Current Practices in Manufacturing of Ceramic Pot Filters for Water Treatment

by Justine Rayner

A research project report submitted in partial fulfilment of the requirements for the award of the degree of Master of Science of Loughborough University

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Dedication

Dedicated to Ron Rivera

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The Ceramic Filter Manufacturing Working Group held bimonthly phone calls during which topics regarding filter manufacturing were discussed. Some ideas presented in this report have been developed from comments made by participants in these discussions.

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Acronyms

ARC	American Red Cross
AFA	Asociación Guatemalteca para la Familia de las Américas (Families of the Americas Foundation)
Cfu	Coliform Forming Units
CS	Colloidal Silver
CWF	Ceramic Water Filter
HWTS	Household Water Treatment and Safe Storage
ICAITI	Instituto Centroamericano de Investigación y Tecnología (Central American Institute of Research and Technology)
IDE	International Development Enterprises
INGO	International Non-governmental Organisation
LRV	Log Reduction Value
NGO	Non-governmental Organisation
PFP	Potters for Peace
POU	Point of Use Water Treatment
PPM	Parts per Million
RADWQ	Rapid Assessment of Drinking Water Quality
RDI – C	Resource Development International - Cambodia
SODIS	Solar Water Disinfection
TC	Total Coliform
TTC	Thermo-tolerant Coliform
UN	United Nations
UNICEF	United Nations Children’s Fund (formerly United Nations International Children’s Emergency Fund)
UV	Ultra Violet
VIP	Vocational Incentive Program
WEDC	Water, Engineering and Development Centre
WHO	World Health Organization

1 Introduction

1.1 Global Need for Access to Safe Water

There are an estimated 4 billion cases of diarrhoea annually (WHO 2009c). Despite being largely preventable and treatable, every year 1.8 million people die from diarrhoeal diseases (WHO 2009b). Eighty-eight percent (88%) of these deaths are attributed to unsafe water supply, inadequate sanitation and poor hygiene (WHO 2009b). Diarrhoea accounts for an estimated 4.1% of the total Disability Adjusted Life Years (DALYs)[1] global burden of disease (WHO 2009a). The many secondary effects can include poor nutrient absorption, contributing to malnutrition and impaired physical growth and cognitive development, decreased schooling, missed work days and increased medical expenses.

The Millennium Development Goals (MDGs) were established to focus efforts and track progress towards the United Nations Millennium Declaration to eradicate extreme poverty. Eight goals, 21 targets and 60 indicators were established to measure progress towards this aim (UN 2009a). Goal 7, target C is to "halve, by 2015, the proportion of people without sustainable access to safe drinking water and basic sanitation". The indicator used to measure sustainable access to safe drinking water is the "proportion of population using an improved drinking water source" (UNICEF 2009). It has been estimated that access to improved water supply can reduce diarrhoea morbidity by 21% (WHO 2009b). For a water source to be considered 'improved', it must provide at least 20 litres of water per person per day and be located within 1 kilometre of the user's home. It can include a household connection, public standpipe, borehole, protected well, spring or rainwater harvesting system.

Although progress monitoring suggests that the world is on the way to meeting the goal for access to safe drinking water (UN 2009b), what is being measured is improved water supply. Although having access to an improved water supply is important and provides many health and non-health benefits, it is not necessarily indicative of having access to safe water. Many piped water supplies in urban areas of developing countries are intermittent, and along with breaks in the system, can introduce microbiological and other contaminants into the water being distributed. Other

[1] DALYs are used to evaluate and prioritise public health concerns. They represent a sum of the number of years lost by premature mortality and the number of years of healthy life lost due to less than full health or disability.

improved water sources such as protected springs or wells can also become faecally contaminated. A Rapid Assessment of Drinking Water Quality report (RADWQ 2006) found that 31% of water samples taken from boreholes in six pilot countries exceeded both WHO guideline values and the national drinking water standards in those countries for faecal contamination (UNICEF 2008). In addition, contamination of water during collection and storage is well documented. A systematic meta-analysis of 57 studies which measured bacteria both at the source and in water stored in the home found that in over half the studies there was significant contamination after collection and the decline in water quality stored in the home was greater where the source water was largely uncontaminated (Wright *et al.* 2004). A comparison of 30 trials to assess the effectiveness of interventions to improve water quality, found that household interventions were more effective than source interventions at preventing diarrhoea (Clasen *et al.* 2006).

1.2 Water Quantity

Basic domestic water quantity needs can be divided into categories including water for drinking, cooking, hygiene, and other domestic purposes, including productive uses. Availability of sufficient water quantity close to the home is important for health, hygiene and quality of life; however, water quality is of primary importance when discussing drinking water. Drinking water needs can vary according to the water content of food consumed, manual labour performed and climatic conditions. In addition, men, children and women have varying needs. Even among women, needs vary when pregnant or lactating. In Table 1-1 suggested daily water requirements for hydration are presented. Since diets vary it is difficult to estimate the amount of fluid obtained from food. The following estimates are for hydration requirements, including fluid obtained from food.

Table 1-1 Drinking Water Requirements

	Average Conditions (litres)	Manual labour or in high temperatures	Pregnant or Lactating
Adult Female	2.2	4.5	4.5 or 5.5
Adult Male	2.9	4.5	
Children	1.0	4.5	

(adapted from: (Howard and Bartram 2003: 7))

1.3 Water Quality

Water can be contaminated both chemically and microbiologically. Of primary concern in efforts to reduce mortality and morbidity caused by infectious disease is the microbiological quality of water. Pathogens transmitted through contaminated drinking water include pathogenic bacteria (ranging about 0.5-3.0 microns in size), viruses (0.02-0.1 micron), protozoa (3.0-30 microns) and helminths (ova are about 45 microns). Although diarrhoeal disease can be transmitted through drinking water, it can also be transmitted via other faecal-oral routes. Transmission pathways include consumption of contaminated food or drinks, poor sanitation and poor personal hygiene. Since water quality alone may not interrupt transmission of diarrhoea, interventions often include increased water quantity, improved water quality, improved sanitation and the promotion of health and hygiene practices.

