DEVELOPMENT OF A CERAMIC WATER FILTER FOR NEPAL

by
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Bachelor of Applied Science
University of British Columbia, Canada, 2001

Submitted to the Department of Civil and Environmental Engineering
In Partial Fulfillment of the Requirements for the Degree of

MASTER OF ENGINEERING IN CIVIL AND ENVIRONMENTAL ENGINEERING

at the

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

June 2003

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Abstract

Countries like Nepal face tough challenges in terms of providing safe, clean drinking water for their citizens. The World Health Organization estimates that nearly 5 million people in Nepal lack access to safe drinking water while globally, 1.1 billion lack access to improved water supplies. Point-of-use water treatment technologies, such as household ceramic water filters, offer an affordable and effective means of treating water to standards suitable for drinking. The fact that ceramic water filters can be manufactured and produced by local ceramists with local materials makes ceramic filters particularly attractive as a point-of-use treatment technology that is affordable, appropriate, and sustainable.

This thesis examines existing ceramic water filter technologies, production processes, and methods for bringing a low-cost ceramic water filter to market in Nepal. Three types of disk filters and five types of candle filters are evaluated in terms of microbiological removal efficiency and flow rate. A red-clay grog disk filter coated with colloidal silver and three of the five candle filters (Katadyn® Ceradyn, Katadyn® Gravidyn, and the Hari Govinda white-clay candle filter capped on both ends) also coated with colloidal silver, performed the best in terms of microbiological removal efficiency (>98%) and flow rate (ranging from 641 mL/hr/candle (Ceradyn) to 844 mL/hr/candle (Gravidyn)). In addition to filter testing, a guideline for developing a ceramic water filter in preparation for bringing a product to market is presented, along with a discussion on the importance of laboratory and field testing to ensure overall product performance. A step-by-step summary of the production process is also presented along with a comparison of the theoretical flow rate through a candle filter versus a disk filter. Recommendations for future work include testing and modifying the current disk-filter prototype design and research on the most appropriate filter element for the proposed prototype.

Thesis Advisor: Susan Murcott
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Thesis Advisor: Patrick Jaillet
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Acknowledgements

What has impressed me the most in the last eight months of research and work on ceramic water filters is the number of individuals and organizations passionately engaged in the quest to improve the health and welfare of those in need in countries like Nepal. Their hard work has inspired me to not only write this thesis, but to consider how I can incorporate development work into my career as an engineer. If engineering is about solving problems, then there is no greater a problem to solve right now than getting clean water to the 1.1 billion who lack access to safe drinking water. I hope this thesis, which is based on the hard work of the following individuals and many others, will contribute to solving this problem.

First and foremost, I would like to thank Susan Murcott, my advisor, for her tremendous support and guidance throughout the last eight months. Susan's work on water and sanitation in developing countries has brought new meaning to the concept of engineering and sustainability. The MIT Nepal Water Project would not exist without her hard work and dedication.

To my fantastic CeraMIT teammates Bobby Wilson, Steve Perreault, and Laura-Ann Jones: thank you for all of your hard work, insight, and business acumen. I would also like to thank Professor Simon Johnson and Professor Richard Locke for including the MIT Nepal Water Project in the Global Entrepreneurship Lab course.

In Nepal, I would like to thank Mr. Hari Govinda Prajapati for his hard work and ongoing collaboration with the MIT Nepal Water Project. A lot of this thesis is based on Hari's work as a ceramist and I wish him all the best in the future.

I would also like to thank Dr. Roshan Shrestha and the ENPHO staff (especially the microbiological lab staff) for providing such a wonderful working atmosphere during my stay at ENPHO. Lunch on the roof was an enjoyable break from testing.

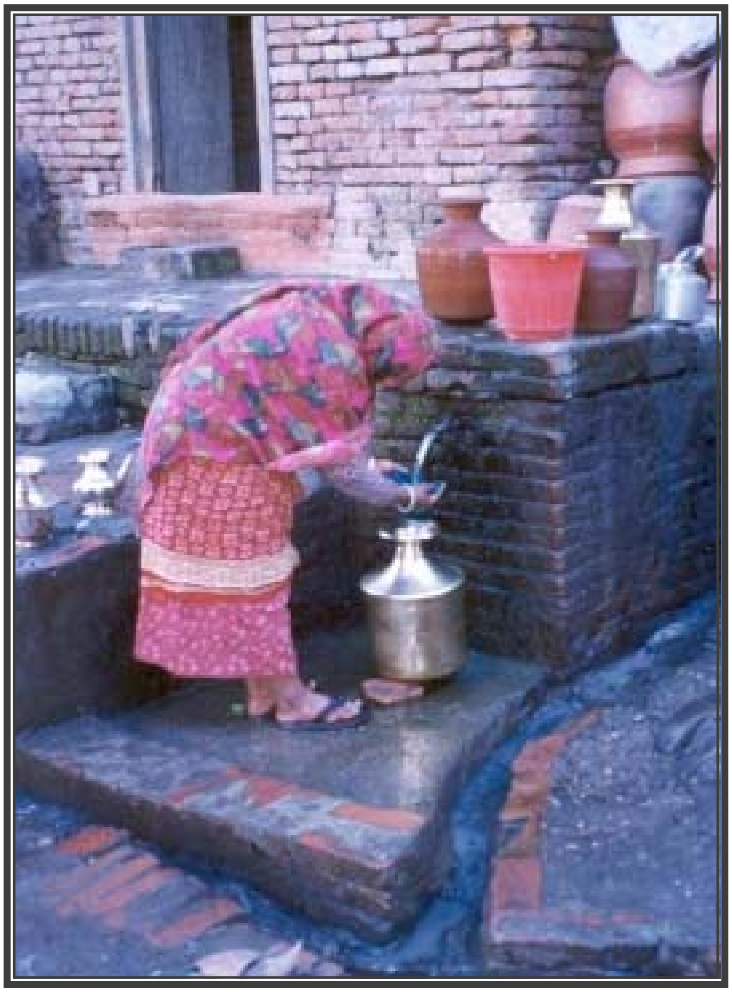
Reid Harvey, Deepak Lochan Adhikari, Chittra Gurung, and Bob Nanes of IDE-Nepal were an immense help to the CeraMIT team during our stay in January. Most of the research work outside of the laboratory was arranged through the effort of Mr. Adhikari. Mr. Gurung also helped me with lab experiments on the roof of ENPHO. Thank you IDE-Nepal for all of your help.

To my MIT Nepal Water Project teammates, cheers to sure flow and thanks for making the Nepal trip so memorable: Xanat Flores, Hillary Green, Saik-Choon Poh, Melanie Pincus, Georges Tabbal, Mandy Richards, as well as Ralph Coffman and Tetsuji Arata for their help doing research as well as climbing mountains.

I would also like to thank Professor E.E. Adams, the Director of the MEng Program, and the rest of the staff in the Department of Civil and Environmental Engineering for organizing and coordinating such a fantastic nine-month program.

There are many others who have contributed either directly or indirectly to this thesis. In particular, the work of Lily Cheung (2003), Rebeca Hwang (2003), C.S. Low (2002), Daniele Lantagne (2001), and Junko Sagara (2000). Furthermore, thanks goes to Ron Rivera and Potters for Peace for providing a wealth of information on ceramic water filters. Lee Hersh was also very helpful at providing information on ceramic material properties.

Finally, I would like to thank Professor Patrick Jaillet, the Head of the Department, for having the time to meet with the CeraMIT team and to provide feedback in his “spare time” between starting his new position as Head of the Department of Civil and Environmental Engineering.



Woman collecting water from a stone tap

Thimi, Nepal.
January 2003.

Development of a Ceramic Water Filter for Nepal

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List of Abbreviations

Acronym	Full Name
CeraMIT	Joint MIT business-engineering student team (2002/2003)
CS	Colloidal Silver
DWSS	Department of Water Supply and Sewerage
ENPHO	Environment and Public Health Organization
HDI	Human Development Index
ICIMDS	International Center for Integrated Mountain Development
IDE	International Development Enterprises
INR	Indian Rupee
LRV	Log Reduction Value
MIT	Massachusetts Institute of Technology
NRs	Nepalese Rupee
NWSC	Nepal Water Supply Corporation
PFP	Potters for Peace
POU	Point of Use
PPM	Pottery Purification Media
RWSSP	Rural Water Supply and Sanitation Support Program
USD	United States Dollar
WHO	World Health Organization

Chapter 1 Introduction

The global community faces a tough challenge: to halve the number of people without access to improved water supply and sanitation by the year 2015. This bold objective, also known as one of the Millennium Development Goals, was again committed to by governments from around the world during the 2002 World Summit on Sustainable Development in Johannesburg South Africa.[60] Considering the World Health Organization's estimate of 1.1 billion people who lack access to improved drinking water supply, the Millennium Development Goal for water works out to delivering access to improved water supply at a rate of ~100,000 people per day between the years 2000 and 2015.[66] Can governments alone realistically meet this ambitious goal by the year 2015 through conventional centralized water supply systems?

In the pursuit of solutions to providing safe drinking water to those in need, point-of-use household water treatment has emerged as a complementary solution to centralized water supply systems. Household ceramic water filters, in particular, offer an affordable and effective means of treating water to a standard suitable for drinking. Although the use of ceramic water collection and storage vessels goes back centuries, there is little documentation and testing of the effectiveness of *low-cost* ceramic water filters both in the laboratory and in the field.

What research has been done suggests that the commercially available ceramic water filter systems in places such as India, Nepal, Nicaragua, and Brazil are adequate, but could be improved to better meet the drinking water needs of citizens – especially the poor. In particular, many commercially available filter systems are too expensive for the poor who are suffering the most from waterborne diseases. Several organizations, including the Massachusetts Institute of Technology (MIT), are currently trying to address this issue by developing a new low-cost ceramic water filter.

1.1 MIT Nepal Water Project

The MIT Department of Civil and Environmental Engineering (CEE) has been working in Nepal since 1999 to help provide clean drinking water and improved sanitation to those in need. MIT engineering student Junko Sagara was the first student to study ceramic water filters in Nepal in 1999/2000 as part of her Master of Engineering thesis.[49] C.S. Low continued research on ceramic water filters in 2001/2002 as part of his thesis on “Appropriate Microbial Indicator Tests for Drinking Water in Developing Countries and Assessment of Ceramic Water Filters”.[35]. Low worked closely with ceramist Mr. Hari Govinda Prajapati of Madhyapur Clay Crafts in Thimi Nepal, who had originally been located and contacted by Junko Sagara, to develop the first version of a ceramic disk filter.

A number of engineering students have also carried out research on ceramic water filters in Nicaragua. In particular, Daniele Lantagne conducted an in-depth study of the Potters for Peace (PFP) Filtron filter in 2001[33,34] and Rebeca Hwang recently carried out research on evaluating the effectiveness of a monitoring program in conjunction with the PFP Filtron.[28]

As part of the ongoing effort to understand and improve ceramic water filters in Nepal, Nicaragua and elsewhere, a team of engineering and business students (named CeraMIT) was formed this year to continue working on developing a ceramic water filter for Nepal. Four students formed the CeraMIT Nepal Team:

- Rob Dies, Department of Civil and Environmental Engineering, MEng Candidate
- Steve Perreault, Sloan School of Management, MBA Candidate
- Bobby Wilson, Sloan School of Management, MBA Candidate
- Laura Ann Jones, Sloan School of Management, MBA/TPP Candidate

CeraMIT conducted a three-week-long field study in Nepal during January 2003. This research culminated in several recommendations for the development of a grassroots ceramic water filter business in Nepal.[10]

On return from Nepal, mechanical engineering senior student Lily Cheung joined the CeraMIT team to develop one of the prototype designs that was recommended by CeraMIT, as part of her senior thesis.[6]

1.2 Thesis Objectives

The intent of this thesis is to lay the foundation for developing a ceramic water filter for Nepal. The overall goal of developing a low-cost ceramic water filter is to provide an affordable means for Nepali citizens to improve their drinking water quality to standards suitable for human consumption. In addition to improving drinking water quality, the development of a sustainable ceramic water filter industry within Nepal will hopefully contribute to economic development whereby local entrepreneurs, such as ceramist Hari Govinda Prajapati of Madhyapur Clay Crafts, can develop a sustainable business through manufacturing and marketing ceramic water filters to higher quality control/quality assurance standards than those currently being produced.

The thesis is based on six months of research and three weeks of field work in Nepal. It builds on the work of past and present MIT students and faculty who have been working on ceramic water filter projects since 1999. In particular, it builds on the work carried out by the CeraMIT team in January 2003. Furthermore, this thesis also builds on the work of many organizations and individuals who have dedicated much of their time and effort to developing and promoting ceramic water filters as an effective household water treatment technology.

1.3 Thesis Outline

The thesis begins with some background on ceramic water filters in Chapter 2, followed by a summary of the laboratory test results of three different disk filters and five candle filters in Chapter 3. Chapter 4 presents an overview of the production process along with a discussion on the parameters that affect filter performance. Chapter 4 also presents the theoretical flow rate for a disk filter versus a single candle filter. A framework for guiding and assessing the progress of developing a ceramic water filter for Nepal is then presented in Chapter 5. Chapter 6 summarizes the current need for clean drinking water in Nepal and includes a preliminary analysis of the potential customers/users of a ceramic water filter. Chapter 6 is followed by an overview of the development of a prototype, focusing on the important product attributes and performance goals that were used to develop the first prototype design. Chapter 7 also includes a discussion on product certification and field testing. Chapter 8 briefly discusses methods for bringing a ceramic filter to market. The last two chapters present a list of conclusions and recommendations respectively. The recommendations are intended to help guide future students, faculty and others involved in taking the CeraMIT water filter to the next step.

Chapter 2 Overview of Ceramic Water Filters

Ceramic water filters have been used in various places around the world as a means of treating drinking water at the household level. Some examples include the Potters for Peace Filtron (Nicaragua), the TERAFIL terracotta filter (India), and the candle filter (India, Nepal, Bangladesh, Brazil, etc).

Ceramic water filters can be categorized according to various key parameters:

1. Shape (e.g.: candle element, disk, pot) (Figure 2.1);
2. Type of clay (e.g.: white kaolin, red terracotta, black clay…);
3. Combustible material (e.g.: sawdust, flour, risk husk…).

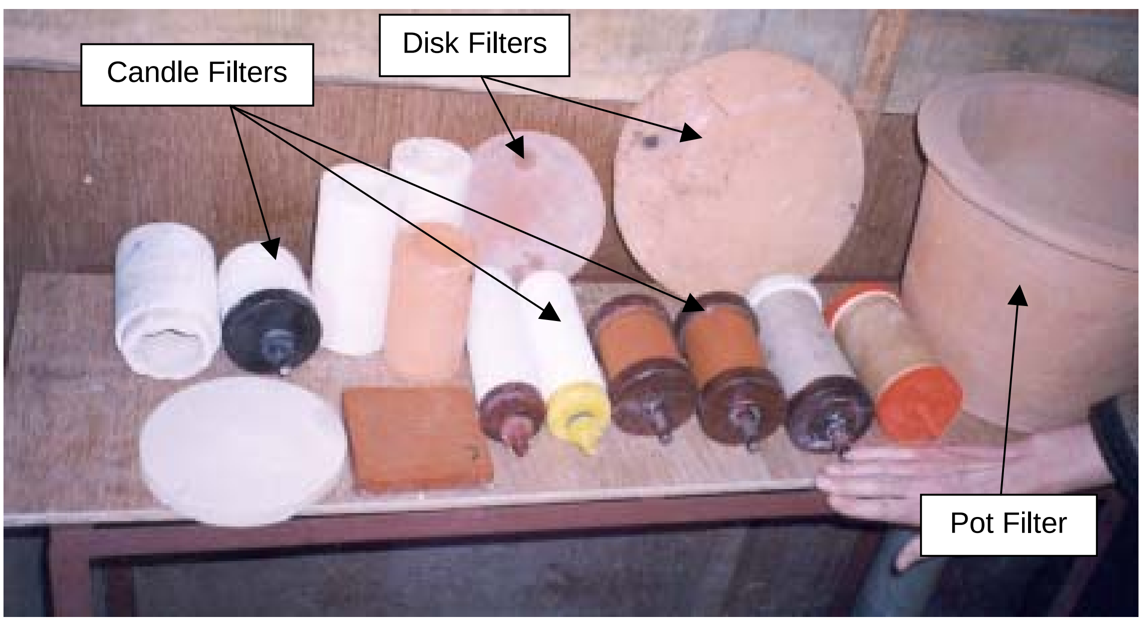


Figure 2.1: Types of Ceramic Water Filter Elements

Ceramic water filters can also be described by their function(s):

1. Microbial removal (e.g.: Potters for Peace Filtron);
2. Chemical contaminant removal such as arsenic and iron (e.g.: 3 Kolshi filter for arsenic) [23,38,55];

3. Secondary contaminant removal like taste and odor (e.g.: Katadyn® Gravidyn ceramic candle filter with activated carbon).

Other key variables that influence the properties of ceramic water filters include:

1. Use of additional materials in production (e.g.: grog, sand, combustible materials…);
2. Firing temperature;
3. Mode of production (e.g.: hand mold, wheel, mechanical press).

The entire filter unit is often defined in terms of two components: the filter *element* or *media* through which water passes and the filter *system* which houses the media, usually consisting of an upper and lower storage vessel for holding water (Figure 2.2)

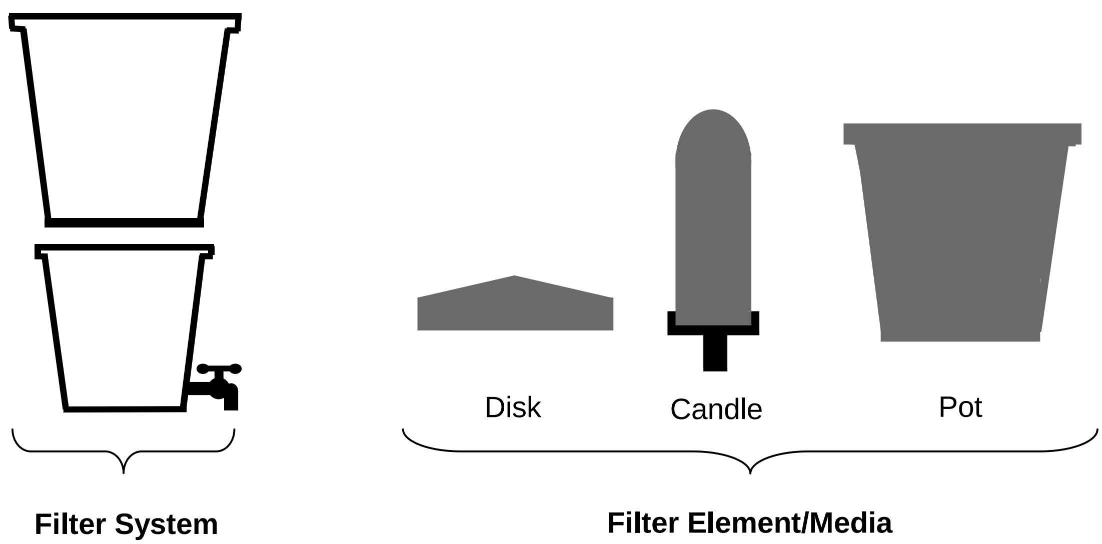


Figure 2.2: Ceramic Water Filter *System* and *Media*

Some general strengths and weaknesses of ceramic water filters are listed in Table 2.1 below. A summary of the three most common ceramic filter media shapes: disk filters, pot filters, and candle filters, is presented in the following sections. An overall summary table is presented in Appendix 1.

Table 2.1: General Strengths and Weaknesses of Ceramic Water Filters

Strengths	Weaknesses
• Relatively cheap to manufacture and produce; • The ceramics trade is well established in many countries; • Materials (clay, sawdust, rice husk…) are often readily available; • If designed and used properly, can remove up to >99% of indicator organisms and reduce turbidity to below World Health Organization guideline values.	• Very slow filtration rates. (typically ranging between 0.5 and 4 L/day); • Filter maintenance and reliability depends on the user – herein lies many non-technical social issues; • Breakage during distribution or use can be a problem since ceramic filters are often fragile; • Requires regular cleaning; • The rate of production as implemented in countries such as Nicaragua and Nepal has tended to be relatively slow; • It is difficult to maintain consistency (quality control is an issue).

2.1 Disk Filters

Ceramic disk filter systems consist of an upper and lower container with a ceramic disk inserted between the two containers. Water is poured into the upper container and then allowed to filter through the disk into the lower collection vessel. A spigot is placed in the bottom container for dispensing the treated water. An example of a 100-year old ceramic disk filter from Spain is shown in Figure 2.3.

A more recent example of a disk filter system from India, called the Indian TERAFIL filter, is shown in Figure 2.4. The TERAFIL consists of two metal or terracotta containers and a ceramic disk fitted into the bottom of the upper container. The disk retails for approximately 25 Indian Rupees (INR 25) (USD $0.49)[a] and a complete set consisting of a disk and two ceramic containers (not metal as in Figure 2.4) retails for approximately INR 180 (USD $3.51).[35]

[a] 1 USD = 51.22 INR (Indian Rupees); 1USD = 76.5 NRs (Nepali Rupees) (8/11/2002)

In January 2002, civil engineering student, Jason Low, and Mr. Hari Govinda Prajapati experimented with different material compositions and production processes to produce a terracotta clay disk filter (Figure 2.5) similar to the TERAFIL filter, but based on variations of the production process shared by Ron Rivera of Potters for Peace, Nicaragua (Section 2.2). They used local red terracotta clay from Thimi, a village outside Kathmandu, as the primary material for both the ceramic disk and the containers. The results from their work are published in Low's thesis.[35] The production cost for these terracotta filters is approximately NRs 76 (USD $1.00) for the disk and NRs 267 (USD $3.50) for the disk filter and two terracotta containers.[44] Mr. Hari Govinda Prajapati's business, Madhyapur Clay Crafts, is now selling a modified version of this disk filter as an arsenic filter (Figure 2.6) as part of a joint program by the Environment and Public Health (ENPHO) and the Nepal Red Cross to remediate the arsenic problem in the Terai.

Figure 2.3: 100-Year Old Disk Filter from Spain

Previous studies of the Indian TERAFIL disk filter show mixed results for filter performance in terms of microbial removal and flow rate. In his 2002 thesis, Low summarized a number of these studies, as well as conducted his own studies on the Indian TERAFIL and the Nepali disk filter that he and Hari Govinda Prajapati had created.[35] Of concern in previous studies, including Low's, was the improved, but unsatisfactory microbial removal rates ranging from 93% to 99.99% (% total coliform removal), which did not meet the strict World Health

Organization (WHO) guideline of 0 coliform forming units (cfu) per 100 milliliters of water.[35,65]. Percent turbidity removal was reported to be quite good, typically approaching 99% removal, below the WHO guideline of 5 NTU. Flow rates were another major issue, ranging from 1.0 to 11.0 L/hr with the average among all of the studies being around 3 L/hr. Most studies concluded that the ceramic filters should be used in conjunction with some form of disinfection such as chlorination, colloidal silver, or solar disinfection.

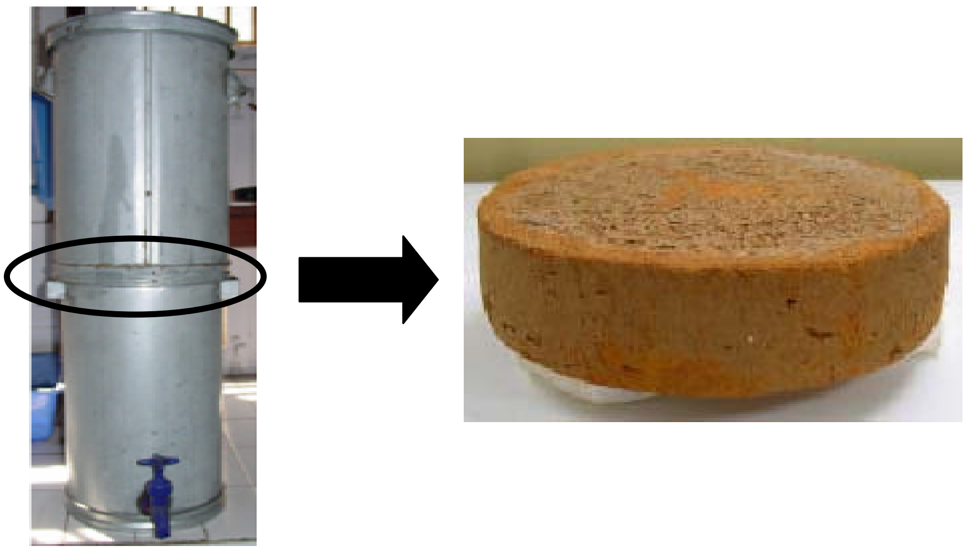


Figure 2.4: Indian TERAFIL Ceramic Disk Filter

Picture Source: Low. 2002 [35].

Tests by Low at MIT on the Nepali terracotta disk filters he had produced with Hari Govinda in Nepal showed comparable microbial removal rates and turbidity reduction as the Indian TERAFIL filters; however, the flow rates were unacceptably low at 0.2-0.3 L/hr.[35] Considering this was the first attempt at making the terracotta disk filters at Madhyapur Clay Crafts, Low concluded that there was considerable room for improving the production process to achieve acceptable flow rates.[35]

Tests by Low on the TERAFIL filter unit at the Environment and Public Health Organization (ENPHO) laboratory in Kathmandu measured flow rates ranging from 5.9 L/hr to 6.9 L/hr[35] while similar tests performed a month earlier at MIT measured flow rates ranging from 1.1 L/hr to 1.9 L/hr. Despite the wide discrepancy in flow rates between the two seemingly identical TERAFIL units, the microbial removal rates of both units were comparable, ranging from 94% to 99.99%.[35] That a relatively high flow rate was achieved in a ceramic water filter without sacrificing microbial removal performance was of considerable interest and formed the basis for the next stage of studies.

Most studies[28,33,34,35] also report that regular cleaning (scrubbing of the filter) is required to maintain filter performance primarily with respect to maintaining satisfactory flow rates.

Figure 2.5: Terracotta Ceramic Disk Filters

Madhyapur Clay Crafts, Thimi, Nepal. January 2002

Picture Source: Low. 2002 [35]

Figure 2.6: Arsenic Filter by Hari Govinda Prajapati

Madhyapur Clay Crafts, Thimi, Nepal

2.2 Pot Filters

The Potters for Peace[a] (PFP) Filtron system consists of a colloidal silver-impregnated ceramic pot perched inside a collection bucket (Figure 2.7). The flower-pot shaped filter unit is approximately 17 L (4.5 gallons) in capacity and the lower storage/collection unit ranges from 7.5 – 20 L (2 to 5 gallons).[43] The PFP filter element is fired as one complete, unit, unlike the disk filters based on the TERAFIL and Low/Prajapati Thimi examples which consist of two materials (ceramic disk element and plastic, terracotta, or metal containers) combined together using a white or gray cement that attaches the disk to the upper container. Thus, the PFP filter eliminates the potential for leakage along the interface between the disk and the container (i.e., if the cement seal cracks in the disk filter, then the filter is more or less useless in terms of removing microbial contamination). Typical flow rates for the PFP Filtron range from 1.0 – 1.75 L/hr.[43]

Figure 2.7: Potters for Peace Filtron

Picture source: Potters for Peace website (http://ww.potpaz.org) [43]

[a] Potters for Peace website: http://ww.potpaz.org

Consultant Daniele S. Lantagne conducted a thorough investigation of the PFP Filtron during 2001[a33,34]. Some of the conclusions from her report are presented below.

- Analysis using a scanning electron microscope found pore sizes typically ranged between 0.6-3 microns. The PFP ideal is a 1.0-micron pore size to physically remove *E.coli* without the need for disinfection.[33]
- The majority of the water appears to filter through the *sides* of the filter and not directly through the bottom. Lantagne's recommendation was to ensure proper application of colloidal silver along the sides of the filter to ensure that water passing along the sidewalls comes in contact with colloidal silver.[33]
- A prior study of the PFP Filtron done in 1984 found the flow rate to decrease by ~50% over a one-year period. Lantagne confirmed that regular scrubbing of the filter should help to rejuvenate the diminished flow rate.[33]
- A summary of historical data showed that the PFP filter was effective at removing 98-100% of the indicator bacteria present in the source water in laboratory testing (Report 1, pg 58), but gave poor indicator bacteria removal rate in actual household practice.[34]
- Studies of two-to-seven year-old PFP filters showed that the filters were still effective at removing microbiological contaminants, suggesting that the colloidal silver may remain effective over extended periods of time [33] (how effective still remains unknown).

The flow rate for every PFP filter produced is measured for quality control before it is sold. The flow rate must fall within a specified range: a minimum for practical purposes (likely 1 L/hr) and a maximum to ensure that the water is in contact with the colloidal silver long enough to achieve disinfection (~2 L/hr).[33] Filters with flow rates outside this range are discarded.

A preliminary cost analysis of the PFP filter shows the total cost of producing one complete unit is approximately USD $6.00 with a wholesale price of USD $9.00.[46] The wholesale price likely depends on the quantity purchased, USD $9.00 probably being for a single Filtron. The price of the filter is roughly equivalent to the price of a machete, which is one of the most important tools required for work in rural areas of Nicaragua.[42]

[a] Online copy of Lantagne's report: http://www.potpaz.org/pfpexecsum.htm

As a point of interest, the PFP website also has a one-page graphical summary demonstrating how to use and maintain their filters (Figure 2.8). This instructional material is also attached to each bucket as a waterproof sticker.

Figure 2.8: Potters for Peace Instructions for Use

Picture Source: Potters for Peace website (http://ww.potpaz.org)[43]

2.3 Candle Filters

Indian candle filters are the most common type of ceramic water filter used in India and Nepal[49] and are also commonly available in other countries such as Brazil. Candle filter systems consist of two containers and one or several ceramic candle filter elements, shaped like a thick candle, screwed into the base of the upper container (Figure 2.9). Water is poured into the upper container and then allowed to filter through the ceramic filter element into the lower collection vessel.

Candle filters can have very low flow rates, and thus it is common to find filter systems with two or three candle filter elements. Recent laboratory tests of five candle elements of different compositions showed flow rates ranging from 300 – 840 mL/hr/candle (Chapter 3).

Figure 2.9: Indian Ceramic Candle Filters (BAJAJ filter on the right)[49]

2.3.1 Indian Candle Filters

A number of Indian companies (e.g.: Puro, Himal, Kimal, Swagat, and Milton) manufacture ceramic candle filter systems[49]. Typical retail prices for these systems (i.e., one or several candles plus the two containers, lid and spigot) in Nepal range from 600 NRs to 1600 NRs (USD $8.00 - $21).[49] The containers are often made of aluminum, stainless steel, or copper in order of price (Figure 2.9). Some Nepalese families purchase plastic buckets at 170 NRs (USD $2.22) and the Indian candle filter unit separately to construct and assemble their own system to reduce the overall costs.[49] A hole is drilled in the bottom of the plastic bucket and the filter element is screwed into place. The candle filter elements are often made with white kaolin clay.

2.3.2 Nepal Candle Filters

Very few candle filters appear to be manufactured within Nepal. One example; however, is a white kaolin clay candle manufactured at Madhyapur Clay Crafts in Thimi by Mr. Hari Govinda Prajapati (Figure 2.10). The white kaolin clay that is used by Hari is imported from India because it is not available locally within the Kathmandu Valley. The upper and lower containers are made of red terracotta clay from Thimi, Nepal. Each container has a holding capacity of approximately 10 L. The candle filter element is roughly 17 cm high and 5 cm in diameter.[49] The complete unit sells for approximately 312 NRs (USD $4.07). Madhyapur Clay Crafts sells the complete unit in bulk quantity to retailers for 175 NRs (USD $2.29) (140 NRs (USD $1.83) for the containers and 35 NRs (USD $0.46) for the candle filter element). Typical replacement time for ceramic candle filters is six to twelve months.[49] The filters must be periodically cleaned with a brush to remove surface buildup of particles.

Figure 2.10: Hari Govinda Prajapati Ceramic Candle Filter

Madhyapur Clay Crafts, Thimi, Nepal.

Picture source: Sagara. 2000[49]

Laboratory tests of the Hari candle filter were performed by Junko Sagara in 2000.[49] Presence-Absence tests for both the unfiltered and filtered water showed positive readings suggesting that the filter was not effective at removing H_2S-forming bacteria, which is used as an indicator species for the presence of pathogens. MPN results for the same filter showed a raw water microbial concentration >8 MPN (bacteria/100mL) and a filtered water microbial concentration of 3.9 MPN (bacteria/100mL) confirming the results obtained from the Presence-Absence tests. The flow rate per candle was also quite low at 240 mL/hr initially, reducing to 80 mL/hr over a 16-hour period[a].

A similar, but slightly different version of the candle tested by Sagara was tested in January 2003 at ENPHO in Kathmandu Nepal (Chapter 3). The candle tested in January 2003 had both ends capped with a piece of plastic (Figure 2.11) as opposed to just one end as shown in Figure 2.10. The results were more favorable, in terms of microbial removal rates – especially for the filter unit that was coated with colloidal silver which removed >99% of the total coliform and *E.coli* bacteria given a raw water concentration of 89 cfu/100 mL and 56 cfu/100 mL for total coliform and *E.coli,* respectively.

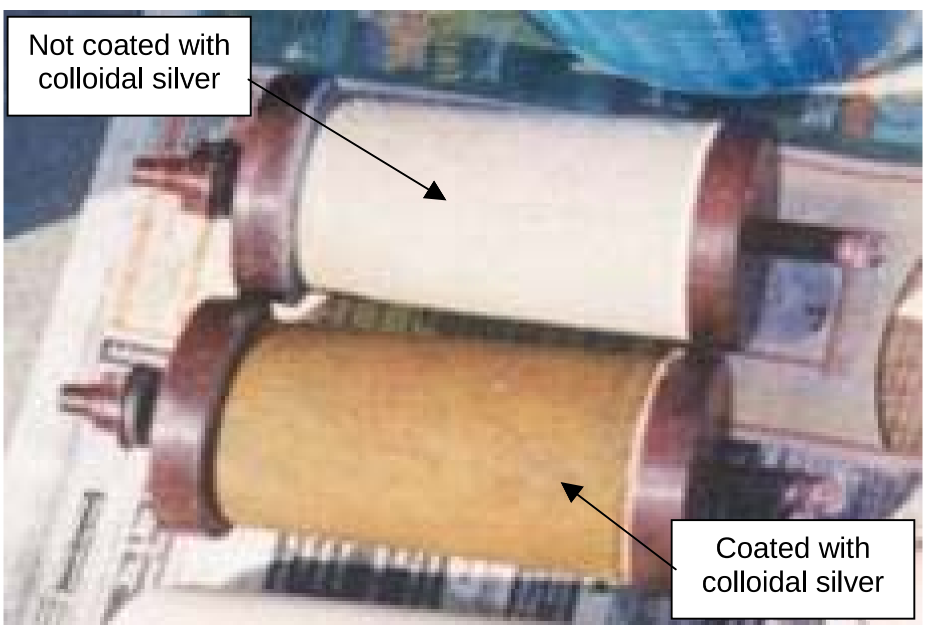


Figure 2.11: Hari Govinda Prajapati Candle Filters with Capped Ends

Madhyapur Clay Crafts, Thimi, Nepal. January 2003

[a] The flow rate was measured under a falling head (height of water in the upper container).

One reason for the improvement in the microbial removal rates for the candles capped on both ends, vis-à-vis the Hari candles with only the bottom-end capped (Figure 2.10) as tested by Sagara, was suggested by ceramic consultant Reid Harvey. Upon inspection of the one-capped end candle elements, Harvey noticed that those candles were manufactured with two pieces of clay: the main shaft piece and a round cap placed on the top-end. Harvey's hypothesis is that the cap-to-shaft interface produces a micro-fracture during the firing process thus allowing a pathway for the water, and possibly microbes, to bypass the filter element, giving rise to the presence of microbial contamination in the filtered water. This fracture can be observed when the filter unit is filled with water from the inside. Watching the point at which the water first exits the filter element, one notices that it typically exits first through the least path of resistance, which happens to be along a line where the interface between the two pieces of clay is roughly located. Harvey's theory is that capping the top-end of the candle eliminates this problem, and thus suggests one reason why the recent laboratory results for the two-capped end candles are better than those results obtained by Sagara.

The potter is making some finishing touches to a candle filter before it is fired. These candles are manufactured by Madhyapur Clay Crafts in Thimi Nepal using white kaolin clay imported from India. Once these candle filters are fired, they will be fitted into a 1-cap plastic base that is then inserted into the upper container of a filter system.

Figure 2.12: Production of a Ceramic Candle Filter

Madhyapur Clay Crafts, Thimi, Nepal. January 2003

2.3.3 Swiss Katadyn® Drip Filters

The Katadyn® Drip Filter is a candle filter manufactured by a Swiss company called Katadyn®[a] (Figure 2.13). Two versions of this filter, the Gravidyn and Ceradyn, currently retail for US $160 and US $190, respectively.[2] The current market for these filters is for use in cabins and base camp expeditions.

