating polluted water, and more acceptable by poppulations in need of clean water. Cultural factors and social wisdom, therefore, has been considered strongly in re- designing filters and development of effective and innovative educational programs for their applications.

Best Available Low Cost Water Treatment Systems

The most commonly used low-cost water purification systems include but are not limited to: sand filters, bio-filters, chlorination units, solar-based systems (i.e. SODIS Solar Pasteurization), bottled or bagged water, and most recently clay-based filters with and without colloidal silver, and Procter & Gamble's PUR Powder which is 100 percent drinkable if boiled for seven minutes. Most water purification systems have a variety of limitations: fragility; frequent cleaning and maintenance; source of fuel; annual replacement, inability to remove pollutants; and other factors that affect adoption and use on a routine basis.

If water purification is needed to kill bacteria, water must be boiled all year, which requires significant and sustained energy use that introduces other problems associated with limited supply and depletion of natural resources. Boiling water has other complications that affect its ready availability; the time needed to boil is 7-20 minutes and a long cool-down period is required. Other issues include the need for pots to boil water, the affect of boiling on taste, the need for a container with a tap to store the water, the need for reliable and plentiful fuel (wood or gas).

Chlorination effectively removes bacteria; but it affects taste and odor of the water and does not remove turbidity. It requires training, established procedures, an appropriate container with a lid and tap to store the water, purchase or transport/storage of chlorine in a safe fashion, limited supply, and risks associated with children or others without training. Bottled water is expensive and occasionally of dubious quality. It could guarantee users quality filtered water quickly and effectively, if available.

Sand filters have ben used for dacades. These filters have strict maintenance procedures, require fine sands that cannot be found easily everywhere. Bacteria are an issue with sand filters as well. A complete process requires a container with a tap is needed to store the water; and chlorine to kill bacteria. Regular cleaning is needed and the degree of acceptance by various populations is not studied well or data is not clear.

Solar disinfection systems has been introduced recently as a mean for trating water. These systems require at least four hours to purify the water in the sun, assuming sufficient amount of sun being available. They also require a cooling period, and storage vessel for water. These systems however, can affect the taste of the water. They also are not very efficient in removing the turbidity.

Clay filters are low cost filteration units that can be locally produced. These filters have potentials to be utilized easily by a families. If designed properly, existing clay filters can eliminate bacteria from water. No fuel is needed (i.e. wood, gas, bio-fuels) for their application, implementation is easy; no container is required for storage of purified water (one system configuration); and equipment needed for its production can be produced and found locally. Such filtration systems can be readily equipped with a faucet, work all year round (if design is sufficient). They alsocan be used in conjunction with other methods to remove turbidity (1).

Ceramic water purification technology was developed in 1981 by ICAITI, an industrial research institute in Guatemala, and intensively promoted since 1998 by Potters for Peace, an NGO operating in Nicaragua (1). These filters have the potential to promote health and hygiene by purifying and disinfecting water for household use in developing countries. These filters have been produced and promoted in Africa, Central America, and Southeast Asia, *but have still not been widely adopted due to poor financial planning, and not meeting expected quality and quantity of water produced*.

The main filter elements are the container and filter medium. The filter element is manually filled with water from a contaminated source, which seeps through the clay at a rate of two to three liters per hour. The filtering effect of the clay eliminates a large portion of water-borne pathogens. Application of the colloidal silver has add on benefits and ensures complete bacteria removal. A study funded by USAID in Nicaragua found that the ceramic filters can remove 98-100 percent of *E. coli*, *Cryptosporidium*, and *Giardia*. This study however suggets that only with sufficient education household filters can both treat water efficiently and meet drinking water standards (2). Colloidal silver is an anti-bacterial agent with a wide range of application in medical practice. It has been used extensively prior to the development of antibiotics in the 1940s and 50s(1). The amount of silver used and also leached from the filter medium is estimated to be negligible and therefore should not be a health concern (1). Teaching communities how to use and maintain filters, however, is the most significant element of such process.