1.4 Assessing Water Quality

Due to the difficulty of monitoring water for specific contaminants, water is examined for the presence of indicator organisms associated with faecal contamination. Commonly used indicator organisms (organisms used to measure treatment effectiveness) include total coliforms (TC), thermo-tolerant coliforms or faecal coliforms (TTC) and *E. coli*. Criteria for indicator bacteria as outlined by the World Health Organisation (WHO) (2006: 142) are that they should be:

- universally present in high numbers in human or other warm-blooded animal faeces
- readily detectable by simple methods
- should not grow in natural water

Some coliforms can grow and survive in water and are often present in the absence of faecal contamination. Therefore, the 'total' coliform count is not useful as an index of faecal contamination, however, it can be useful as an indicator of treatment effectiveness (WHO 2006: 283). Thermo-tolerant coliforms are those of the total coliform group which are able to ferment lactose at 44-45°C. *E. coli* is often the predominant thermo-tolerant organism and is rarely found in the absence of faecal contamination. For this reason, *E. coli* is slightly more reliable as an indicator bacteria, however, other thermo-tolerant coliforms are also acceptable (WHO 2006: 284).

Although *E. coli* has been established as the most suitable indicator by the WHO, it is also noted that the absence of *E. coli* does not ensure water safety since some pathogens are more resistant to some disinfectants. Therefore "verification may require analysis of a range of organisms, such as intestinal enterococci, (spores of) *Clostridium perfringens* and bacteriophages" (WHO 2006: 142).

In contrast to *E. coli* which are gram-negative bacteria, intestinal enterococci are gram-positive, which have a thicker cell wall. Intestinal enterococci are primarily of faecal origin and can be used as an index of faecal contamination. *Clostridium perfringens* are also gram-positive and resistant to UV irradiation, temperature, pH extremes and disinfection processes (WHO 2006: 288). Due to their long survival times, they are not recommended for routine monitoring; however, they may be useful indicators for filtration effectiveness. *C. perfringens* should be removed by filtration processes designed to remove enteric viruses or protozoa (WHO 2006: 289). Bacteriophages (phages) are viruses which use bacteria as hosts and share many characteristics with enteric viruses. They are useful models to assess behaviour, sensitivity to treatment and disinfection, however, they are not necessarily reliable as an index for faecal contamination since viruses have been found in water which tested negative for phages. There are two main types of phages: Somatic and F-RNA, the latter is better both as an index of faecal contamination and indicator for virus behaviour (WHO 2006: 289-291).

1.5 Drinking Water Quality Guidelines

Since different exposure levels might affect populations differently, the probability of infection is difficult to estimate based on water quality. The WHO guideline is that *E. coli* or thermo-tolerant coliform bacteria should not be detectable in any 100-ml sample of drinking water (WHO 2006: 143), however risk levels can be evaluated using a classification system for the microbiological quality of water presented in Table 1-2 (WHO 1997: 78).

Table 1-2 Water Quality Risk Levels

Number of Thermotolerant (faecal) coliforms or *E. coli* per 100 ml water sample	
0	Conforms to WHO guidelines
1-10	Low Risk
10-100	Intermediate Risk
100-1000	High Risk
1000+	Very High Risk

1.6 Household Water Treatment and Safe Storage

Household water treatment and safe storage systems (HWTS) are increasingly being promoted in both development and emergency contexts to improve the quality of drinking water and reduce exposure to water-borne pathogens. HWTS have been found to reduce the number of diarrhoeal episodes by 45% (WHO 2009b). Although for some the current evidence does not support the health benefits claimed and is not sufficient to justify the widespread promotion of HWTS (Schmidt and Cairncross 2009), others suggest that there is "conclusive evidence that simple, acceptable, low-cost interventions at the household and community level are capable of dramatically improving the microbial quality of household stored water and reducing the attendant risks of diarrhoeal disease and death" (Sobsey 2002: 2-3). In 2003, sponsored by the World Health Organization, an International Network to Promote Household Water Treatment and Safe Storage was formed with the aims of accelerating reliable access to safe drinking water by promoting advocacy, communication, research and implementation of HWTS systems. The network now has a membership of over 100 organisations and is moving into phase two, the scaling-up of HWTS implementation (HWTSNetwork 2009).

A comprehensive review of household water storage and treatment options identified ceramic filtration, chlorination with improved storage, solar disinfection, thermal disinfection and combination systems using chemical coagulation-flocculation, sedimentation, filtration and chlorination as the most promising, accessible and effective means of improving the microbiological quality of water (Sobsey 2002).

In a critical examination of five of the most effective and widely promoted technologies, (chlorination with safe storage, combined coagulant-chlorine disinfection systems, SODIS[2], ceramic filter and the bio-sand filter), household ceramic and bio-sand water filters were identified as having the greatest potential as effective, affordable and sustainable ways of improving drinking water quality (Sobsey *et al.* 2008). The ranking system and assigning of scores in this analysis have been criticised, and attention has been called to the omission of important sustainability criteria such as consumer preference, economic considerations, cultural practices and variations in water quality (Lantagne, Meierhofer *et al.* 2009). However, in an analysis of 30 trials, filtration also appeared to offer the most consistent and effective results among household interventions (Clasen *et al.* 2006).

[2] SODIS, Solar Water Disinfection, uses solar UV-A radiation and temperature to inactivate pathogens. Plastic PET bottles are filled with water and placed in the sun for a number of hours.

Although ceramic filtration has shown promising results, no single HWTS will be appropriate in all situations, therefore interventions need to be evaluated relative to specific circumstances. An appropriate HWTS technology ought to have certain technical characteristics including the ability to improve and maintain the microbiological quality of water, to treat a variety of water sources (or a specific water source) and to treat sufficient water to meet a family's drinking water needs. In addition, it should be both culturally and socially acceptable, relatively easy to use, affordable, have a reliable supply chain and not negatively affect the taste of the water.

1.7 Ceramic Filters

Ceramic filtration is a common form of household water treatment in many parts of the world. Several types of both industrially made and locally-produced ceramic filters are currently available on the market and being promoted. Industrially produced 'candle' filters include brand names such as: Katadyn, Stephani, Pozzani, and Doulton. Candle filters are also produced locally in Africa and Cambodia, among other places. Disc filters currently being produced include the TERAFIL (India) and Thimi (Nepal). One of the most widely available locally-produced ceramic water filters, the subject of this study, is the colloidal silver enhanced ceramic 'pot' filter promoted by Potters for Peace (PFP). This low-tech, low-cost technology is currently being manufactured in at least 18 countries by local artisans using primarily locally available materials and local skills and labour. Despite being a recommended form of HWTS, "further efforts are needed to define and implement appropriate manufacturing procedures and product performance characteristics of these filters in order to achieve products of acceptable quality that are capable of adequate microbe reductions from water" (Sobsey 2002: 33).