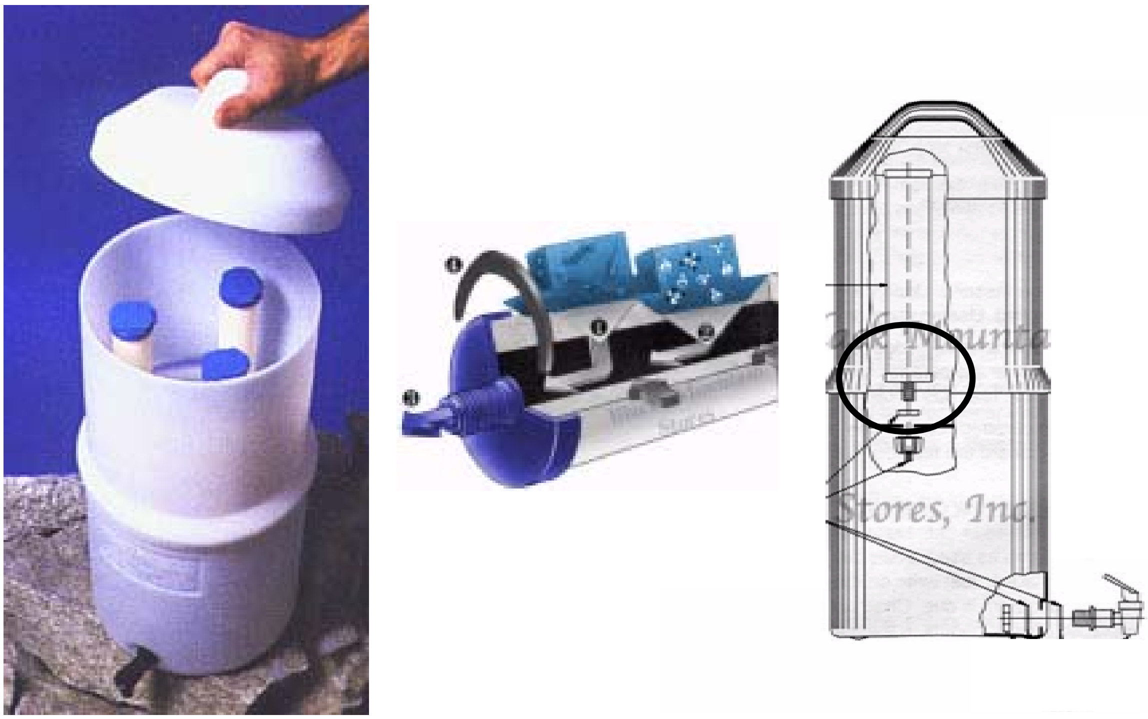


Figure 2.13: Katadyn® Drip Filter

Picture source: Black Mountain Stores Website: http://www.Katadyn.net/Katadyn_drip.html

The filters are rated for removing bacteria, protozoa and cysts (but not 99.9% viruses) and are quoted on their website to operate at a flow rate of 4 L/hr per 3 candles or 1.3 L/hr/candle.[b2] The pore-size of both filters is 0.2 microns. The estimated service life for the Gravidyn is 6 months and the Ceradyn ~150,000 L[2]. Both of the filter elements are impregnated with a fine silver powder. The Gravidyn also incorporates granular activated

[a] Katadyn® website: http://www.katadyn.com

[b] First Water® Ltd has a rating system from Grade A through to Grade B depending on a filter's log-reduction value (LRV). Katadyn filters are rated Grade A filters (the highest quality). This is discussed in Chapter 7.

carbon, which helps to improve taste and odor. Both filter elements are approximately 0.45-m in height and are capped with plastic on both ends[a].

The filter system (containers, lid and spigot) is made of a heavy translucent white plastic and the containers are shaped such that the upper container fits into the lower container for ease of transport. An exact imitation of the filter system (containers, lid, and spigot) is being manufactured by Hong Phuc® Co. Ltd but with a one-cap standard white candle element (Section 2.3.4).

Katadyn® has an extensive collection of laboratory test results demonstrating filter effectiveness dating back to the 1940's. The filter performance, according to these tests, is very good in terms of log reduction value (LRV) efficiencies and the range of organisms tested.[32] Overall, these filters appear to be excellent candle filters in terms of treating water for microbial contamination; however, the cost of the filters is beyond the range of most households in Nepal where the annual GDP is $1,224/year/capita (purchasing power parity) or $239/year/capita USD, or most other developing countries for that matter.

2.3.4 Hong Phuc® Candle Filters

The Hong Phuc® candle filter (Figure 2.14) is manufactured by Hong Phuc® Co. Ltd., located in Vietnam. The filter system (bucket, lid, and tap) is identical to the Katadyn® filter system; however, the filter element is similar in shape to the typical one-end cap Indian candle filter elements that are available in market areas of Nepal and India.

The Hong-Phuc® media is composed of diatomaceous earth[26]. Diatomaceous earth filters are apparently efficient at removing waterborne pathogens, but are impractical for household water treatment since they require special materials, construction and regular maintenance.[54] They also pose a potential respiratory hazard for the production workers due to the fine particles.[54]

The average lifespan of a Hong Phuc® filter element is quoted on a company brochure as being four years.[25] Cleaning with a soft brush and clean water is recommended once every two weeks. The total capacity of the system is 20 L (upper container = 10 L and lower

[a] Three 10-year old Katadyn filter candles obtained from IDE-Nepal in January 2003 used stainless steel end caps.

container = 10 L). The specified filter rate for a complete system (3 filter elements) is 1.5-2.5 L/hr. The company also offers a 6-month free-of-charge warranty.

Figure 2.14: Hong Phuc® Candle Filter

Hong Phuc® has apparently sold 250,000 units in 18 provinces in Vietnam since August 1995.[25] Furthermore, UNICEF apparently distributed 17,500 Hong Phuc® drip filters throughout Vietnam.[9] According to Simon Collin of First Water® Ltd., the entire filter system including three candle filters retails for US $7.50.[9] First Water® Ltd and Oxfam GB are currently testing the Hong Phuc® filter in Cambodia. Preliminary results have shown 3 log reductions in Klebsiella terrigena.[9]

2.3.5 Kisii Water Filter Bucket

The Rural Water Development Programme (RWD), located in Western Kenya, has developed a filter system called the Kisii Water Filter Bucket. The Kisii filter system is composed of two translucent food-grade polyethylene containers and a tap in the bottom container (Figure 2.15). The containers are available in local markets and are manufactured by a company called Kentainers Ltd., based in Embakasi, Nairobi Kenya[a].

[a] Kentainers Ltd. Website: http://www.kentainers.com/

Figure 2.15: Kisii Candle Filter (Western Kenya)

Picture Source: RWD Promotional Brochure.

RWD uses two types of candle filters: a “slow” speed ceramic candle filter from India ($1 USD) that filters approximately 3 L of water per day and a “high” speed ceramic candle filter ($12 USD) from Brazil that filters 20 L of water per day. The Brazilian candle filter uses silver and activated carbon.

RWD uses translucent containers so that users can see when the system needs refilling and if the containers need cleaning. Moreover, the users can watch the water filter through the candle filters into the lower container. RWD has observed that users have more trust in the system if they can view what is going on inside.[48]

An Italian-made “ball” tap is chosen for the spigot after experiencing difficulty with low-quality plastic taps that leaked after awhile.

Various container capacities are offered, one in particular being a “jumbo” container system with 5-8 candle filters, which is typically offered to small hospitals, schools, and kitchens.

RWD offers a weekly pay-back system for customers who cannot to pay for the filter system in one installment. Observation has shown that users tend not to value the system if it is simply given away at a subsidized price. RWD promotes the fact that the filter project operates at cost plus a small profit with no subsidization of the price.

Chapter 3 January 2003 Laboratory Tests of Ceramic Filter Media

Laboratory tests of twelve disk filters (three types) and five candle filters were carried out by engineering student Rob Dies at the Environment and Public Health Organization (ENPHO) in January 2003. The results from these tests are presented in this chapter.

3.1 Research Objective

The purpose of the laboratory testing of various ceramic filter element shapes and media was to do a preliminary comparison of filter shapes (candle versus disk); filter media (white clay versus red clay versus black clay); filter flow rates; production methodology; and to evaluate the effectiveness of colloidal silver at removing microbial contamination across a fairly broad range of materials and products. This testing distinguishes the testing from previous years where only one type of ceramic filter (e.g.: Hari Govinda candle filter, Potters for Peace Filtron, TERAFIL disk filter) was tested.

3.2 Study Design

Twelve disk filters (three types) and five candle filters were tested by Rob Dies at ENPHO for microbial removal efficiency (total coliform and *E.coli*) and flow rate. The tests were performed over a seven-day period starting January 12, 2003.

Building on the knowledge base and experience of ceramists Hari Govinda Prajapati of Madhyapur Clay Crafts, Reid Harvey, and Ron Rivera from Potters for Peace, as well as previous research by MIT students, specifically engineering student C.S. Low[35], three different types of disk filters were developed by Prajapati and Harvey for testing. Two of the filters were based on Harvey's method of using grog (See Chapter 4). The third disk used the same white kaolin clay (imported from India) that Prajapati uses for the production of his candle filters. In comparison, Low and Prajapati developed and tested a disk filter similar in composition to the Potters for Peace Filtron in January 2002.[35]

All of the disk filters had the same dimensions (diameter: 152-mm (~ 6 inches); thickness: 40-mm (~1.5 inches thick)), while the candle filters varied in shape. Half of the disk filters were soaked in colloidal silver. For the Hari candle filters, of which there were two, one was coated with colloidal silver. The purpose of coating the filters with colloidal silver was to measure the effectiveness of colloidal silver at removing microbial contamination. A summary of the filters that were tested is presented in Table 3.1.

Table 3.1: Ceramic Water Filters Tested at ENPHO during January 2003

Filter Element	#	Coated with CS	Production Method	Comments
White Clay Disk	2	No	Hari Govinda Prajapati	White kaolin clay imported from India. Prajapati uses the same clay for production of his candle filters.
White Clay Disk	2	Yes	Hari Govinda Prajapati	White kaolin clay imported from India. Prajapati uses the same clay for production of his candle filters. Disk soaked in colloidal silver.
Red Clay Grog Disk	2	No	Reid Harvey	Red Thimi clay from Thimi, Nepal mixed with grog made from Red Thimi clay. Production methodology uses grog. Disk soaked in colloidal silver.
Red Clay Grog Disk	2	Yes	Reid Harvey	Red Thimi clay from Thimi, Nepal mixed with grog made from Red Thimi clay. Production methodology uses grog. Disk soaked in colloidal silver.
Black Clay Grog Disk	2	No	Reid Harvey	Black Bhaktapur clay from Bhaktapur, Nepal mixed with grog made from Red Thimi clay.
Black Clay Grog Disk	2	Yes	Reid Harvey	Black Bhaktapur clay from Bhaktapur, Nepal mixed with grog made from Red Thimi clay.
Katadyn® Ceradyn Candle	1	Yes	Katadyn®	Impregnated silver powder candle filter with 2-capped ends (plastic).
Katadyn® Gravidyn Candle	1	Yes	Katadyn®	Impregnated silver powder candle filter plus granular activated carbon with 2-capped ends (plastic).

Filter Element	#	Coated with CS	Production Method	Comments
Hari White Clay Candle Filter	1	No	Hari Govinda Prajapati	Similar to the current white clay (imported from India) candle filter that Prajapati manufactures, except both ends are capped with plastic.
Hari White Clay Candle Filter	1	Yes	Hari Govinda Prajapati	Similar to the current white clay (imported from India) candle filter that Prajapati manufactures, except both ends are capped with plastic.
Hong Phuc® Candle Filter	1	No	Hong Phuc®	The Hong Phuc® candle filter is manufactured by Hong Phuc® in Vietnam.

3.3 Material Setup

Plastic buckets and taps were purchased from local shops for housing the disk and candle filters (for dimensions, see Figure 3.1). The bottoms of the upper containers were cut to fit the disk or candle filters. The 152-mm (six-inch) disk filters required a ~108-mm (4 ¼-inch) diameter hole and were glued to the bottom of the buckets using silicone. The candle filters required a ~15-mm (½-inch) diameter hole and were screwed into place with a plastic nut.

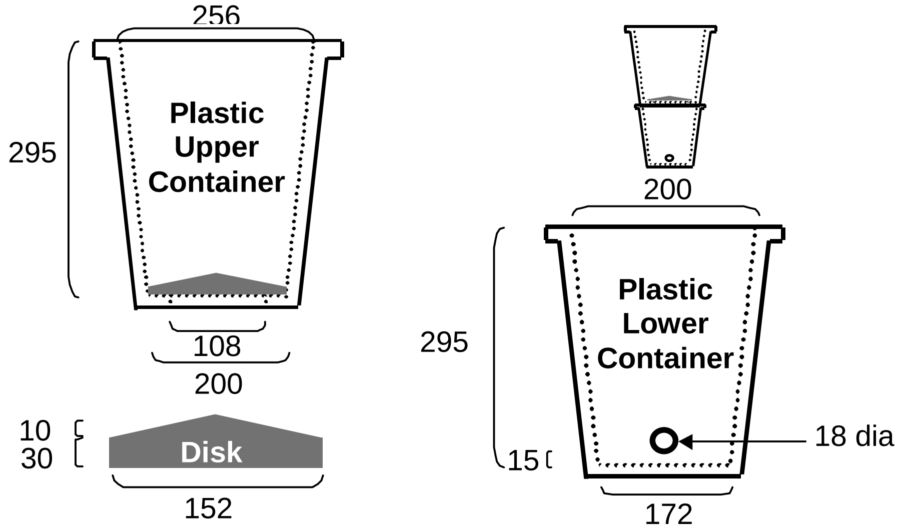


Figure 3.1: Laboratory Setup – Schematic of Container System Dimensions

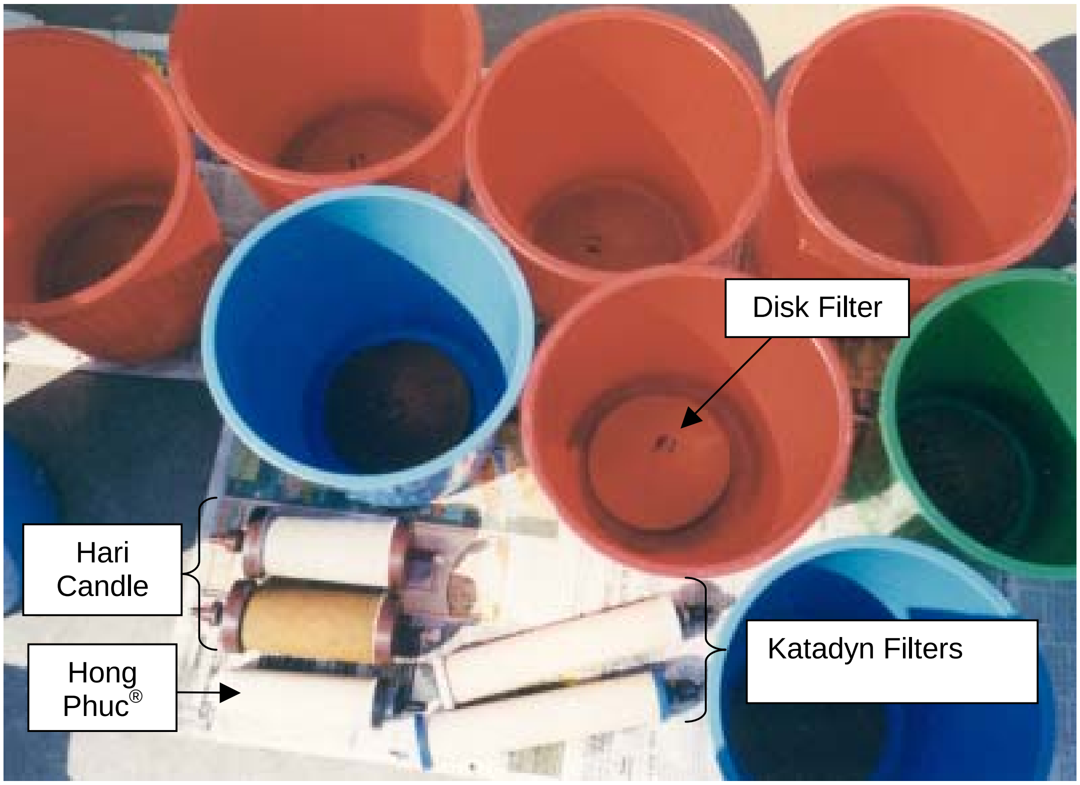


Figure 3.2: Laboratory Setup – Disks and Candle Filters

Figure 3.3: Laboratory Setup – Filter Systems Ready for Testing

Plastic lids were used to cover the upper containers. A layer of tape was put around the interface between the upper and lower containers (Figure 3.3) to ensure that the inside of the lower container was sealed off from the external environment.

3.4 Testing Methodology

Three separate test runs were completed as summarized in Table 3.2. The first test consisted of all five candle filters. The second test consisted of just the Hari Govinda Prajapati white clay disk filters. The third test consisted of all the Reid Harvey disk filters.

Table 3.2: Summary of Filter Tests Performed in January 2003

Test Number	Filters Tested	# of Filters Tested	Raw Water Concentration (cfu/100 mL)	
			Total Coliform	*E.coli*
1. Candles	Katadyn® candle filters (Ceradyn and Gravidyn); Hari candle filters (1 coated with CS; 1 without); and Hong Phuc candle filter.	5	89	56
2. Hari Disks	Hari white clay disk filters (4: 2 coated with CS; 2 without)	4	2,861	1,550
3. Reid Disks	Reid Harvey Grog Disk Filters (4 red clay + red clay grog: 2 coated with CS; 2 without. 4 black clay + red clay grog: 2 coated with CS; 2 without)	8	2,500	1,561

3.4.1 Testing Procedure

Each of the three tests was carried out over a period of approximately six hours. The filters were primed overnight with tap water to ensure that they would be saturated at the beginning of the test. In the morning, the buckets, taps, and lids were cleaned with soap and water (water from the roof tap) and allowed to dry completely in the sun for one to two hours. Each filter element was cleaned by lightly brushing the surface of the filter with an abrasive scrub brush.

A sample from the Dhobi Khola River was collected and mixed with tap water in an 80-L container (garbage pail purchased at a local market) to achieve the desired raw water coliform concentrations (See the next Section 3.4.2). A raw water sample was then collected from the 80-L container for microbial analysis.

The upper containers of the filter systems (Figure 3.3 for picture) were then filled with the raw water to a height of ~240-mm for the candle filters and 170-mm for the disk filters[a]. The time was recorded as time T = 0 hours.

The filters were then left to operate for approximately two to three hours to allow water to collect in the lower containers. A water sample was then taken from each of the lower containers for microbial analysis. Most of the water samples were collected within three hours of the upper containers being filled with raw water (T = 3 hours). The time of collection depended on how fast the lower containers filled. All water samples were collected at the same time and analyzed within one hour of collection at the ENPHO Laboratory.

3.4.2 Raw Water Preparation

The raw water was prepared by mixing various combinations of river water from the Dhobi Khola River next to the bridge in New Baneswor and water from the tap on the roof of ENPHO. ENPHO often uses water from the Dhobi Khola River to prepare raw water for water quality testing in their lab. For the SODIS project, for example, ENPHO uses approximately 200 mL of Dhobi Khola River water per 20 L of tap water, collected from the tap on the roof, to create a microbial concentration of approximately 4,000 – 5,000 colony forming units (cfu)/100 mL.[52] The roof-top tap water originates from the municipal drinking water supply.

The roof-top tap water was tested twice in January 2003 for the presence of coliform bacteria:

- January 12, 2003
    - total coliform = 3 cfu/100 mL

[a] In retrospect, the water elevation in the upper containers should have been the same for all tests so that the flow rates for the candle filters and the disk filters could be compared for a given water column height.

  - *E.coli* = 0 cfu/100 mL
- January 15, 2003
  - total coliform = 1,550 cfu/100 mL
  - *E.coli* = 0 cfu/100 mL

The large discrepancy in total coliform concentrations is likely due to the refilling of the rooftop reservoir, which occurred sometime between January 12th and 15th. It is possible that refilling the tank either brought in contaminated water or mixed the contents of the tank (the tank may contain contaminated sediments/organic material that has settled over time) causing a spike in the concentration of total coliform.

The raw water for the candle filter test run # 1 was produced by mixing approximately 10 mL of river water with 40 L of tap water in an 80-L clean container (garbage pail). The resulting total coliform concentration was measured to be 89 cfu/100 mL and the *E.coli* concentration was 56 cfu/100 mL.

The raw water for the remaining two filter test runs # 2 and # 3 was produced by mixing approximately 80 mL of river water with 40 L of tap water. The proportion of river water was increased to achieve greater microbial concentrations since the raw water microbial concentrations in the first run were too low. The resulting microbial concentrations measured for Test # 2 were 2,861 cfu/100 mL (total coliform) and 1,550 cfu/100 mL (*E.coli*). The raw water microbial concentrations for Test # 3 were 2,500 cfu/100 mL (total coliform) and 1,561 cfu/100 mL (*E.coli*).

3.4.3 Flow rate Calculation

The flow rate was calculated by dividing the volume of water measured in the lower container by the time at which the volumetric measurement was taken (Equation 3.1).

$$Flow\ Rate = \frac{Volume\ of\ water\ measured\ at\ time\ T\ (mL)}{Elapsed\ time,\ T,\ from\ start\ of\ test\ (hours)}$$

Equation 3.1: Flow Rate Calculation

The time over which the flow rates were calculated varied slightly between the three tests[a]:

- Test 1 (Candle Filters): 4.2 hours
- Test 2 (Hari Disk Filters): 3.0 hours
- Test 3 (Reid Disk Filters): 5.0 hours

3.4.4 Microbial Testing Methodology

The water samples that were collected from the containers were collected using sterilized whirl packs. The samples were analyzed within two hours of collection. Standard methods were employed using a Millipore Membrane Filtration unit and Millipore mColi Blue broth to measure both total coliform and *E.coli* concentrations in terms of colony forming units (cfu) per 100 mL.

The raw water samples were diluted approximately four times. Five plates were prepared using 47-mm Millipore Microbiological Dishes with sterilized pads and mColi Blue broth. One plate was used as a blank and the remaining four plates for each of the dilutions. The plate with the appropriate number of colony units (i.e.: 20-80 colonies) was used to calculate the final microbial concentrations. The remaining plates including the blank were used as checks (for example, the 10^3 dilution plate should have 10 times as many colonies as the 10^4 dilution plate).

The filtered-water samples were usually diluted one time. Three plates per water sample were thus prepared using the same equipment and materials as for the raw water samples. One plate was used as a blank and the remaining two plates were used for the 1:1 dilution and the 1:10 dilution. The 1:1 dilution plate count was typically used since the resulting microbial concentrations tended to be low (less than 100 cfu/100 mL).

3.5 Test Results

The test results for the candle filters are summarized in Table 3.3 and the test results for the disk filters in Table 3.4. Graphical representations of the results are also shown in Figures 3.4 through 3.9.

[a] Ideally, the three times should be the same in order to compare the average flow rates for all of the filters. This will be discussed in Section 3.6.

3.5.1 Flow Rate

The flow rates for the candle filters ranged from 641 mL/hr for the Katadyn® Ceradyn to 844 mL/hr for the Katadyn® Gravidyn, with the exception of the Hong Phuc® candle filter which had a flow rate of 300 mL/hr.

The average flow rate for the Hari white clay disk filter without colloidal silver (CS) was 377 mL/hr and for the filter with CS, 353 mL/hr.

The average flow rate for the Reid Harvey red clay grog disk filter without CS was 850 mL/hr and for the filter with CS, 756 mL/hr. The average flow rate for the Reid Harvey black clay grog disk without CS was 412 mL/hr and for the filter with CS, 341 mL/hr.

3.5.2 Microbial Concentrations

Microbial removal efficiency is presented in terms of Log Reduction Value (Equation 3.2) and % Removal Efficiency (Equation 3.3).

$$Log\ \mathrm{Re}duction\ Value\ (LRV) = \frac{Log_{10}(untreated)}{Log_{10}(treated)}$$

Equation 3.2: Log Reduction Value (LRV)

$$\%\ \mathrm{Re}moval\ Efficiency\ = \frac{(untreated - treated)}{untreated} \cdot 100\%$$

Equation 3.3: % Removal Efficiency

Where,

- untreated: microbial concentration in the raw water sample (cfu/100 mL)
- treated: microbial concentration in the filtered water sample (cfu/100 mL). Note: if the treated concentration = 0 cfu/100 mL, then a value of 1 cfu/100 mL was used for both equations.

The total coliform LRV/% Removal for the candle filters ranged from 0.80/84% for the Hari white clay candle filter without CS and the Hong Phuc® candle filter to 1.95/>98% for the remaining three candle filters (both of the Katadyn® filters and the Hari white clay candle filter coated with CS). The *E.coli* LRV/% Removal for the candle filters ranged from 0.90/88% for the Hari white clay candle filter without CS to 1.75/>98% for the remaining four candle filters (both of the Katadyn® filters, the Hari white clay candle filter coated with CS, and the Hong Phuc® candle filter).

The total coliform LRV/% Removal for the Hari white clay disks without CS was 2.34/99.2% and for the disks with CS was 3.46/>99.9%. The *E.coli* LRV/% Removal for the Hari white clay disks without CS was 2.53/99.3% and for the disks with CS was 3.19/>99.9%.

The total coliform LRV/% Removal for the Reid Harvey red clay grog disks without CS was 0.71/80% and for the disks with CS was 2.63/99.8%. The *E.coli* LRV/% Removal for the Reid Harvey red clay disks without CS was 0.69/79.5% and for the disks with CS was 2.89/99.9%.

The total coliform LRV/% Removal for the Reid Harvey black clay grog disks without CS was 2.52/99.6% and for the disks with CS was 2.29/99.1%. The *E.coli* LRV/% Removal for the Reid Harvey red clay disks without CS was 2.84/99.8% and for the disks with CS was 2.53/99.3%.

Table 3.3: Summary of Candle Filter Test Results

Filter Name	Producer	Average Hourly Flow Rate	Total Coliform Bacteria LRV / % Removal Efficiency	*E.coli* LRV/ %Removal Efficiency
Ceradyn filter	Swiss Katadyn®	641 mL/hr	1.95 / >98% (given raw water: 89 cfu/100mL)	1.75 / >98% (given raw water: 56 cfu/100mL)
Gravidyn filter	Swiss Katadyn®	844 mL/hr	1.95 / >98% (given raw water: 89 cfu/100mL)	1.75 / >98% (given raw water: 56 cfu/100mL)
White clay filter without silver colloidal	Hari Govinda Prajapati	742 mL/hr	0.80 / 84% (given raw water: 89 cfu/100mL)	0.9 / 88 % (given raw water: 56 cfu/100mL)
White clay filter with silver colloidal	Hari Govinda Prajapati	678 mL/hr	1.95 / >98% (given raw water: 89 cfu/100mL)	1.75 / >98% (given raw water: 56 cfu/100mL)
Hong Phuc® candle filter	Hong Phuc®	300 mL/hr	0.84 / 85% (given raw water: 89 cfu/100mL)	1.7 / >98% (given raw water: 56 cfu/100mL)

Note. The raw water concentration was < 100 cfu/100 mL, which is an order of magnitude lower than that used in the tests performed on the disks filters; so it is difficult to compare results between the candle and disk filters.

Table 3.4: Summary of Disk Filter Test Results

Filter Name	Producer	Average Hourly Flow Rate	Total Coliform Bacteria LRV/% Removal Efficiency	*E.coli* LRV/% Removal Efficiency
White Clay Disk without colloidal silver	Hari Govinda Prajapati	377 mL/hr	2.34 / 99.2% (given raw water: 2,861 cfu/100mL)	2.53 / 99.3% (given raw water: 1,550 cfu/100mL)
White Clay Disk with colloidal silver	Hari Govinda Prajapati	353 mL/hr	3.46 / >99.9% (given raw water: 2,861 cfu/100mL)	3.19 / 99.9% (given raw water: 1,550 cfu/100mL)
Red Clay Filter without colloidal silver	Reid Harvey	850 mL/hr	0.71 / 80.2% (given raw water: 2,500 cfu/100mL)	0.69 / 79.5% (given raw water: 1,561 cfu/100mL)
Red Clay Filter with colloidal silver	Reid Harvey	756 mL/hr	2.63 / 99.8% (given raw water: 2,500 cfu/100mL)	2.89 / 99.9% (given raw water: 1,561 cfu/100mL)
Black Clay Filter without colloidal silver	Reid Harvey	412 mL/hr	2.52 / 99.6% (given raw water: 2,500 cfu/100mL)	2.84 / 99.8% (given raw water: 1,561 cfu/100mL)
Black Clay Filter with colloidal silver	Reid Harvey	341 mL/hr	2.29 / 99.1% (given raw water: 2,500 cfu/100mL)	2.53 / 99.3% (given raw water: 1,561 cfu/100mL)