Due to their low cost and ease of use, clay filters can provide an immediate and effective solution to the problem of providing safe drinking water. Strong attention, however, must be given to the Design and Education elements of water purification programs evolving around clay-filters. If education and training is not sufficient, or design is not competent, these units will be unefficient and can not be trusted to treat contaminated water properly. Upon improper use, filtered water may have a poor quality and fail to meet needed water quality goals and standards set for drinking water by the health organizations and/or governmental agencies.

Table 1 shows a comparison made between various methods for obtaining potable water in rural communities and presented project (3, 4).

Table 1. Alternatives for obtaining drinking water in rural communities (3, 4).

Method	Advantages of this technology over our proposal	Disadvantages of this technology versus our proposal
Boiled Water	• Technique known and accepted • Water can be boiled all year round.	• pots or recipient are needed (with lid) • affects the taste of the water • fuel needed (wood or gas) for every boiling procedure • turbidity not removed • Cannot be applied by children
Chlorination	• Effectively removes bacteria • Low cost • Technology accepted by the population • Can be used at any time	• Affects the taste of the water • Set procedures must be followed • Container required (with lid) • Turbidity is not removed
Clay filters without colloidal silver	• This method works in a similar way than our project.	• Does not remove pollutants • Fuel needed for production • Needs to be renewed each year

Disadvantages of Clay Filters and Need for Improvement.

Potters for Peace, which has managed many international clay-based (filter) water purification programs, in their recent report has clearly identified the need for cooperation among research organizations and/or private enterprises to introduce innovative projects that encourage sustainable production, implementation and commercialization of clay filter-based water purification programs. Such programs could benefit underdeveloped, and developing countries in order to: (1) Guarantee clean water at affordable prices for the poorest population in each country, (2) Assure : (a) project sustainability, quality control, health education, (b) efficient follow-up programs, and (c) monitoring and evaluation of process performance, and (3) Provide easy access to technical assistance for participating regions, develop effective customer service and training programs and strong community networking. Experience has shown that despite effectiveness and ease of production, people only use filters for a fraction of their drinking water. Filters currently have a low flow rate, and may not be compatible with chlorinated water sources due to demonstrating the need for better consumer education, in addition to clogging and loss of silver which commonly experienced.

Project Objectives

This paper outlines an approach for improving the filtration system by changing the design, and developing customized training that creates broader awareness, encourages adoption on a much larger scale and stimulates local production and support.

The main objective of this research project, therfore, was to improve water purification through filtration as an affordable, low-tech process. Research, focused on design modification, composition change, and enhancement of filter potentials to remove multiple pollutants. The specific project objectives, were to : (1) Improve design structure, silver life and bacteria removal capability, and capability for removing multiple pollutants, (2) Develop and demonstrate a highly modular and customizable training program for using filters, (3) Develop business plans for creation of micro-enterprises to manufacture, and market clay pots in local communities, and (4) develop a plan for broad implemention of micro- enterprises. The overall goal of project was to promote health and hygiene and behavior change.

Focusing on the technical, economic, marketing and cultural factors associated with developing an improved low-cost water filtration system project addressed a spectrum of issues begining with refining the design to improve performance and life while strengthening the possibilities for manufacture using local materials and labor. An additional innovative aspect of the project is development of a training program module, customized for various local cultures to create awareness about the water purification device, and thus stimulate interest, trial and adoption. The project focused on spanding research, development, design optimization, pilot manufacture, testing, analysis, training module development, testing, business planning and finally implementation.

In order to meet project objectives, researchers at Illinois Institute of Technology joined forces with chemical engineering faculty and students at the Monterrey Tec. University , monterrey campus, in Mexico. The research team worked closely on design modification, business plan development and conveyance of market research and education.

The ultimate goal of the collaboration is to advance project to the stage of micro-enterprise formation in Mexico using a well developed business plan around a technology which focuses on using the improved clay-based water filtration system.