Photo 1-1 Ceramic Pot Filter
(PottersforPeace 2009)

1.8 Background to this Project

In February of 2009, 76 people attended the first International Conference on Ceramic Pot Filters in Atlanta, GA, USA. Responding to recommendations that minimum standards in filter production be established, the Ceramics Filter Manufacturing Working Group was formed including members of government, academia, non-governmental organisations and filter manufacturers (for a complete list, see Appendix 1). The goal of this working group is to "provide guidance to assist filter factories in producing the lowest-cost, most-effective ceramic filters possible” by summarizing existing knowledge on ceramic filter production, the effects of production variables, identifying lessons learned from existing filter factories, making recommendations on how to produce the lowest-cost, most-effective filters, and identifying needs for further research (CFMWG 2009). The main output objective is a document which outlines minimum recommended standards in the production of ceramic pot filters. The report from the Ceramics Filter Manufacturing Working Group will describe the variation in filter manufacturing and evaluate and make best practice recommendations to minimize production variables which impact filter efficacy without adversely influencing aspects such as production cost, breakage, environmental impact, end-user requirements and health and safety standards.

1.9 Aim

The aim of this project was to identify the various filter factories worldwide and to survey and document existing production practices to provide data that will help the Ceramics Filter Manufacturing Working Group make appropriate manufacturing recommendations, which are expected to help filter factories improve the quality of filters being produced.

1.10 Research Questions

1. What are the current production procedures at the various ceramic water filter factories?
2. What are some of the lessons learned and where are recommendations needed in the production process?
3. What is known about some of the manufacturing variables which affect the microbiological efficacy of the filters?
4. What further research is needed in order to make recommendations for standardisation or best practice?

1.11 Structure of this Report

This report is divided into nine sections. In the Introduction (1) the global need for access to safe water, HWTS and ceramic filters are introduced and the background to this project, including the aim and research questions are presented. In Section 2, Background, the history and evolution of the pot filter, an overview of the manufacturing process of ceramic water filters and some manufacturing variables which affect the filter are discussed. In the Literature Review (3), literature on field studies which have been carried out on the filters, a comparison of filter production procedures from available production manuals or guidelines, and lastly the physical characteristics and mechanisms by which the filter works are reviewed. The methods used in carrying out this project, including the development and implementation of the survey, are detailed in Section 4, Methodology. Results from the survey are detailed in Section 5. In Section 6, the results of both the literature review and survey are discussed, lessons learned presented and recommendations and further research needs are outlined. In Section 7, Conclusions and Recommendations, a summary and review of this project and recommendations for future research work are presented. There is a Glossary at the end of the report. Several Appendices follow, including a copy of the survey and the data collected from participating factories.

2 Background

2.1 History of the Pot Filter

The colloidal silver ceramic pot water filter was developed in Guatemala by Dr. Fernando Mazariegos during a study financed by the World Bank/Inter American Bank, to evaluate ten models of low-cost domestic water filters (ICAITI 1980). The ten models were evaluated on the following criteria:

- Filtration flow
- Bacteriological efficiency
- Ease of manufacture
- Availability of materials
- Final cost
- Contribution to artisan activity
- Ease of distribution

Prototypes of two filter models which met the above criteria, a clay filter with feldspar, sand and colloidal silver and a clay filter with sand, sawdust, and colloidal silver, were made and evaluated for tolerance of the filters to vary in proportions of ingredients, types of wood, colloidal silver application methods and the influence of colloidal silver on the bacteriological removal efficiency. The criteria for evaluation were microbiological efficacy and filtration rate. The design used today has evolved from the clay, sand, sawdust and colloidal silver impregnated ceramic water filter 'thrown' on a potter's wheel.

In 1999, in response to the devastating effects of Hurricane Mitch, Potters for Peace (PFP) established a ceramic water filter factory in Nicaragua. In an effort to increase standardisation and ease of production, Potters for Peace designed a press with a mould, based on the filter designed by Dr. Mazariegos, to press filters rather than 'throwing' them on a potter's wheel. Since then, Potters for Peace has been providing technical assistance with the establishment of filter factories and the manufacturing of ceramic water filters around the world.

2.1.1 How Pot Filters are Made

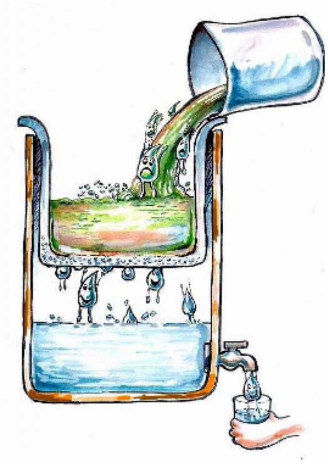


Figure 2-1 Ceramic Pot Filter (PottersforPeace 2009)

The Potters for Peace colloidal silver-enhanced ceramic pot water filter is a slightly conical shaped pot with a rim and a flat-bottom. It rests on the rim of a receptacle or bucket fitted with a tap for dispensing filtered water. Source water is poured into the filtering element and filters through at a rate of 1-3 litres an hour. If the source water is especially turbid, it is recommended that water be strained through a pre-filter or cloth. A lid is placed on top as a cover. Filter elements are made by mixing a pre-established ratio of clay and burn-out material, which can be sawdust, rice husks or other agricultural waste. Both the clay and the burn-out material are milled and sifted to ensure quality and consistency of particle size. Dry materials are mixed before water is added. Once mixed, clay balls or cubes are formed, placed in a mould, and pressed into the filter shape using a hydraulic car jack.

Photo 2-1 Filter Press (Rayner 2006)

The pressed filter is stamped with a serial number which is used to trace the filter throughout the manufacturing process and eventually to its final destination. The filtering element is dried slowly to prevent cracking and then fired in a kiln. After the filter has been fired and cooled the flow rate of each filter is tested. Filters are first soaked to ensure they are fully saturated, then filled with water. The amount of water which filters through the filter in the first hour is the 'flow rate'. The low end of the flow rate range of one litre per hour is to ensure the filter can treat enough water to meet a family's drinking water needs. Filters which flow beyond the maximum flow rate might have larger pores or internal cracks which may allow pathogens to pass through. The fast flow rate will also reduce contact time with colloidal silver which is thought to be important for the deactivation of bacteria. Filters also pass visual and auditory inspections for cracks, deformities or other defects. Filters which do not pass flow rate tests or inspection are considered unsuitable or unsafe and are therefore broken and discarded to prevent future use. Filters which pass both the flow rate test and inspections are dried and coated with colloidal silver. Once dry, they are packaged for sale with a lidded receptacle, a tap, and an instructional sticker. General filter production process is outlined in the Filter Production Flow Chart in Figure 2-2.