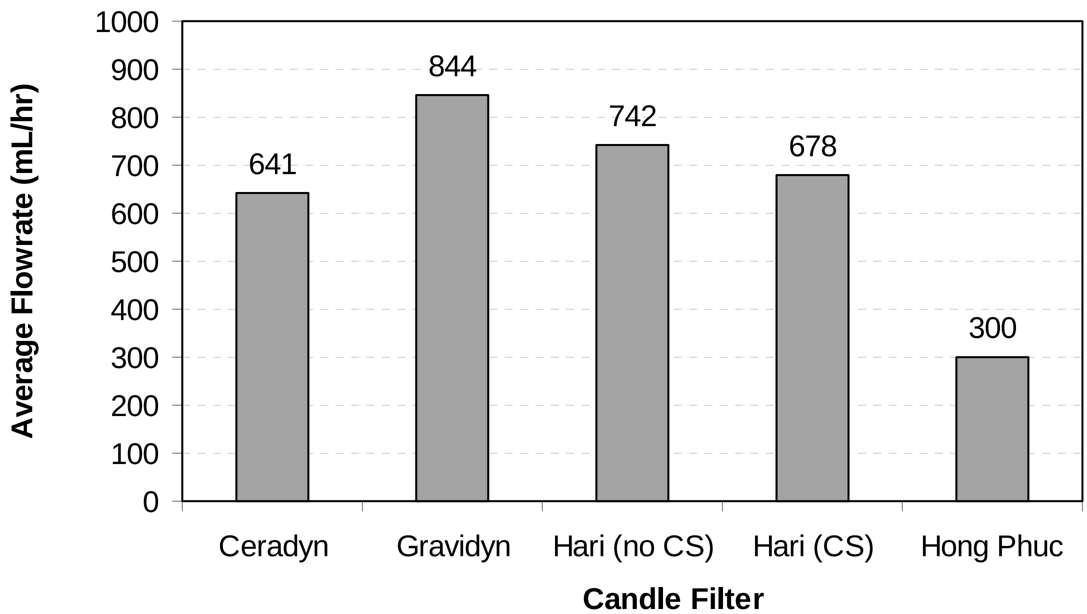


Figure 3.4: Average Flow Rate Results for the Candle Filters

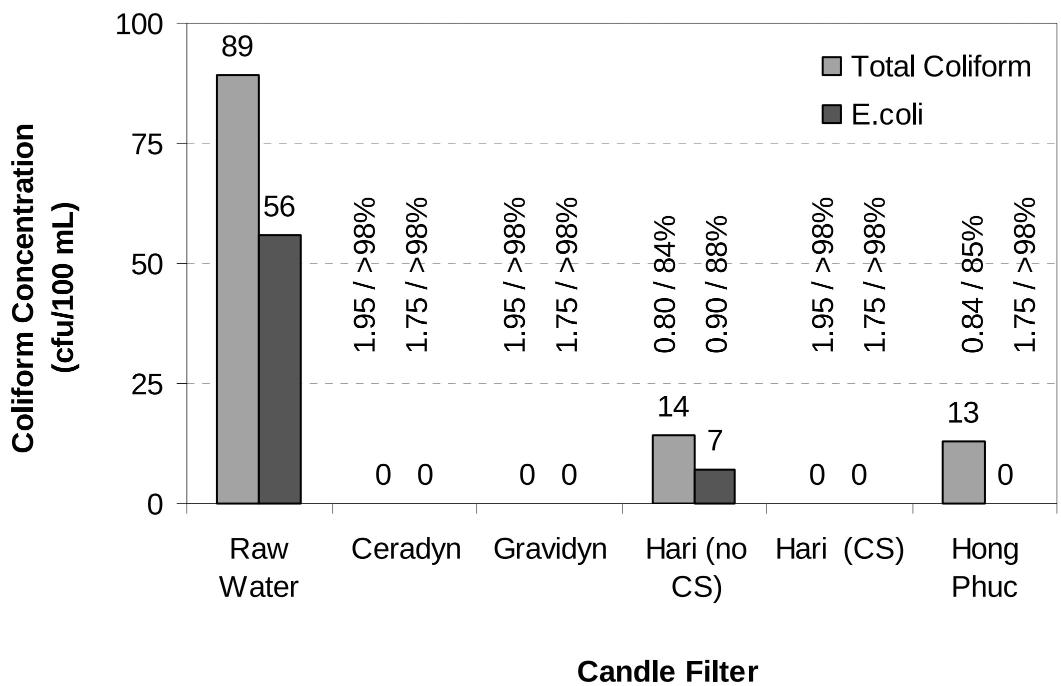


Figure 3.5: Microbial Reduction Results for the Candle Filters

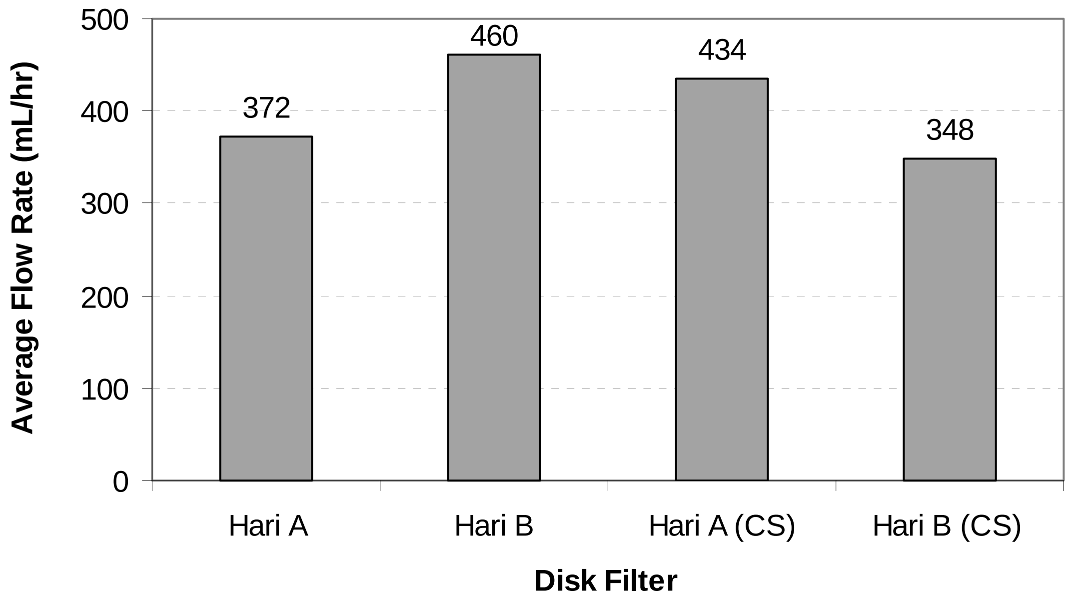


Figure 3.6: Average Flow Rate Results for the Hari White Clay Disk Filter

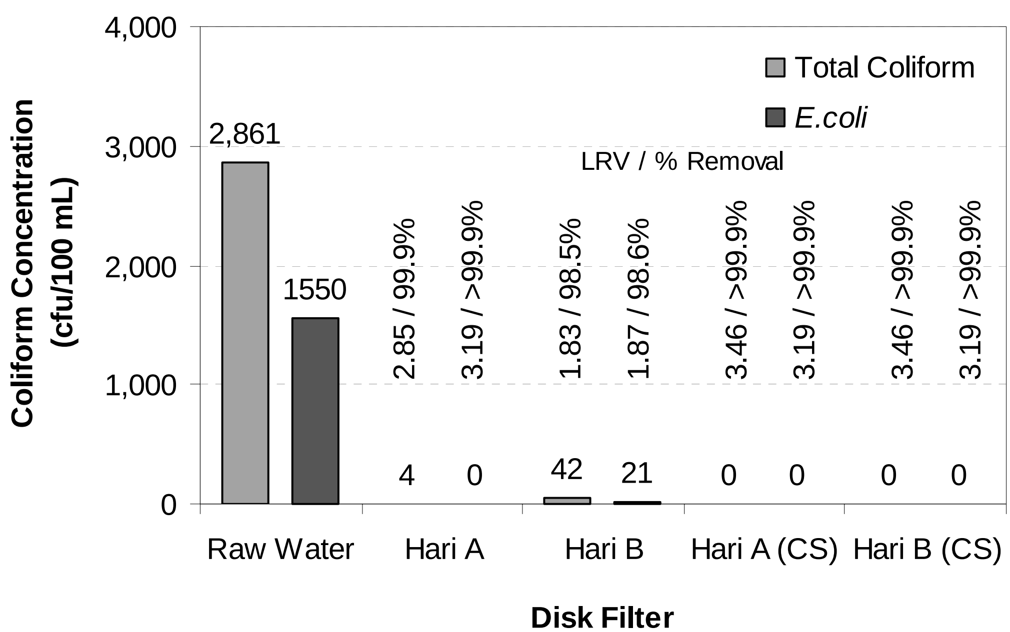


Figure 3.7: Microbial Reduction Results for the Hari White Clay Disk Filters

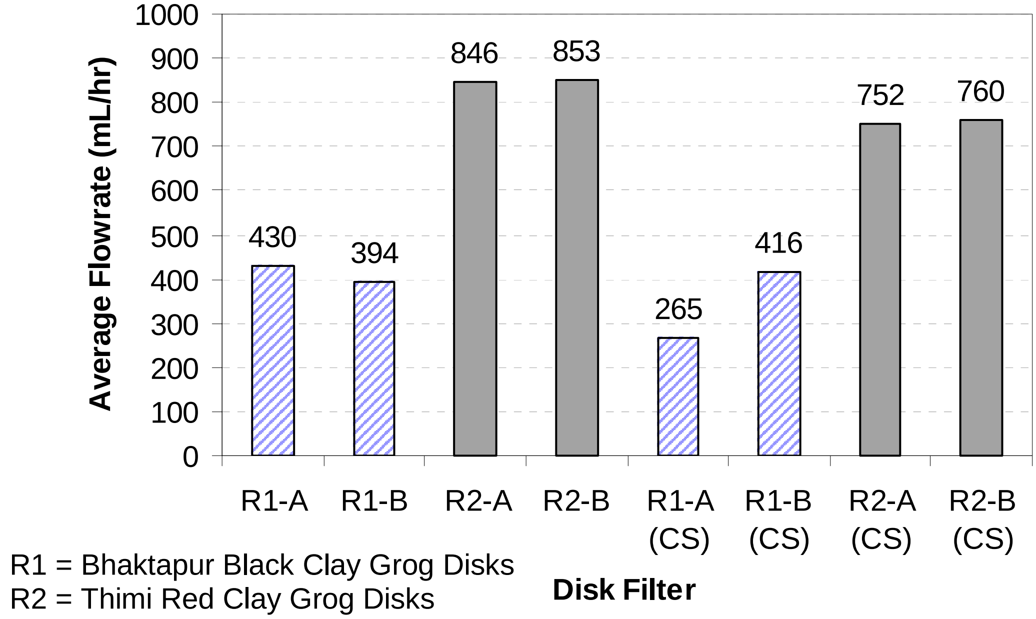


Figure 3.8: Average Flow Rate Results for the Reid Harvey Grog Disk Filters

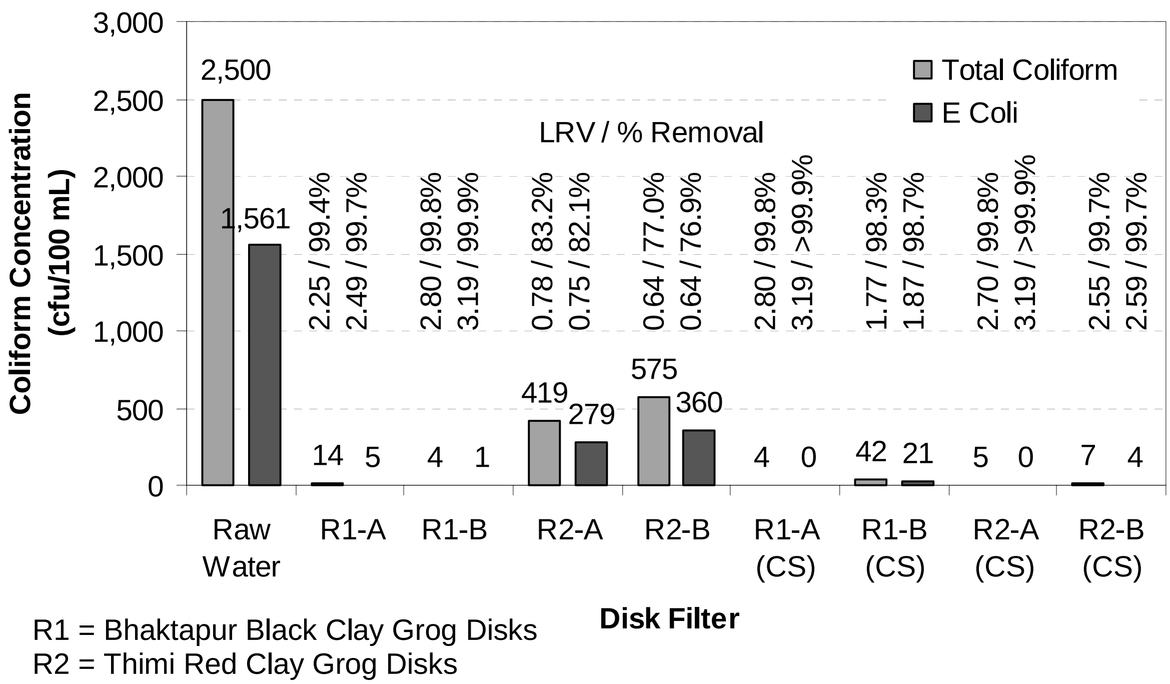


Figure 3.9: Microbial Reduction Results for the Reid Harvey Grog Disk Filters

3.6 Limitation of Results

There are a number of important limitations to consider when analyzing the results. The first limitation is related to comparing the flow rates between test runs. The time over which the flow rates were calculated varied between the three test runs as was discussed in Section 3.5.1. The reason for this was simply that the author was unable to measure the volumetric flow rates at the same time due to time constraints of having to process the water samples. The instantaneous flow rate through the filter element likely decreases over time as the water-column height above the filter element drops. Thus, the average flow rate for any given period of time starting from time T = 0 will decrease for increasing periods of time. For example, the average flow rate for the first 2-hour period will most likely be higher than the average flow rate for the first 8-hour period. Strictly speaking, therefore, the flow rates between test runs cannot be directly compared since the time value used to average the flow rates differed between each run.

The second limitation is regarding the validity of the results for extended periods of time. The results are limited to the period of time over which the testing was completed (less than one day) and thus do not provide any indication of how well the filters will perform over periods of time greater than one day. This is an important consideration with respect to making any conclusions as to the effectiveness of colloidal silver at reducing microbial contamination. In order to evaluate filter performance over time, further testing both in the field and laboratory is absolutely necessary. In particular, long-term testing (weeks to months) is required to evaluate filter performance in terms of microbial removal efficiency and flow rate. Field testing is also necessary to evaluate performance under non-laboratory conditions. Rebeca Hwang recently completed the first such six-month field evaluation of the Potters for Peace ceramic filter in Nicaragua.[28] Joe Brown of Cambridge University is likewise engaged in a six-month monitoring and evaluation of the Katadyn candle filter in Bolivia.[3]

The third limitation is that the raw water concentrations for the first test run with the candle filters was nearly thirty times less than the raw water concentrations for the second and third tests with the disk filters. Thus, it is difficult to compare the candle filter microbial removal efficiency results with the disk filter test results. The candle filter test was one of the first runs and so the correct proportion of river water to tap water to make the raw water had not yet been determined.

The results are also limited to the accuracy of the laboratory equipment and test procedures. In particular, counting the number of colony forming units on the plates is somewhat subjective since many colonies are either too small to see or are overlapping. However, the plate results for these experiments did turn out quite well, with clearly defined colony-forming units being the norm.

3.7 Discussion of Results

Despite the limitations discussed in the previous section, the results do provide some *preliminary* indications of the effectiveness of various types of filters and colloidal silver.

The flow rates for the Katadyn® candle filters, Hari candle filter, and Reid red clay disk filter were comparable, varying between 650 mL/hr to 850 mL/hr per candle. The flow rate for the Hong Phuc® filter element was surprisingly low at 300 mL/hr. The low flow rate may be due to the material properties of the filter element as well as its relatively smaller size and surface area compared to the other filter elements. The flow rate for the other two disk filters, Hari's white clay and Reid's black clay, were also very low at less than 430 mL/hr. The reasons for these two disks having a low flow rate are likely due to the different properties of the clay material and the thickness of the disks. The white Indian clay used for Hari's disk and the black Bhaktapur clay used for Reid's are of higher quality and are not as sandy as the red Thimi clay used in the other clay disk made by Reid. The sandier red clay may produce a more porous filter compared to the black Bhaktapur clay and the white kaolin clay. Furthermore, the disks were considered to be relatively thick at 40-mm compared to what would normally be used for a disk filter with the given properties.

The results support the hypothesis that colloidal silver (CS) acts as a bactericide and aids in the inactivation of indicator microorganisms such as total coliform and *E.coli* bacteria. As an example, Reid's red clay disk painted with CS showed LRV = 2.63 (99.8%) removal of total coliform and 2.89 (99.9%) removal of *E.coli* compared to LRV = 0.71 (~80%) removal for both total coliform and *E.coli* for the *same* filter but *with no* CS. Furthermore, the flow rate for the Reid red clay disk (850 ml/hr) was the greatest for all filters. The benefit of using CS is that it appears to improve the microbial removal efficiency of a filter beyond the filter's ability to physically remove microbial bacteria through filtration. Thus, it may be possible to achieve a higher flow rate with a porous disk coated with CS while still maintaining acceptable microbial removal efficiencies.

It should be noted that the disk filters with CS were *soaked* in a solution of CS and distilled water (~20-30 mg/L CS). In comparison, Potters for Peace *paints* the CS (roughly the same concentration) onto their Filtron filters. Soaking the disks in a concentration of CS probably allows more CS to enter the disk filter into the pore structure.

The results demonstrate an important distinction to make between reporting microbial reduction efficiencies in terms of Log Reduction Value (LRV) and % Removal Efficiency. The LRV's provide some indication of the magnitude of the raw water concentration whereas % Removal Efficiency does not. For example, the total coliform LRV for the Ceradyn Filter was 1.95, which was equivalent to 100% removal efficiency whereas the total coliform LRV for the Hari white clay disk filter with CS was 3.46, which was also equivalent to 100% removal efficiency. The raw water concentration for the former test was 89 cfu/100 mL and for the latter, 2,861 cfu/100 mL. Reporting both results as 100% removal efficiency is clearly misleading. Regardless of the methodology chosen for reporting results, including the raw water concentration along with the results does help to clarify the values that are reported.

This test run should be considered as a preliminary screening test to determine which filters to begin modifying and/or testing in the future. The results from these tests suggest that the Hari white clay candle filter capped on both ends and coated with CS and the Reid Harvey red clay grog disk filter coated with CS are worth considering for future testing.

Chapter 4 Ceramic Water Filter Production Process

The ceramic water filter production process follows some common steps regardless of the type of filter being manufactured. The process typically begins with material selection and processing; followed by shaping and pressing the filter element into a mold; firing; drying and then potentially treating the filter with a disinfectant.

This chapter begins with an overview of the materials and equipment used in the production of ceramic water filters. A summary of the production process is then presented. Throughout the production process, the ceramist – i.e., the potter manufacturing the filter – can control certain parameters to produce filters with specific characteristics. This is discussed in the last section of the chapter, along with a derivation of the theoretical flow rate for a candle filter and a disk filter.

The examples provided throughout the chapter relate primarily to Madhyapur Clay Crafts in Thimi Nepal; although other examples, especially the Potters for Peace (PFP) manufacturing process in Nicaragua, are incorporated into the discussion as well.

4.1 Materials

The primary materials used in the production of ceramic water filters are clay, water, combustible material, and/or grog (a non-plastic material used to reduce shrinkage and warpage and possibly to control porosity). Usually these materials require processing such as grinding and sieving before they can be mixed together into a uniform mixture that is then pressed or molded into a filter shape (production process is discussed in Section 4.3). Colloidal silver (CS) is also used sometimes as a bactericide. CS is painted onto the filter element as the last step, after the element has been fired and dried.

For convenience, a brief summary of materials used in the production of ceramic water filters is presented in Table 4.1. A detailed description of each material is then presented in the following section.

Table 4.1: List of Materials Used in the Production of Ceramic Water Filters

Material	**Brief Description**	**Examples**
Clay	➢ Clays are fine-particulate geologic materials that have the unique property of being plastic when wet and hard when fired. Their plasticity allows ceramist to form shapes that maintain their form before being fired. Once fired, the clay hardens and the shape becomes permanent.	• White kaolin clay from India • Red clay from Thimi, Nepal • Black clay from Bhaktapur, Nepal
Water	➢ Controls workability/ plasticity as well as shrinkage	
Combustible Material	➢ Used to increase the porosity of the ceramic since the combustible material will burn off during the firing, leaving behind pores or voids through which water will travel.	• Sawdust (e.g.: oak, pine) • Flour (e.g.: wheat flour, corn flour) • Rice husk ash
Temper or Grog	➢ Temper is defined as all non-plastic material used to reduce shrinkage/warpage and to control porosity to some extent. The term grog is used more frequently in the production of ceramic water filters and refers to pre-fired ceramic material that is mixed with raw clay, water, and/or combustible material to form a ceramic filter unit.	• Ground bricks • Pre-fired disk that is ground and sieved (see Grog Section 4.1.3.
Colloidal Silver	➢ Colloidal silver consists of silver particles suspended in distilled water or proteins. It is coated onto the surface of the filter element after it has been fired and dried. CS is used as a disinfectant to help reduce microbial contamination.	• Microdyn (Mexican product)

4.1.1 Clay

Clay originates from the chemical and/or physical weathering of igneous rock over long periods of geologic time. There are three primary classes of clay: kaolinite, montmorillonite, and illite.[51] Each class differs slightly in its structure and presence of impurities; however in general, all clays have a distinct crystalline structure that resembles "platy" sheets stacked on top of each other. The chemical composition generally consists of hydrous aluminum silicates combined with trace amounts of mineral impurities like potassium or iron, which give rise to notable clay characteristics like color. Clays have the unique property of being plastic, or workable, when saturated with water. The plasticity of the clay and the cohesive forces acting between the clay particles, allow the ceramist to form or manipulate clay into shapes that maintain their form.

Ceramic wares are often categorized as earthenware, stoneware, or porcelain depending on the composition of the clay that is used to form the ware. Fired earthenware objects are the most porous of the three types with after-firing porosities in the order of 10-15% by weight; stoneware 2-5% and porcelain 0-1%.[8] Earthenware clays are the most commonly found form in nature[51], which makes them a suitable choice for the production of ceramic water filters. Earthenware clays also have the lowest firing temperature at which they mature, due to their relatively high concentration of iron and other mineral impurities. The natural red, gray, or brown colors that are common to earthenware clays are a function of the mineral content of the clay structure. The presence of iron oxide, for example, typically gives rise to red clays.

There are a number of clay sources within the Kathmandu area; two in particular are red clay from Thimi and black clay from Bhaktapur. The red Thimi clay is sandier than the black Bhaktapur clay and is thus slightly less expensive as well. The black color of the black Bhaktapur clay is likely due to the presence of organic material.[22]

Mr. Hari Govinda Prajapati of Madhyapur Clay Crafts also uses white kaolin clay imported from India for the production of his ceramic candle filters. The white kaolin clay is finer than the red and black clays – kaolin clays in general tend to be "purer" than red clays and have a finer pore structure than typical red clays.[21]

At Madhyapur Clay Crafts, the clay is purchased by the cart-load and placed on the floor of the shop to dry for a week or so. A ceiling fan is sometimes used to help dry the clay. The dried clay is then ground to a powder (Figure 4.1), and stored for use later. Usually it will be sieved to a desired grain size distribution[a] before it is mixed with the other materials. Grain size distribution is controlled using screens with specified sizes defined in terms of mesh size or the number of openings within one square inch (e.g.: 30 mesh means 30 openings within 1 square inch). As an example, Potters for Peace screens clay between 60-mesh and 30-mesh screens, keeping what is left between the two screens.[43]

Figure 4.1: Raw Clay (left) and Processed Clay in Powder Form (right) used in the Production of Ceramic Water Filters at Madhyapur Clay Crafts

Madhyapur Clay Crafts, Thimi, Nepal. January 2003.

From personal observation by the author, it appears that a 40-mesh screen is often used at Madhyapur Clay Crafts. From discussions and observations, it also appears that the clay material that passes *through* the screen is used, although this is not verified. In comparison to Rivera's method of screening between two mesh-sizes (#30 and #60), the method employed at Madhyapur Clay Crafts likely results in a well-graded (poorly sorted) grain size distribution (i.e., grain sizes probably vary over a wider range compared to the PFP method of screening between two screens). Grain size distribution may play a role in filter performance in terms of porosity, durability, and resulting microbial removal efficiency.

[a] A measure of grain size distribution is a measure of the range of grain sizes present in a sample. Grain size distribution can range from uniform (a narrow range of grain sizes) to well graded (a wide range of grain sizes, often poorly sorted). In the PFP example of sorting grain size between two screens (#30 & #60), the resulting grain size distribution will be relatively uniform (particle sizes will range between a # 30 and # 60 screen).

4.1.2 Combustible Material

Combustible material is used to increase the porosity of the ceramic filter media by creating voids within the media structure after the material has been incinerated during firing. Some examples are: sawdust, corn flour, wheat flour and rice husk ash. Madhyapur Clay Crafts uses both pine sawdust collected from local furniture manufacturers and wheat flour.[20] The flour is sieved using a 300-mesh[a] screen before it is mixed with the clay, water and/or grog.[19] Again, it appears that the combustible material that passes through the screen is used; however, this has not been verified. As discussed on the Potters for Peace website[b], the size of the combustible material influences the final pore size in the ceramic filter: too large a particle size makes the filter become too porous and fragile; too small makes the filter chalky or dusty.[43] This would imply that screening for a uniform grain size distribution using two screens would be more beneficial than screening with just one sieve.

One final note that will be discussed further in Section 4.3.2, it is important to mix the clay and water first before mixing in the combustible material. Otherwise, the combustible material, rather than the clay, will absorb too much of the water.

Figure 4.2: A Potter Preparing Sawdust.

Madhyapur Clay Crafts, Thimi, Nepal. January 2003.

[a] 300-mesh screen = 300 square openings per square inch

[b] Potters for Peace website: http://www.potpaz.org/pfpfilters.htm

4.1.3 Grog or Temper

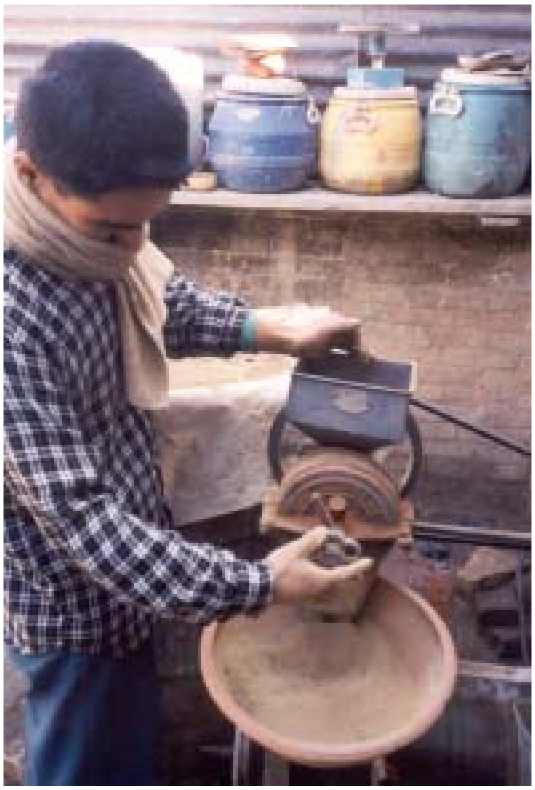
Temper is a term used in pottery-making to describe non-plastic material that is often mixed with clay to help control shrinkage and to avoid cracking.[51] Grog is often considered to be a sub-set of temper, referring specifically to non-plastic material that has been pre-fired, such as ground brick or tile.[51] The term grog appears to be used more often than temper in the literature on ceramic water filters, and thus will be used throughout the remainder of this paper.

Ceramist Reid Harvey has been developing his own grog for filter projects in Bangladesh and currently in Nepal as part of his Pottery Purification Media (PPM).[19] Harvey was recently granted a patent for his porous grog media.[17] The PPM grog Harvey is developing typically consists of 63 parts clay, 37 parts flour, and 20 parts water by weight.[19] The process begins by mixing the 63 parts of clay with 20 parts water and leaving this in a plastic bag to saturate overnight. 37 parts combustible material, wheat flour in the case of the project in Nepal, is then added to the mixture the following day. This mixing process is very labor-intensive, considering it takes a lot of work to blend the flour into the clay-water mixture.

The grog composition is then pushed through a 10-mesh screen to help mix the materials. The mixture is then left to dry until the moisture content is ideally between 8%-10% by weight.[17] The relatively dry mixture is then dry-pressed into tiles or disks and finally allowed to dry for two to three days before firing. The tiles/disks are then fired between 900°C and 1050 °C for ~24 hours. The combustible material typically incinerates at around 500°C and at this point, the temperature increase must be gradual to ensure that the ceramic does not break apart as the combustible material (wheat flour in this case) burns. After firing and cooling, the grog disks are crushed and sieved using a 30-mesh screen (Figure 4.3). The ground grog is finally mixed with clay and water to form the final filter disk element.

The author was not able to find a full scientific explanation as to why and how grog influences the final characteristics of the filter media. Harvey's explanation is that during the second phase of firing, the clay shrinks away from the grog, which does not shrink, thus leaving behind a slightly more porous ceramic media depending on the material properties.[21]

Another possible explanation[a] is that using very fine pre-fired particles and firing them to the sintering point can produce pores that are about 1/3rd the size of the particles.[24] A certain firing temperature must be achieved so that enough sintering takes place to offer sufficient structural strength, yet not high enough to collapse the porosity. The general firing process is described in Section 4.3.4 Firing & Drying.



The worker is grinding crushed grog using a "Plate Mill". The crushed grog is then sieved using a 30-mesh screen. The grog is then mixed 50:50:10 grog:raw clay:water to form a relatively dry composition that is then pressed into the desired filter shape.

Figure 4.3: Worker Grinding Grog Using a Plate Mill

Madhyapur Clay Crafts, Thimi, Nepal. January 2003

4.2 Equipment

Equipment, including the workshop and property, are major capital investments for a potter. Realistically, most equipment and materials will be purchased locally to minimize costs. Furthermore, sources of energy in developing countries are often unreliable and/or

[a] This explanation was offered by Rod Bagley via an email from Lee Hersh. Lee Hersh is a retired chemist from the Corning Corporation and an active contributor to the MIT Nepal Water Project. Rod Bagley is the inventor of the die-extrusion process used to make honeycomb-like porous ceramics. Rod was recently elected to the National Inventor's Hall of Fame.

expensive, if at all available, and so choosing equipment that does not rely on electricity or fossil fuels for energy is often an important consideration.

For convenience, a list of equipment used in the production of ceramic filters is presented in Table 4.2. The Potters for Peace website[a] and the Pottery Purification Media website[b] also provide good summaries of the equipment needs for manufacturing ceramic water filters.

Table 4.2: List of Equipment Typically Required for the Production of Ceramic Water Filters

Equipment	Brief Description
Grinder	➢ Grinders or crushers are used to grind dry clay or fired temper/grog down to small uniform grain sizes. A picture of a grinder was shown in Figure 4.3.
Screens	➢ Screens are used to sieve clay, combustible material, and/or grog to specific grain sizes. Screens are measured in terms of mesh size per inch: for example, a 1-inch section of a 30-mesh screen is divided into 30 equal squares. Screens are used to sieve both wet and dry material. For example, Potters for Peace screens dry clay & sawdust between 60 and 30-mesh screens, keeping what is left on top of the 30-mesh screen.[43]
Mixers	➢ Mixers are used to mix clay, combustible material, water, and/or grog. Mixing seems to be done most often by hand, as is the case at Madhyapur Clay Crafts; however, mechanical mixers are available. Two examples of mechanical mixers available within the Kathmandu region are pan mills and pin mills. Pan Mills consist of two heavy wheels that rotate over the mixture while pin mills consist of pins that rotate around each other.
Filter Press	➢ Filter presses are used to press the clay mixture into a desired shape (disk, candle filter, or pot). A picture of a filter press is shown in Figure 4.6.
Molds	➢ Molds are used to shape the filter element into a desired shape (disk, candle, or pot). Molds are typically made of plaster or metal to provide a

[a] Potters for Peace website: http://www.potpaz.org/pfpfilters.htm
[b] Pottery Purification Media website: http://www.purifier.com.np/

	non-stick surface so that the pressed filter separates from the mold. Furthermore, the mold must be able to withstand the repeated stress from the filter press.
Kiln	➢ Kilns are used to heat the filter element to a desired temperature. Reid Harvey suggests that a kiln with internal volume = 1.3 m^3 has a production capacity of 240 candles per day.[19] Kilns that can reach temperatures between 900 ºC and 1100 ºC are beneficial to producing ceramic water filters.
Buckets & Scales	➢ Buckets and scales are used for measuring material proportions. For consistency, the same bucket(s) should be used for different production runs. Materials are often measured with buckets in terms of relative proportions (one scoop of this added to two scoops of that) – rather than using a more systematic approach where each material is measured by volume or weight. Whether or not using a systematic approach to measuring makes a difference is unknown; however, it would be beneficial to know the exact volume & weight of materials used so that clay-recipes could be transferred more readily between projects.
Surface/ Storage Area	➢ Surface/storage area is required for material (clay, combustible material, and grog), drying raw clay, mixing materials, drying pre-fired filters, drying post-fired filters, and storing inventory for sale.

4.3 Production Process

The production process involves the following general steps:

1. Material Processing & Preparation
2. Mixing
3. Filter Pressing or Hand Molding
4. Drying & Firing
5. Application of Colloidal Silver (if used)
6. Quality Control

The production process is summarized in the flow diagram shown in Figure 4.4. Although this diagram is based primarily on the production process at Madhyapur Clay Crafts, it is believed to be generic to most drinking water filter production projects including, for example, the Potters for Peace production process in Nicaragua.

4.3.1 Material Processing & Preparation

Clay, water, combustible material, and or grog are the primary materials used in the production of filters, as was discussed in Section 4.1. Most of these materials, with the exception of water (usually), require processing before they can be mixed together. Section 4.1 detailed the steps required for processing these materials.

In general, processing usually begins with grinding the material to a more uniform and smaller grain size. The material is then sieved using screens with specific mesh sizes. The choice of screen size depends on the characteristics of the material being used and will also depend on the desired characteristics of the final ceramic filter. In general, clay is sieved using screen sizes anywhere between #10 (i.e., # of squares per square-inch) and #60 mesh while combustible materials are often screened between #100 and #600.

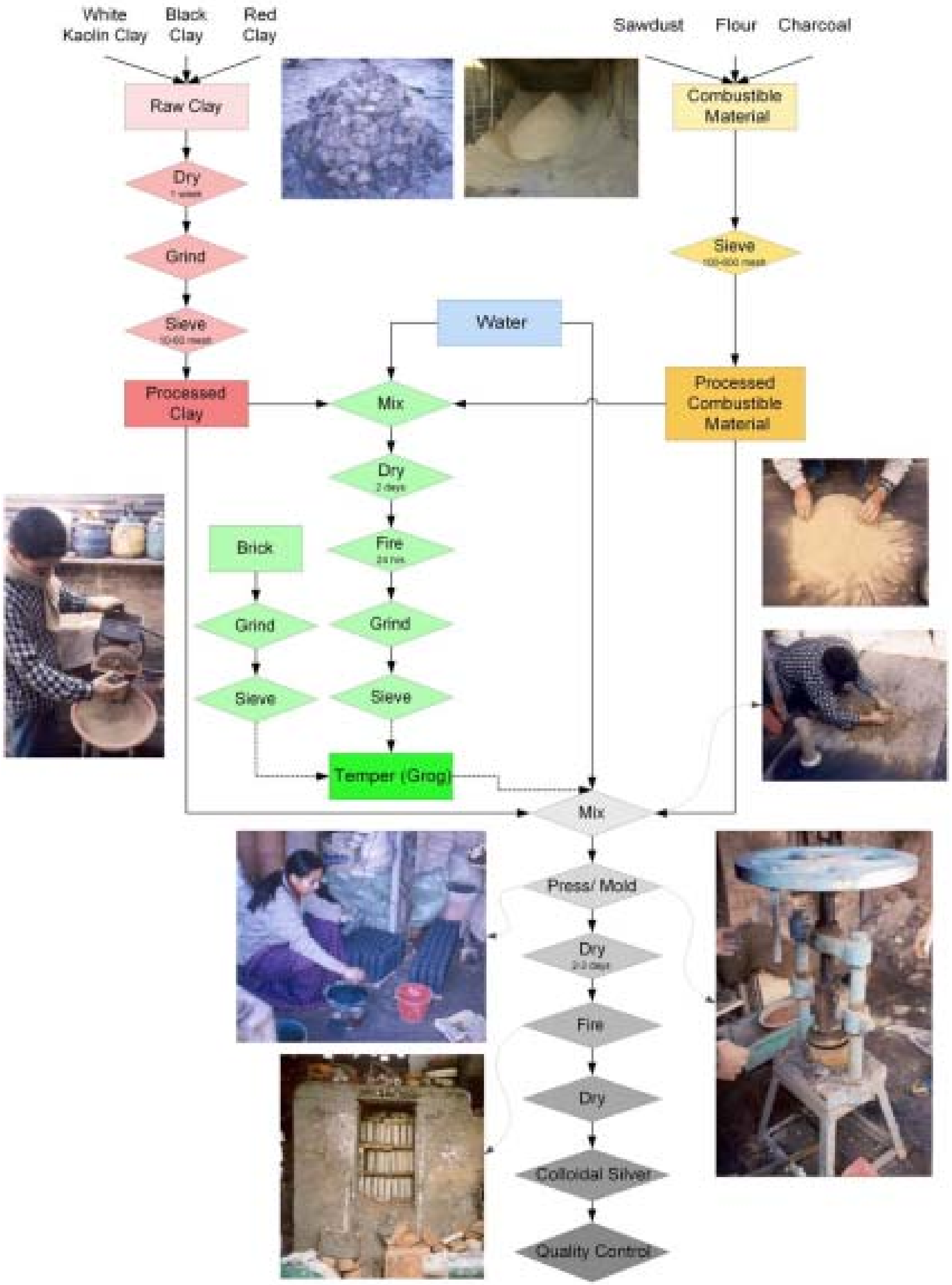


Figure 4.4: Ceramic Water Filter Production Process based on Madhyapur Clay Crafts in Thimi, Nepal

4.3.2 Mixing

Various combinations of clay, water, combustibles, and/or grog are mixed together to form a relatively dry, but cohesive, mixture that is then pressed or molded into a filter shape. The most optimal material combination, or recipe, depends on the properties of the materials, the equipment used, and the methods employed by the ceramist throughout the production process. These recipes are determined partly by experience and partly by trial-and-error. A recipe for one location may not work at another location with different materials, equipment, and or methodology. In particular, the properties of the clay will dictate what mixing recipe is most optimal in terms of filter performance.

Mixing can be a long and labor-intensive process; especially if it is done by hand (Figure 4.5). Mixing is one of the current bottlenecks in the production of ceramic water filters at Madhyapur Clay Crafts.[45] Hari Govinda Prajapati believes that he can produce 100 candles or 200 disks per day using Reid Harvey's Pottery Purification Media method, which uses grog. He currently has a production capacity of 150 candles per day using his methods and materials (white kaolin clay imported from India mixed with a combustible, but no grog).

The ceramist is mixing 50 parts raw clay (red clay from Thimi): 50 parts grog: 10 parts water. The mixture is relatively dry as can be seen in the picture. The mixture will be placed in a mold and then pressed.

Figure 4.5: Worker Preparing a Mixture of Clay, Grog, and Water

Madhyapur Clay Crafts, Thimi, Nepal. January 2003.

The mixing time could be reduced with the use of a mixing machine such as a Pan Mill, which consists of two heavy wheels that sit inside a pan and rotate over the mix, or a Pin Mill which consists of two rotating pins and can be used with dry mixes.[45] Both of these machines are readily available on the market in Nepal.

4.3.3 Filter Pressing or Shaping

The next step in the production process is the shaping of the filter element. This typically involves the use of a mold, which can either be a hand-mold, into which the clay is pressed by hand, or a component of a filter press machine to compact the material into its desired shape. Pressing the clay manually into a mold is very time consuming. Filter press machines offer a number of important advantages over manually pressing the clay: the two most critical being speed and consistency. The speed in which filter elements are produced can be increased dramatically by virtue of a press machine, eliminating the need to shape the element by hand. The consistency between elements is maintained more readily with the use of a press machine compared to molding the filter element by hand or throwing[a] a shape on a wheel.

Pressing ceramic filters with a press machine is often referred to as dry pressing due to the low water content of the material being pressed.[18] In fact, it is because of the dry composition of the material that the filter units require a press machine to properly compress the clay mixture. In contrast, pressing a shape by hand requires the clay mixture to contain relatively more water so that the material maintains its shape and holds together.

A mold, often called a “die”, of the desired shape of the filter unit is typically made of metal or plaster. The material properties of plaster (namely, its open pore structure) allows for quick release of the clay that is pressed into the die shape.[1] For an in-depth discussion on die-making, see Pressing Ceramics with Air[1] or visit the Ceramique d’Afrique website for a discussion by Reid Harvey[b].

The complexity of low-cost filter presses ranges from simple metal frames with a car jack to hydraulic ram presses (Figure 4.6). Car jacks tend to wear out quickly due to repetitive loadings; plus they require a lot of manual labor to input energy to the mechanical system by cranking the jack arm.[43] Hydraulic presses tend to be more robust and are less labor

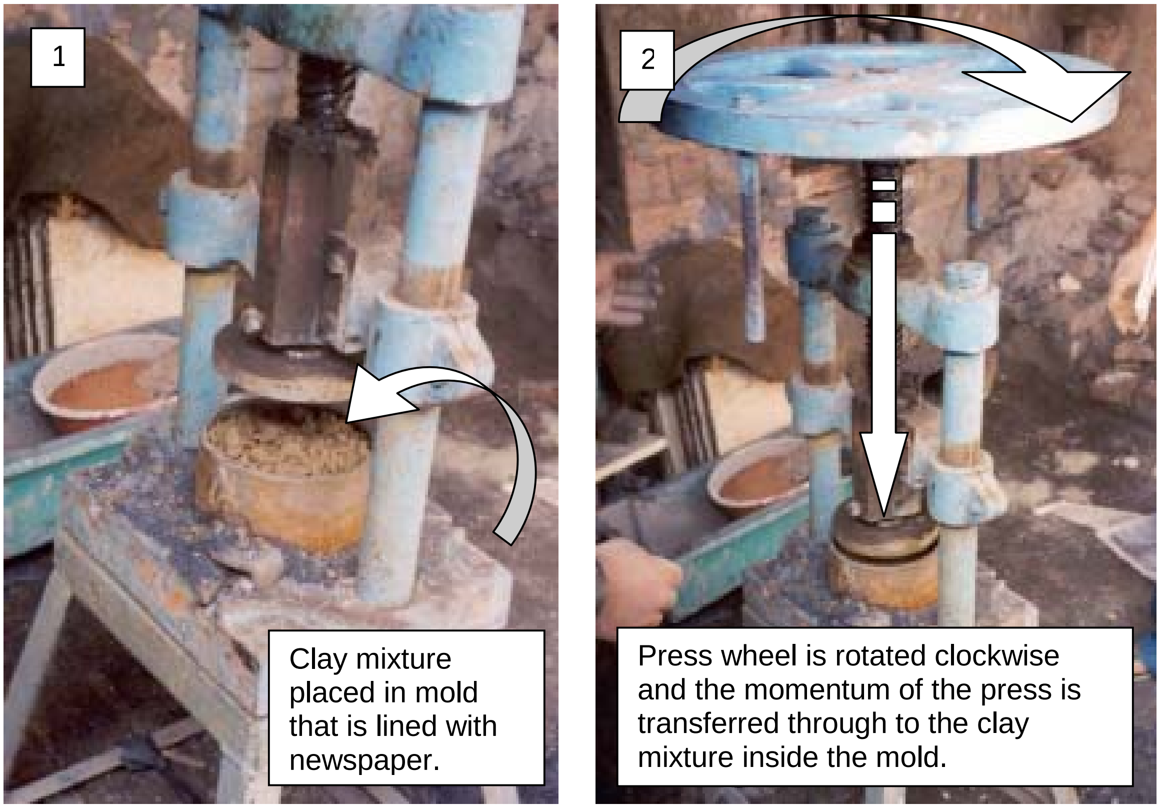
[a] “Throwing” is the act of forming a shape out of clay on a pottery wheel.
[b] Ceramique d’Afrique website: http://www.geocities.com/ceramafrique/

intensive; however, they usually require electricity, which is often a rare commodity in developing countries.