The training module, and business plans for implementation of the filter project were developed focusing on the need for flexibility and potentials for cusomization. According, business plan, and educational program will be developed to the need of highly localized populations in Mexico in need of clean water.

Methodology

Need Identification

There are several states in Mexico, with in sufficient potable water services. Studies reported by *INEGI* (Table 2) clearly indicate the need for clean water in a numerous states in Mexico. Particularly, in States like Veracruz or Oaxaca.

Table 2. Percentage of the population with potable water service by state in 2003. Source: *INEGI*

México (national average)			89.4
Lowest level States		**Highest level States**	
Veracruz	71.3	Coahuila	99.7
Guerrero	71.5	Aguascalientes	99
Tabasco	71.9	Distrito Federal	99
Oaxaca	73.8	Colima	98.3
Chiapas	77.8	Nuevo León	97.4

Design Modification

Two teams of students and faculty at IIT and Monterrey Tec. participated in this project. While working closely, teams were advised to approach design modification for the clay-based water filters separately. Following sections provides information on design modifications performed at the Monterrey Tec. And

IIT. Both research groups concentrated on using clay and the saw dust as primary medium for making filter elements. To prepare filtration units, clay was mixed with sawdust prior to shaping and forming the units in order to provide sufficient porosity and needed flow rates. In order to maximize filter efficiency in removing bacteria, colloidal silver was applied to the medium as a varnish.

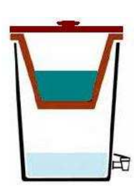
Using what nature provides brings plenty of advantages and even more if is a material that can be found in almost at every place. Clay, therefore was selected as primary material used to produce the Filter. The capacity for fabrication of filter units, depended on the grains, particle size, and plasticity of the clay. Due to the need of market, filter making was pursed using materials found in Mexico. Small pilot study identified existing and locally available resources of the clay for this project. The most logical approach was to use common surface clay which is the most abundant, and using clays that can be found all over the country. Pilot study also indicated that the biggest clay deposits are located in the state of Durango, at the north. This clay is mainly of bentonite nature. Other important deposits are in Puebla, Oaxaca, Tlaxcala, Zacatecas and Guanajuato. Clay in those states is ferruginous, contains great amounts of iron and its color changes from red ochre to black [3]. Fig. 1 shows the main clay dregs in Mexico.

Figure 1. Location of principal clay deposits in Mexico

Silicium and aluminium are the main components of Mexican surface clay; also the soil is rich in iron, explaining the red color of the earthware of the region.

Monterrey Tec. approach

Design modification in Monterrey focused on filtration mechanism. Accordingly study focused on the filter medium, filtration rate and surface loading ($m^3/min/m^2$), contact time, and solid loads. Following procedure outlined by Potters for Peace, researchers at the Monterrey Tec. used the pot shaped filters (Fig. 2) and decided to build filter elements around the PFP design. The pot shape provides a large filtration area, and potentials to filter a high amount of water (10 L) with a sufficient hydraulic pressure and flow rate. However, since flow rate has a significant impact on the contact time needed for the purification (time for water and filter medium to contact), its value needs to be evaluated and monitored carefully. The other expected advantage has been ease of production for these types of filters. Potters are expected to be familiar with these pot-shaped pieces; therefore they would not have great difficulties with building it.



a) Initial sketch design b) Actual form of filter

Figure 2. Monterrey Tec. Initial Filter design

In order to provide a sufficient contact time, IIT filter configuration was used to develop a new model for the filter at Monterrey. This new configuration consisted of multi-stage pots (Figure 3.). The main objective of the multi-stage filtration unit is to make sure sufficient contact is provided between colloidal silver and polluted water. Disadvantage of this design is its weight, potential for contamination, and breakage.