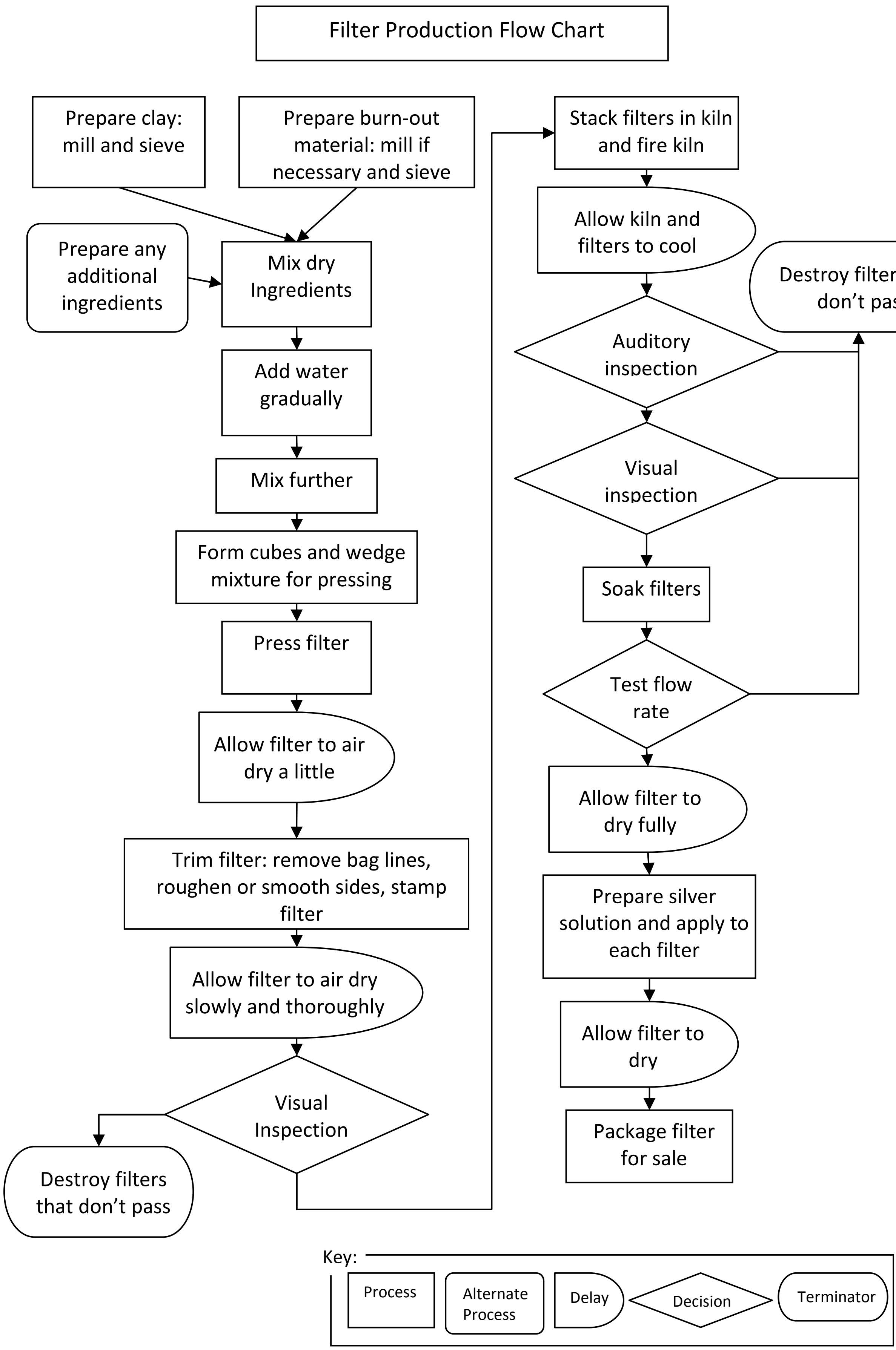


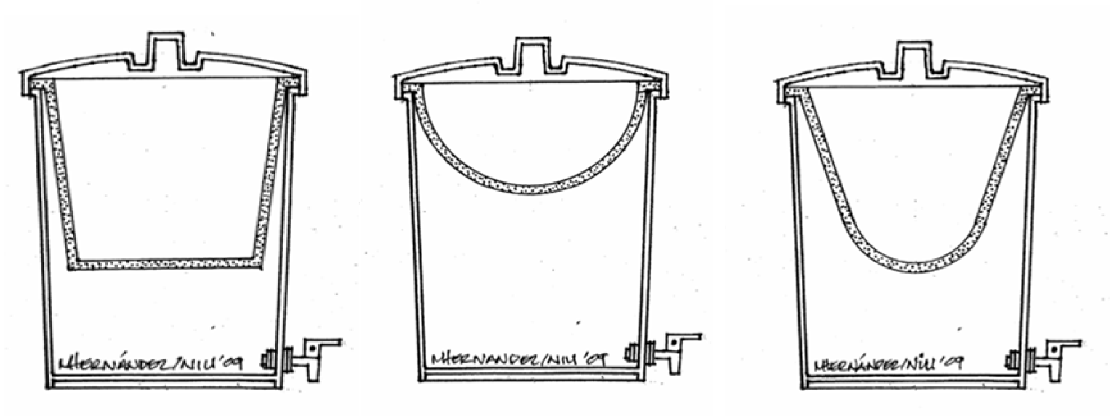
Figure 2-2 Filter Production Flow Chart

2.1.2 The Evolution of the Pot Filter

One of the primary advantages of this technology is that it is made from locally available raw materials and its ease of manufacture makes it easily transferable to places with a source of clay and a tradition of pottery. Currently there are more than 30 filter factories world-wide, producing filters in countries in Central and South America, the Caribbean, Africa and Asia.

Each of the filter factories world-wide has adapted the manufacturing process to some extent to meet local conditions, using local knowledge, materials and experience. Because of this, there are variances from factory to factory including mould size, burn-out material, types of silver and application methods, materials processing, firing temperatures and quality control measures. In addition to the PFP mould shape, other filter shapes have been designed and some manufacturing processes modified.

In 2003, a semi-spherical mould was designed by the NGO Thirst-Aid (then known as the Vocational Incentive Program or VIP) to address issues such as secondary contamination from placing the flat-bottomed filter on potentially contaminated surfaces, increasing filter capacity, programme development costs and ease of manufacture. Over 10,000 of these filters were produced in Thailand supported by VIP. Thirst-Aid is now working in Myanmar as Quality Assurance Monitors for eight filter factories which produce a variation of this semi-spherical filter. Silver nitrate is used instead of colloidal silver (Thirst-Aid 2009a).