Figure 4.6: Example Filter Presses: Metal Frame and Car Jack (left), Hydraulic Jack System used by Potters for Peace (right).

Picture Source: Left: Ceramique d'Afrique website (www.geocities.com/ceramafrique/)

A screw press (Figure 4.7) is used at Madhyapur Clay Crafts for pressing disk-shape filters, while a drill-like press (Figure 4.8) is used to press candle filters. The screw press is somewhat unique in that the thread angle is very steep such that when the top wheel is turned, the travel length of the press is relatively long (i.e. a sharp torque of the top wheel-handle and the press will rotate all the way to the bottom with little resistance and with a lot of momentum).



The press wheel is rotated to an upright position and the wheel is then held in place with a rope (1). The mold, located at the bottom on the wooden block, is lined with a layer of newspaper and filled with the clay mixture (1). The newspaper is used to prevent the clay from sticking to the mold. The wheel is then given a sharp clockwise torque (2). The momentum from the rotating shaft and wheel is rapidly transferred to the mold below, thus compressing the clay mixture within the mold. The process is repeated two to three times until the clay mixture is sufficiently compact (3).

Figure 4.7: Screw Filter Press used at Madhyapur Clay Crafts

Madhyapur Clay Crafts, Thimi, Nepal. January 2003

Figure 4.8: Candle Filter Press used at Madhyapur Clay Crafts

Madhyapur Clay Crafts, Thimi, Nepal. January 2003.

4.3.4 Drying and Firing

After pressing the clay material, the filter element is left to dry for two to three days. The purpose of drying is to prevent the clay from cracking due to rapid drying or heating during the firing process. The initial rate of drying (rate of water escaping from the disk due to evaporation at the surface) is comparable to the evaporation from a free water surface up to the point where the moisture within the smaller pore spaces is held back by capillary forces.[51] At this point, the rate of drying can decrease dramatically. The time it takes for the filter to dry enough for firing depends on many factors and is determined partly by experience and partly by trial-and-error.

The filter unit is ready for firing in a kiln (Figure 4.9) once the drying stage is complete. Traditional kiln designs in many developing countries achieve maximum internal temperatures of ~700 °C.[19] To achieve a more optimal temperature of 900 °C to 1000 °C for the production of ceramic water filters requires heat-resistant kiln bricks that can withstand repeated firings at these higher temperatures. Ceramist Reid Harvey suggests that a relatively low-cost heat resistant brick can be developed using clay, sand and sawdust – as opposed to buying a more expensive brick that is made especially for kilns.[19]

Figure 4.9: Pottery Kiln used at Madhyapur Clay Crafts, Thimi, Nepal

Madhyapur Clay Crafts, Thimi, Nepal. January 2003.

The Potters for Peace website[a] describes the construction of a kiln called the Minnesota Flattop, or “Mani” kiln that has been used in Nicaragua for the production of the PFP Filtron filter. A further refinement to the Mani kiln is the development of a fuel burner system which uses sawdust as opposed to logs or gas/oil. The sawdust can be collected from other industries such as, in the case of Kathmandu and vicinity, local furniture manufacturers, of which there are many. A well designed kiln will, in turn, be energy efficient in terms of minimizing the loss of heat to the surrounding environment – this is why sawdust is used in the production of the kiln bricks to increase the porosity of the bricks and in turn their insulating capacity.

There are three distinct firing phases: dehydration, oxidation, and vitrification.[51]

1. Dehydration

Dehydration occurs at low temperatures and involves the removal of excess water trapped within the pottery. The rate of temperature increase must be monitored closely to ensure that the rate of dehydration is kept within the limits of the filter’s ability to withstand the imposed stress caused by the water evaporating from the small pores – too rapid firing (temperature increase) will cause the filter to shatter.[51]

2. Oxidation

Oxidation follows with the burn-off of carbonaceous material as well as other compounds that are oxidized. The temperature and time over which oxidation occurs depends on the properties of the clay. An important consideration for ceramic water filters is the temperature at which the combustible material, such as sawdust or flour, oxidizes. The ceramist must be careful to slow the rate of temperature increase at the point when the combustible material begins to oxidize so as to minimize the stress imposed on the filter element. For example, the grog produced at Madhyapur Clay Crafts by Reid Harvey contains flour, which oxidizes at temperatures around 500 °C. Thus, the rate of increase in firing temperature is reduced as the temperature inside the kiln approaches 500 °C to allow the flour particles to slowly burn off.

3. Vitrification

[a] Potters for Peace website: http://www.potpaz.org

During vitrification, the constituents of the clay material begin to soften and adhere into a glass-like material. The temperature over which this occurs again depends on the properties of the clay material. It is interesting to note that the density of the pottery increases and thus the porosity decreases during vitrification.[51] The porosity of the final ceramic material can, in fact, be used to measure the degree of vitrification that takes place during firing.[51] Earthenware pottery by definition is “low-firing” pottery for the very reason that the pottery does not completely vitrify or “mature” and is thus the most porous pottery of the three general types: earthenware, stoneware, and porcelain (in order of decreasing porosity). Porcelain, for example, is fired at much higher temperatures and results in a ceramic material that is virtually impervious.[15]

If some degree of vitrification does take place during the firing process, to what extent does it affect the porosity of the final ceramic water filter? This question ties in with understanding how grog affects the final properties of ceramic water filters – namely porosity or hydraulic conductivity.

4.3.5 Colloidal Silver

One of the unique features of some ceramic water filters, specifically the Katadyn®[a] filters and the Potters for Peace[b] Filtron filters, is the use of colloidal silver (CS) to control bacterial growth/regrowth within the filter element and/or as a bactericide to chemically and/or biologically inactivate microorganisms. Some studies of ceramic water filters coated with CS indicate that it plays an important role in reducing the number of indicator organisms present in water. Recent laboratory tests in Nepal support this hypothesis as was discussed in Section Chapter 3.

CS consists of silver particles suspended in distilled water or proteins. Proteins are necessary for higher concentrations where the silver would otherwise be unstable within water. An example of this is the product Microdyn[c], which is used on the PFP Filtron filters, where the silver concentration is 3.2% or roughly 3,200 mg/L. The PFP filters are coated with the CS after firing with a mixture of two milliliters of Microdyn and 300 mL of bottled water to

[a] Katadyn® is a Swiss-based company that began manufacturing CS-impregnated ceramic candles in the 1940’s. See Section 2.3.3 for more information.

[b] Potters for Peace is an NGO working primarily in Nicaragua to develop a pot-type ceramic filter called the Filtron. See Section 2.2 for more information.

[c] Microdyn is the chief product of a Mexican company that manufactures CS products for use as a disinfectant Microdyn is readily available in supermarkets throughout Mexico.

form a ~21 mg/L solution of CS. Two-thirds of this solution is painted on the inner part of the filter unit and one-third on the outer part.[33]

The WHO recommended drinking water guideline for silver is 0.1 mg/L based on half of the "no observed adverse exposure limit" (NOAEL) standard lifetime intake of 10 g of silver over 70 years.[65] The US Environmental Protection Agency's secondary standard for silver is also 0.1 mg/L.[62] The most common health affect of silver, although quite rare, is argyria, which results from the deposition of silver in the skin and hair, giving rise to a gray-bluish coloring.[65] A study of the CS concentration in filtered water using the PFP Filtron filter coated with different concentrations of CS, up to ~50 mg/L silver, concluded that the CS concentration in the filtered water did not exceed the WHO or EPA guidelines.[33] The maximum CS concentration achieved in the filtered water was 37 μg/L or 0.037 mg/L, which is approximately 40% of the recommended guideline.[33]

Many proponents of CS claim that it is effective against diseases and cancer; however, the US Federal Drug Administration (USFDA) does not support these claims and in fact issued a ruling in 1999 that such claims are unfounded based on the lack of substantial scientific evidence proving that silver is effective against diseases.[64] The USFDA is not; however, concerned with or under jurisdiction to regulate CS as a disinfectant as this falls under the jurisdiction of the US Environmental Protection Agency (USEPA).[34] A report on the PFP Filtron filter by Lantagne concludes after reviewing the USFDA and USEPA regulations that it would be legal to market a CS-coated ceramic water filter in the United States provided the concentration of silver in the filtered water is less than 0.1 mg/L.[34]

Two different home-based methods of producing CS by electrolysis (high-voltage[a] and low-voltage methods) are shown in Figure 4.10. The high-voltage example shown on the left uses two 99.99% pure $5 Canadian silver coins attached to two separate electrodes composed of 99.9% pure silver and suspended in distilled water that has been seeded with a small amount of CS to initiate the reaction (the initial CS acts as an electrolyte which is necessary for electrolysis to take place). Silver oxide forms as a sooty-looking black film on the positive anode, while silver ions are released into solution from the negative cathode electrode.

[a] WARNING: The high-voltage method is very dangerous and should not be performed without a thorough understanding of how the system works and how to avoid getting electrocuted.

The low-voltage DC method shown on the right in Figure 4.10 uses a 27-volt battery with polarity switching every minute (reversing the direction of the current). The burner is apparently used to evaporate the water and thus concentrate the CS solution. The material and instructions for this method are described on the Pottery Purification website[a].

It is worth noting that high concentrations of CS, such as 3,200 mg/L for Microdyn, are unstable in water and are only achieved by suspending the colloidal silver in protein. Thus, the two methods of producing CS discussed above will not produce concentrations equivalent to Microdyn. Regardless, the concentration that is used on the filter units by PFP is around 20 mg/L, which is achievable by the methods discussed. In terms of scale-up production; however, it may be necessary to make a more concentrated version like Microdyn.

Left: High Voltage Electrolysis
Below: Low Voltage Electrolysis

Figure 4.10: Colloidal Silver Production

[a] Pottery Purification Media website: http://www.purifier.com.np/

4.3.6 Quality Control

The final step in the production process is quality control to ensure that the filter units are performing properly. In theory, it would be beneficial to test every filter for flow rate, microbial removal efficiency, and other desired performance parameters. The reality is that these tests take time and can be expensive depending on the type of microbiological indicators tested for. To date, the most practical and affordable quality control method is to measure flow rate and to use this as a proxy for determining the microbial removal efficiency. For example, Potters for Peace measures the flow rate of every Filtron to ensure that it falls within a specified range: a minimum for practical purposes and a maximum to ensure that the pore spaces within the ceramic water filter are not too large, that the water passing through the filter is in contact with the CS long enough to achieve disinfection, and to ensure that there are no cracks for water and microbes to bypass the filter element.

4.4 Parameters That Affect Filter Performance

Ceramic filter performance in terms of flow rate can be described by Darcy's Law for flow across a porous material (Figure 4.11). This simple mathematical model helps to conceptualize and anticipate how changes in parameters such as surface area or disk thickness *should* affect the flow rate. The flow rate in turn can be used as a simple proxy to evaluate filter performance in terms of microbial removal: if the flow rate is very high (say 10 L/hr), then it is likely that the filter is too porous to provide proper removal of bacteria and protozoa cysts, and if it is too low (say below 0.5 L/hr) then it is simply impractical in terms of supplying enough water to a typical household. It is very important to realize that flow rate is not a measure of microbial inactivation, but rather an *indicator* of water flow-through and possible ease with which bacteria-size particles could flow through as well.

Referring to Figure 4.11, the flow rate, Q, can be related to the surface area of the disk, A, the hydraulic conductivity of the media, K, and the hydraulic gradient across the thickness of the disk, H/L using Darcy's Law.[11] The surface area is a function of the diameter of the disk, and increases with the square of the diameter.

The hydraulic conductivity is a measure of the "flowability" of the media and is a function of the properties of both the media and the water. If the media is porous, then the hydraulic conductivity is relatively high, thus allowing water to flow more readily through the media. In this model, hydraulic conductivity is related to permeability, k, times the density of water divided by the viscosity of water. Permeability is only a function of the media, whereas hydraulic conductivity is a function of both the media and the water. For ceramic filters, the properties of the water – namely the density and viscosity – are more or less the same, so the primary parameter that influences hydraulic conductivity is permeability k.

Permeability is a function of the porosity and the connectivity between pore spaces within the media. A ceramic filter, for example, could have a large pore space entrapped within the filter media yet have very small channels traveling to and from the pore space. Thus, the channels, or connectivity, and not just the porosity are important when considering the permeability of a filter.

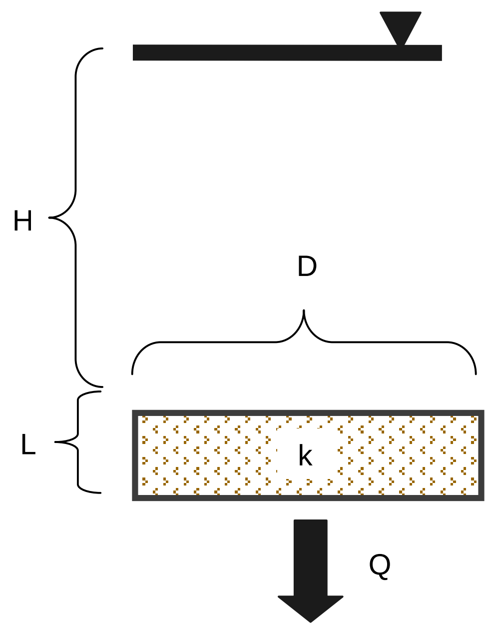


Figure 4.11: Relating the Flow Rate to the Properties of a Ceramic Disk Filter

$$Q = A \cdot K \cdot \frac{H}{L} = \pi \frac{D^2}{4} \cdot \frac{k \cdot \rho_w \cdot g}{\mu} \cdot \frac{H}{L}$$

Equation 4.1: The Theoretical Flow Rate through a Disk Filter based on Darcy's Law.

Where,

Q = flow rate (m^3/s)

A = surface area of disk (m^2)

d = diameter of disk (m)

K = hydraulic conductivity (m/s)

k = permeability (m^2)

ρ_w = density of fluid (kg/m^3)

μ = viscosity of fluid (kg/m-s)

H = water head (m)

L = disk thickness (m)

The hydraulic gradient, H/L, is a measure of the force that is pushing the water through the ceramic media. The gradient can be large if H, the water column height, is high or L, the thickness of the disk, is small, or both. The higher the water column height, for example, the higher the flow rate will be for a given disk thickness L. The thinner the disk, the higher the flow rate will be for a given water column height H.

Taken together, it is now useful to see how flow varies with these parameters (Table 4.3). Increasing all of the parameters except for the disk thickness will increase the flow rate. Increasing the disk thickness will decrease the flow rate by a factor of $1/\Delta L$. Note that the flow rate increases faster for a given increase in surface area since Q is proportional to the diameter squared.

Table 4.3: Summary of How Disk Filter Properties influence Flow Rate

Disk Property	**Impact on Flow Rate**
↑ D, disk diameter ⇒	↑ Q (by $\sim\Delta d^2$)
↑ k, disk permeability ⇒	↑ Q
↑ H, water column height ⇒	↑ Q
↑ L, disk thickness ⇒	↓ Q

4.5 Theoretical Flow Rate

Debate surrounds the question whether, in theory, a disk filter provides a higher flow rate per unit surface area compared to a candle filter. Intuitively, it would seem that the ceramic disk filter would have a greater flow rate than a single candle filter for a given surface area and thickness, but by how much?

The theoretical flow rate for a single candle filter and a single disk filter is developed below based on the diagram shown in Figure 4.12. The main assumptions are that the water column height above the bottom of the container remains constant through time and that both filter elements are composed of the same material (and thus have the same hydraulic conductivity). Furthermore, the candle filter in this example is assumed to be capped on both ends.

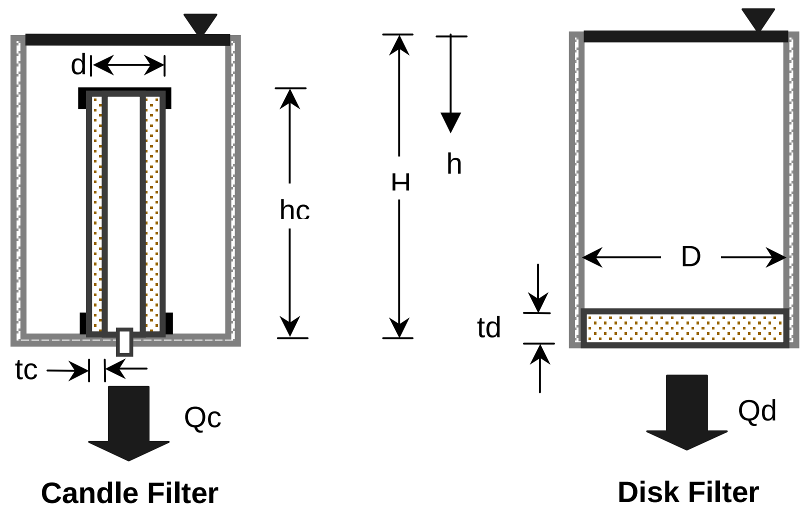


Figure 4.12: Definitional Diagram Showing Dimensions of Candle and Disk Filters

Derived Candle Flow rate, Qc

$$q_c = K\left(2\cdot\pi\frac{d}{2}\right)\frac{h}{tc}dh$$

$$Q_c = \int_{H-hc}^{H} q_c dh = \int_{H-hc}^{H} K\left(2\cdot\pi\frac{d}{2}\right)\frac{h}{tc}dh$$

$$Q_c = K\pi\frac{d}{2}\frac{H^2}{tc} - K\cdot\pi\frac{d}{2}\frac{(H-hc)^2}{tc}$$

$$Q_c = K\cdot\pi\frac{d}{2}\frac{H^2}{tc} - K\cdot\pi\frac{d}{2}\frac{H^2}{tc} + K\cdot\pi\frac{d\cdot H\cdot hc}{tc} - K\cdot\pi\frac{d}{2}\frac{hc^2}{tc}$$

$$Q_c = K\cdot\pi\frac{d\cdot H\cdot hc}{tc} - K\cdot\pi\frac{d}{2}\frac{hc^2}{tc}$$

Derived Disk Flow rate, Qd

$$Q_d = K\frac{\pi\cdot D^2}{4}\frac{H}{td}$$

Where,

K = hydraulic conductivity (m/s)

d = average diameter of the candle (m)

D = diameter of disk (m)

H = total hydraulic head (constant) (m)

h = hydraulic head (m)

hc = height of candle filter (m)

tc = thickness of candle filter (m)

td = thickness of disk filter (m)

Qc = flow rate through candle (m^3/s)

Qd = flow rate through disk (m^3/s)

Converting the flow rate to liters per hour:

$$Q_c = \left(K \cdot \pi \frac{d \cdot H \cdot hc}{tc} - K \cdot \pi \frac{d}{2} \frac{hc^2}{tc} \right) \cdot 3600000$$

Equation 4.2: Theoretical Flow rate through a Candle Filter with Constant Head

Where Qc = flow rate (L/hr)

$$Q_d = K \frac{\pi \cdot D^2}{4} \frac{H}{td} \cdot 3600000$$

Equation 4.3: Theoretical Flow rate through a Disk Filter with Constant Head

Where Qd = flow rate (L/hr)

Dividing the theoretical flow rate for a disk filter (Equation 4.3) by the theoretical flow rate for a candle filter (Equation 4.2):

$$\frac{Q_d}{Q_c} = \frac{K \frac{\pi \cdot D^2}{4} \frac{H}{td} \cdot 3600000}{\left(K \cdot \pi \frac{d \cdot H \cdot hc}{tc} - K \cdot \pi \frac{d}{2} \frac{hc^2}{tc} \right) \cdot 3600000} = \frac{D^2 \cdot H \cdot tc}{2 \cdot d \cdot td \left(2H \cdot hc - hc^2 \right)}$$

Equation 4.4

Assuming that the thickness of the disk filter, td, equals the thickness of the candle filter, tc, (Equation a) and that the volumes of each filter are equal (Equation b):

$$td = tc$$

Equation a

$$Vd = Vc = \frac{\pi \cdot D^2}{4} td = \pi \cdot d \cdot hc \cdot tc$$

$$hc = \frac{D^2}{4 \cdot d}$$

Equation b

Substituting Equation a and Equation b into Equation 4.4 yields:

$$\frac{Q_d}{Q_c} = \frac{D^2 \cdot H \cdot td}{2 \cdot d \cdot td\left(2H \cdot \frac{D^2}{4 \cdot d} - {\frac{D}{16 \cdot d^2}}^{4}\right)}$$

$$\frac{Q_d}{Q_c} = \frac{D^2 \cdot H}{\frac{2 \cdot d \cdot D^2}{16 \cdot d^2}\left(8 \cdot d \cdot H - D^2\right)}$$

$$\frac{Q_d}{Q_c} = \frac{8 \cdot H \cdot d}{\left(8 \cdot H \cdot d - D^2\right)}$$

$$\frac{Q_d}{Q_c} = \frac{8 \cdot H \cdot d}{\left(8 \cdot H \cdot d - D^2\right)}$$

Equation 4.4: Theoretical Ratio of Flow Rate through a Disk Filter to Flow Rate through a Candle Filter.

Thus, the theoretical ratio of flow rate through a disk filter divided by flow rate through a candle filter is greater than one for all values of D>0. The main assumptions for Equation 4.4 are:

- Constant water column height, H
- The same hydraulic conductivity for both filters, K
- The same thickness for both filters, td = tc = t
- The same volume of material for both filters, volume of disk = volume of candle

An example is shown in Table 4.4. Given the same material composition (and thus hydraulic conductivity K) and the same hydraulic head or water-column height H, then the theoretical flow rate for a disk of diameter 22 cm and thickness 2 cm and a candle of average diameter 6 cm, thickness 2 cm, and height 20.1 cm would be 2.05 L/hr (Equation 4.3) and 1.36 L/hr (Equation 4.2), respectively. The ratio of the theoretical disk flow rate to candle flow rate for this example is 2.05/1.36 = 1.51, which is the same result using Equation 4.4. The dimensions for the given filter elements are such that the surface area and volume of the two elements are equal. The ratio of Qd/Qc = 1.51 demonstrates that the disk is approximately 50% more efficient than a single candle filter, *for the given example*. Three candle filters would give a total flow rate of ~4.08 L/hr; however, three times as much material would be required to get only twice as much flow per hour.

Table 4.4: An Example Comparing Flow Rate through a Disk Filter to Flow Rate through a Candle Filter

Candle			**Disk**		
Hydraulic conductivity, K	10^{-6}	m/s	Hydraulic conductivity, K	10^{-6}	m/s
Hydraulic head, H	0.3	m	Hydraulic head, H	0.3	m
Diameter, d	0.06	m	Diameter, D	0.22	m
Candle Height, hc	0.201	m	Thickness, td	0.02	m
Thickness, tc	0.02	m			
Surf Area	0.038	m^2	Surf Area	0.038	m^2
Volume	0.00076	m^3	Volume	0.00076	m^3
Qc (Equation 4.2)	1.36	L/hr	Qd (Equation 4.3)	2.05	L/hr
Qd/Qc	1.51		Qd/Qc (Equation 4.4)	1.51	

Chapter 5 Development of a Ceramic Water Filter for Nepal

MIT environmental engineering student, C.S. Low, began to develop a ceramic disk filter during his research work with Hari Govinda Prajapati at Madhyapur Clay Crafts in Nepal in January, 2002.[35] At the time, Prajapati was manufacturing candle filters using imported clay from India and shortly thereafter, began manufacturing arsenic candle filters for ENPHO using local terracotta clay. Low wanted to develop a disk-shaped filter similar to the TERAFIL disk filter discussed in Section 2.1 and based on a material composition similar to the Potters for Peace Filtron filter (Section 2.2) where different proportions of clay, sawdust, and water are used. Low also tried adding rice husk ash in various proportions to see what affect it had on filter performance.

Although the disk filters did not perform as well as the TERAFIL filters, it was a first step in the process of developing a prototype. This year, we continued to research new filter media designs as was documented in Chapter 3 with the testing of three different types of disk filter elements and five different types of candle filter elements. This research was carried out with Hari Govinda Prajapati working in parallel with IDE-Nepal[a] and Reid Harvey. Our research also advanced one step further by focusing on a filter system for housing the filter element (Chapter 7). Furthermore, a joint business-engineering student team, CeraMIT, investigated some of the business aspects of developing a ceramic water filter for Nepal.[10]

5.1 A Framework for Developing a Ceramic Water Filter

At this time, it is useful to consider where the ceramic water filter research at MIT fits into the overall picture of developing a ceramic water filter for Nepal. Figure 5.1 shows the various stages of product development starting from an assessment of need to monitoring, evaluation, and feedback of product performance. The MIT research work being carried out in Nepal currently falls in the stage of prototype development considering the previous work done by Low, CeraMIT, and Lily Cheung, a new member of the CeraMIT team who is developing a working prototype of a ceramic water filter as part of her mechanical engineering senior thesis.[6] Furthermore, MIT's ongoing laboratory and field testing of existing

[a] International Development Enterprises (IDE) Nepal is an NGO specializing in technology dissemination and business development. Website: http://www.ideorg.org

ceramic water filters in both Nepal and Nicaragua[28,33,34,35,49] fall within the field and lab testing stage in the diagram, as well as the monitoring, evaluation, and feedback stage.

Figure 5.1 is presented as an aid in understanding the process of developing a point-of-use (POU) household ceramic water filter for Nepal. As the diagram shows, the process of developing technology and product(s) is not linear, but involves feedback based on monitoring and evaluation in order to achieve continual product improvement over time. Furthermore, various organizations, identified in green, play important roles at different stages throughout product development. Academic institutions like MIT, for example, play an important role in terms of monitoring and evaluating performance of POU treatment technology; thus providing valuable feedback on product performance to organizations such as Potters for Peace and Madhyapur Clay Crafts who essentially act as the entrepreneurial agents that bring the product to market.

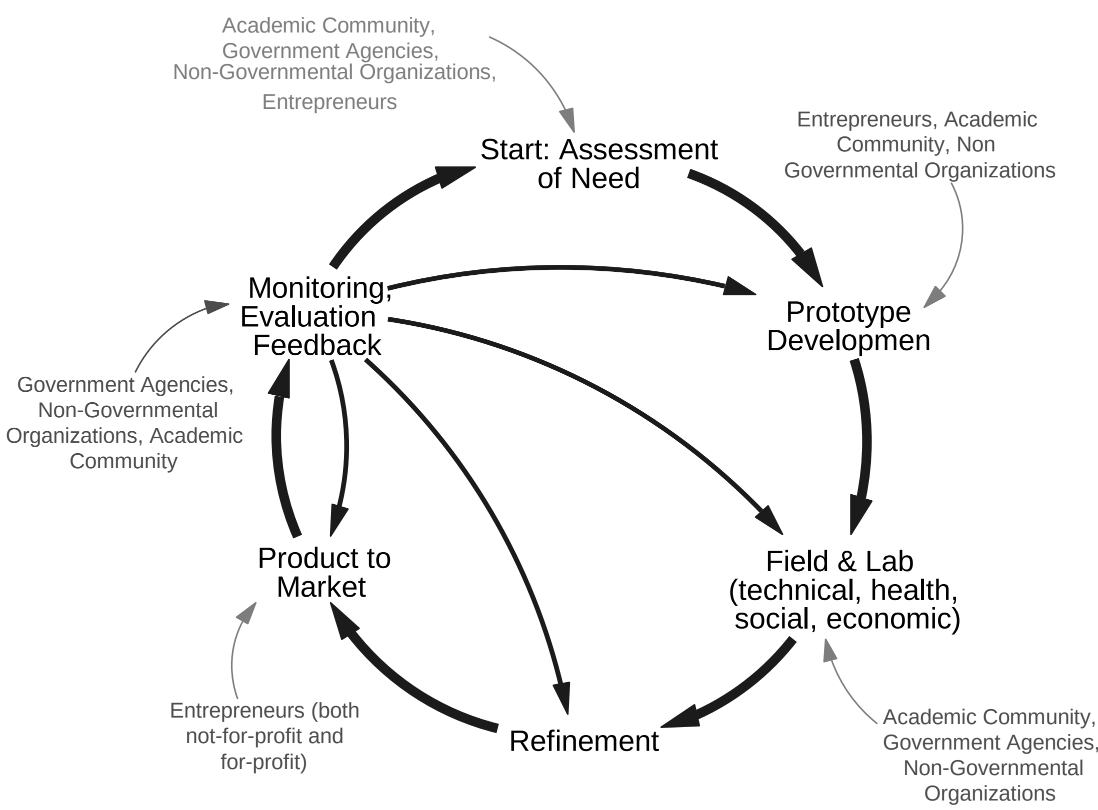


Figure 5.1: Framework for Developing a Ceramic Water Filter

5.2 Organizations Engaged in the Development of a Ceramic Water Filter

The number of organizations that are getting involved in the development of ceramic water filters both in Nepal and in other countries is growing. Along with this growth emerges some complexity in terms of the relationships and collaborations between the various organizations. It would be fair to say that all organizations involved support a common vision to *help solve the drinking water quality crisis that exists in Nepal and in many other countries worldwide*. However, each organization has its own objectives and strengths and so it is useful to list the organizations to get a better picture of how best to collaborate in order to achieve the shared vision for clean drinking water and improved human health. The organizations and individuals involved in the development of a ceramic water filter in Nepal are listed below. Some of these entities are not directly involved, but can provide important feedback on product design.

Massachusetts Institute of Technology Nepal Water Project

MIT has been working in Nepal since 1999 through the leadership of Susan Murcott to help provide clean drinking water and improved sanitation to those in need. The research work on ceramic water filters has evolved from testing water filters to more recently conducting preliminary market research and developing a prototype. MIT works closely with the Environment and Public Health Organizations (ENPHO) as well as Hari Govinda Prajapati who is the owner of Madhyapur Clay Crafts, a pottery cooperative in Thimi Nepal.

MIT can play an important role in terms of conducting laboratory and field tests to evaluate product performance. Furthermore, the resources available at MIT are well suited for developing filter system prototypes as Mechanical Engineering student Lily Cheung is current doing for her senior thesis.[6]

Environment and Public Health Organization (ENPHO)

ENPHO is a self-supporting Nepali non-governmental organization (NGO) established in 1990 with a fully equipped scientific laboratory that conducts environmental studies and training. ENPHO is the main partner organization to the MIT Nepal Water Project, kindly providing their guidance and expertise and sharing their space with our engineering graduate students during the month of January.

ENPHO can play an important role in terms of conducting laboratory and field tests to evaluate product performance. They are well-respected and have the capability to carry out long-term laboratory and field testing of ceramic water filters. Furthermore, they have some experience developing and bringing products to market such as Piyush, which is a chlorine solution made from bleaching powder used to disinfect drinking water.[37]

International Development Enterprises (IDE)

IDE is an international NGO that specializes in technology dissemination and business development. IDE has had success launching local entrepreneurs in the sale of human-powered irrigation pumps and drip irrigation systems. IDE-Nepal is the recipient of a $20,000 grant from the Development Support Foundation of New York via ceramics consultant Reid Harvey to develop a low-cost ceramic water filter. The IDE-Nepal staff was an immense help to CeraMIT during their research in January 2003, introducing the team to a number of expert organizations and village groups

IDE-Nepal can play an important role in helping to bring a product or prototype to market. Their philosophy is to help entrepreneurs establish a business around a technology and to then back away over time as the business becomes established. IDE-Nepal is currently working in parallel with the CeraMIT team to develop their own ceramic water filter with ceramists Reid Harvey and Hari Govinda Prajapati at Madhyapur Clay Crafts.

Entrepreneurs

One could think of an entrepreneur as one of the leading agents of change – the entity that decides, in this case, to bring a ceramic water filter to market. An entrepreneur can be motivated by the opportunity to develop a business out of selling ceramic water filters, by philanthropic reasons to bring clean drinking water to those in need, or a combination of both. Regardless of whether the organization is not-for-profit or for-profit, the entrepreneur runs an operation that must be financially sustainable, where revenue from the sale of products and/or from external subsidies or aid covers the operational, manufacturing and capital costs.

As one example, Hari Govinda Prajapati is a small-scale entrepreneur who lives and works in Thimi, a pottery community about thirty minutes outside of Kathmandu. He is the owner and managing director of Madhyapur Clay Crafts, a pottery shop on the Arniko Highway near

Bhaktapur. He is also the chairman of the Nepal Ceramics Cooperative Society, a seven-year-old cooperative that serves potters in the Kathmandu Valley and Janakpur in the Terai.

An example of a nonprofit entrepreneurial organization would be Potters for Peace[a]. PFP manufactures and markets the Filtron filter primarily in Nicaragua (See Section 2.2) and has worked closely with the MIT Nepal Water Project the last few years.

Ceramic Consultants

Ceramic consultants like Ron Rivera of Potters for Peace and Reid Harvey of Pottery Purification Media[b] play an important role in terms of providing technical expertise on developing ceramic water filters – especially the filter media.

Federation of Business & Professional Women Nepal (FBPWN)

The FBPWN helps to create equal business and professional opportunities for women in the economic, civil and political life of Nepal. CeraMIT met with Ms. Mangala Karanjit who is a member of the board of the FBPWN and one of the two lead organizers of the 2nd Women and Water Conference held in 1998 in Kathmandu. She is also the Chief of the Information Division of the Melamchi Water Supply Development Board and has worked for the past two decades for the Nepal Water Supply Corporation, the government agency responsible for urban water supply.

FBPWN can play an important role ensuring that women are actively engaged in the development and marketing of a ceramic water filter. The reason this is so critical is that women are the primary caretakers of water in the household and are therefore the primary customer of ceramic water filters. The FBPWN could also help us explore opportunities to involve women directly in the development of a ceramic water filter business–whether they are involved in manufacturing, distribution, or sales or helping to develop an awareness program to educate users on how to maintain and use a ceramic water filter properly.

Other Organizations

A growing number of organizations are interested in pursing the development of ceramic water filters in Nepal. While some level of friendly competition is beneficial to elevating the

[a] Potters for Peace website: http://www.potpaz.org/
[b] Pottery Purification Media website: http://www.purifier.com.np/

performance of ceramic water filter technology and the industry as a whole, it will be important to encourage collaboration whenever the opportunity exists since ultimately all organizations are pursing the same vision to bring safe clean drinking water to those in need.

Chapter 6 Assessment of Need and Market for Clean Drinking Water

The first step in developing a ceramic water filter is to build the case for doing so by analyzing the current need for clean drinking water and to demonstrate the value that ceramic water filters can bring to potential consumers. This chapter begins by examining the global need for clean drinking water as well as the benefits of point-of-use household water treatment technologies like ceramic water filters. The regional needs in Nepal are then described followed by a preliminary consumer analysis to help focus the development of a ceramic water filter that meets the needs of these potential customers.

6.1 Global Need for Clean Drinking Water

Water is essential for life: both in terms of quantity and quality. As of the year 2000, one sixth of the world's population, roughly 1.1 billion people, lacked access to improved water supply, and two fifths, or 2.4 billion people, lacked access to improved sanitation.[66] Every year, approximately 3.4 million people die due to water-related diseases with the majority being young children under the age of five.[68] Diarrhea diseases alone account for 2.1 million deaths. Other types of diseases associated with poor water quality include cholera, typhoid, arsenic poisoning, schistosomiasis or "snail fever", and trachoma, which causes blindness. The risks of contacting these diseases can be considerably minimized with access to clean drinking water, adequate sanitation facilities, and proper hygiene practices.

The link between health and water quality and quantity is an important relationship that was intuitively understood by ancient civilizations as indicated in this Sanskrit quote:

> "heat foul water by boiling and exposing to sunlight and by dipping seven times into a piece of hot copper, then to filter and cool in an earthen vessel"[14]

It was not until the mid 1800's that people began to fully understand the scientific link between water quality and health. Epidemiologist Dr. John Snow proved in 1855 that a cholera epidemic in London was attributed to a public well contaminated by sewage.[63] The germ theory of disease later emerged from Louis Pasteur's research into fermentation. Soon chlorine was being used as a disinfectant in water supply systems to kill potential pathogens or microorganisms that cause disease and illness. Industrialized countries moved forward with the development of rather large centralized water supply and treatment systems which to this date have performed relatively well in comparison to the water supply systems that exist in many developing countries.

So why not transfer the technology and knowledge that exists in industrialized countries to developing countries to help solve the mounting water crisis? This may work in theory and in some specific cases, but in reality there are too many political, economic and geographic issues – let alone people – to realistically expect that the one billion plus who lack access to safe drinking water will receive clean potable water from a household tap by 2015 vis-à-vis the Millennium Development Goal for clean water.

6.2 Point-of-Use Household Water Treatment Technology

In countries like Nepal, most people – predominately women – spend a portion of their day collecting, carrying and storing water for drinking. The water that ends up in the house does not originate from a typical water treatment plant and supply system, but comes to them from a variety of sources including local dug wells, tube wells, springs and stone taps (Figure 6.1). If the water is not already contaminated at the source, it often becomes contaminated at some point during transport and/or during storage before it is consumed.