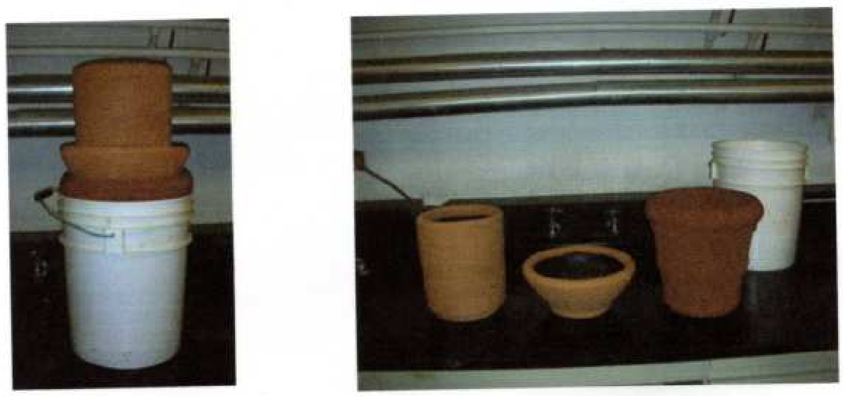


Figure 3. Filter design in Monterrey Tec.

The flow rate for a series of filters produced at Monterrey Tec. Varied between 0.25-1.5 L/hour depending on the filter media composition (i.e. percent of clay and saw dust). A grain analysis for clay and sawdust was performed in order to identify particle size distribution and particle diameter of the raw materials. Analysis indicated a bimodal behavior for both clay and saw dust used in this study (Figure 4.).

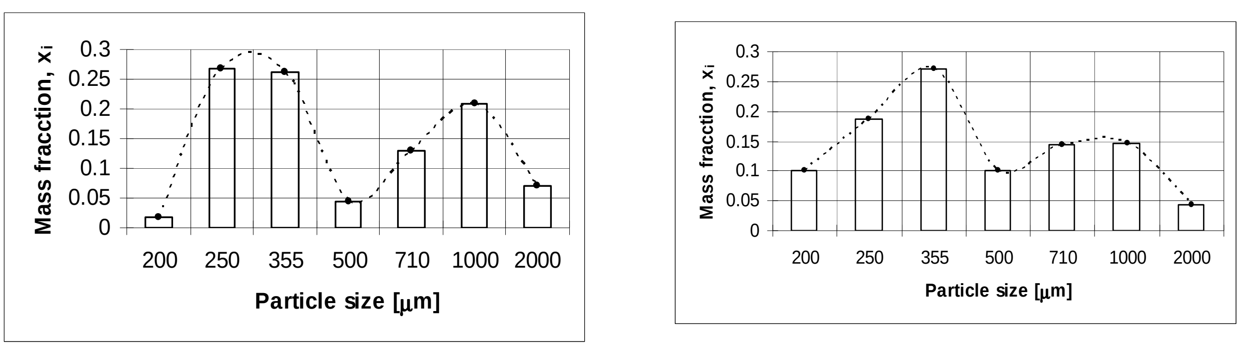


Figure 4. Particle size distribution (differential) for a) Clay and b) Sawdust

The size of clay and sawdust is significant because affects the pore's dimensions. A balance should be reached between porosity and residence time. The alteration on the water taste is one of the social reasons of why several cleaning methods are rejected. Normal flowing water was poured into the clay filter, already varnished with colloidal silver, and then the filtered water was tasted, no changes in color, odor or taste were identified.

IIT approach

IIT design concentrated on production of a new filter configuration and a program for its implementation. Filter designed at IIT is identified as KlarAqua. Figure 5 shows overall configuration of the Klaraqua. Similar to Monterrey Tec., IIT design was inspired by PFP clay-based ceramic filters. Work at IIT, however, was focused on taking PFP design to the next level providing opportunities for ceramic filters to be used at much broader spectrum. Klaraqua is a water filtration system for personal or household use which is made completely from locally available materials. It consists of a bowl, and up to three ceramic disks housed in a cone shaped casing. Local water is poured in the top of the bucket; the water passes through the three tiers of filters, and is collected at the bottom of the bucket. The filtering discs are made from clay and sawdust through a simple process that any local potter can master. These discs are then brushed with colloidal silver, which acts as the bacteria-killing agent. Colloidal silver can be found in many rural areas, but if it cannot be purchased locally, a simple process of using a battery to suspend silver ions in solution can be used to produce it. The inner casing, which holds the three filters inside the bucket, can be made using any scrap piece of plastic via vacuum formation.