Potters for Peace   Thirst Aid[3]   Filter Pure

Figure 2-3: Illustrations of Filter Shapes

(Hernandez 2009)

[3] This filter is slightly more parabolic than depicted in the illustration. It is designed to have both the correct diameter to fit locally made receptacles and a 10 litre capacity.

Another filter shape, an oblong, round-bottomed filter and a new press were designed by Manny Hernandez and implemented at factories in the Dominican Republic in 2006 and Tanzania in 2008. Filter Pure, the exclusive buyer of these filters, has implemented other changes to the filter making process including firing colloidal silver into the filters and leaving a carbon residual within the walls of the filters (Ballantine and Hawkins 2009).

Photo 2-66 Example of Carbon Line in Filter Walls
(Source: Unknown)

In addition to the existing PFP, Thirst-Aid and Filter Pure factories, factories have just been set up or feasibility studies are underway in at least six countries (PottersforPeace 2009). With the scaling up of decentralised ceramic pot filter factories underway, it is important that variables in production which affect the quality of the filter are defined and evaluated.

2.2 Variables in Manufacturing

The flow rate (see Section 2.1.1) of each filtering element is used as a primary form of quality control once a filter mixture formula has been established and effectiveness confirmed with microbiological testing. There are many variables in the manufacturing process which are considered to influence the flow rate and/or effectiveness of the filtering element including the type of clay (particle size, distribution, sand content and plasticity), the burn-out material (type and size, humidity of burn-out material), the clay to burn-out ratio, the amount of water added to the mixture, the manufacturing method (moulded by hand, pressed, wheel thrown), drying time and conditions, firing temperature, time and location in kiln, size of the filtering element, capacity and the thickness of the filter. The many variables in the manufacturing of ceramic pot filters are presented in the mind-map in Figure 2-4. They are organised into six sections: Materials, Silver, Filter Production, Firing & Kilns, Quality Control, and Delivery. These topics will serve as chapters in the working group's report. In addition, six cross-cutting themes are presented: microbiological efficacy, end-user considerations, breakage, cost, health and safety and environmental impact. The development of the mind-map is further discussed in Section 4.4.

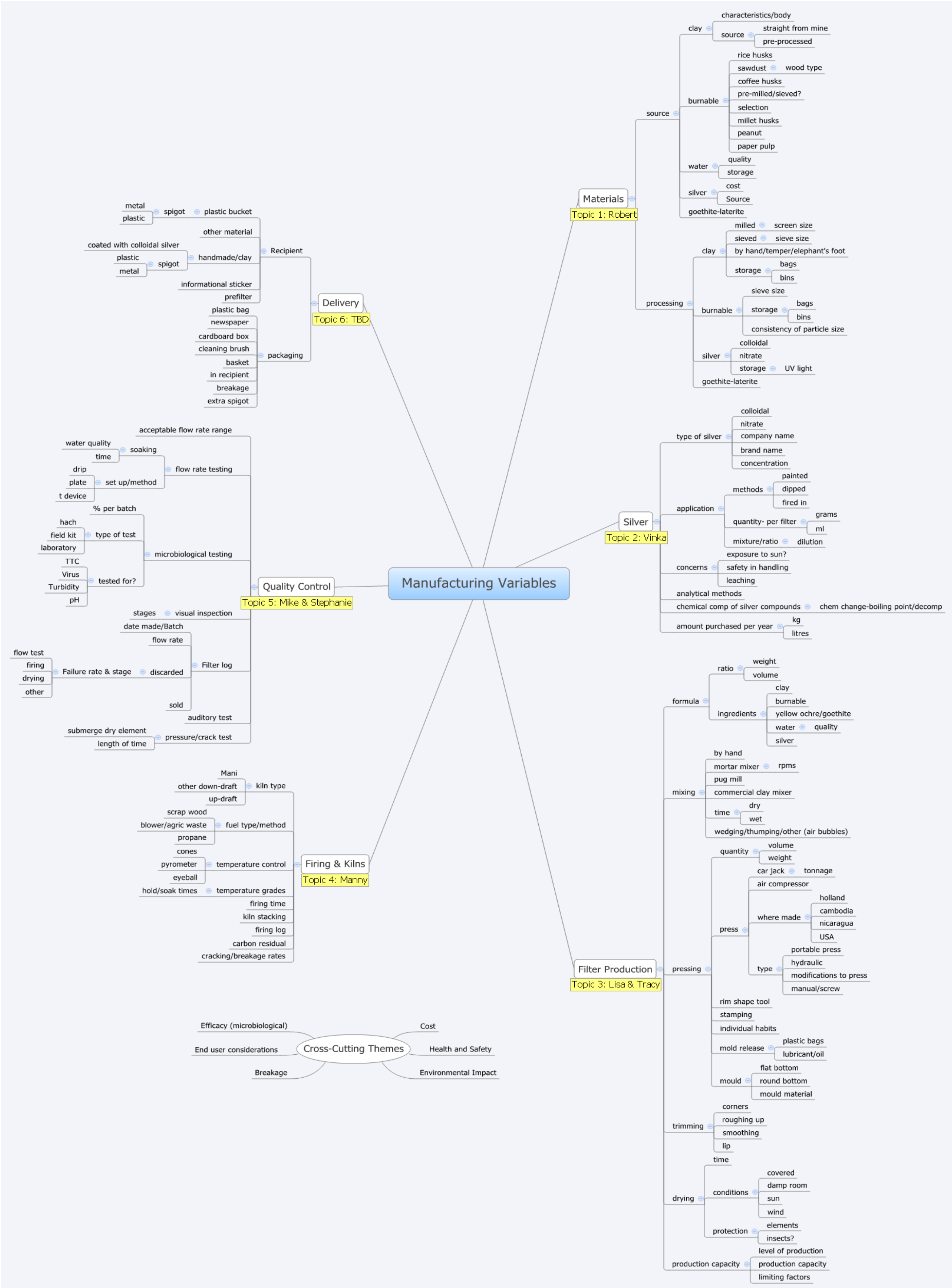


Figure 2-4 Production Variables

3 Literature Review

3.1 Introduction

As mentioned in Section 2, there are more than 30 filter factories world-wide. Although based on the same principles and methods, manufacturing processes have been adapted to meet local circumstances. With the promotion of this technology, it is important that local variations do not adversely affect filter performance. This literature review is divided into three sections: 1) findings from field studies; 2) comparison of production manuals; and, 3) the physical characteristics of the filter and how it works, as well as some of the studied effects of variables on the filter. Additional findings on production procedures were obtained from the interviews and questionnaires, and are presented and discussed in Section 5 and Section 6.