Considering the reality in many developing countries like Nepal, where individuals are responsible for ensuring they have safe drinking water, it seems reasonable to focus on household water treatment technology as a means to providing clean drinking water. In fact, household water treatment appears to be gaining recognition within international development organizations such as the World Health Organization (WHO) which recently published a report on Managing Water in the Home[54] and UNICEF which sponsored an online virtual forum on Household Water Security in cooperation with WHO and the Network for Cost-effective Technologies in Water Supply and Sanitation.[57] A recent statement issued by the United Nations Committee on Economic, Cultural, and Social Rights goes one step further by declaring water as a human right[a], which, taken into the context of the Millennium Development Goals, puts pressure on governments to live up to their commitment to halve

[a] Human Right to Water: http://www.who.int/water_sanitation_health/Documents/righttowater/righttowater.htm

the number of people without access to improved water supply and sanitation services by the year 2015.

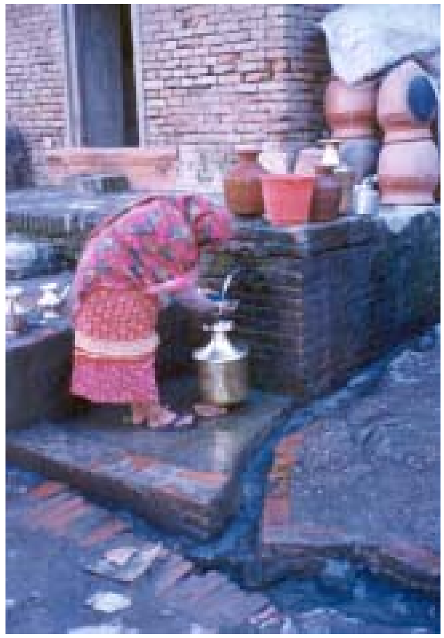


Figure 6.1: Nepali Woman Collecting Drinking Water from a Stone Tap

Thimi, Nepal. January 2003.

Ceramic water filters are one example of a household water treatment technology that is potentially affordable and effective at improving water quality. A variety of products are being used throughout the world such as the TERAFIL disk filter in India, the Indian PURO candle filter, a white-kaolin candle filter manufactured by Madhyapur Clay Crafts in Nepal, and the Potters for Peace Filtron in Nicaragua. The ceramic and pottery trades being centuries old and well-established in most developing and developed countries are an added benefit in terms of encouraging economic development of locally manufactured ceramic water filters.

A lot of work documenting filter effectiveness and product design still needs to be completed. The literature on filter effectiveness - especially over extended periods of time and under "field" conditions (i.e. realistic household settings) is minimal. Yet individuals, organizations, and a handful of academic institutions are beginning to actively investigate ceramic filters for use in countries like Nepal.

6.3 Regional Needs for Clean Drinking Water in Nepal

Nepal is located along the northern border of India and southern border of Tibet. The geography of Nepal is remarkable, rising from nearly sea level along the southern Terai region bordering India to the world's tallest mountains in the Himalayas along the border with Tibet. The country can be divided into three geographic regions: the lower Terai in the south, the Hills running roughly west-east in the middle, and the Himalayas in the north (Figure 6.2).

Figure 6.2: Map of Nepal and Regional Districts

Picture Source: ICIMOD (www.icimod-gis.net) [30]

The transportation system is minimal, at best. Most villages in the Hills and Himalayas, especially in the northwest, must be accessed from the main highway that travels east-west along the Terai (Figure 6.3). Transportation and distribution of a ceramic water filter throughout Nepal will be particularly challenging considering the lack of roads and the difficult terrain.

Administratively, the country is divided into 5 development regions and 75 districts[50] (Figure 6.2). The Department of Supply and Sewerage (DWSS) has representatives in each of these districts and is the government agency responsible for the development of rural water supply and sanitation services throughout the Kingdom. Other government agencies active in water supply and sanitation projects include the Nepal Water Supply Corporation (NWSC), District Development Committees and Village Development Committees. In addition to these government agencies, there are many non-governmental organizations working within Nepal including the Nepal Red Cross, UNICEF, the Environment and Public Health Organization (ENPHO), Rural Water Supply and Sanitation Support Services (RWSSP), Water Aid, and others.

Figure 6.3: Map of Road Density

Picture Source: ICIMOD (www.icimod-gis.net)[30]

The population of Nepal as of 2001 was 23,592,000 with an annual growth rate of 2.4%.[67] Approximately 88.2% of the population lives in rural villages and towns loosely scattered throughout the Hills and Terai regions.[59] A 1991 survey of population density by district shows the highest population density in southeastern Terai (Figure 6.4). Population growth from 1981 to 1991 occurred mostly within the Terai region as well (Figure 6.5) and this trend has likely continued through to the present time.

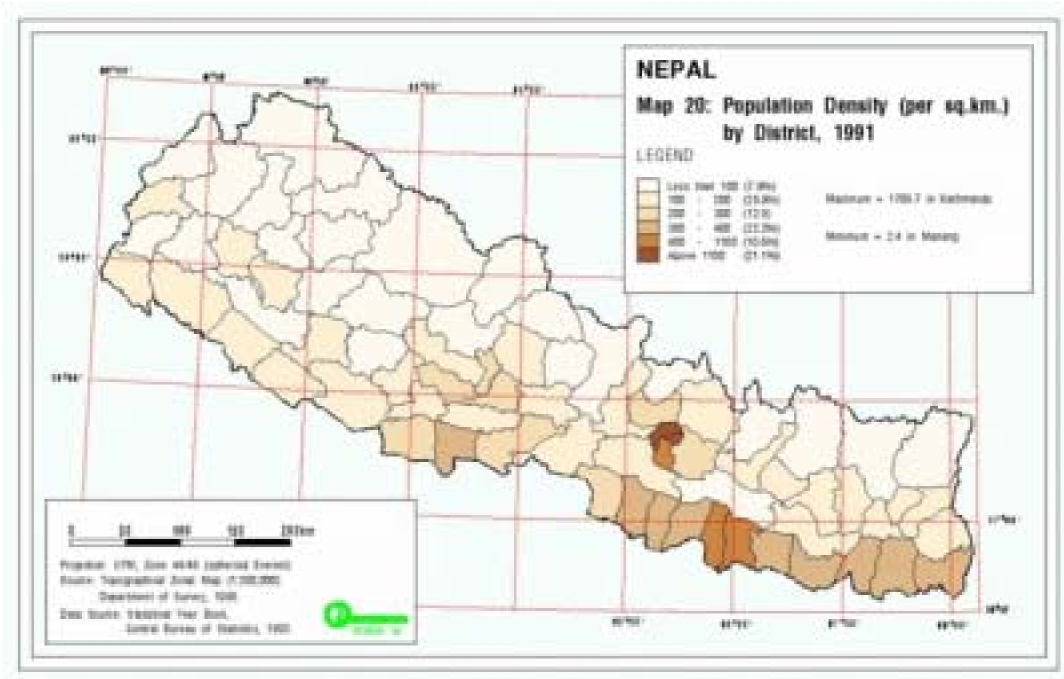


Figure 6.4: 1991 Population Densities by District

Picture Source: ICIMOD (www.icimod-gis.net) [30]

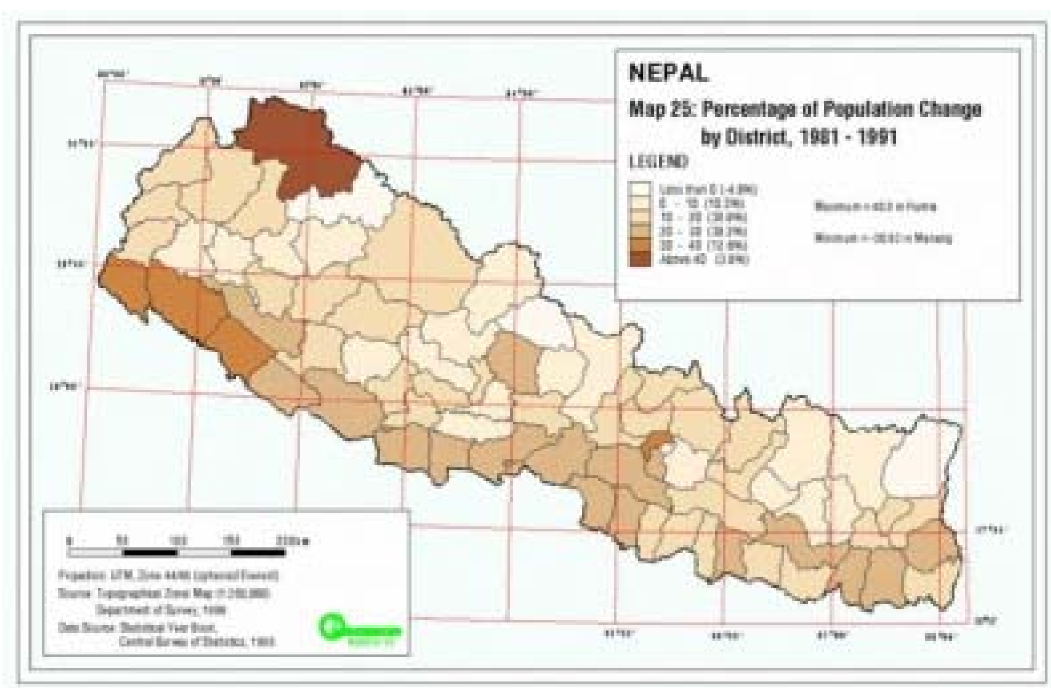


Figure 6.5: Percentage Population Change by District, 1981-1991

Picture Source: ICIMOD (www.icimod-gis.net) [30]

The United Nations Development Programme Human Development Index (HDI) for Nepal is 0.49, ranking Nepal 142nd out of 173 countries.[59] The HDI is a composite index that is used to measure human development and to compare human development between countries.

Nepal's relatively poor ranking in comparison to the other 173 countries is reflected in the following statistics:

• Life expectancy at birth	58.6 years
• GDP per capita ($PPP)[a]	$1,224
• Literacy Rate[b]	41.8%
• Population below income poverty line $2/day[c]	82.5%
• Children under height for age[d]	54%
• Child under-five mortality rate[58]	91/1000

The International Centre for Integrated Mountain Development (ICIMD) has also developed their own set of 39 development indicators for Nepal and ranked the 75 districts in order of the Composite Index of Development (1 being least developed and 75 being most developed)[31] (Figure 6.6). The least developed districts, according to the ICIMD report, are located within the northwestern region of the country as well as some areas just east of Kathmandu.

According to the World Health Organization's 2000 "Global Water Supply and Sanitation Assessment Report", nearly five million people in Nepal lack access to safe drinking water and nearly eighteen million lack access to improved sanitation.[66] The ICIMD also prepared a map showing the drinking water coverage by district based on information provided by the DWSS[30] (Figure 6.7). According to the map in Figure 6.7, the eastern Hills districts have the worst coverage.

[a] Purchasing Power Parity in international dollars. International dollars are used to account for the relative differences in purchasing power between countries. The Nepal total GDP for 2000 was USD $5.5 billion which is approximately USD $239/capita.

[b] % age 15 and above

[c] 1993 PPP USD$

[d] % under the age of 5

Figure 6.6: Ranking of Districts in Terms of Development

Picture Source: ICIMOD (www.icimod-gis.net) [30]

When visiting and talking with many individuals and organizations in Nepal, however, it is readily apparent that more than five million people are *vulnerable* to problems with drinking water quality since the majority lack access to adequately treated water. There is very little monitoring of rural water supplies and the integrity of the urban systems in places like Kathmandu is often questioned by the general public and media.[50] In May of 1995, for example, the Environment and Public Health Organization (ENPHO) found that 39 of 42 drinking water samples taken from the Kathmandu municipal water supply system were contaminated with fecal coliform bacteria and that 98% of the samples had no free residual chlorine.[53] A more recent sample taken from a tap on the roof of ENPHO, supplied by the municipality, in January 2003 showed a total coliform concentration of 1550 cfu/100 mL. This sample was; however, taken the day after the water storage tank on the roof had been filled – the day previous to refilling the tank showed a total coliform concentration of 3 cfu/100mL. Nevertheless, this demonstrates some of the problems associated with the municipal water supply system as a whole – even if the water coming directly from the municipal system is clean, many citizens use storage tanks to store this water and these tanks in turn add another level of risk of water contamination.

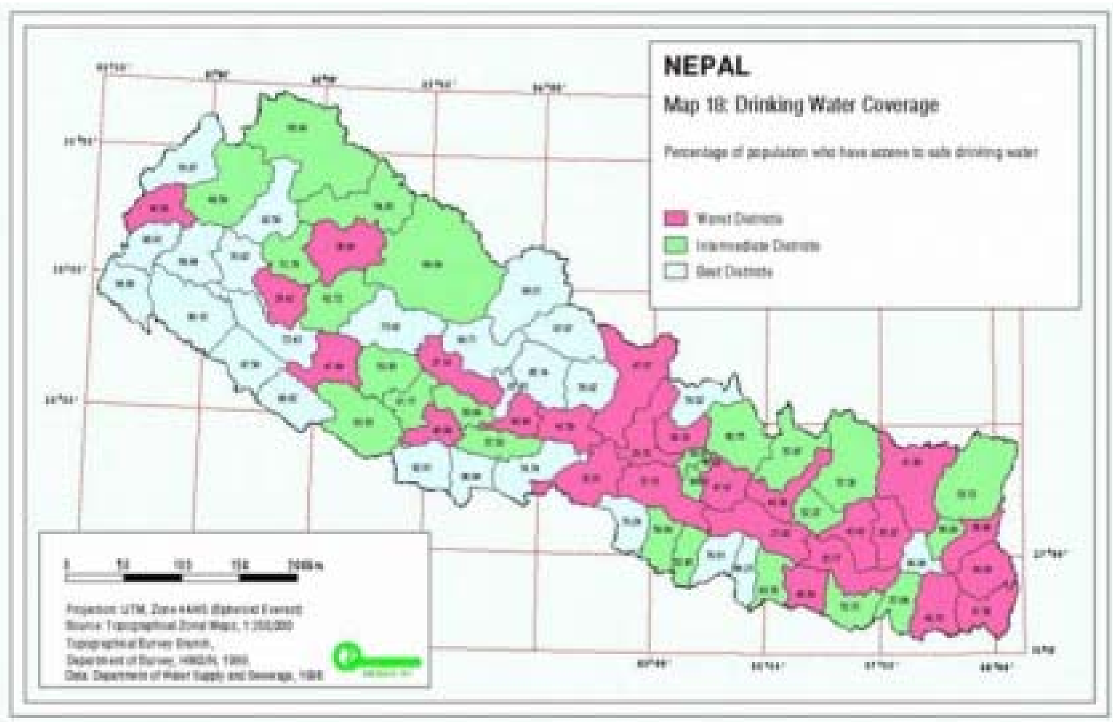


Figure 6.7: Drinking Water Coverage

Picture Source: ICIMOD (www.icimod-gis.net) [30]

Essentially, the infrastructure for supplying clean water across Nepal – both rural and urban areas – is minimal compared to that in industrialized countries, leaving citizens to treat their own water if they realize the need to do so and can afford to. Most of the population relies on decentralized water supply systems such as tube wells, open wells, springs, and stone taps connected to local reservoirs. While some of these water sources may be relatively clean, many are not, and those that may be now are still quite vulnerable to contamination in the future as development proceeds and stress on the environment and water resources persists. Springs, as an example, are perceived by many to be a relatively clean source of water; however, a survey of the percentage distribution by mode of drinking water (piped water, handpump/tap, well, spring, and other) of children under five years of age with diarrhea showed that 23% of the cases originated from springs – the second highest percentage behind "other" at 24%, suggesting that springs are more vulnerable to contamination than is commonly perceived[50]. A random test of two hitigah or dhungedhara[a] wells used for both drinking water and cleaning in the Naikap district near Kathmandu in

[a] "walk-in" wells with stone steps leading into the well.

January 2003 showed total coliform concentrations of 1,660 and 2,130 cfu/100mL and *E.coli* concentrations of 5 and 74 cfu/100mL respectively for the two locations, demonstrating again that spring or well water is not necessarily clean, even though it is often perceived as clean by villagers.[10]

The political, economic, social and geographical characteristics of Nepal make it an ideal context in which to test the appropriateness and sustainability of a ceramic water filter product. If a successful product can be developed and marketed within Nepal, then the lessons learned from this will be invaluable for helping to develop more ceramic water filter markets within countries like Nicaragua and Bolivia, for example, where students in the MIT Master of Engineering program and the Cambridge University Master of Philosophy program are currently working.

6.4 Preliminary Consumer Analysis

A consumer analysis is usually carried out as part of the marketing plan for a product or service (Chapter 8). Every potential customer or target market is thoroughly defined and characterized. Four or five alternative target market scenarios are then defined based on the consumer analysis, and one scenario is ultimately chosen. Each scenario essentially prioritizes the targeting of specific consumer groups in an effort to identify the most optimal marketing strategy.

Potential ceramic water filter customers are characterized below in a first attempt at defining target markets. Note that this is just a preliminary consumer analysis – a more detailed analysis would likely include specific regions as well as villages that could be targeted in conjunction with a monitoring and evaluation study to see how the product performs in the field.

Two types of general users are defined: end users and third-party users. End users are people or households that actually use the filter system. Third-party users are defined as the agents that purchase the filter systems and then distribute them to end users – either free of charge or for financial exchange. These different groups are briefly discussed in the following sections.

End Users	Third Party Users
• Urban Poor	• Retailers
• Rural – Accessible	• Government Agencies
• Rural – Remote	• Non-Governmental Agencies
	• Others

6.4.1 End-Users

End-users are defined as the individuals or households that actually use the ceramic water filter to clean their drinking water. They may either purchase the filter directly from a retailer or have it donated to them/subsidized by a third party like, for example, the Red Cross. They are the most important consumer group to understand since they are the actual users and therefore determine the success of the ceramic water filter.

Three general end-users have been defined: urban users, rural users that are relatively accessible by road, and remote rural users. There are many sub-groups within each general group. At some point, these sub-groups will have to be well defined in order to choose specific villages/regions to target distribution of the filter system.

Above all else, women are the primary caretakers of water in the household and are thus the primary consumer group to consider regardless of the region. This is partly why an organization such as the Federation of Business and Professional Women Nepal can play a critical role in helping to understand the needs of women and to engage them in the development of a ceramic filter system.

6.4.1.1 Urban Users

Urban users represent a relatively small fraction of the total target market since approximately 88% of the total population lives in rural areas. The largest city is Kathmandu, the capital city, with just over 1,000,000 residents. Other cities like Pokhara, Patan, and Bhaktapur are noticeably smaller, but have similar water supply problems related to the quantity and quality of the water being delivered.

The water quality and quantity in urban areas like Kathmandu is arguably the worst in the country and thus the urban poor are at high risk to waterborne diseases. Water demands typically exceed available water supply and so a number of projects like the Melamchi Project in Kathmandu are underway to help increase supply capacity.

Case Study: Urban Poor in Kathmandu

Madhyanna Women's Group (MWG) is a group of 16 women responsible for households in Lalitpur Municipality #20 Nayag, which is an urban area within the Kathmandu Valley region. MWG took two members of the CeraMIT team to Lalitpur Municipality #20 to interview some of the families.

The families in this group were much poorer than the other villages that the CeraMIT team visited. The typical family size was significantly larger than the other villages with 6 persons being the smallest and 18 persons the largest. The families were very price sensitive, indicating that they would consider purchasing a filter if it were 100-200 NRs (USD $1.31 - $2.61), with a maximum at 300 NRs (USD $3.92). They had no concerns about using plastic to store water. They were the only group that expressed concerns about having enough space for the filter.

Culturally, the large cities are very diverse compared to the smaller towns which tend to be more homogeneous, taking on the values of the regions in which they reside. Family sizes in the cities, in our observations, were larger than in the countryside; especially among the urban poor. The urban poor were also much more price sensitive than the families we interviewed on the periphery of urban centers like Kathmandu and Pokhara.

The Kathmandu Valley region would be a good location to begin marketing a ceramic water filter. There are numerous villages of 50 to 100 households throughout the region that could be targeted along with a monitoring and evaluation program to measure the effectiveness of a ceramic water filter system at the household level. Furthermore, if a production facility were to be located at Madhyapur Clay Crafts in Thimi, then it would make sense to try marketing some filter systems in a local village that is close to Thimi.

The lower class in the cities is a tough sell for a water filter. The urban poor are very price sensitive having very little money (if any at all). Significant health gains can often be achieved through proper sanitation practices (provided an NGO or other agency is available to teach them). Education is generally better in the cities than in the Hills, but the economic situation for the urban poor was the worst observed during January 2003.

The middle and upper classes often use household filtration systems, such as the metal Indian candle filters. These systems are relatively expensive, ranging in price from 600 NRs to 1600 NRs (USD $8.00 - $21).[49] Most of the middle and upper class will also boil their water, typically before filtering; however, it is recommended to boil the water after filtering as a final step in eliminating microbial contamination. It is important not to ignore these legacy systems when addressing the water problem; many consumers would be put off if they had to purchase an entirely new system, rather than a replacement filter element.

Case Study: Suburban Village near Kathmandu

Naikap is a village of over 100 households in the hills at the western periphery of the Kathmandu valley. An NGO (Conserve Nepal), with the support of Susan Murcott, distributed 24 aluminum candle filters over a two year period (12 in 1999, 12 in 2000). CeraMIT held a group discussion with 16 women and 3 men, all but 2 of which were participants in the filter program. This discussion provided an interesting perspective about longer-term use of ceramic filters.

Of the 24 households who received filters in the study, 14 were represented in the discussion. Two of these households were still using filters, though these were not the original filters. They purchased stainless steel filter systems within the Kathmandu marketplace to replace the aluminum ones that had originally been distributed. Approximately 75% of the filters stopped functioning properly during normal use. The women cited three modes of failure: *broken candles*, *leaking taps*, and *aluminum corrosion*. Three of the families bought new candles or new taps, which worked for a while but broke again; the families then stopped using the filters. Two families upgraded to the stainless steel filters, and continue to use them and are pleased with their performance. These two families observed health benefits from the original filter and decided it was worth spending the money on a better filter.

The villagers at Naikap expressed concerns about the durability of plastic, and that water would smell if stored in plastic. They did say they would consider plastic systems if the product is less expensive. Since they have experienced corrosion of the aluminum filters, the corrosion-free nature of plastic might be used as a selling point to them, and possibly as an example to others.

6.4.1.2 Rural Users – Accessible

Rural users that are accessible by road represent the largest fraction of the potential target market. Most of these villages are located in the Terai and Middle Hills regions in the south and east.

Terai

The Terai being on the border with India has a predominately Hindu population. The caste system is a part of life in this area, and issues may arise when selling a product between castes. Some higher castes will not purchase goods from the occupational castes, which may make distribution of a filter product more challenging.

While most of the Hills and Himalayas are fed from springs and streams, the Terai region is fed predominately by groundwater supply. Thousands of tube wells dot the countryside; most range in depth from 20-200 feet. The primary water quality concern in the Terai is microbiological contamination as well as arsenic and iron contamination. Arsenic and iron contamination are relatively recent discoveries, and research is underway to determine the extent of the problem, and to provide solutions.[23,41,38,29]

Many families in the Terai will not drink water that was fetched the previous day since they believe it is not fresh and therefore unsuitable for consumption. This could be an issue with people letting water filter overnight. Also, among traditionalists, when women are menstruating, they are considered impure, and anything they touch during this time is believed to be contaminated. This may or may not be an issue with a plastic or metal container system provided the user feels confident that it can be disinfected or sterilized.

The weather is very hot during the summer monsoon season and so ceramic storage vessels are preferred over plastic since they keep water cool.

Middle Hills

The terrain in the Hills is very steep and is characterized by the well-known terraced slopes which farmers use to grow crops on and maintain slope stability. Water quantity is often a problem in the Hills considering many villages rely on local public taps or wells that are fed by shallow streams or springs.

Domestic water usage by residents in the Hills is likely less than in the Terai considering the climate is not as hot during the summer. One expert we spoke with mentioned that the lower Hills region is susceptible to calcium buildup. Some government installed pipes have slowly filled with calcium, restricting flow. This could pose a problem with using a ceramic filter if calcium buildup on the filter element clogged the pore spaces.

While the caste system still exists in some areas, its influence is slowly fading as the younger generation pays less heed to traditions and restrictions. Thus, problems in terms of distributing a filter system between castes would not be as challenging as it may be in the

Terai. Furthermore, our field research suggested that residents will use water from the previous day for non-consumption uses, such as for washing and animals.

Case Study: Rural Village near Pokhara

Begnas is a lakeside village of 100 households in the Hills of Kafki district, near Pokhara. CeraMIT held a group discussion with two women and four men, translated by Deepak Adhikari of IDE-Nepal and another member of IDE's Pokhara field office.

Villagers suggested that filter capacity should be 15-20 liters. They also expressed some concerns about plastic containers. Villagers currently use metal containers, and believe that plastic would be less effective at keeping water cool in the hot season. They joked that cool water is important, because Nepali people like spicy food.

Begnas has some trouble with waterborne illnesses among children and spends up to 2,000 NRs (USD $26.14) per household on medicine each year. They expressed that they would be willing to spend up to 500 NRs (USD $6.54) on an effective filter. When they are sick, they boil their water, but they do not like the taste of boiled water. One party to the discussion did have a filter and used it actively. He cleaned the filter weekly, without removing the candle, and has broken the candle twice.

Electricity is a rare commodity in the Hills and so other forms of energy, such as wood, are required for cooking. The use of wood has also been discouraged in many areas where deforestation and unsustainable forestry practices are ruining the local environment. Considering the economic cost of using fuel to boil water, many people only do so when absolutely necessary, such as when a family member is sick. Thus, there is an economic case to be made for using a point-of-use filtration system where users otherwise have to rely on expensive means of boiling their water for drinking, or simply going without treating the water.

The differences between nearby villages can be great. For example, many villages do not speak Nepali and are not able to communicate with the people in nearby villages who themselves have their own dialect. This is probably more of an issue for remote rural villages where there is less travel to and from the village.

Case Study: Rural Village near Pokhara

Kaun is a village of approximately fifty households near a new India-built hospital in the Hills outside Pokhara. CeraMIT held a group discussion with nine women and two men, translated by Deepak Adhikari of IDE, and were accompanied by three members of IDE's Pokhara field office.

A typical 5 person family in Kaun uses 5-8 liters of drinking water each day, with a maximum of 10 liters in the hot season. Roughly 40% of the households in Kaun already have a candle filter system, though only a quarter of those households (10% of total) used the filters. Complaints about the existing filters were that they had a *low flow rate* and were *difficult to clean*.

The villagers discussed some issues regarding the water use and handling. First, villagers do not like to drink "stale" water: water that has been left sitting in its container for too long. Villagers will use water collected the previous day, if it is kept outside overnight, but not for drinking. They usually keep drinking water in a covered container, but will leave it uncovered if using it soon.

This village claims to not have much difficulty with waterborne illnesses. One man estimated that he spends 40-50 NRs (USD $0.52-$0.65) per month on treatment of such diseases. Since these villagers do not have a significant problem with waterborne illnesses, they are unlikely to purchase a filter, but if they did have a problem, they say they would spend whatever was necessary to correct the problem. Contrary to some reports of villages in the Hills, the villagers in Kaun differentiate between water for drinking and water for other uses. However, Kaun has participated in some Red Cross educational campaigns, which may explain part of the reason they do this.

6.4.1.3 Rural Users – Remote

Remote rural villages represent a somewhat smaller fraction of the total population. Water quality in the Himalayas may not be so much of a problem as water quantity.

In addition to being farmers and herders, the Himalayan people are also traders, and travel throughout the country, sometimes for months at a time. This can be just a single member of the family, or the entire family. This nomadic lifestyle would probably drive them to minimize their possessions and thus, they may be reluctant to own a filter system that they would have to carry with them.

The biggest challenge for marketing a ceramic filter system would be accessing the villages in these regions. Roads are few and far between (Figure 6.3), and the population density of the region makes distribution of any sort of product very challenging. If the water problem is less about quality than quantity, then it would be more beneficial to help design water supply schemes that deal with the quantity issue rather than the quality.

6.4.2 Third-Party Users

Although third-party users do not use the filters directly, they do represent potential customers that would purchase ceramic water filters for distributing or selling to end-users. Examples are presented below.

Retailers

Retailers include store owners as well as any individual or group that might choose to purchase ceramic water filters in bulk quantity to be sold to individual end users. Besides considering a traditional model of selling bulk quantities to retailers with stores, another model to consider is the Avon model of direct sales where individual representatives can earn a commission on the quantity of goods they sell directly to customers.

Case Study: Interview with Two Storekeepers in Pokhara

CeraMIT interviewed two storekeepers while visiting Pokhara in January 2003. In both stores, sales of ceramic water filter products exhibit a strong seasonal pattern. Sales are 2-4 systems per day during the rainy season, when water sources have visible turbidity. Very few systems are sold during the remainder of the year. One storekeeper estimated 2-3 filter systems per month in the cold season. The best selling systems are between 13 and 21 liters in size.

The aluminum filter systems were the lowest priced filters, ranging between 360 and 580 NRs (USD $4.70 - $7.58) depending on size and number of candles. Stainless steel and copper filter systems were more expensive, ranging from 700 to 1800 NRs (USD $9.15 - $23.53). Each storekeeper prices the filters to earn 15-20% margin, as they may have to lower the price by 10% during haggling.

Both storekeepers were willing to sell a plastic model provided that it was of good quality plastic and that the tap was drip-free. One of the storekeepers expressed that Nepali people prefer metal because it is more durable, and also because they believe that plastic containers cause water to smell. The storekeepers also thought they could sell a disk shaped filter, provided that the seal was good and available as a spare part. One also thought the disk had good potential because the candles often break. She sells 20-30 replacement candles each month.

Current customers for ceramic filters often purchase the filters as wedding gifts. They tend to ask questions about the overall quality of the product, but very few ask about the effectiveness of microbial removal. Some customers will ask how to use and clean the filter. As a preemptive measure against product returns, one of the storekeepers teaches all customers how to use and clean the filter unless the customer claims to know already. People do not ask about the filtration rate, yet a number of people cited low flow rate as the reason they stopped using the filters.

Government Agencies

Various government agencies involved in health and water-related activities could be potential customers of ceramic water filters. As was discussed above, Nepal is divided into 5 development regions and 75 districts[50] (Figure 6.2). District Development Committees and Village Development Committees help make strategic decisions at the district and village level, respectively. Working with government organizations to help establish distribution networks could help to market a ceramic water filter both across major regions and down to the village level.

Non-Governmental Agencies

NGO's, such as the Red Cross, represent another potential customer that would purchase ceramic water filters to distribute to end users. The Red Cross, for example, might purchase filters for distribution during a crisis such as a flood or major earthquake. There are thousands of NGO's in Nepal and many work directly and indirectly with water-related issues. It is also worth looking into NGO's that are working on other issues aside from drinking water. For example, an NGO working on a literacy campaign could potentially help to facilitate an educational campaign about drinking water and the potential benefits of household water treatment.

Others

Other potential third-party agents include schools, village leaders, health practitioners, and religious leaders. A thorough consumer analysis is required to determine the most optimal consumer groups to target and to help direct the methods of marketing the product to those group(s).

Chapter 7 Prototype Development

During January 2003, the CeraMIT team conducted interviews with experts (Appendix 1) and various consumer groups (Chapter 6 and Appendix 3) with the help of IDE-Nepal. A literature review of ceramic water filter systems was also completed (Chapter 2). Furthermore, laboratory tests were carried out at ENPHO on three different types of disk filters and five different types of candle filters (Chapter 3). Upon returning to Cambridge, mechanical engineering student, Lily Cheung, joined the CeraMIT team and began to develop a working prototype of a ceramic disk filter system as part of her senior engineering thesis[6].

This chapter presents a summary of the product design goals that were considered for the development of a prototype. A discussion on lab certification and field testing is also presented, along with some prototype drawings, and a preliminary financial analysis.

7.1 Product Design Goals

Based on the research conducted over the past eight months and discussed in the previous chapters, CeraMIT formulated a number of important product attributes, or performance goals, for the design of a ceramic water filter system (Table 7.1). The filter system and the filter element or media are considered separately. For reference, a diagram showing the filter system and element is shown in Figure 7.1.

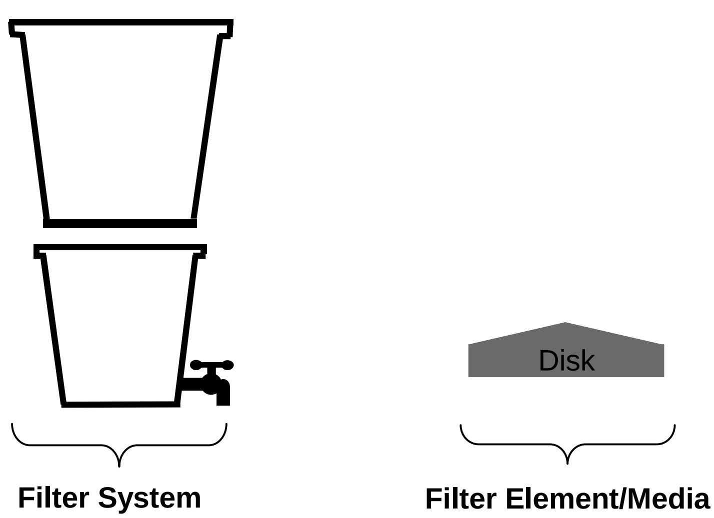


Figure 7.1: Filter System and Filter Element/Media

Table 7.1: Product Attributes to Consider for the Development of a Ceramic Water Filter System for Nepal

System	Media
• Low cost; • 20 L capacity and/or a range of capacities; • Container material should not affect taste or smell of water; • Light and durable; • Easy to carry & maneuver; • Easy to maintain & clean; • High-quality tap; • Compact for transport & storage (ideally, one bucket should fit into the other); • Lid to cover the top bucket; • Optional stand.	• Low cost; • High flow rate (2L/hr minimum); • Disk filter unit, 9” diameter; • A candle filter unit for legacy systems; • Durable – particularly when cleaning with a semi-abrasive brush/cloth; • Easy to maintain & clean; • Complete seal between the media and the system; • Disk element should be replaceable just like the candle filters; • Coated with colloidal silver.

7.1.1 Filter System Material and Capacity

In terms of the material of the filter system itself, CeraMIT proposed using a high-quality clear plastic for ease of distribution and durability. As an example, Figure 7.2 shows the Kisii Filter System from Kenya (left) and another example of a durable clear plastic container used by catering services in Kathmandu to hold water.

Many of the potential consumers we interviewed were hesitant about using plastic. The two main reasons were due to the taste of water caused by plastic containers and the inability to keep water cool. However, the benefits of a transparent plastic system are as follows (note that these benefits should be emphasized when promoting the product to potential users):

- Light and durable and thus easy to distribute throughout the country;
- Light and therefore easier to handle by the user;
- Does not degrade as fast as metal containers – a number of users complained about the metal containers “rotting” (especially the aluminum containers);
- The system can be compacted down to the size of one bucket provided one container can fit into the other container;

- Translucent material allows users to view the water moving through the system. This may have some added benefits in terms of education and awareness;
- Easy to clean and maintain – easier to clean than a ceramic storage vessel;
- Possibly cheaper than ceramic storage vessels or metal containers;
- Quality assurance/quality control in terms of mass production;
- Adaptability in terms of storage capacity – different size storage containers could be manufactured to target different family sizes/uses.

Ceramic storage vessels or metal containers should also be considered where applicable, especially if field monitoring shows that users are not adopting the filter system due to the plastic. A ceramic storage vessel might be more suitable for the Terai region considering the hot summers and the desire to keep water cool.

Figure 7.2: Kisii Filter System, Kenya (left);
Example of a Durable Clean Plastic Container (right)

Picture Source: (Left) Rural Water Development Programme, Western Kenya[47]

The type of plastic that is used is an important variable in determining the desired product characteristics, including the price of the product. In order of preference, our group decided that the following types of plastic should be considered (without considering the price of the plastic at this time).

1. A thick, clear durable plastic made of Polyethylene Terephthalate, PET. PET is used in plastic soda bottles. The Kisii Filter System from Kenya is a good example of a clear/translucent plastic container (Figure 7.2) (The Kisii may or may not be composed of PET plastic).
2. A thick, translucent High Density Polyethylene, HDPE. An example would be the Katadyn® filter system (Figure 2.13) or the Hong Phuc® filter system (Figure 2.14).

In terms of container capacity, our design goal was 20 L based on the fact that many of the existing ceramic filter systems on the market have a total capacity (upper and lower containers combined) equal to approximately 20 L. A recent study on domestic water quantity, service level and health suggests that the basic minimum requirement for an individual is 7.5 L/person/day based on estimates of requirements of lactating women who engage in moderate physical activity in above-average temperatures.[27] Considering these two numbers, it would also be beneficial to provide a range of filter system capacities to target specific groups of individuals (small families, medium-sized families, and large families); with priority given to the medium (20-L) capacity system.

- Small Size: 15 L capacity (roughly 7.5 L for each container): individuals/small families
- Medium Size: 20 L capacity (roughly 10 L for each container): small-medium families
- Large Size: 30+ L capacity (roughly 15+ L for each container): large families

7.1.2 Spigot

A number of users that we interviewed complained of leaking taps (spigots). Considering the spigot will get a lot of use, it should be durable above all else. Either metal or plastic designs would work, but preferably plastic simply to help reduce costs and to prevent corrosion. Potters for Peace has found that most users prefer brass manufactured spigots, but that the cost of these spigots increases the cost of the filter dramatically.[43] An alternative spigot that they suggest on the website is a spring-operated plastic spigot where the user pushes a level down to unload water from the bottom container (Figure 7.3). Releasing the lever automatically closes the tap.