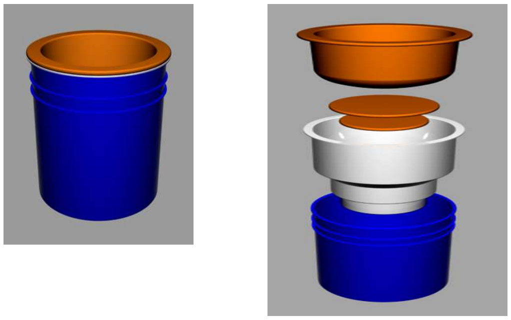


Figure 5. Filter design and configuration at IIT.

In urban areas, industrial manufacturing technology could be used for this portion, but in rural areas it can be done locally use recycled materials. The three discs can be manipulated to meet the needs of a specific community. For example, bacterial contaminants may be removed by one filter, while the next filter may remove nitrates form fertilizer residues and the final filter may remove bad taste and odor. This flexibility of interchanging the discs addresses the diverse nature environmental issues throughout the world.

This filter has potentials to provide sufficient flow rate and bacteria removal from contaminated waters. Our studies indicated that disks and bowl are capable of removing 80-100% of bacteria by only by filtration mechanism. Silver application would provide an added value to the filter. The flow rates through the disks are impacted by the disk composition and configuration, therefore, it has been varying between 0.5-1 L/hour.

Filter design and associated training program developed at IIT has focused on both Effectiveness and Education. Teaching communities on how to make, use and maintain filters have been the focus of the project. It has become evident that the most significant element of a successful household based water purification program is the education and availability of a “Know How” manual. IIT Klaraqua team is working closely with the Monterrey Tec. to develope an effective, and innovative educational program for implementation of the filter project in selected pilot areas of Mexico. Social wisdom and cultural factors are the core of the educational program and “know How” material developemnt. The focus of this collaboration, therefore, has been on not only design modificastion but also development of strategies to ensure effective household usage/treatment, and safe storage of water in areas of need in Mexico. The aim of our efforts is to ensure efficient use of filters and treatment of contaminated water to a level that it can meet water quality standards set for drinking water by health organizations and/or governmental agencies in Mexico.

Conclusion and Future Work

In continuing efforts to address global problem with water pollution, researchers at IIT and Monterrey Tec. initiated a study of existing ceramic filters and have designed two new clay-based water filters. The proposed designs were inspired by the work of PFP. Filtration is one of the most used techniques for water purification. It is an economically sound process which requires no chemicals, energy, or electricity to purify the water (water pressure is used to force the water though the filter). The only required maintenance for the designed filters is the replacement of the filter element due to clogging or deactivation. As long as the cost of the replacement filter elements is reasonable, owning a clay based filter can be very inexpensive if the long term costs are observed and compared it with other solutions. The composition of mixture for filters, which produces a filtrate flow that satisfies the regular water consumption in the rural communities of the country, could vary significantly. There has been a strong link between results of a pilot study conducted in areas close to the Monterrey and final design configurations. The proposed filter shape, pot-type, was suggested by potters in Mexico. Therefore, based on our data, we are confident that both IIT and Monterrey Tec. filters can be easily produced by Mexican local potters.

Future activities associated with this project include but is not limited to modifying filter configuration, and testing its capacity for removing other pollutants. Change in filter medium composition and configuration calls for new tests. Example tests include but are not limited to flow rate measurements for the prototype, determination of the filter life. It is also important to measure the quality of the filtered water, in order to determine filter efficiency and examine its potentials for meeting requirements set by Mexican government agencies for drinking waters.

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