3.2 Methodology

Literature pertaining to ceramic water filter production and filter effectiveness was collected from a variety of sources and reviewed. Searches were carried out on Loughborough University's MetaLib database using key words including: "ceramic water filter", "potters for peace", "point of use water treatment", "household water treatment", "water quality", and "appropriate technology". In addition, searches were carried out both on Google and Google Scholar using similar keywords. The Water, Engineering and Development Centre (WEDC) database of conference papers was also searched. References from other reports and studies were reviewed and searches were carried out for specific articles of interest. Various filter manufacturers' websites were checked for additional information and reports pertaining to the subject. Articles were solicited and shared among various members of the Ceramic Filter Manufacturing Working Group. Literature was also reviewed in the process of establishing appropriate methods to carry out this research.

3.3 Field Studies

3.3.1 Introduction

In this section findings from field studies carried out in Nicaragua, Ghana, Guatemala and three studies in Cambodia are presented. These field trials have shown the effectiveness of ceramic pot filters at improving water quality in the field, regardless of manufacturing location and variables. Virus removal is discussed in Section 3.7. In addition, several studies suggest that ceramic filters have an impact on reducing diarrhoea in users versus non-users and that they are acceptable to users. Primary reasons for disuse are breakage of the element or tap.

3.3.2 Microbiological Effectiveness

Several field trials carried out in different countries have found ceramic pot filters to be effective at improving the quality of drinking water and in reducing diarrhoea. A study carried out in three regions of Guatemala reported that ninety-one percent (91%) of the filtered water tested was free of faecal coliforms (AFA 1995). In Nicaragua, water quality analysis was performed on 24 filters in seven communities. Of 15 homes that had *E. coli* in their source drinking water, eight (53%) tested negative for *E. coli* after filtration (Lantagne 2001b). In Cambodia, water quality tests were carried out after 1,000 ceramic filter pots were distributed (Roberts 2004) and results showed that after up to one year in use, 99% of the filters produced water falling into a 'low-risk' range of fewer than 10 *E. coli* per 100mL (see Section 1.5 on Water Quality Guidelines). It was also concluded that the source water quality did not seem to affect the efficacy of the filter. Another field trial in Cambodia (Brown and Sobsey 2006), with 80 test and 80 control households, found that filters in the field reduced *E. coli* by a mean of 98% and as much as 99.99%. Filters in this trial were in use for up to four years. Yet another field study in Cambodia (Brown *et al.* 2008) with 120 test and 60 control households, found that the filters reduced *E. coli* by a mean of 96%, with 60% falling within the low risk range of fewer than 10 E. coli/100 ml. In comparison, 85% of control households had greater than 101 cfu/100ml in their drinking water (high risk). In Ghana, household surveys and water quality analyses were carried out in over 60 traditional households in 2006 and 2007 (Johnson *et al.* 2008). Filters in Ghana were found to reduce *E. coli* by 99.7%. Average *E. coli* detected were fewer than 10 cfu/100ml, falling within the 'low risk' range.

Suggestions have been made as to why several of the field trials found filtered water with increased amounts of *E. coli* in comparison to the source water. In Nicaragua, seven homes (out of 24) had increased total coliforms in filtered water and some had increased *E. coli* (Lantagne 2001b). In Cambodia, 5% had greater concentrations of *E. coli* in treated than in stored water (Brown *et al.* 2008). Another study in Cambodia, 46 of 79 filters (58%) had negative log reduction values and 11% of those were confirmed on multiple visits (Brown and Sobsey 2006). Researchers have suggested that contamination of the receptacle or filtering element occurred during cleaning. This is a reasonable explanation since post contamination has been documented as a widespread occurrence (Wright *et al.* 2004). Lantange (2001b) observed that the homes where filtered water tested positive for *E. coli* were less clean than the other homes in the study. In the Cambodia trial, both boiled and filtered water had similar declines in water quality after treatment. In addition, users reported cleaning filtering elements with cloths and 29% reported cleaning the receptacle with raw (untreated) water. Brown and Sobsey (2006) also suggested that the stored water might not be from the same source as the filtered water, or it could have been stored under conditions which improved its microbiological characteristics.

3.3.3 Filter Life Span

Filter replacement has been typically recommended at 1-2 years since little research has been carried out to indicate otherwise. A field study in Cambodia did not find a relationship between time in use and microbiological effectiveness, suggesting that filters can remain effective for up to four years and possibly longer (Brown and Sobsey 2006). Roberts (2004) found that after nearly one year in use fewer filters removed all *E. coli*, yet they still produced water of 'low risk' quality or better. Campbell (2005) found that filters collected from the field after five years of use when tested in a laboratory were successful at removing 100% of *E. coli*.

A recent laboratory study (Bielefeldt *et al.* 2009) two approximately four year old filters from the field were tested alongside filters with limited laboratory use and found that while filters achieved a 3-4 log reduction for the first batch of *E. coli* spiked water (10^6 CFU/ml) regardless of their history, removal efficiency reduced with each spiked batch. In addition, when filled with clean water, indicator bacteria not only re-suspended in the filtering element, but passed through into the effluent water. A re-application of colloidal silver reduced this; however, the field filters' removal efficiency was not sustained, indicating that perhaps the colloidal silver did not adhere as well to the ceramic after years of field use. This study in conjunction with reported increased *E. coli* in effluent water in the field is worrying. When compared with the drinking water of control groups in the field, however, the quality of filtered drinking water is significantly better (Brown and Sobsey 2006; Brown *et al.* 2008).

3.3.4 Diarrhoeal Reduction

Field studies on the ceramic water filter have also reported significant reduction in diarrhoea. Roberts (2004) found that 17-20% more households reported no diarrhoea in test groups than control groups. Also, there were half as many cases of diarrhoea per person, filter owners had one-half to one-third of treatment expenses and 4-5 times fewer work/school days missed than non-filter users. In Cambodia, filter users reported a 49% reduction in diarrhoea versus non-filter users in one study (Brown *et al.* 2008) and a 46% reduction in another (Brown and Sobsey 2006).