The connection between the tap and the storage vessel is difficult to completely seal since the two surfaces that are connecting to each other do not have the same surface angles (the spigot has a flat surface and the bucket is curved). Katadyn® has alleviated this problem by making a small flat section on the inside of the bottom storage vessel at the point where the spigot connects through to the inside. The spigot is securely connected to the lower vessel by screwing a nut from the inside to the inlet of the spigot. Having the flat surface on the sidewall of the vessel allows the nut to fasten securely to the sidewall making a good seal. Furthermore, the plastic at this section of the sidewall is thicker than the sidewall thickness making the area surrounding the spigot stronger.

Figure 7.3: Potters for Peace Filtron with Spring-Operated Spigot

Picture Source: Potters for Peace website: http://www.potpaz.org

7.1.3 Filter Media/Element

Our decision to go with a disk filter versus a candle or pot shape was for a number of important reasons, discussed below:

Easier to Manufacture

- Manufacturing a disk is easier than a candle or pot – especially when using a press machine to compact the clay mixture. Candle and pot filters require molds that are more complex than a mold shaped for a disk.

Problems with Candle Filters

- Candle filters are often made by "capping" the top with a final piece of clay after the main tube or body has been pressed. The interface between the main body and cap is a potential pathway through which water can flow after the candle has been fired. Placing water inside a dry candle turned upside down and watching where the water first exits the candle is a good indication if there is a preferential flow path through the interface between the cap and main body. If there is a crack, moisture on the outside of the candle will first appear along the interface between the two pieces of clay.

- A number of people we talked to in January 2003 complained about candles breaking. Our goal was to create a filter system where the disk could be easily removed, cleaned and/or replaced, if necessary, without the user having to apply a direct force to the ceramic media in order to secure it in place. Candle filters require the user to screw the candle element into the upper bucket, which usually requires holding the filter element while the bottom nut is screwed into place. This puts a lot of pressure on the filter element and is a reason why the candles often break.
- It may be cheaper to manufacture one disk rather than one to three candles that are typically required for a filter system.

Problems with Pot Filters

- The Potters for Peace (PFP) pot filter is difficult to transport due to weight and durability of the ceramic material.
- The PFP filter has a high breakage rate, as was determined by Rebeca Hwang in her Master of Engineering thesis.[28]
- The filter press mold for the pot filters is more complicated and difficult to use than for a disk filter.
- Hari Govinda Prajapati of Madhyapur Clay Crafts was shown how to make a PFP Filtron filter a few years ago, but he never ended up carrying the design forward because of his sense that there was no market in Nepal for this type of filter.

Flow Rate

- In theory, the flow rate per unit surface area for a disk is more efficient than for a candle filter. This theory is presented in Section 4.5. If this is correct, then savings on the filter element (less material = less cost) would help to reduce the overall cost of the filter system.

7.1.4 Interface between the Filter Element and Filter System

Arguably the most critical challenge or risk associated with our decision to design a disk filter system is ensuring that a proper seal is formed between the disk and the containers. Under no circumstances should water from the top container bypass the disk and enter the bottom container. Otherwise, the integrity of the disk filter system is jeopardized.

Designing a proper connection has proven to be the most challenging design consideration. CeraMIT originally proposed two different filter designs in terms of the connection between the filter element and the filter system: the Clamp System (Design 1) and the Screw System (Design 2). Mechanical engineering student Lily Cheung modified the latter system to develop the Lily Filter (Design 3). A fourth design (Design 4) is presented in this section as a modification to Design 1.

7.1.4.1 Design 1: Clamp System

For the Clamp System, a 22-cm (9-inch) disk is sandwiched between the upper and lower containers which are squeezed together using toggles attached to the outer surface of the upper and lower storage containers. The disk filter is fitted with a rubber ring gasket that covers the entire outer edge of the disk like a tire over the hub of a wheel. The soft rubber would deform under pressure to fit the contours of the disk and the filter containers thus sealing off the upper and lower containers.

7.1.4.2 Design 2: Screw System

In the Screw System, the disk is permanently fixed with white cement to a third piece of plastic that is then screwed into the bottom of the lower bucket. The upper bucket combination is then placed on top of the lower collection vessel. When cleaning the disk, one removes the top bucket, unscrews the plastic assembly, and scrubs the disk in a bucket of clean water. To replace the disk, one removes and discards/returns the disk/plastic assembly, and purchases another from a local store. It may eventually be possible to reuse the plastic part to which the filter is attached.

7.1.4.3 Design 3: The Lily Filter

Mechanical engineering student Lily Cheung is currently doing her senior thesis, under the supervision of Susan Murcott, on developing a prototype based on the ideas presented by the original CeraMIT team[6]. Cheung has refined Design 2 such that there is no need to screw the third piece of plastic or “cartridge” into the upper container (Figure 7.4). Instead, the cartridge rests on top of the lower storage vessel and the upper container fits into the top of the cartridge as shown in the figures below. With this design, the ceramic disk filter is cemented into the cartridge using white cement.

Note that the prototype shown in Figure 7.4 is constructed of PVC. The final version will be constructed of HDPE or PET plastic material.

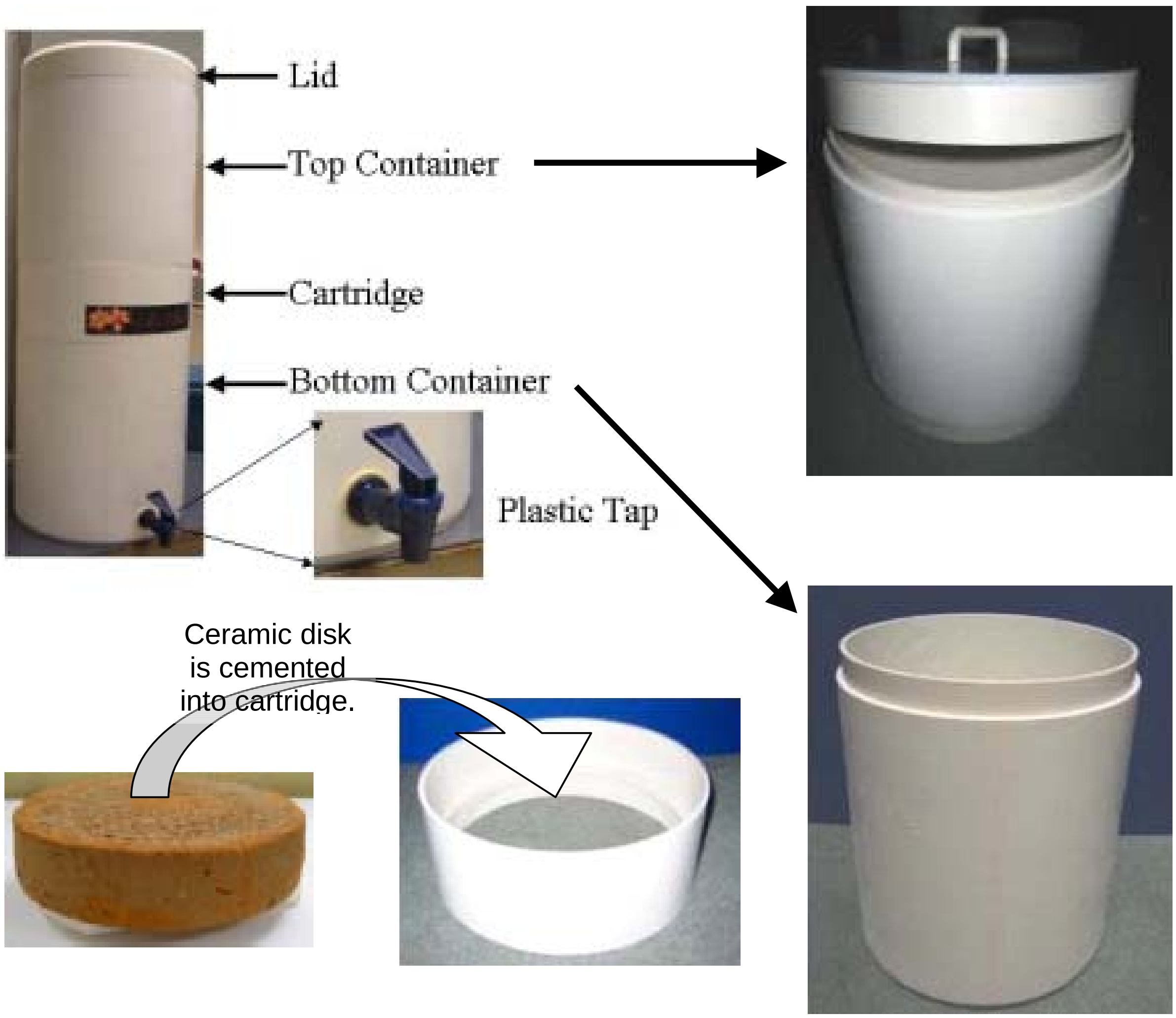


Figure 7.4: Design 3: The Lily Filter (Prototype)

Picture Source: Lily Cheung[6]

The Lily Filter is an excellent step forward in terms of developing the first working prototype. Some things to consider in the first round of testing:

- Can a proper seal be formed between the ceramic disk and the cartridge using white cement?

- How much force is required to dislodge the disk filter from the cartridge if pushed from below?
- How messy will the cartridge look if it is made of clear PET plastic material where the white cement will show through?
- How difficult is it to remove the cartridge from the upper container?

7.1.4.4 Design 4: A Mechanic Connection

Another prototype design is shown in Figure 7.5. This is similar to the Clamp System (Design 1), with some minor modifications. For one, the disk is not enclosed by a rubber gasket as is proposed in Design 1. Instead, a soft rubber material is glued to the container systems and the disk is sandwiched between the upper and lower containers. The rubber acts as a cushion between the filter disk and the rigid plastic containers.

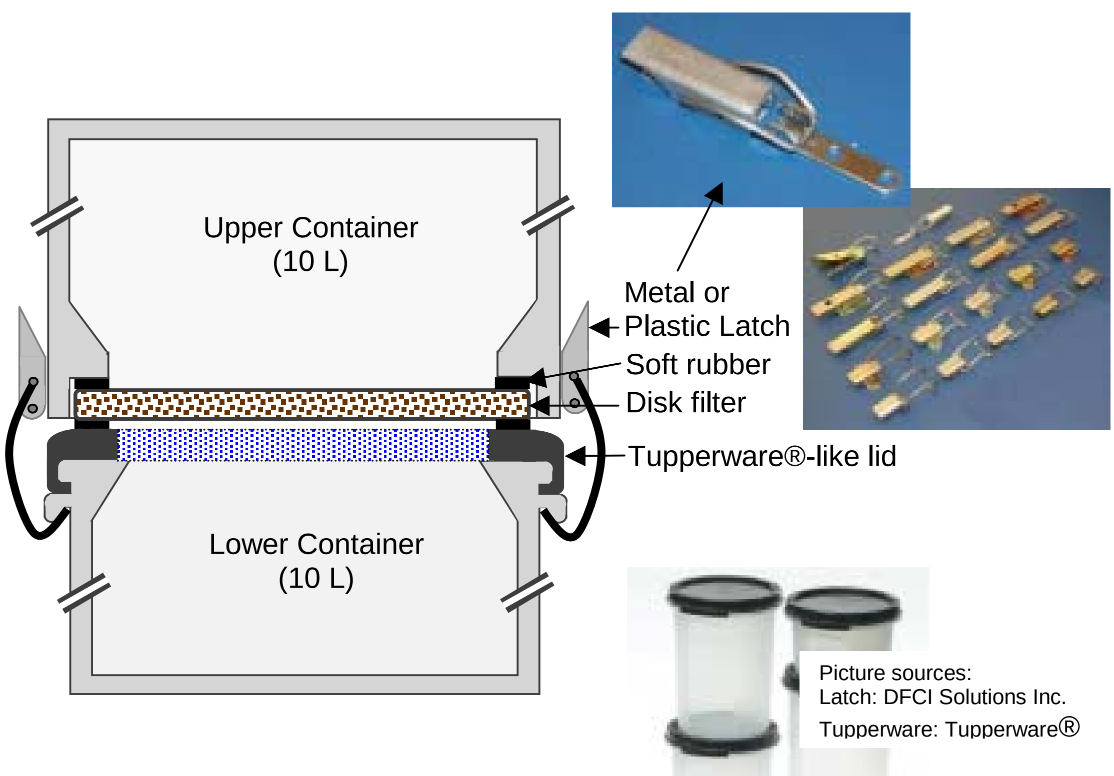


Figure 7.5: Design 4: Filter System with Mechanical Latch

A series of clamps (4-6) are placed around the edge of the upper container, as show in the diagram. The clamps will be metal or plastic, depending on the cost and the durability.

A Tupperware®-like lid is placed on top of the bottom container (snapping into place). Alternatively, the lid can be permanently fixed to the lower container (i.e., the upper edge of the lower container can be formed into the same shape as shown in the diagram). The center of the Tupperware®-like lid is cut-out forming a 22-cm (~9-inch) diameter hole. The top edge or lip of the lid along the circumference of this hole is horizontal, with a width roughly equal to 3-cm. A ring of soft rubber (i.e., a gasket), roughly 3-cm in width, is glued, or placed, along the top surface of the ring. A ~28-cm (~11-inch) ceramic disk is then placed on top of the rubber gasket[a].

The upper container is then lowered onto the ceramic disk. The bottom section of the upper container is designed to fit around the edge of the ceramic filter, helping to protect the outer edge of the disk. The upper container sits on top of the ceramic disk filter along a 3-cm wide ridge that runs along the inside wall of the upper container. A 3-cm wide rubber gasket is glued to the bottom of this ridge.

The ends of the clamps fit into notches located along the upper edge of the bottom container. The latch is pulled upwards and towards the side-wall of the upper container to “pull” the system together and thus to sandwich the disk filter between the upper and lower containers. Enough force is required to create a proper seal between the disk and the rubber gaskets. This is required to prevent water in the upper container from escaping between the rubber gasket and the ceramic disk. Similarly, no water should enter the lower container from the outside via the seal between the lower-surface of the disk filter and the bottom rubber gasket. The vertical edge of the disk is left “open” to the outside so that water pressure does not build up and potentially pass through the interface between the disk filter and the bottom rubber gasket (i.e., any water that does come in contact with the vertical edge of the disk will shed off of the disk onto the outer edge of the container).

The vertical edge of the disk filter element will have to be painted with an impervious material to prevent water from filtering out through the vertical sides. Another possibility is to glaze the vertical-edge of the disk, during a second firing, making the edge of the disk impervious. This will also help to prevent moisture from the external environment from entering through the vertical edge of the disk. Furthermore, the top and bottom surfaces of the disk could be

[a] A 28-cm disk is used in the example so that the effective surface area for water to pass through is roughly 22-cm, or 9 inches, which meets the original specs proposed by CeraMIT.

painted or glazed along the 3-cm wide ring where contact is made with the rubber gaskets. This could help provide a good seal between the rubber gasket and the ceramic filter media.

7.2 Product Performance Goals: Certification and Field Testing

Field and laboratory testing were identified in Chapter 5 as indispensable components of product development; especially for a product such as this where there are human health ramifications. Testing serves the purpose of providing feedback to designers who can then in turn improve product design and performance. Indeed, much of the work carried out by students in the MIT Nepal Water Project is focused on technical evaluation of existing or proposed point-of-use (POU) water treatment technologies like ceramic water filters. This information is then fed back to our own MIT design teams and/or to organizations developing ceramic water filters such as Potters for Peace and Madhyapur Clay Crafts, who in turn try to improve product performance.

In the last few years, some students have begun to investigate the reasons why POU technologies often perform poorly in the field despite their technical capabilities as measured in the laboratory. For example, Lantagne found in her research of the PFP Filtron that the performance of the filter in the field was significantly worse than in the lab.[34] A recent study by Hwang on the effectiveness of a six-month monitoring program of the PFP Filtron filter showed relatively better results in terms of filter performance in the field; however, there was concern that the local staff person responsible for monthly sampling was providing only optimistic results.[28] Thus, there is an important distinction to make between technical performance of a filter system under laboratory conditions and actual performance in the field.

Section 7.2.1 discusses a potential process for certification of POU water treatment technologies, such as ceramic water filters, under laboratory conditions. Section 7.2.2 then discusses field testing as the next step in determining overall filter performance while in use in the field.

7.2.1 Technical Certification

The technical performance of a POU water treatment technology, such as a ceramic water filter, is a measure of how well the product performs compared to a standard or guideline. At this time; however, there is no universal standard for evaluating the performance of low-cost

POU water treatment technologies such as ceramic water filters. Most of the literature on ceramic water filters compares filter performance, in terms of water quality, against the World Health Organization (WHO) Guidelines for Drinking Water Quality.[65] For example, the WHO guideline for total coliform concentration in drinking water is 0 colony-forming-units (cfu) per 100-mL of water sample. Although this value is well justified, it is arguably quite strict and not entirely conducive to encouraging the use of POU treatment technologies that, at a minimum, could improve drinking water quality by a significant factor, but not to the absolute requirement of 0 cfu/100 mL in this example. Thus, there is an emerging need for an international organization such as the WHO or the National Sanitation Foundation International (NSF)[a] to define POU treatment technology standards that are relevant to the circumstances under which these products are being developed.

The author did find two relevant standards for evaluating the performance of ceramic water filters. The United States Environmental Protection Agency (EPA) developed a "Guide Standard and Protocol for Testing Microbial Water Purifiers" in 1987.[61] Ceramic filter units (specifically candle filters) are included in the guide. NSF International has also developed two standards that are potentially relevant to the certification of ceramic water filters:

- NSF/ANSI 42: Drinking Water Treatment Units – Aesthetic Effects, and
- NSF/ANSI 53: Drinking Water Treatment Units – Health Effects.

The certification of a drinking water treatment product under NSF standards follows four steps: structural integrity, material evaluation, contaminant reduction testing, and literature review.[40] Structural integrity determines the product's ability to withstand extended periods of use. Material evaluation ensures that the product materials in contact with water do not introduce contaminants to the drinking water. Contaminant reduction testing evaluates the product according to the methodology and criteria of the standard that is being claimed by the company/organization. Literature review involves reviewing all of the product literature to ensure that it complies with the standards and criteria for which the claims are being made.

[a] NSF International, The Public Health and Safety Company™ is a not-for-profit NGO that develops health and safety standards for product certification. Companies who sell products that meet NSF certification can then market their products as NSF certified. This in turn provides valuable information to consumers who make decisions between purchasing different products. NSF is widely recognized worldwide and is therefore a potential candidate for proposing health based standards for certifying POU water treatment technologies.

According to First Water® Ltd, NSF/ANSI Standard 53 only covers cysts and does not cover standards for bacteria or virus removal.[13] A recent NSF newsletter makes reference to the development of safe water standards for microbiological treatment technologies[39]. The standard will apparently be a revision of the current NSF/ANSI 55 Standard, which covers ultraviolet microbiological water treatment systems.

First Water® Ltd. also has a grading system whereby filter units are graded A through C based on their log-reduction value (LRV) of microbial organisms.[7] Grade A filters are the best with LRV > 6. Grade B ranges between LRV = 4 and 5 and Grade C LRV = 2 and 3.

Based on the US EPA guide and First Water® Ltd.'s grading method, the following testing procedures for evaluating filter performance, and possibly certifying a filter in the future, is presented for further consideration. Ideally, the next step would be for the emerging Household Water Treatment System Network[a], or some sub-committee thereof, to agree upon a standard, and/or for an organization such as NSF International to define a method for certification.

The choice of parameters to measure depends on the purpose for which the filter is being utilized. For the ceramic water filter being considered in this thesis, the primary goal is to remove microbial contamination. Thus, microbial removal and flow rate are chosen as preliminary performance parameters.

7.2.1.1 Microbial Performance

The microbial reduction requirements suggested by the US EPA in their guide for water purifiers are presented in Table 7.2. The basis for these values is discussed in the EPA guide.[61]

[a] The Household Water Treatment System Network is a public private partnership, coordinated by the World Health Organization.

Table 7.2: Suggested US EPA Microbial Reduction Requirements for Water Purifiers[61]

Organism	Influent Challenge	Minimum Required Reduction	
		LRV	%
Bacteria: Klebsiella terrigena	10^7/100 mL	6	99.9999
Virus: a. Poliovirus 1 (LSc)	10^7/L	4	99.99
b. Rotavirus (Wa or SA-11)	10^7/L	4	99.99
Cyst (Protozoan): Giardia muris or Giardia lamblia	10^6/L	3	99.9

Log Reduction Value (LRV) was defined in Equation 3.2, and is presented here for reference:

$$LRV = Log\ \mathrm{Re}dction\ Value = Log_{10}\left(\frac{untreated}{treated}\right) \qquad \text{Equation 3.2}$$

Where,

untreated = concentration of organism in untreated water (usually # cfu/100 mL)

treated = concentration of organism in treated water (usually # cfu/100 mL).

Note that the equation is not valid if the concentration of organisms in the treated water is measured as 0 cfu/100 mL. For cases when this occurs, a value of 1 cfu/100 mL should be used.

Microbial removal is often reported as percent-removal efficiency, as was defined in Equation 3.3. For reference, percent-removal efficiency is defined as:

$$\%\ \mathrm{Re}moval = \frac{(untreated - treated)}{untreated} \cdot 100\% \qquad \text{Equation 3.3}$$

Where,

untreated = concentration of organism in untreated water (usually # cfu/100 mL)

treated = concentration of organism in treated water (usually # cfu/100 mL).

The results for this value should correspond to the % removal efficiencies recorded in the last column of Table 7.2. In particular, the number of significant figures is absolutely critical to properly reporting the % removal of microbial contamination. It is best to include the untreated concentration value along with the % removal efficiency just to clarify the accuracy of the value that is reported.

Using LRV (Equation 3.2) to report microbial reduction efficiency is recommended over using % removal efficiency simply due to the problems associated with reporting % removal values to the correct significant figure. For example, a lot of the literature reports 100% removal efficiency, which is simply unrealistic both in theory and practice.

First Water® Ltd.'s grading system for water purifiers in terms microbial reduction efficiency, as well as a number of other performance parameters, is presented in Table 7.3.

Table 7.3: The First Water® Ltd Grading System for Water Purifiers

Grade Level	LRV	Bacteriostasis	Quality Control	Capacity (Liters)	Candle Cost ($US)
A	>6	Impregnated Silver	Total	50,000	9-10
B	4-5	Coated Silver	Some	12,500	2-3
C	2-3	None	None	5,000	1

As an example of the results for a Grade C filter:

Example 1:

- Microbial concentration in untreated water = 1,500 cfu/100 mL
- Microbial concentration in treated water = 5 cfu/100 mL

$$LRV = Log_{10}\left(\frac{untreated}{treated}\right) = Log_{10}\left(\frac{1500}{5}\right) = 2.5$$

Example 2:

- Microbial concentration in untreated water = 1,500 cfu/100 mL

- Microbial concentration in treated water = 0 cfu/100 mL

$$LRV = Log_{10}\left(\frac{untreated}{treated}\right) = Log_{10}\left(\frac{1500}{1}\right) = 3.2$$

From these examples, one can see that the order of magnitude of the microbial concentration in the untreated water dictates the upper limit of the LRV. A 3-order microbial concentration (1000-9999 cfu/100 mL) at best will show an LRV of 4.0 (3.999). Similarly, a 2-order microbial concentration (100-999 cful/100mL) at best will show an LRV of 3.0 (2.99). Therefore, to demonstrate that a filter is a Grade B filter requires the microbial concentration in the untreated water to be greater than 10,000 cfu/100 mL[a].

The US EPA guide outlines the certification test procedures in detail. Readers interested in performing these tests are encouraged to download a copy of the procedures from the First Water® Ltd Website at:

First Water® Ltd website: http://www.firstwater.info/noflash/td_test_certify.html

United States Environmental Protection Agency. **Guide Standard and Protocol for Testing Microbiological Water Purifiers**. Registration Division, Office of Pesticide Program, Criteria and Standards Division, Office of Drinking Water. Revised April 1987.

In summary, the US EPA suggested methodology for testing microbiological water purifiers to determine their microbial reduction efficiency as per Table 7.2 is presented below.[61]

1. 3 Units be tested simultaneously for 10 ½ days
2. The test water be prepared to specified standards as described below. For filters with colloidal silver, three test water samples are required:
    a. General test water
        - pH: 6.5-8.5,
        - Total organic carbon: 0.1-5.0 mg/L
        - Turbidity: 0.1-5 NTU
        - Temperature: 20°C +/- 5°C
        - Total dissolved solids (TDS): 50-150 mg/L

[a] It is important to reiterate that this section is on certification and the results from testing would reflect laboratory conditions. The next section discusses REAL world conditions or field conditions, where microbial contamination, for example, will vary greatly and user behavior influences overall filter performance.

b. Challenge test water

- pH: 9.0 +/- 0.2,
- TOC: > 10 mg/L
- Turbidity: > 30 NTU
- Temperature: 4°C +/- 1°C
- TDS: 1500 mg/L +/- 500 mg/L

c. Leaching test water for units containing colloidal silver

- pH: 5.0 +/- 0.2,
- TOC: ~1 mg/L
- Turbidity: 0.1-5 NTU
- Temperature: 20°C +/- 5°C
- TDS: ~100 mg/L

3. The guide recommends a sampling plan where challenge tests begin on day 7. See Section 3 of the guide. The guide also recommends a separate 3-day test of colloidal silver concentration using the leaching test water.

Some additional notes that the guide makes with respect to ceramic filters:

- Samples that are collected for analysis should be immediately treated to neutralize any residual disinfectant. For silver-based disinfectants, the guide recommends using thioglycollage-thiosulfate neutralizer solution. *"All results are invalid unless samples are neutralized immediately upon collection."*[61]
- Two cleanings of the filter should be performed according to the manufacturer's directions. No cleaning should be done near the time of microbiological sampling.
- The geometric mean of all microbiological reductions must meet or exceed the LRV requirements of Table 7.2 for no less than 10% of the total number of samples. See the guide for specific instructions on how to determine if the results meet the requirements.
- The lifespan of the filter must be clearly indicated by the manufacturer.

The standards for certification should be strict, but not too strict to impede people from developing POU technologies. Consistency in terms of evaluating performance is more important than having to necessarily meet strict drinking water quality guidelines or standards. The US EPA's required LRV values presented in Table 7.2 are strict (and well-justified in the guide), but possibly too strict for some of the POU treatment technologies being developed for developing countries. Thus, a grading system such as that proposed by

First Water® Ltd in Table 7.3 is a possible remedy to relaxing the guidelines slightly and to encourage the development of POU treatment technologies.

7.2.1.2 Flow rate

Flow rate is an important performance parameter for two reasons. Firstly, there is a minimum flow rate required to provide the basic human requirement of 7.5 L/person/day, which is based on estimates of requirements for lactating women engaged in moderate physical activity in above average temperatures.[27] Thus, at a bare minimum, a filter should have a flow rate of 1 L/hr such that over an eight hour period (say overnight), 7.5 L of water will be treated. For practical purposes and based on the literature on ceramic water filters, 1-4 L/hr seems readily achievable and should be held to a minimum standard.

Flow rates above 4 L/hr are relatively rare, although some of the literature reports flow rates in excess of 4 L/hr. For example, in his 2002 Master of Engineering thesis, C.S. Low measured flow rates for the TERAFIL Indian disk filter as high as 6.9 L/hr, and this was achieved *without* sacrificing microbial removal efficiency.[35]

At some point, the flow rate will become too high to substantiate efficient removal of microbial contamination through physical means (i.e. filtration). A measure of abnormally high flow rate is usually a good indication of cracks or breaks in the filter media and/or seal with the filter system. Thus, setting the maximum allowable flow rate for a filter can be used as a quick method for quality control to ensure some level of reliability in terms of microbial efficiency.

Two pieces of information should be reported along with the calculation of flow rate:

1. The dimensions of the filter element
2. The recorded water-column height throughout the experiment – in particular, if it changes with time or whether it is held constant.

The flow rate for a filter should ideally be reported in terms of a constant column height of water so that an average value can be calculated. If the water column height is allowed to decrease over time, then the flow rate will obviously decrease as well making it difficult to calculate a representative flow rate value. Thus, ideally, flow rates should be reported for conditions where the water-column height is held constant.

On a final note, it may be beneficial in the future to propose a flow rate grading system similar to the First Water® Ltd. microbiological grading system introduced in Table 7.3, for the sake of comparing the efficacy of different POU water treatment technologies. Some technologies, for example, might have a relatively low microbiological grade (i.e. say a Grade C), but could have a high flow rate, thus providing some benefits in terms of water quantity.

7.2.1.3 Other Parameters

The decision to include additional parameters for testing depends on the purpose of the filter and the conditions under which it is being tested. This thesis has focused on the development of a ceramic water filter for reducing microbiological contamination. Arsenic filters, which often use a relatively porous ceramic filter to remove coagulated arsenic, are an example where the parameter of importance would be arsenic as opposed to microbiological contamination. Turbidity is another parameter that is often measured along with microbiological contamination, especially in the field during rainy seasons when water turbidity is high. The WHO water quality guideline for turbidity is 5 NTU[65].

7.2.2 Field Testing

The previous section outlined a procedure for certifying a ceramic water filter. Certification may be done periodically to ensure a filter is performing to well-defined standards <u>under laboratory conditions</u>. Once certification has been completed, the filter system is ready for a period of ongoing field testing.

Field testing is slightly different since one is testing for the performance of the filter under actual-use conditions. Field testing methodology should follow standard methods as applicable to the field conditions under which testing takes place. For example, MIT students have been using portable Millipore Membrane Filtration units when conducting field tests in Nepal and Nicaragua and have performed *E.coli*, fecal coliform, and total coliform tests.

Whether or not test results should be reported in terms of LRV (Equation 3.2) or percent removal (Equation 3.3) is up for debate. Considering field conditions often yield low microbial counts (less than 100 cfu/100 mL) means that LRV values will be less than 2; possibly misrepresenting the “grade” of the filter. Thus, reporting results in terms of percentage removal *along with reporting of the source/contaminated water microbial concentration* may be the most representative way of reporting field test results. The latter reading of source concentration is often left out, which can result in misleading interpretations of results[a]. The LRV method could also be used along with reporting of the source/contaminated water microbial concentration.

Aside from evaluating the technical performance of filters in actual-use, field testing can reveal many non-technical behavior-based issues that are arguably just as important in terms of measuring “performance” of a filter system, or, more specifically, finding the root causes for why the filter system is not performing to the standards that were achieved during certification. This is particularly relevant for the developing country context since users are so intimately involved in the treatment of their water. The success of a ceramic water filter in the home, for example, depends on the user’s acceptance of the technology as well as behavior with respect to filter maintenance and general hygiene around the filter system.

Thus, field testing requires more than just measuring the technical performance of a filter system if the reasons for the results are desired. It is useful to consider both technical performance of the filter system and user behavior as separate, yet interdependent, factors that lead to an improvement or deterioration of human health, as affected by the quality of the drinking water. The interconnections between human health, technical performance, and user behavior are demonstrated in Figure 7.6 as performance gaps. The technical and behavior gaps are defined in terms of the difference between an ideal state, or goal, and the actual state that is measured. A gap then leads to action, which is directed at changing the actual state to meet the intended goal and to eventually close the gap. Some factors that can affect user behavior, like education/awareness and product design, are listed in the figure. Monitoring and evaluation is the activity that drives this process of improving overall product performance and, more importantly, human health over time.

[a] A good example of this is reporting “100%” removal when the source/contaminated water concentration is say 100 cfu/100 mL.. As was discussed in 7.2.1.1, realistically it is not possible to achieve 100% removal efficiency.

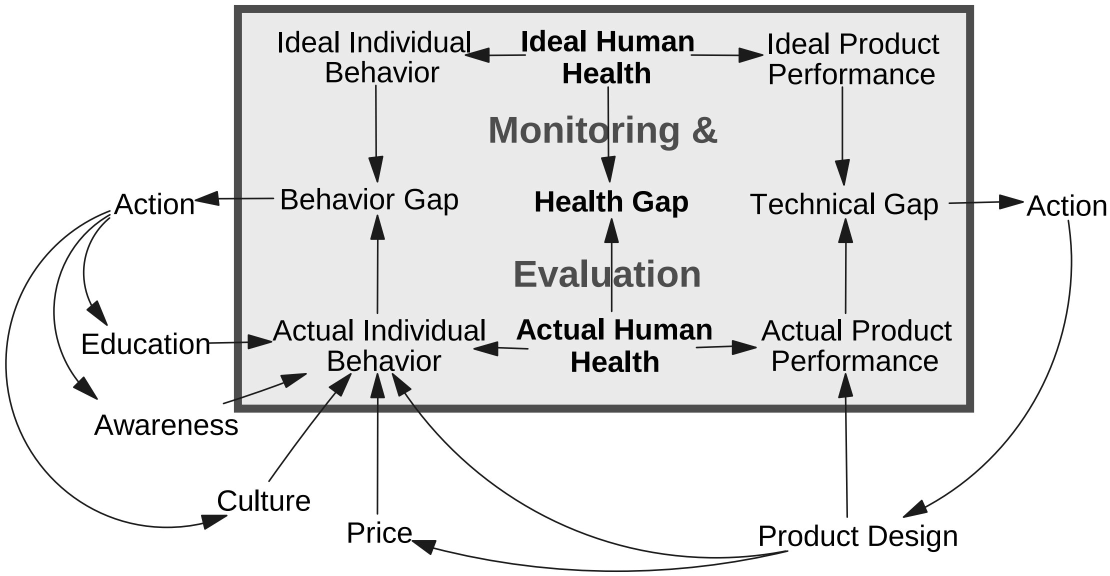


Figure 7.6: Closing the Behavior and Technical Gaps Associated with Using Point of User Technology to Treat Drinking Water

7.3 Preliminary Financial Analysis

A ***preliminary*** cost analysis is presented in Table 7.4 as a *rough* estimate of the cost to produce a single complete ceramic disk filter system. The cost estimate is for a generic disk filter system. It is based on research conducted in January 2003 as well as a cost analysis of the Potters for Peace Filtron provided by Ron Rivera.[46] A better estimate will be possible once Lily Cheung's working prototype is completed in May, 2003.

The total wholesale cost of a complete system is estimated at 475 NRs ($6.21 USD). A 15% retail markup equates to 546 NRs ($7.14 USD) (Table 7.4).

Table 7.4: *Preliminary* Cost Analysis

Part	NRs	USD	% Total Cost	Estimates based on:
Filter Disk				
Filter Disk	40	$0.52	8.4%	Hari's estimate
Colloidal Silver	10	$0.13	2.1%	PFP[1]
Sub Total	50	$0.65	10.5%	

Filter System				
Top Bucket	80	$1.05	16.8%	Cost of simple bucket in market
Bottom Bucket	80	$1.05	16.8%	Cost of simple bucket in market
Seal/Cartridge	80	$1.05	16.8%	Estimate
Lid	20	$0.26	4.2%	Cost of simple lid in market
Spigot	80	$1.05	16.8%	PFP*
Assembly/Labor	45	$0.59	9.5%	PFP*
Shipping	30	$0.39	6.3%	PFP*
Packing	10	$0.13	2.1%	PFP*
Sub Total	425	$5.56	89.5%	
Disk Filter Sub Total	50	$0.65	10.5%	
Wholesale Cost	**475**	**$6.21**	**100%**	
Markup (15%)	71	$0.93		Pokhara Retailers
Retail Price	**546**	**$7.14**		

PFP* = Potters for Peace Filtron cost estimate provided by Ron Rivera[46]

76.5 NRs = $1.00 USD

The estimate of the filter disk is based on Hari Govinda Prajapati's estimate of how much it would cost to manufacture a grog disk filter like Reid Harvey's grog disks. Hari's white candle filter currently costs 35 NRs. Manufacturing a grog disk takes longer than what it would take for manufacturing a disk filter made of clay, combustible material, and water since the grog has to be manufactured first. The disk requires less material than the candle filter (to get the same flow rate as was discussed in Section 4.5), so it is conceivable that the cost of a non-grog disk could be more along the lines of 20-30 NRs.

Costly items include the container systems and spigot. The cost of a typical 10-15 L bucket that can be purchased in marketplaces throughout Nepal is roughly 80 NRs. It may be possible to reduce the costs of the container systems through mass production and or using a cheaper plastic material or perhaps using ceramic containers instead.

The cost of the seal/cartridge, which is one of the most critical design parameters, is probably the most uncertain cost estimate. The seal issue was discussed in Section 7.1.4. The estimate is probably low considering the system may require some additional features to ensure a proper seal (like latches, for example). Cementing the disk into the cartridge is probably the cheapest alternative, but possibly the most susceptible to problems with respect to the seal breaking.

A more drastic measure to reduce costs would be to eliminate the spigot and replacing it with a length of rubber hose and a clamp for clamping off the hose. The cost of a piece of rubber tubing is probably no more than a quarter of the estimated price for a spigot.