In Guatemala, 50% fewer cases of diarrhoea were reported in children under five years of age (AFA 1995). In Ghana, filter users in traditional households were 70% less likely to have diarrhoea (Johnson *et al.* 2008). There are several transmission routes for diarrhoea causing pathogens, therefore awareness and health and hygiene education might also play a role in reducing the number of diarrhoeal episodes in filter users. The reliability of self reported diarrhoea as an indicator has been called into question, however, as it is a subjective outcome measure and may be misleading (Schmidt and Cairncross 2009).

3.3.5 Filter Disuse

Regardless of any technology's ability to improve water quality, it must also be acceptable to the user as compliance is important for health gains. There are many factors which can contribute to the disuse of any intervention, but with the ceramic pot filters, breakage seems to be a primary cause. In a Cambodian field trial where filters were distributed for free, 20% disuse was reported for filters up to one year post implementation. Of those who reported not using the filter anymore, 71% was due to the tap breaking and 20% due to the element (pot) breaking. In this case, replacement elements were not available, so replacing the filter was not an option. Other reasons for discontinued use included: preferring boiled water, too busy or unwilling to clean the filter, belief that their water does not need to be treated, or that the filter did not treat sufficient water (Roberts 2004). Interestingly, more than 1/3 of the households reported having enough water for additional uses. In Nicaragua (Lantagne 2001b), the flow rate in 14 of the 24 households was inadequate to provide sufficient drinking water for the family. The recommendation was made to scrub the filters to regenerate the flow rate (Lantagne 2001b), which has since been incorporated into general operation and maintenance instructions. The reader is referred to Section 3.5.3 for further discussion on flow rates.

Another Cambodian field trial (Brown and Sobsey 2006) documented a 2% per month disuse rate. Of this 2%, 65% of disuse was due to breakage of the element, container or tap. An additional 5% stopped using the filter because it was too slow and didn't meet their drinking water needs. Five percent (5%) stopped using the filter because it had exceeded its recommended useful life. Continued use was associated with, most importantly, time since implementation but also user investment, water source, access to sanitation and water, and sanitation and hygiene awareness.

High user compliance is suggested by a field trial in Cambodia (Brown *et al.* 2008) where 100% of respondents reported that they used filtered water for all of their drinking water needs and 86%

reported using filtered water for drinking water only. In another field trial in Cambodia (Roberts 2004), 95% of users reported that they were satisfied with the filters, that the filtered water tasted good, the filter was easy to maintain and was important to the family because of health benefits and eliminating the need to boil water. In Ghana (Johnson *et al.* 2008), users reported that filters worked well, were easy to use and that they would recommend them to others, in addition, non-users surveyed were interested in using filters.

3.4 Comparison of Production Procedures

3.4.1 Introduction

During this research the author tried to locate all published and unpublished production manuals. Production manuals have been published for two filter factories in Cambodia, Resource Development International - Cambodia (RDI-C) (Hagan *et al.* 2009), and International Development Enterprises (IDE) (IDE 2008). In addition, a manual was written for the set-up of a factory in Iraq (Nardo 2005), for the Nicaragua facility (Rayner 2006), and a general manual was drafted by Ron Rivera (Rivera 2006). The following sub-sections compare the manufacturing procedures described in each of these documents. Information collected on production practices at other factories during this research is presented and discussed in Sections 5 and 6.

3.4.2 Clay

Clay suitable for other pottery production should be suitable for making filters (Hagan *et al.* 2009), however, plasticity is particularly important as 50-60% non-plastic (burn-out) material is added to the clay (Rivera 2006). Clay should have an acceptable level of plasticity, rate of dry shrinkage, and after firing, acceptable rates of total shrinkage and absorption (Nardo 2005). RDI-C gets its clay from a local brick factory in the form of air-dried, unfired, extruded bricks. In the RDI-C, IDE, Nicaragua and Iraq manuals, dry clay is first crushed by hand and then milled in a hammer mill. At IDE the hammer mill screen has 1 mm openings, equivalent to 16 mesh[4] (see Appendix 3 for a chart on Tyler Mesh Equivalents). RDI-C does not indicate a screen size, but notes that grinding clay to a powder is sufficient. Rivera's manual, the Nicaragua manual and the Iraq manual suggest sieving the milled clay through a 30 mesh (about 0.55mm opening, see Appendix 3) kitchen sieve to ensure the removal of non-clay particles, including sand and organic matter, to ensure the

[4] The mesh number represents how many openings there are per linear inch in a screen or sieve using the Tyler Mesh Equivalent.

purity of the clay. Clay which does not pass through the sieve the first time can be re-milled and re-sieved (Rayner 2006).

3.4.3 Burn-out Material

Burn-out material, such as sawdust, rice husks, or other agricultural by-product is added to the clay to create the required porosity of the fired element, which affects the flow rate of the filters. The material can vary depending on local availability (Rivera 2006). Both of the Cambodia factories use rice husks which have a high silica content. At IDE the rice husks are sifted with a 16 mesh sieve. The manual notes that there is no control of particle sizes smaller than 1 mm. At RDI-C, rice husks from the supplier are approximately 1 mm in size; however, the formula is adjusted according to the estimated particle size, using less rice husk by weight if they appear larger. Rivera (2006) recommends sifting burn-out material to a 30 mesh, however both the Nicaragua and Iraq manuals describe using a standard wire mosquito netting which is about an 8 mesh (about 2.4 mm openings).

3.4.4 Mixing

The proportion of clay to burn-out material and water varies depending on the local clay and is adjusted until the appropriate filtration rate in the fired elements is reached (Rivera 2006). Nicaragua, IDE and Iraq use only clay, water, and a burn-out material in their mix. At RDI-C, laterite[5] is an optional addition which is thought to add viral binding sites to the filter aiding in virus removal (Hagan *et al.* 2009). Since the laterite increases porosity, the amount of rice husk in the formula is reduced (Hagan *et al.* 2009). Filter mixture formulae are detailed in Table 3-1.

Table 3-1 Filter Mixture Ratios

Factory	Clay	Burn-out	Type	Water	Laterite
RDI-C	30 kg	8.2 kg	Rice husk	12.5	2 kg
	30 kg	9.5 kg	Rice husk	12.5 L	
IDE	26 kg	8 kg	Rice husk	10 L	
Nicaragua	24 kg	2.5 kg	Sawdust	10 L	
Iraq	60 (vol)	40 (vol)	Rice husk	30% (weight)	

Dry materials are mixed at IDE for eight minutes. Water is added in two amounts with four minutes mixing time after each addition. At RDI-C clay and burn-out material are measured by

[5] Laterite is a soil layer consisting of several minerals including goethite, an iron-oxide. Laterite and goethite are used interchangeably in this document.

weight and water by volume. Mixing is for ten minutes dry and ten minutes wet. Water is added gradually using an automated mixing system. At the Nicaragua facility, clay and burn-out are measured by weight and water is measured by volume. Dry ingredients are mixed for ten minutes. Water is added gradually and mixed for an additional ten minutes to ensure a homogenous mixture. In Iraq, thorough mixing of dry materials, measured by volume, is recommended before adding water, measured by weight, to the mix.