If the cost of the disk filter element can be reduced to 25 NRs; the containers to 50 NRs each; and the spigot to 50 NRs, then the total wholesale cost would come to = 370 NRs ($4.84) and retail price to 426 NRs ($5.56). This is still above the willingness to pay (300 NRs or ($3.92 USD)) of the poorest families that we interviewed. Most of the other families we visited were willing to pay more provided the system made a difference (Section 0).

Chapter 8 Bringing a Product to Market

The development of a business or marketing plan for the current prototype is beyond the scope of this thesis. Furthermore, it is too early to develop a thorough business and marketing plan at this stage since the current Lily Filter prototype has yet to be tested either in the laboratory or field. Nevertheless, the concept of a business and marketing plan is presented in this section with some general comments on the steps that an entrepreneur can take to bringing a ceramic water filter to market. In particular, some comments on marketing strategies are presented below.

8.1 Business Plans

A business plan is a useful tool for any entrepreneur intending to bring a ceramic water filter product to market and/or managing an existing filter technology; regardless of whether the entrepreneur operates as a not-for-profit organization or a for-profit venture. In short, a business plan is simply a tool for systematically evaluating a market and demonstrating to someone else how a product or service can meet the needs of that market. Quite often they are used to convince investors of the value of investing in a product or service, but they can also be used internally by organizations to help define and clarify strategic goals and operating procedures.

An example of a generic business plan outline is presented in Appendix 4[56]. In general, a business plan begins with an <u>executive summary</u> that summarizes the key points of the plan. The first few sections review the <u>industry, the company, and the potential market</u> along with a description of <u>the product(s) and or service(s)</u> that are proposed to meet the assessed needs of the market/customers. Following this, there will likely be some sections on the <u>economics and finances</u> of the proposed venture to demonstrate how the organization plans to remain stable financially through time. A <u>marketing strategy</u> will then demonstrate how the organization plans to market the product(s) and or service(s) to the potential customers. In the case of developing a ceramic water filter, it would also be useful to have a section describing the <u>manufacturing and production plans</u> to demonstrate how and where the product will be manufactured and assembled. Furthermore, because there may be a number of partnerships involved in the development of a ceramic water filter product, it would be important to define the organizational structure and functional roles of each stakeholder along with any compensation arrangements that would need to be clarified. Lastly, potential risks and major assumptions should be identified.

Another useful template for marketing a product within a developing-country context is the Centers for Disease Controls (CDC) handbook on "*Safe Water Systems for the Developing World: A Handbook for Implementing Household-Based Water Treatment and Safe Storage Projects*".[4] The CDC's handbook follows along the lines of a business plan, with particular emphasis on marketing strategies and how to change behavior. This is relevant to developing a ceramic water filter for Nepal considering some of the unique behavior components of implementing such a system within the home.

The basic components of a marketing strategy (one aspect of the overall business plan) are outlined below with respect to marketing a ceramic water filter in Nepal.

8.2 Marketing Strategy

Chapter 6 presented an assessment of the need for clean drinking water in Nepal along with a preliminary consumer analysis. Indeed, the market research section of the business plan, where the market and potential customers are characterized, is one of the most important sections of the plan and should be one of the first tasks to complete. [56] The preliminary consumer analysis presented in Section 0, identified three primary users: urban users, rural users (accessible), and rural users (remote). These are very general user groups that need to be characterized in more detail and categorized into specific consumer groups. Once these groups are identified and characterized, then a marketing strategy can be customized to meet the needs of these target groups. For Nepal, it would be useful to identify specific villages to target when the ceramic water filter is first being tested in the field. A monitoring and evaluation program could then follow to provide feedback in terms of user behavior and user reaction to the product.

For now, the general components of a marketing strategy: product, price, distribution, and promotion are introduced along with some suggestions for future consideration when a thorough marketing plan is developed.

8.2.1 Product Strategy

A proposed product line strategy is presented below. This is a list of the products/spare parts that would be available to customers. These product(s) may be offered by a single organization or multiple organizations. For now, just a preliminary list of products is presented, without considering the organization(s) that would market/supply these products.

1. Provide **multiple filter system capacities**: small (15 L total capacity); medium (20 L total capacity); and large (30+ L total capacity).
2. Provide a **filter system that uses a ceramic disk filter** (i.e., the current prototype being developed)
3. Provide a **filter system that uses a candle filter**. The system should be as similar in shape and size as the disk filter system (i.e., the upper and lower containers should be identical; the only difference being the method for installing the filter element).
4. Provide **replacement disk** filter elements.
5. Provide **replacement candle** filter elements (primarily for legacy systems).
6. Provide **replacement parts** such as spigots, lids, connecting pieces, etc.
7. The upper and lower containers and lid should be made of high-quality, clear Polyethylene Terephthalate (**PET**) **plastic** or High Density Polyethylene (HDPE). Also consider using ceramic containers where appropriate, such as in the Terai where there are added benefits to keeping water cool by using a ceramic container as opposed to plastic. Be prepared to adapt a plastic version to a ceramic version if users reject using plastic.
8. Consider marketing water-purification products, such as Piyush[a] (liquid chlorine solution) that can be used in conjunction with the ceramic water filter to encourage a **multi-barrier approach** to water purification.

8.2.2 Price

The pricing strategy summarizes prices for the various products offered in the product line. For this thesis, a <u>preliminary</u> financial analysis of a disk filter system estimated the retail price for a complete system to be 546 NRs ($7.14 USD) (Section 7.3). This estimate will be refined

[a] ENPHO manufactures and markets Piyush as a disinfectant for treating drinking water for microbial contamination. Three drops of Piyush are mixed with 1 L of water and allowed to sit for 1 hour before consumption. ENPHO encourages using Piyush with candle filter systems – putting drops of Piyush in the upper container of a filter system. More information: www.enpho.org.

once a working prototype is brought to Nepal to determine how much it will cost to manufacture the complete filter system.

The urban poor that we visited in January 2003 indicated that they would be willing to pay no more than 300 NRs ($3.92 USD). The current price estimate is thus nearly double what the urban poor, who represent the lowest-income bracket of all groups that we surveyed, are willing to pay. Most of the other village groups seemed willing to pay more provided the product demonstrated tangible benefits.

One option to explore in terms of dealing with the price issue is to consider micro-financing schemes through a micro-financing lending institution like the Grameen Bank in Bangladesh[a]. The Grameen Bank provides small financial loans for income-generating ventures (highest interest rate), housing (medium interest rate), and education (smallest interest rate). The Bank grants loans without requiring collateral, such as land, to receive the loan. The process is based on mutual trust and the loan repayment rate is 98%, which, considering the perceived risk of lending to the poor, is quite remarkable.[16] In 2002, the bank had approximately 2.4 million borrowers, 95% of whom were women, which reflects the strong emphasis on engaging women as entrepreneurs.[16]

A number of companies that have spun off of the Grameen Bank use the micro-lending scheme and institutional network provided by the Bank to their advantage in terms of developing a business. For example, Grameenphone Ltd.[b] is a company that delivers cellular phone services to rural villages throughout Bangladesh. “Telephone-Ladies” take out a loan to buy the mobile phones, which they can then offer as a service in their home villages. Grameenphone Ltd. uses the existing network of people and channels provided by the Grameen Bank to find suitable entrepreneurs (women with good credit ratings), methods to collect bills, etcetera.

There are branches of the Grameen Bank in Nepal as well as other similar micro-finance institutions. In 1998, approximately 75 different organizations were providing micro-financing schemes to nearly 8.2 million people in Nepal.[5] The geography of Nepal poses significant challenges for micro-financing organizations to reach remote villages where the need is often

[a] Grameen Bank website: www.grameen-info.org
[b] Grameenphone Ltd.: www.grameenphone.com

the greatest. A good summary of the various micro-financing lending organizations in Nepal is presented on the Center for Micro Finance in Nepal webpage[a].

As another example, the Rural Water Development Program (RWD) in Western Kenya provides a pay-back system for customers who cannot afford to pay for the Kisii Water Filter Bucket (Section 2.3.5) in one installment. The customers pay for the filter system in small weekly installments until the filter system has been paid for by the user. RWD has noticed that users tend not to value the system as much if it is simply given away at a subsidized price. Thus, they insist on selling the filter at cost and help users pay for the system over time.

There may be opportunities to partner with a micro-financing lending institution to help finance the cost of a ceramic water filter system if it is beyond the immediate willingness to pay. The Grameen Bank, for example, expands its loan portfolio with customers over time to meet diverse development needs such as lending credit for building sanitary latrines, installing tubewells for supplying drinking water and supplying credit for leasing equipment and machinery.[16] Research on the potential for using micro-financing as a means to help market and promote a ceramic water filter is worth investigating further.

8.2.3 Production and Distribution

The production and distribution strategy describes how the product will be manufactured and distributed throughout Nepal. As a start to building this strategy, a list of the activities leading up to the sale of a filter system is presented in Table 8.1. Some examples of potential agents who would carry out the activities are also presented. For example, ceramists such as Hari Govinda Prajapati of Madhyapur Clay Crafts, would manufacture the disk filter while a plastics company would manufacture various parts for the filter system such as the containers and spigot.

There are numerous ways to organize how the product would be assembled and distributed. One method is to have the ceramist assemble and package the product and to then distribute the product to points of sale. Another method is to hire agents to assemble the product.

[a] Center for Micro Finance in Nepal: http://www.cmfnepal.org

In terms of packaging, the container system should be designed such that one of the containers fits into the other container. The various parts – spigot, filters, etc. – can then be placed inside the compacted container system for transportation.

Shipping and transportation will be a major issue considering the geography of Nepal and the poor transportation system. As was recommended by CeraMIT[10], the initial phase of taking the product to market would concentrate on marketing the product in villages close to Kathmandu. This could be tied in with a monitoring and evaluation program carried out as part of the field testing required to ensure that the product works properly under actual conditions. Later stages of the business would require some novel transportation solutions in order to move the product to some of the farther reaches of Nepal, such as the northwest. This is partly why plastic was chosen for the filter system since it is light to carry.

Table 8.1: List of Activities Leading to the Sale of a Filter

Activity	Responsibility	Example
Manufacture Disk Filter	Ceramist	Hari Govinda Prajapati of Madhyapur Clay Crafts
Manufacture Filter System parts	Plastics company & other manufacturers/suppliers	There are a number of plastics manufacturers within the Kathmandu Valley
Assemble Filter System	Ceramist, retailer, separate assembler/distributor…	Hari Govinda Prajapati
Transport Filter System	Assembler/distributor…	Tie in with established distribution networks…
Sell Filter System	Retailer, individuals/direct sale	Village women
Monitor & Evaluate Filter Performance	Government agencies, non-governmental organizations, academic institutions.	Environment & Public Health Organization (ENPHO), MIT

8.2.4 Promotion

The promotional strategy focuses on methods for marketing and selling the proposed product line. In the case of developing a ceramic water filter, this strategy could also tie in with a monitoring and evaluation program, as part of field testing, to gather pertinent information for developing the promotional strategy.

There are a number of unique challenges to selling the benefits of a ceramic water filter. For example:

- How to demonstrate to users the link between good health and clean water?
- How to convince potential customers that ceramic water filters can improve drinking water quality?
- How to quantify the health-related costs associated with poor drinking water quality and in turn, to justify the cost of a ceramic water filter system?

The CeraMIT team made a number of marketing recommendations[10], which have been slightly modified and elaborated on below.

Branding

CeraMIT recommended creating a strong brand name and/or image to market the product.[10] A brand name/image essentially embodies the characteristics of a product or service into a feeling or an emotion that is invoked upon recognition of the brand name or image. For example, Coca-Cola's bottled water products in Nepal are marketed with the comment "100% Trust" printed on the bottle. "Trust" is certainly an important factor to associate with a ceramic water filter product, considering the primary purpose of a filter system is to improve drinking water quality and in turn, human health. Finding a Nepali name or image that embodies trust would provide a good starting point for developing a brand name/image.

Certification

Certification could help to market a product to organizations that are familiar with the certification process. Many users may not recognize a certification body such as NSF International, but most of the larger aid organizations, such as UNICEF and the Red Cross, will. If these organizations become potential customers, as described in Section 6.4.2, then it would be beneficial to promote a product as being certified under an internationally-recognized organization like the NSF International.

Engaging Women in the Sale of Ceramic Water Filters

Women are the primary caretakers of water and so it makes sense to focus on women as important contributors to an overall marketing campaign. A successful model to consider is the Avon Model where women act as sales representatives, selling products directly to customers (primarily women) at the village level. The Grameenphone does this to some degree with "Telephone Ladies" who purchase cellular phones from Grameenphone and then offer phone services to customers in local villages. Similarly, "Water Women" could organize orders for ceramic water filters from villagers and then send in bulk orders to the nearest distributor/assembler. Water Women would be rewarded financially depending on the number of orders generated. They would be able to build on an existing network of family and friends. Furthermore, they could provide local support to users when maintenance/operational problems arise. For example, they could be trained on how to fix problems, ensure proper maintenance and use, and possibly to carry out simple presence-absence tests[a] as part of an ongoing monitoring and evaluation program. Whatever marketing strategy is used, women should be engaged as central facilitators of the strategy, considering the role women play in managing water at the household level.

Collaborating with Well-Established Networks/Campaigns

A lot of work has already gone into establishing networks for promoting national health and development campaigns. Well-established health and development-based campaigns should be considered as potential networks to tap into. Grameenphone, for example, used the existing Grameen Bank network of people to identify potential candidates for selling the phone services, to collect bill payments, etc...

As another example, part of receiving a loan from the Grameen Bank requires customers to participate in the "sixteen decisions" which are intended to help improve socio-economic conditions through education and awareness of such issues as health care, family planning, and, incidentally, water use. Decision Number 10 states that, "We shall drink water from tubewells. If it is not available, we shall boil water or use alum." (Figure 8.1). Partnering with an education and awareness program such as this would help to encourage customers to use ceramic water filters as another option.

[a] Presence-absence tests detect the presence or absence of hydrogen sulfide, a gas that is often generated by H_2S-forming bacteria. The presence of H_2S-forming bacteria serves as an indication of microbial contamination. If H2S is present, then the water sample will turn a dark color.

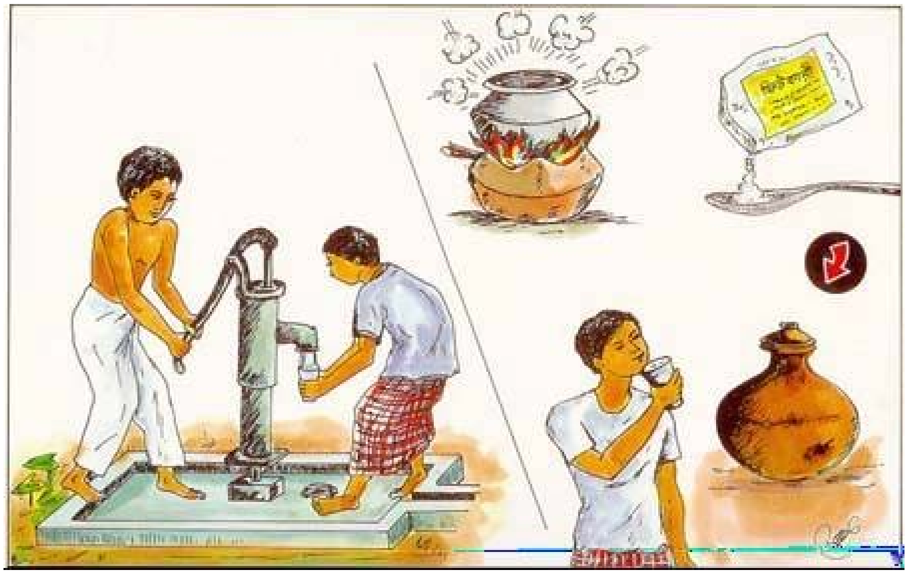


Figure 8.1: Grameen Bank Decision Number 10: "We shall drink water from tubewells. If it is not available, we shall boil water or use alum. "

Picture Source: Grameen Bank website: www.grameen-info.org

Demonstrating Benefits/Value: Health and Economic Savings

Arguably the toughest selling point of a ceramic water filter will be to demonstrate that it makes a positive contribution to the health and well-being of a family/individual. How does one sell the virtues of clean drinking water when it is difficult to demonstrate the link between water quality and human health, let alone to actually quantify this link?

One direct method of demonstrating that water is unsafe to drink is to perform a simple presence-absence test of the raw water and the filtered water. If the presence-absence test is positive for the raw water, then it will turn black indicating the presence of H_2S-forming bacteria, which are indicators of microbial contamination. Comparing the presence-absence results for the raw water versus the filtered water would provide a visual indication of product performance.

Using clear plastic containers also helps to demonstrate the benefits of a ceramic water filter by visually demonstrating the improvement in the color of the water if the raw water is highly turbid (Figure 8.2).

Figure 8.2: Demonstrating Benefits: Turbid Raw Water and Clear Filtered Water

Picture Source: Tom Clasen, First Water Ltd. Doulton Candle Filter, Bolivia

Furthermore, it will also be important to demonstrate the economic savings of having a water filter. For example, data on the health costs associated with waterborne diseases, such as diarrhea, would be useful marketing information. Lastly, cost savings associated with not having to boil water would also help make the case for water filters; although most people cannot afford to boil their water.

Chapter 9 Conclusions

Countries like Nepal face tough challenges in terms of providing safe, clean drinking water for their citizens. Centralized water supply systems may be a solution in the long-term, but the immediate need for clean drinking water necessitates new approaches that can provide solutions and solve the crisis now. Household water treatment technologies, such as ceramic water filters, offer a potentially viable solution to providing clean drinking water by treating water at the point-of-use. Advancements in low-cost ceramic water filter technology coupled with the pressing need for clean drinking water offers an attractive business opportunity for local Nepali entrepreneurs – especially local ceramists who have the resources and capability to manufacture ceramic water filters.

The first section of this thesis, Chapters 2 through 4, provided a comprehensive overview of ceramic water filter technology, including some recent laboratory tests performed on disk and candle filters in Nepal (Chapter 3), and the production processes involved in the manufacturing of ceramic water filters (Chapter 4). The last sections, Chapters 5 through 8, provided a guideline for bringing a prototype to market. In particular, Chapter 6 assessed the current needs for drinking water in Nepal and presented a preliminary consumer analysis. Chapter 7 provided an overview of the development of a prototype and Chapter 8 concluded with a brief introduction to the components of a business plan and some market strategy ideas to consider in the future. In summary, the information and research compiled in this thesis provides a basis for future work on developing a ceramic water filter for Nepal.

A number of relevant conclusions can be drawn from this thesis.

9.1 Laboratory Test Results

Three different types of disk filters and five types of candle filters were tested for microbial removal efficiency and flow rate. Based on microbial removal efficiency and flow rate, the most promising filter elements that were tested were the Katadyn® drip filters (Ceradyn and Gravidyn); the modified-Hari Govinda candle filter coated with colloidal silver; and the Reid Harvey red-clay grog disk filter coated with colloidal silver. All four filters had comparable flow rates ranging from 650 to 800 mL/hr/filter. The microbial log-reduction value (LRV) for all three candle filters was 1.9 for total coliform and 1.7 for *E.coli*, given a raw water total coliform concentration of 89 cfu/100 mL and *E.coli* concentration of 56 cfu/100 mL. The LRV for Harvey's disk filter was 2.6 for total coliform and 2.9 for *E.coli*, given a raw water total coliform concentration of 2,500 cfu/100 mL and *E.coli* concentration of 1,561 cfu/100 mL. No conclusions can be drawn comparing the three candle filters to the one disk filter since different raw-water microbial concentrations were used; however, these four filters offer a starting point for future product development and research.

The results support the hypothesis that colloidal silver acts as a bactericide and aids in the inactivation of indicator microorganisms such as total coliform and *E.coli* bacteria; howver, more testing is required to determine the effectiveness of colloidal silver over longer periods of time (greater than one day) and after repeated usage of the filter system.

9.2 Theoretical Flow Rate Calculation

The theoretical flow rate through a disk filter was compared to the theoretical flow rate through a single candle filter with equivalent surface area and volume (Equation 4.2 and Equation 4.3). The theoretical flow rate through the disk filter is greater than the theoretical flow rate through the candle filter for a given surface area/volume of material and height of water above the base of the upper container (constant head). Thus, a disk filter is more efficient, or economical, in terms of flow rate per unit surface area or volume of material used (*in theory*). This result supports the decision to develop a disk filter prototype by the CeraMIT team and Lily Cheung.[6,10]

9.3 Prototype Development

Four prototype designs were discussed and one prototype design, the Lily Filter, has recently been fabricated.[6] A preliminary financial analysis of the cost and price of a ceramic disk filter was completed. The estimated cost of manufacturing a ceramic disk filter is 475 NRs (USD $6.21) and the estimated price, with a 15% markup, is 546 NRs (USD $7.14 USD). The price is nearly double the willingness to pay of the poorest urban group (300 NRs, USD $3.92) that our team interviewed in January 2003. The financial estimate will be improved once a physical prototype is brought to Nepal to get accurate production cost information from plastics manufacturers and ceramists.

Chapter 10 Recommendations

The following recommendations are intended to help guide future work on the development of a ceramic water filter for Nepal. A schedule of tasks is presented in Appendix 5 and discussed in Section 10.9.

10.1 Colloidal Silver Research

More research is needed to determine the effectiveness of colloidal silver over time. In particular, how does colloidal silver physically and/or chemically remain within the filter element, how does it bio-chemically inactive microorganisms, and how long does it remain active? Further studies by a student in the MIT Chemistry Department, Chemical Engineering, and/or Environmental Engineering is recommended.

10.2 Colloidal Silver Production Process

Colloidal silver is not commercially available in Nepal to our knowledge; however, a centuries-old metal working craft industry is well established. There will be a need to either produce colloidal silver locally or to import it from elsewhere if it is further proven effective as a disinfectant for use in ceramic water filters. The production of colloidal silver should ideally be done by a laboratory or an organization that is capable of managing the quality of the colloidal silver that is produced.

10.3 Ceramic Media/Material Research

More research is needed to understand how the ceramic filter element works on a microscopic level. In particular, what mechanisms lead to an effective filter element that reduces microbial contamination while still maintaining an acceptable flow rate? This research should tie in with the ceramic filter production process, to understand how material characteristics (i.e.: clay and combustible material) and production procedures (i.e.: material preparation, material mixtures, and firing) affect filter performance. For example, to what extent does the ceramic material vitrify during the firing process and how does this level of vitrification affect filter performance in terms of microbial removal efficiency and flow rate?

Further studies by a student in the Department of Materials Science and Engineering are recommended.

10.4 Hydraulic Studies

Erikson[33], Lantagne[33], and Fahlin[12] have conducted hydraulic studies of the Potters for Peace Filtron filter. In particular, the authors were interested in determining the hydraulic conductivity and tortuosity of the Filtron. It would be useful to extend the theoretical flow rate equations derived in Section 4.5 to the research conducted on the PFP Filtron. This research would tie in with the research on material/media properties (Recommendation 10.3) to understand the pore structure, hydraulic conductivity, permeability, tortuosity, and overall hydraulics of both disk and candle filters.

10.5 Product Certification

There is currently no method for certifying low-cost point-of-use water treatment technologies such as ceramic water filters. An international organization, such as the National Sanitation Foundation International (NSF), should develop such standards or MIT should collaborate with other organizations, such as the Household Water Treatment System Network, to develop a global standard. The standards for removal of microbial contamination could be based on the US Environmental Protection Agency (EPA) draft guideline for water purifiers[61] (developed in 1987) as well as a grading system that has been proposed by First Water® Ltd (Table 7.3). A certification and grading system would provide a benchmark for assessing and comparing the effectiveness of different POU treatment systems under controlled laboratory conditions.

10.6 Field Testing

Just as certification is important for ensuring a level of product quality, field testing is equally important in terms of understanding the effectiveness of a POU treatment system under normal household conditions. Field testing of the current prototype is absolutely necessary and should be carried out once the prototype is ready to be taken to the field. Such field testing by Master of Environmental Engineering students in the Department of Civil and Environmental Engineering is recommended.

It would also be useful to perform laboratory tests on the prototype – as per the certification process proposed by the US EPA in 1987 – prior to taking the prototype to the field. In the future, the procedure for testing a ceramic water filter should begin with certification, and then move on to continual field testing with periodic certification testing. Not only will field testing provide feedback on user behavior and acceptance of the technology, but it will also provide information on long-term technical performance.

10.7 Prototype Development

A prototype ceramic water filter system (all components except for the filter element) has been designed by Lily Cheung[6] of the Mechanic Engineering Department at MIT. The next step is to test the Lily Filter system; focusing particularly on the effectiveness of the seal formed between the filter disk element and the filter system cartridge. A proper seal between the disk and the filter system is one of the most critical design challenges to overcome with the decision to go with a ceramic disk filter system.

Once a working prototype has been completed, then the prototype can be brought to Nepal as well as other project sites. The benefit of having a working prototype is that it can be used to test various ceramic disk filter media that are being developed by local ceramists. MIT students could request ceramists to make disks of a certain size that would fit into the prototype. Such a prototype would save a lot of time having to build custom filter systems to house the disk filters for testing. Furthermore, it would provide a method for consistently testing different filter media compositions.

10.8 Ceramic Filter Element/Media

MIT has yet to develop, or choose, a ceramic filter element to go with the complete filter system. Preliminary laboratory tests on three different ceramic disk filters and five candle filters showed favorable results, but more testing by future Master of Environmental Engineering students is recommended. Based on the laboratory results, the most promising locally-produced filter elements are the Hari Govinda Prajapati white clay candle filters (capped on both ends) coated with colloidal silver and the Reid Harvey red-clay grog disk filters also coated with colloidal silver. Thus, future testing in Nepal should begin with these two filter media designs. Continuing to partner with Mr. Prajapati, owner and managing director of Madhyapur Clay Crafts in Thimi Nepal, on developing a ceramic disk filter is recommended considering MIT has now worked with Mr. Prajapati since 1999.

10.9 Future Work: Project Schedule

A recommended schedule of project tasks is presented below along with a Gantt chart in Appendix 5. The recommended schedule of tasks is geared for the MIT Nepal Water Project and thus the timing of tasks reflects the academic terms in which students will be available to complete the required tasks. There is some room to shorten the schedule length if more students are available to do the work; a long-term student commits to the project (i.e., a PhD student); and/or MIT collaborates with external organizations to help carry out the work. For example, there is a large gap during the end of 2004, where we would have to wait until returning to Nepal in January 2005 to work with plastics manufacturers/suppliers to make the first round of products in preparation for field testing. This activity could potentially start in April 2004 with the aid of an organization in Nepal.

10.9.1 Complete Certification Protocol and/or Grading System

Goal: December 2003

Aim to have a procedure or guideline for objectively assessing the “Grade” of a filter in terms of removal of microbial contamination under laboratory conditions as per First Water® Ltd.’s Grading System (Table 7.3) and the draft version of the US EPA Guide for certification of water purifiers (Section 7.2.1). Having a procedure provides a method for objectively assessing and comparing the technical merits of different filter media. Ideally, the emerging Household Water Treatment System Network, or some sub-committee thereof, should agree upon a standard, or, an organization such as NSF International would define a method for certification. In the meantime, develop our own in-house system based on the First Water® Ltd. grading system and the US EPA Guide.

10.9.2 Complete Final Prototype Design

Goal: December 2003

Aim to have a working prototype with design drawings ready to be taken to Nepal in January 2004. The current Lily Filter needs to be evaluated, tested, and then possibly modified before being taken to Nepal to be tooled at a local plastics manufacturer. It is highly recommended that another graduate student continue the work of Lily Cheung to ensure this is completed by January 2004.

10.9.3 Complete Prototype Financial Analysis

Goal: January 2004

Once in Nepal, contact local plastics manufactures and potential parts suppliers to complete a financial analysis of the proposed filter system design. Collect information on the costs of different parts/methods for production so that the design can be modified accordingly if necessary. For example, find out the cost of manufacturing different shapes or designs to determine how costs could be reduced.

10.9.4 Prepare for Field Testing

Goal: January 2004

Aim to locate one to three villages/consumer groups that will be used for the first round of field testing that will begin in January 2005 (Task 10.9.8). Collect demographic information and other relevant data to prepare a proper monitoring and evaluation plan (See Task 10.9.8).

10.9.5 Preliminary Filter Element/Media Testing

Goal: January 2004

The purpose of this task is to work with Hari Govinda Prajapati of Madhyapur Clay Crafts to develop two or three different filter elements for testing (1 candle filter and 1-2 disk filters). Contact Mr. Prajapati in November so that he can have some filter designs ready when students arrive in early January. Some refinements to the designs may be required over the course of January, so be prepared to do one or two production runs with Mr. Prajapati. Suggested filters to begin testing:

- A candle filter capped on both ends and coated with colloidal silver (i.e., like the Hari candle filters tested this year – Section 3.2.)
- An up-to-date version of one or two of Reid Harvey's grog disk filters (i.e., like the red grog disk filter tested this year – Section 3.2 .)

The first test should consist of a simple flow rate test. Discard any filter designs that do not pass an initial flow rate test as per Section 7.2.1.2.

The second test should be a 1-day test for removal of microbial contamination. Follow a similar procedure as outlined in Chapter 3 of this thesis, but use a minimum raw-water microbial concentration of 1000 cfu/100 mL. Ideally, try 10,000 cfu/100 mL to determine where the filter might fall within the grading system proposed by First Water Ltd. (Table 7.3).

Choose the 2-3 best filter designs and bring duplicates or triplicates back to MIT for testing as per Task 10.9.6.

10.9.6 Filter Element/Media Laboratory Testing

Goal: February – April 2004

Perform laboratory tests on the filters brought back from Nepal.

Microbial Reduction & Colloidal Silver:

- 5-10 day continuous test
- Try to follow the guidelines proposed by the US EPA (Section 7.2.1.1) as closely as possible – at least try to follow the general concept. Ideally, the test would be performed over 10.5 days, but this may be too arduous for one student to do.
- Test for total coliform, *E.coli*, and the presence of colloidal silver.
- The raw water concentrations should ideally exceed 10,000 cfu/100 mL to determine the grade of the filter as per First Water® Ltd.'s proposed grading system (Table 7.3). Removal of 10,000 cfu/100 mL, for example, would result in an LRV of 4, putting the filter into Class B.
- Measure the concentration of colloidal silver in the filtered water to determine how it changes over time.

Flow Rate:

- 2-day test, which can be done before and/or after the microbial tests.
- Day 1: prime the filters by filling the upper container with water and allowing the filters to operate for one full day.

- Day 2: fill the upper container to a specified column height and then maintain this column height throughout the 6-hour experiment. Measure the volume of water that enters the lower chamber at 1-hour increments for 6-hours total (or longer if possible).

10.9.7 Recommend Complete Filter Design

Goal: April 2004

Aim to have a recommended design by the end of April 2004. This will include both a recommendation for the filter system and the filter element.

10.9.8 Complete Field Testing Design and Implementation

Goal, Design: December 2004

Goal, Implementation: January – June 2005.

Aim to design a monitoring and evaluation program for testing the first round of filters in the field. This will be based on the information collected during January 2004 (Task 10.9.4). Based on the cumulative experience over several academic years of field studies in Nepal, Nicaragua, and Haiti and based on lessons learned about pilot study design by the Center for Disease Control Safe Water System, WHO, and others, develop a pilot project study design that is more rigorous, reproducible, and that incorporates technical and health-based performance parameters, social acceptability, and willingness to pay aspects. This plan may require an organization such as the Environment and Public Health Organization (ENPHO) to help carrying out the field testing, ideally over a period of six months.

10.9.9 First Production Run

Goal: January 2005

Aim to manufacture a small quantity of filter systems in preparation for field testing. Ideally, the filters could be manufactured after the recommended prototype design is completed in April 2004 (task 10.9.7), but this may have to wait until the MIT Nepal Water team returns to Nepal in January 2005. Another option is to work with an organization such as ENPHO or IDE-Nepal to manufacture the first batch of products.

10.9.10 Develop Business Plan

Goal: September 2005 Onwards

Investigate methods for transferring the technology and product(s) to a local entrepreneur. This would be a good opportunity to engage business students to help develop a business plan for the product(s). This process could begin in January 2005 along with the field testing. In some ways, however, it would be convenient to complete field testing before designing a business and marketing plan since the field testing would provide a lot of valuable feedback.

Appendix 1. Summary of Literature Review

Filter	Date	Reference	Flow Rate (L/hr/filter element)	Estimated Pore Size (micron)	Total Coliform (Raw Water Concentration (CFU/100 mL)/	E Coli	Fecal Coliform	Turbidity Removal (Raw Water NTU/% Removal)	Application of Colloidal Silver (CS)	Durability (Longevity)	Price	Notes
Indian TERAFIL	1999	2	2	1-5	>1100/>99%				No	5 years		Pore size - Khuntia, 2001; Longevity - Khuntia, 2001;
Indian TERAFIL	2001	3	2.6-3					60/98.3%	No			Tested TERAFIL's distributed in Orissa after a cycle during Oct 1999 - Mar 2000.
Indian TERAFIL	2000	1	1.8-2.5			N.A./93%-99%			No			Concluded that the TERAFIL cannot be recommended for appropriate inactivation of microbial contamination
Indian TERAFIL	N/A	12	2.7 Avg.		426-1300/95%-99%				No			Recommended that water be disinfected after filtration to ensure proper inactivation of microbial contamination. Was not confident in filter's ability to inactivate microbial contamination
Indian TERAFIL	2001	5	1-11 (5 Avg)				241/93%-96%	27/>99%	No			
Indian TERAFIL	2002	10	5.9-6.9		(222-14500) 7450/94%; 222/99.55%	(30-7000) 1425/80%; 880/99.89%	(56-6850) 1740/80%; 125/100%	38-70/97%-99%	No		$3.77	Cost - Low, 2002. This version of the TERAFIL, tested at ENPHO, showed flowrates between 5.9-6.9 L/hr without sacrificing microbial removal efficiency.
Indian TERAFIL	2001	10	1.1-1.9		(500-12333) 1000/95.3%; 8750/99.99%			2-4/53%-94%	No			
Red Terracotta Disk (Nepal)	2002	10	0.2-0.3		(625-1295) 625/89%; 1295/99.69%	(18-48) 28/96.43%; 18/100%	(15-43) 100%	3.4/57%-84%				Manufactured based on the PFP design
Red Terracotta Disk by Reid Harvey (No CS) (Nepal)	2003	4	0.85		2500/80.2%	1561/79.5%			No			
Red Terracotta Disk by Reid Harvey (CS)	2003	4	0.76		2500/99.8%	1561/99.9%			Yes			
Black Clay Disk by Reid Harvey (No CS) (Nepal)	2003	4	0.41		2500/99.6%	1561/99.8%			No			
Black Clay Disk by Reid Harvey (CS) (Nepal)	2003	4	0.34		2500/99.1%	1561/99.4%			Yes			
White Clay Disk by Hari Govinda (No CS) (Nepal)	2003	4	0.38		2861/99.2%	1550/99.3%			No			
White Clay Disk by Hari Govinda (CS) (Nepal)	2003	4	0.35		2861/100%	1550/100%			Yes			
Hari Candle Filter (Nepal)	2000	11	0.25-0.1 (0.18 Avg)		Presence/Absence tests were positive for both total coliform and E Coli. MPN tests for H2S-producing bacteria showed 3.9 MPN/100 mL with raw water > 8.8 MPN/100 mL.			14/94.3%			System + Candle (retail) $4.00-$6.00; Candle (retail) $0.72; System + Candle (wholesale) $2.75; System (wholesale) $1.83; Candle (wholesale) $0.46	Prices based on Sagara, 2000 except for the retail candle price which is based on CeraMIT, 2003. CS concentrations greater than 99 ppm reduced H2S-producing bacterial contamination below the detection limit of 1.1 bacteria/100 mL.

Filter	Date	Reference	Flow Rate (L/hr/filter element)	Estimated Pore Size (micron)	Total Coliform	E Coli	Fecal Coliform	Turbidity Removal (Raw Water NTU/% Removal)	Application of Colloidal Silver (CS)	Durability (Longevity)	Price	Notes
					(Raw Water Concentration (CFU/100 mL)/							
Hari Candle Filter (capped ends) (No CS) (Nepal)	2003	4	0.74		89/64.3%	56/99.7%			No			This candle filter is a variation of the candle filters tested by Sagara in 2000. Both ends are capped with a plastic cap.
Hari Candle Filter (capped ends) (CS) (Nepal)	2003	4	0.68		89/100%	56/100%			Yes			
Indian Bajaj Stainless-steel Ceramic Candle	2000	11	0.32-0.2 (0.26 Avg)		Presence/Absence tests were positive for total coliform and negative for E Coli. MPN tests for H2S-producing bacteria showed 1.6			14/96.2%			$7.84-$23.53 (600-1800 NRs)	12 cm height by 7 cm dia; price based on 3-candle system & CeraMIT research January 2003
Katadyn - Ceradyn Candle Filter (Switzerland)	2003	4	0.64		89/100%	56/100%						
Katadyn - Gravidyn Candle Filter (Switzerland)	2003	4	0.84		89/100%	56/100%						
Katadyn - Ceradyn	2002	7	1.33	0.2	Protection against bacteria, protozoa, and cysts					150,000 L or 2-3 Years	$190	
Katadyn - Gravidyn	2002	7	1.33	0.2	Protection against bacteria, protozoa, cysts, and chemicals					6 Months	$160	
Hong Phuc Candle Filter (Vietnam)	2003	6	0.6							4 Years	$5	
Vietnamese Hong Phuc Candle Filter	2003	4	0.3		89/65.4%	56/100%						
Potters for Peace Filters (Nicaragua)	2001	8	1.5-1.75	0.6-3	98-100% removal rate				Yes			
Potters for Peace Filters (Nicaragua)	2001	9	0.98		6% filters removed total coliform; 25% removed H2S-producing bacteria, and 53% removed E.coli			10/83%	Yes	Some were still in use after 7		

References

1 Birkhofer, B.H., Koster, W., Wagelin, M.. (2000) **Removal of Bacteria and Bacteriophages with the Help of the TERAFIL Filter Device**. Swiss Federal Institute for Environmental Science and

2 Council of Scientific & Industrial Research. (1999) **Laboratory Tests on TERAFIL**. Bhubaneswar, India.

3 Council of Scientific & Industrial Research. (May 2001) **Report on Performance of Terracotta Water Filters (fitted with TERAFIL) Distributed in Super Cyclone Affected Areas of Orissa During**

4 Dies, R., Jones, L.A., Perreault, S., Wilson, R.. (February, 2003) **CeraMIT Report of Activity for January 2003**. Massachusetts Institute of Technology. Cambridge, MA.

5 Environment and Public Health Organization (ENPHO). (2001) **Five Months Performance Trial of Home Based Filters - two sand filters and one TERAFIL filter**. Kathmandu, Nepal.

6 Hong Phuc brochure. (December 2002) Received December 2002.

7 Katadyn (www.katadyn.com); Black Mountain Stores (http://www.katadyn.net/katadyn_drip.html) and First Water (www.firstwater.org)

8 Lantagne, D.S.. (December 2001) **Investigation of the Potters for Peace Colloidal Silver Impregnated Ceramic Filter - Report 1: Intrinsic Effectiveness**. Alethia Environmental.

9 Lantagne, D.S.. **(November 18, 2001) Investigation of the Potters for Peace Colloidal Silver Impregnated Ceramic Filter - Report 2: Field Investigations**. Alethia Environmental.

10 Low, C.S.. (June 2002) **Appropriate Microbial Indicator Tests for Drinking Water in Developing Countries and Assessment of Ceramic Water Filters**. Master of Engineering Thesis. Department of

11 Sagara, J.. (May 2000) **Study of Filtration for Point-of-Use Drinking Water Treatment in Nepal**. June 2000. Master of Engineering Thesis. Deptartment of Civil and Environmental Engineering. MIT.

12 Shriram Institute for Industrial Research. (Undated) **Study of the Effectiveness of TERRACOTTA FILTER - A Household Water Treatment Device**. Delhi, India.

Appendix 2. Interviews with Experts

The Engineering-Sloan team CeraMIT conducted a number of interviews with experts while visiting Nepal in January 2003[10]. A brief summary of the feedback received during these interviews is presented below.

Nepal Red Cross Society and Japanese Red Cross Society

The International Red Cross is well known worldwide for its disaster relief and health education programs. The Nepal Red Cross works very closely with the Japanese Red Cross Society in providing these types of programs to the people of Nepal. Their feedback:

- The product should be: light, durable, inexpensive, and easy to carry.

Integrated Development Society (IDS)

IDS is a Nepali NGO, dedicated to improving the quality of life in Nepal by implementing sustainable community-based infrastructure development programs. Their feedback:

- Villagers will believe that saving money is more important than saving time.
- Target schools and persons of status as potential early adopters.

Gurkha Welfare Scheme (GWS)

GWS is a Nepali NGO that works to develop the home villages of retired Gurkha soldiers returning from careers in the British army. Mrs. Bhim Kumari Aale, director of the GWS Water and Sanitation division, provided expert insight into conditions in rural villages surrounding Pokhara. She confirmed that there is a problem with drinking water quality in the Hills, but that the main concern for most villagers is quantity, especially during the dry season. Her feedback:

- Partner with NGO's working on sanitation education
- Contrast the filter with boiling as the filter will require less time and fuel and therefore less money in the long run.

Mr. Poshan Nath Nepal

Mr. Poshan Nath Nepal is the former Secretary of the Ministry of Science and Technology. His feedback:

- People will accept the product if it is inexpensive, easily transportable, and effective at microbial removal.
- A disk shaped filter may be better due to a constant filtration surface area as well as being easier to transport.
- He estimates that at least 80% of villages are accessible by transportation.
- He also estimates the cost of boiling drinking water for the average Nepali family that uses electricity as a heat source is 600 NRs per year.

Department of Water and Sanitation Services (DWSS)

DWSS is the agency of the Nepali national government responsible for providing water and sanitation services to all of Nepal except for municipalities, which provide these services for their residents. Their feedback:

- Ram Mani Sharma informed us of a lime problem in the low Hills, which would result in a hard scale that could clog our filtration media.
- Thakur Pandit directed us to a village called Naikap where filters had been distributed by the Conserve Nepal NGO a few years ago. We visited this village to evaluate their current situation.

Ms. Mangala Karanjit

Ms. Mangala Karanjit is the Chief of the Information Division of the Melamchi Water Supply Development Board. She is also a member of the board of the Federation of Business and Professional Women and one of two lead organizers of the 1998 2nd Women and Water Conference held in Kathmandu. Her feedback:

- She expressed concern about the use of plastic. In traditional households during menstruation women are considered impure and everything they touch must be purified or discarded. Plastic could not be purified by flame; a metal container could.

- She also stressed the importance of ensuring that any gasket used with the filter should not react with chlorine, as city water supplies are chlorinated.

Professor Subodh Sharma

Dr. Sharma is a professor in the Department of Biological and Environment Sciences at Kathmandu University. He has developed a portable lab kit, allowing him to analyze water samples for numerous parameters in the field. He has conducted sampling in many areas of Nepal. His feedback:

- He estimates that 85% of the rivers and streams and 70-75% of the springs that he has sampled are contaminated.

- He suggested that sometimes villagers will not admit to breaking traditional practices (for example drinking collected rainwater), even though they do if they deem it necessary.

Appendix 3. Interviews with Villagers

The Engineering-Sloan team CeraMIT conducted a number of interviews with villagers while visiting Nepal in January 2003.[10] A brief summary of the feedback received during these interviews is presented below.

Kaun: Small Village near Pokhara

Kaun is a village of approximately fifty households near a new India-built hospital in the hills outside Pokhara. CeraMIT held a group discussion with nine women and two men, translated by Deepak Adhikari of IDE, and were accompanied by three members of IDE's Pokhara field office. Important information gathered during this visit:

- A typical 5 person family in Kaun uses 5-8 liters of drinking water each day, with a maximum of 10 liters in the hot season.
- About 40% of the households in Kaun have a filter, though only a quarter of those households (10% of total) use their filter.
- Complaints about the existing filters were that they had a low flow rate and were difficult to clean.
- The villagers expressed that they do not like to drink "stale" water: water that has been left sitting in its container for too long.
- Villagers will use water collected the previous day, if it is kept outside overnight, but not for drinking. They usually keep drinking water in a covered container, but will leave it uncovered if using it soon.
- Villagers claim to not have much difficulty with waterborne illnesses. One man estimated that he spent 40-50 NRs (USD $0.52-$0.65) per month on treatment of such diseases.
- Villagers differentiate between water for drinking and water for other uses, which apparently is not the case with some villages in the Hills near Pokhara. Kaun has participated in some Red Cross educational efforts and so this may explain why they do this.

Begnas: Small Village near Pokhara

Begnas is a lakeside village of 100 households in the hills of Kafki district, near Pokhara. CeraMIT held a group discussion with two women and four men, translated by Deepak

Adhikari of IDE, and were accompanied by one member of IDE's Pokhara field office. Important information gathered during this visit:

- Villagers suggested that the filter capacity should be 15-20 liters.
- Villagers expressed concern about plastic containers. Most people currently use metal containers, and believe that plastic would be less effective at keeping water cool in the hot season.
- Begnas apparently does have some trouble with waterborne illnesses among children and each household spends up to 2,000 NRs (USD $26.14) per year on medicine.
- Villagers expressed that they would be willing to spend up to 500 NRs (USD $6.54) on an effective filter.
- When villagers are sick, they boil their water. They expressed that they do not like the taste of boiled water.
- One party to the discussion did have a filter and used it actively. He cleaned the filter weekly, without removing the candle, and has broken the candle twice.

Retailer Interviews in Pokhara

While visiting Pokhara, CeraMIT interviewed two storekeepers who sell existing ceramic filters. Most of the storekeepers' customers were from the town of Pokhara. Important information gathered during this visit:

- In both stores, sales exhibit a strong seasonal pattern. Sales are 2-4 filter systems per day during the rain season, when water sources have visible turbidity. During the remainder of the year, very few units are sold; one storekeeper estimated 2-3 per month in the cold season.
- The best selling units are between 13 and 21 liters in size.
- The aluminum filters are the lowest priced filters, between 360 and 580 NRs (USD $4.70 - $7.58) depending on size and number of candles. Stainless steel and copper filters are more expensive, ranging from 700 to 1800 NRs (USD $9.15 - $23.53).
- Each storekeeper prices the filters to earn 15-20% margin, as they may have to lower the price by 10% during haggling.
- Both storekeepers would be willing to sell a plastic model provided it is made of good quality plastic, and that the tap does not drip.

- One storekeeper expressed that Nepalis prefer metal because it is more durable, and also because they believe that plastic containers cause water to smell.
- Both storekeepers believed they could sell a disk shaped filter, provided that the seal was good and available as a spare part. One also thought the disk had good potential because the candles often break. She sells 20-30 replacement candles each month.
- Current customers for ceramic filters often purchase the filters as wedding gifts.
- Customers tend to ask questions about the overall quality of the product, but very few ask about the effectiveness of microbial removal.
- Some customers will ask how to use and clean the filter. As a preemptive measure against product returns, one of the storekeepers teaches all customers how to use and clean the filter unless the customer claims to know already.
- Although most customers do not inquire about the filtration rate, many people we spoke with cite low flow rate as the reason they stop using the filters.

Naikap: Small Village in Kathmandu Valley

Naikap is a village of over 100 households in the Hills at the western periphery of the Kathmandu valley. An NGO (Conserve Nepal), with the support of Susan Murcott, distributed 24 aluminum candle filters over a two year period (12 in 1999, 12 in 2000). CeraMIT held a group discussion with 16 women and 3 men, all but 2 of which were participants in the filter program. Important information gathered during this visit:

- Of the 24 households who received filters in the study, 14 were represented in the discussion. Two of these households were still using filters, though these were not the original filters. They purchased stainless steel filters to replace the aluminum ones.
- Approximately 75% of the filters stopped functioning properly during normal use. The women cited three modes of failure: broken candles, leaking taps, and aluminum corrosion. Three of the families bought new candles or new taps, which worked for a while but broke again; the families then stopped using the filters.
- Two families upgraded to the stainless steel filters, and continue to use them and are pleased with their performance. These two families observed health benefits from the original filter and decided it was worth spending the money on a better filter.

- Villagers expressed concerns about the durability of plastic, and that water would smell if stored in plastic. They did say they would consider it if the product is consequently less expensive.
- They were asked about the concern with women's "impurity" during menstruation raised by Ms. Mangala Karanjit and they felt that it did not apply to plastics, only to ceramics.
- A new water source was developed a few years ago and since that time, villagers have noticed a significant improvement in the quality of their water supply.

Madhyanna Women's Group

Madhyanna Women's Group is a group of 16 women responsible for households in Lalitpur Municipality #20 Nayag. The group that CeraMIT met with was very poor and lived in relatively high poverty compared to the other village groups. Important information gathered during this visit:

- The group had no concerns about using plastic to store water.
- They seem to be much more price sensitive, quoting target filter prices of 100-200 NRs (USD $1.31 - $2.61), with a maximum at 300 NRs (USD $3.92).
- They are the only group that expressed concerns about having enough space for the filter.
- The family sizes were significantly larger than the other families in the villages we visited. The size was 6 persons and the largest was 18 persons.

Appendix 4. Business Plan Outline

The following business plan is an excerpt from the book, New Venture Creation, by Jeffrey Timmons (IRWIN, 1999. Exhibit 11-2, Page 374)[56]. The business plan is presented in its entirety and thus, some sections may not be applicable to an organization developing a business for a ceramic water filter in a country like Nepal. Nevertheless, it provides a useful template for systematically planning a successful venture.

I. EXECUTIVE SUMMARY

A. Description of the Business Concept and the Business
B. The Opportunity and Strategy
C. The Target Market and Projections
D. The Competitive Advantages
E. The Economics, Profitability, and Harvest Potential
F. The Team
G. The Offering

II. THE INDUSTRY AND THE COMPANY AND ITS PRODUCT(S) OR SERVICE(S)

A. The Industry
B. The Company and Concept
C. The Product(s) or Service(s)
D. Entry and Growth Strategy

III. MARKET RESEARCH AND ANALYSIS[a]

A. Customers
B. Market Size and Trends
C. Competition and Competitive Edges
D. Estimated Market Share and Sales
E. Ongoing Market Evaluation

[a] Timmons recommends completing the market research section first. (pg 379).

IV. THE ECONOMICS OF THE BUSINESS

A. Gross and Operating Margins

B. Profit Potential and Durability

C. Fixed, Variable, and Semi-Variable Costs

D. Months to Breakeven

E. Months to Reach Positive Cash Flow

V. MARKETING PLAN

A. Overall Marketing Strategy

B. Pricing

C. Sales Tactics

D. Service & Warranty Policies

E. Advertising and Promotion

F. Distribution

VI. DESIGN AND DEVELOPMENT PLANS

A. Development Status and Tasks

B. Difficulties and Risks

C. Product Improvement and New Products

D. Costs

E. Proprietary Issues

VII. MANUFACTURING AND OPERATIONS PLAN

A. Operating Cycle

B. Geographical Location

C. Facilities and Improvements

D. Strategy and Plans

E. Regulatory and Legal Issues

VIII. TEAM ORGANIZATION

A. Organization

B. Key Management Personnel

C. Management Compensation and Ownership

D. Other Investors

E. Employment and Other Agreements and Stock Options and Bonus Plan

F. Board of Directors

G. Other Shareholders, Rights, and Restrictions

H. Supporting Professional Advisors and Services

IX. OVERALL SCHEDULE

X. CRITICAL RISKS, PROBLEMS, AND ASSUMPTIONS

XI. THE FINANCIAL PLAN

A. Income Statements and Balance Sheets

B. Pro Forma Income Statements

C. Pro Forma Balance Sheets

D. Pro Forma Cash Flow Analysis

E. Breakeven Chart and Calculation

F. Cost Control

G. Highlights

XII. PROPOSED COMPANY OFFERING

A. Desired Financing

B. Offering

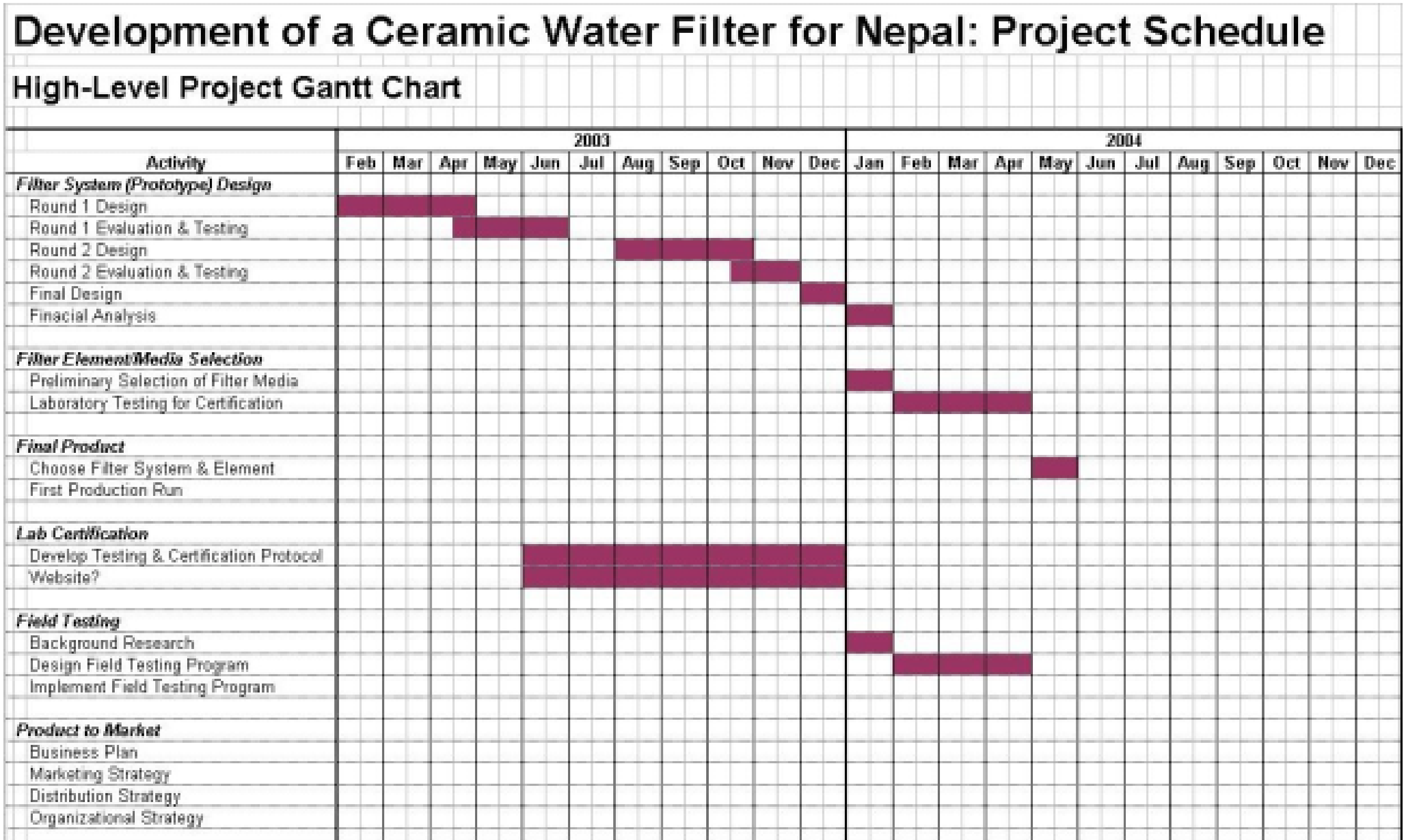
C. Capitalization

D. Use of Funds

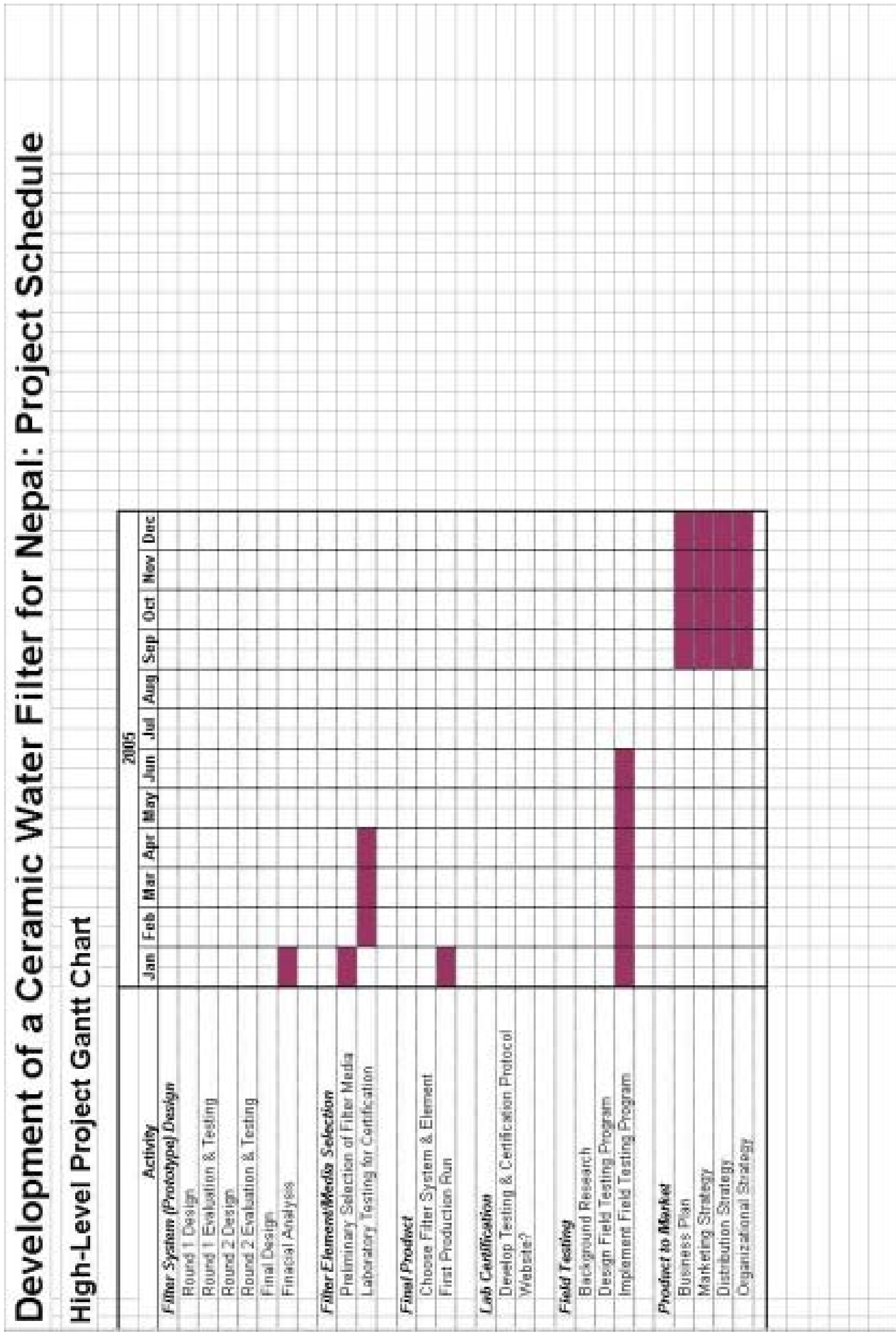
E. Investors Returns

XIII. APPENDICES

Appendix 5. Project Schedule



The Gantt chart is primarily for the MIT Nepal Water Project and thus the timing of some activities corresponds to the academic term (i.e.: when students will be available to do the required work). There is a large gap during the end of 2004, in preparation for bringing the prototype design to Nepal to be built for the first run of field testing. It may be possible to close this gap if the initial production run could begin sometime in the summer of 2004 or fall of 2004. This could be coordinated with a Nepali partner such as ENPHO or IDE-Nepal.


Development of a Ceramic Water Filter for Nepal: Project Schedule
High-Level Project Gantt Chart
Activity
2005
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Filter System (Prototype) Design
Round 1 Design
Round 1 Evaluation & Testing
Round 2 Design
Round 2 Evaluation & Testing
Final Design
Finacial Analysis
Filter Element/Media Selection
Preliminary Selection of Filter Media
Laboratory Testing for Certification
Final Product
Choose Filter System & Element
First Production Run
Lab Certification
Develop Testing & Certification Protocol
Website?
Field Testing
Background Research
Design Field Testing Program
Implement Field Testing Program
Product to Market
Business Plan
Marketing Strategy
Distribution Strategy
Organizational Strategy

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Bibliography

1. Appropriate Technology Transfer in Ceramics. (December 1993) “Pressing Ceramics with Air Release”. Northampton, MA, USA. Pg 6.

2. Black Mountain Stores. Website: <http://www.katadyn.net/katadyn_drip.html> (Last accessed: May 1, 2003).

3. Brown, Joe. (Undated) “Ceramic Microfiltration for Household-Scale Drinking Water Treatment in Rural Bolivia”. Presentation. MPhil Candidate, Department of Geography, University of Cambridge, Cambridge, United Kingdom.

4. Centers for Disease Control and Prevention CDC. (2001) “Safe Water Systems for the Developing World: A handbook for implementing household-based water treatment and safe storage projects”. Atlanta, CDC. Website: <http://www.cdc.gov/safewater> (Last accessed: May 9, 2003).

5. Center for Micro-Finance, Nepal. (Undated) “Micro-Finance and HIV/AIDS Partnership Building: A Concept Paper”. Website: <http://www.cmfnepal.org> (Last accessed: April 30, 2003>.

6. Cheung, Lily. (May 2003) “Design of a Prototype Household Drinking Water Containment System”. Bachelor of Science thesis. Department of Mechanical Engineering, Massachusetts Institute of Technology, Cambridge, MA.

7. Clasen, Thomas; Collin, Simon. (March 2003) “Safe Household Water Treatment and Storage Using Ceramic Filtration”. PowerPoint presentation. First Water® Ltd.

8. Clay Times. (Undated) “Clay Basics”. Website: <http://www.claytimes.com/claybscs.htm#anchor509923> (Last accessed: March 11, 2003>.

9. Collins, Simon; Murcott, Susan. (October 30, 2002) “Email correspondence between Simon Collin (First Water® Ltd.) to Susan Murcott (MIT)”.

10. Dies, Rob; Jones, Laura-Ann; Perreault, Steve; Wilson, Bobby. (February 15, 2003) “CeraMIT Report of Activity Nepal: January 2003. Report for Global Entrepreneurship Laboratory”. Sloan School of Management, Massachusetts Institute of Technology, Cambridge, MA.

11. Domenico, P.A.; Schwartz, F.W.. (1998) Physical and Chemical Hydrogeology. 2^{nd} Ed. John Wiley & Sons, Inc.. Equation 3.1 (pg 34) and Equation 3.16 (pg 37).

12. Fahlin, Christopher J.. (March 7, 2003) “Hydraulic Properties Investigation of the Potters for Peace Silver Impregnated Ceramic Filter.” Undergraduate Independent Study Research, University of Colorado at Boulder, College of Engineering.

13. First Water® Ltd.. Website: <http://www.firstwater.info/noflash/td_test_certify.html> (Last accessed: April 26, 2003).

14. Fuhrman, Elizabeth. (December 1, 2002) “Building from the Past: The History of the Treatment of Drinking Water”. National Driller. Website: <http://www.drilleronline.com/CDA/ArticleInformation/coverstory/BNPCoverStoryItem/0,3641,87525,00.html> (Last accessed: April 15, 2003).

15. Glendale Community College, California. (Undated) “Art 186 – Introduction to Ceramics”. Website: <http://netra.glendale.cc.ca.us/ceramics/clay.html> (Last accessed: May 8, 2003)

16. Grameen Bank. Website: <http://www.grameen-info.org> (Last accessed April 30, 2003).

17. Harvey, A. Reid. (March 25, 2003) “Porous grog composition, water purification device containing the porous grog and method for making same”. Patent # 6,537,939. United States Patent and Trademark Office. Website: <http://www.uspto.gov> (Last accessed: May 8, 2003).

18. Harvey, A. Reid. Ceramique d’Afrique website: <http://www.geocities.com/ceramafrique/> (Last accessed: May 8, 2003).

19. Harvey, A. Reid. Pottery Purification Media website: <http://www.purifier.com.np> (Last accessed: May 8, 2003).

20. Harvey, A. Reid; Prajapati, Hari G.. (January 2003) Meeting at Madhyapur Clay Crafts. Thimi, Nepal.

21. Harvey, A.R.; Sikder, A.M.; Walker, W.J.. (Undated) “A Permeable Grog for a Low Cost Water Purifier”. Arsenic Research Group, Dhaka. Website: <http://phys4.harvard.edu/~wilson/remediation/ACER.html> (Last accessed: May 8, 2003).

22. Harvey, A. Reid. (January 2003) Correspondence with Reid Harvey. Kathmandu, Nepal.

23. Hurd, Jessica J.. (May 11, 2001) “Evaluation of Three Arsenic Removal Technologies in Nepal”. Master of Engineering thesis. Department of Civil and Environmental Engineering, Massachusetts Institute of Technology. Cambridge, MA.

24. Hersh, Lee. (March 27, 2003) Email correspondence.

25. Hong Phuc® Private Business. (December 2002) Brochure. Received by email from by Mr. Hong Phuc. Vietnam.

26. Hong Phuc® Private Business. (December 2002) “The Letter of Self-Introduction”. Received by email from by Mr. Hong Phuc. Vietnam.

27. Howard, G.; Bartram, J.. (2003) “Domestic water quantity, service level and health”. Water Engineering and Development Centre, Loughborough University, UK and Water, Sanitation and Health, World Health Organization. © WHO.

28. Hwang, Rebeca. (February 28, 2003) “Six-Month Field Monitoring of Point-of-Use Ceramic Water Filter by Using H_2S Paper Strip Most Probable Number Method in San

Francisco Libre, Nicaragua". Department of Civil and Environmental Engineering, MIT. Master of Engineering Thesis.

29. Hwang, Soon K.. (May 17, 2003) "Point-of-Use Arsenic Removal from Drinking Water in Nepal Using Coagulation and Filtration". Master of Engineering thesis. Department of Civil and Environmental Engineering, Massachusetts Institute of Technology. Cambridge, MA.

30. International Centre for Integrated Mountain Development. ICIMD GIS Web Portal. Website: <http://www.icimod-gis.net> (Last accessed March 2003).

31. International Centre for Integrated Mountain Development. (1997) "Districts of Nepal: Indicators of Development". GPO Box 3226, Kathmandu, Nepal. 1997. ISBN: 92 9115 693 0. Website: <http://www.icimod.org.np/hkh/nep_indic.htm> (Last accessed March 2003).

32. Katadyn®. (July 31, 1997) "Review of all tests performed with Katadyn Ceramics" (Summary table). Document reference 970219.

33. Lantagne, Daniele S.. (December 2001) "Investigation of the Potters for Peace Colloidal Silver Impregnated Ceramic Filter – Report 1: Intrinsic Effectiveness". Alethia Environmental. Allston, MA.

34. Lantagne, Daniele S.. (December 2001) "Investigation of the Potters for Peace Colloidal Silver Impregnated Ceramic Filter – Report 2: Field Investigations". Alethia Environmental. Allston, MA.

35. Low, C.S.. (May 13, 2002) "Appropriate Microbial Indicator Tests for Drinking Water in Developing Countries and Assessment of Ceramic Water Filters". Master of Engineering thesis. Department of Civil and Environmental Engineering, Massachusetts Institute of Technology. Cambridge, MA.

36. Maag, Benoit. (May 2000). "Nepal Water Project Report". Department of Civil and Environmental Engineering, Massachusetts Institute of Technology, Cambridge, MA.

37. Morganti, Luca. (May 10, 2003) "Sodium Hypochlorite Generation for Household Water Disinfection: A Case Study in Nepal". Master of Engineering thesis. Department of Civil and Environmental Engineering, Massachusetts Institute of Technology. Cambridge, MA.

38. Ngai, Tommy K.K.. (May 10, 2002) "Arsenic Speciation and Evaluation of an Adsorption Media in Rupandehi and Nawalparasi Districts of Nepal". Master of Engineering thesis. Department of Civil and Environmental Engineering, Massachusetts Institute of Technology, Cambridge, MA.

39. NSF Drinking Water Treatment Unit Program. (Spring, 2003) "NSF remarks". DWTU Standards Update. Ann Arbor, MI.

40. NSF International. (Undated) "NSF Drinking Water Treatment Units – A Certification Guide". Company brochure. Website: < http://www.nsf.org/DWTU/> (Last accessed: May 8, 2003).

41. Poole, Barika R.. (May 10 2002) “Point-of-Use Water Treatment for Arsenic Removal Through Iron Oxide Coated Sand: Application for the Terai Region of Nepal”. Master of Engineering thesis. Department of Civil and Environmental Engineering, Massachusetts Institute of Technology, Cambridge, MA.

42. Potters for Peace. (December 2002) Correspondence with a Potters for Peace representative. 2.009 Student Presentations. Massachusetts Institute of Technology, Cambridge, MA.

43. Potters for Peace. Website: <http://www.potpaz.org> (Last accessed: May 8, 2003).

44. Prajapati, Hari G. (May, 9, 2002) Email correspondence with Jason Low. Owner of Madhyapur Clay Crafts, Thimi, Nepal.

45. Prajapati, Hari Govinda. (January 2003) Personal Communication. Thimi, Nepal.

46. Rivera, Ron. (Undated). “Costs Analysis for the Production of Filtering Elements and a Complete Filtron Unit (with plastic pail, top and faucet) Draft”.

47. Rural Water Development Program. (Undated) Brochure. Western Kenya.

48. Rural Water Development Programme. (December 2002) “The Kisii Water Filter Bucket. Proposal of the Rural Water Development, Western Kenya, for the 2003 Water Action Contest as part of the 3rd World Water Forum”. Tokyo, Japan.

49. Sagara, Junko. (2000). “Study of Filtration for Point-of-Use Drinking Water Treatment in Nepal”. Master of Engineering thesis. Department of Civil and Environmental Engineering, Massachusetts Institute of Technology. Cambridge, MA.

50. Shakya, R.; Sharma, S.P.. (September 1996) “Drinking Water Quality Surveillance Program in Nepal”. World Health Organization/SEARO.

51. Shepard, Anna. (1968) <u>Ceramics for the Archaeologist</u>. Carnegie Institution of Washington. Washington, DC. Publication 609.

52. Sherpa, Mingma G.. (January 2003). Correspondence with Mingma at Environment and Public Health Organization. Baneshwor, Nepal.

53. Shrestha, R.. (2000) “Drinking Water Crisis in Nepal. Environment and Public Health Organization”. Kathmandu, Nepal.

54. Sobsey, M.D.. (July 2002) “Managing Water in the Home: Accelerated Health Gains from Improved Water Supply”. World Health Organization. Geneva, Switzerland.

55. Tabbal, Georges. (May 2003) “Technical and Social Evaluation of Three Arsenic Removal Technologies”. Master of Engineering thesis. Department of Civil and Environmental Engineering, Massachusetts Institute of Technology, Cambridge, MA.

56. Timmons, Jeffry A.. (1999) <u>New Venture Creation, Entrepreneurship for the 21st Century</u>. 5th Ed., IRWIN/McGraw-Hill, ISBN: 0-256-19756-3. Exhibit 11.2, pg. 374.

57. UNICEF. (October 2002) “Household Water Security Conference”. Online conference held October 14 – November 1, 2002. Website: <http://www.unicef.org/programme/wes/econf.htm> (Last accessed May 8, 2003).

58. United Nations Children’s Fund (UNICEF). (2001) “Child Statistics”. Website: <http://www.childinfo.org/cmr/revis/db2.htm> (Last accessed: May 8, 2003).

59. United Nations Development Programme. (2002) “Human Development Indicators 2002”. Website: <http://hdr.undp.org/reports/global/2002/en/indicator/indicator.cfm?File=cty_f_NPL.html> (Last accessed: May 8, 2003).

60. United Nations. (September 2002) “World Summit on Sustainable Development - Key Outcomes of the Summit”. Johannesburg, South Africa. August 26 to September 4, 2003. Website: <http://www.johannesburgsummit.org> (Last accessed: May 8, 2003).

61. United States Environmental Protection Agency. (April 1987) “Guide Standard and Protocol for Testing Microbiological Water Purifiers”. Registration Division, Office of Pesticide Program, Criteria and Standards Division, Office of Drinking Water.

62. United States Environmental Protection Agency. (July 2002) “National Secondary Drinking Water Regulations”. Website: <http://www.epa.gov/safewater/mcl.html#sec> (Last accessed: May 9, 2003).

63. United States Environmental Protection Agency. (December 1999) “25 Years of the Safe Drinking Water Act: History and Trends”. Office of Water. EPA 816-R-99-007.

64. United States Food and Drug Administration. (August 17, 1999) “FDA Issues Final Rule on OTC Drug Products Containing Colloidal Silver”. U.S. Department of Health and Human Services, Rockville, MD. Webpage: <http://www.fda.gov/bbs/topics/ANSWERS/ANS00971.html> (Last accessed: . August 17, 1999.

65. World Health Organization. (1996) “Guidelines for drinking-water quality, 2nd ed. Vol. 2. Health criteria and other supporting information”. Geneva, Switzerland.

66. World Health Organization. (2000) “Global Water Supply and Sanitation Assessment 2000 Report”. Geneva, Switzerland. Website: <http://www.who.int/water_sanitation_health/Globassessment/GlobalTOC.htm> (Last accessed: May 8, 2003).

67. World Health Organization. (2001) “Selected Indicators for Nepal”. Website: <http://www.who.int/country/npl/en/> (Last accessed: February 27, 2003).

68. World Health Organization. (August 28, 2002) “Water, Sanitation and Hygiene Links to Health – Facts and Figures”. File: <http://www.who.int/water_sanitation_health/General/facts&fig.pdf> (Last accessed: May 8, 2003).