3.4.5 Pressing, Touching-up & Drying

Clay is removed from the mixer and formed into balls or cubes the appropriate size for the specific mould (Rayner 2006). This process includes wedging[6] the clay to remove any air bubbles and ensure a homogenous mixture (Nardo 2005). IDE has both a screw press and a hydraulic press, each require a different amount of clay due to the amount of pressure applied and the amount of clay ejected. The screw press uses 8.8 kg of mixture and the hydraulic press requires 9.5 kg of mixture. RDI-C uses 8-8.2 kg per filter, Nicaragua about 8 kg.

Photo 3-1 Wedging Filter Mixture
(Rayner 2006)

Although the Nicaragua manual recommends that prepared mixture be pressed the same day, at RDI-C the mixture is routinely covered and left in the mixer overnight to reduce start up time the following day. IDE wraps the measured clay in plastic until pressed so that the surface does not dry out.

All four manuals mention the use of plastic bags as a mould release (to prevent the clay from sticking to the mould). RDI-C has tried using oil, but reported that it did not work as a mould release. At IDE, filters are left to dry for 30 minutes before smoothing and touching-up the filter, and two hours before stamping. At RDI-C, rims and plastic bag marks are touched-up immediately and the rim is checked for circularity using a plastic bowl. Filters are left to dry for 3-4 hours or overnight before the sides and insides are touched up and stamped and the outsides are roughened (with an old hack-saw blade) to open the pores. In Nicaragua, the filters are gently cleaned and stamped immediately upon removal from the press, but allowed to dry for two days before trimming. Rivera (2006) recommends waiting one day before stamping the filter.

[6] Wedging is a pottery term for working clay; it can be compared to kneading bread dough.

Drying is very important as rushed or uneven drying, especially initially, can cause cracking. Filters will dry faster in hot, dry and windy conditions and slower in cold, damp and still air (Rayner 2006). Therefore, depending on the conditions, freshly pressed pots may need to be protected from drying too quickly and can be stored either in a damp room or covered with plastic, gradually reducing coverage for slow drying to avoid deformation and cracking (Rayner 2006). In Nicaragua, filters are covered with a plastic bag for the first three days. The Iraq manual warns against placing the freshly pressed element in the direct sunlight especially during the hot summer months. At IDE, filters take about 5-7 days to dry in the dry season or 7-10 days in the wet season. At RDI-C, filters dry in 7-15 days in the dry season or 15-18 days in the wet season. Rivera (2006) suggests allowing filters to dry for seven and 21 days in the dry and wet seasons respectively.

Photo 3-2 Filters Drying (Rayner 2006)

3.4.6 Firing

It is important to ensure filters are sufficiently dry before firing. Since the burn-out material retains moisture, the filtering elements will take longer to dry than typical pottery (Rivera 2006). If filter elements are not dry enough prior to firing it will increase the chances of them exploding or cracking during the firing (Nardo 2005). Rivera (2006) suggests weighing the elements to get an idea of the water loss during drying. RDI-C notes that over 3 kg of water will be lost between pressing and the completion of the firing process. When ready for firing, the filtering element should make a "leathery sound" when flicked with a finger (Hagan *et al.* 2009). By moving filters which are almost ready for firing to near the kiln, the warmth from the kiln can aid in drying (IDE 2008).

Photo 3-3 Stacked Kiln (Rayner 2006)

Filters can be stacked in kilns mouth to mouth, bottom to bottom or alternating. If stacked directly on top of each other a slight carbon mark may remain on the filters, however, this should not affect the functioning of the filter (Rivera 2006). To avoid this, however, and to allow for complete circulation of heat and air during firing both IDE and RDI-C use small pieces of clay as spacers between filters.

Temperature can be monitored with the aid of a pyrometer and/or pyrometric cones. A pyrometer measures the ambient temperature inside the kiln whereas pyrometric cones[7] indicate the temperature the clay has reached (Rayner 2006). At the Nicaragua factory, a pyrometer with two additional thermocouples is used along with three pyrometric cones. The first cone (guide cone) serves as a warning that the kiln has nearly reached the desired temperature, the second cone (firing cone) melts when the desired temperature has been reached and the third cone serves as the control (guard cone). If the guard cone melts, the desired temperature has been exceeded. Cone blocks (sets of three) can be placed in different locations in the kiln to check for temperature variation within the kiln (Rayner 2006). At IDE, one 014 cone is used (830°C). A pyrometer is not used, but rather, the experience of the kiln master is relied upon. At RDI-C a pyrometer and two cones (numbers 014 and 012 for 830°C and 866°C respectively) are used to measure the temperature.

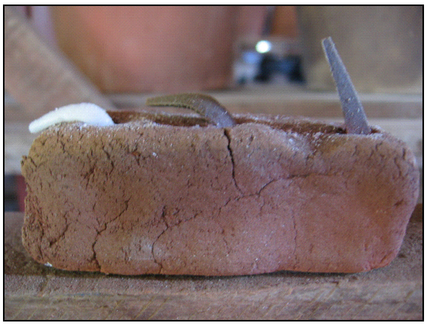


Photo 3-4 Cone Block (Rayner 2006)

Although the 'maturing' temperature will vary for each clay type (Rivera 2006), the firing process is similar but may vary depending on the size and type of kiln, fuel used, and other factors. The temperature should be increased slowly until reaching 100°C so that moisture remaining in the clay has the chance to escape before reaching boiling temperature (Nardo 2005). It is recommended that if filters are being fired in a downdraft kiln[8], the temperature increase during the first three hours should not exceed 50°C per half-hour. Subsequently the temperature can be raised gradually by 100°C per hour (Rivera 2006). RDI-C heats the kiln to 100°C and maintains that temperature for two hours to dry off any excess water in the filters. IDE has an initial heating stage which lasts 5-6 hours after which, by monitoring the change in the smoke output (from black to white), the heat is increased and the kiln is fired for an additional five hours. At the Nicaragua factory the kiln temperature is raised by 50°C per half hour until reaching 200°C, then 100°C per hour until reaching 400°C. The temperature is then raised 60°C per half hour for the following five hours until the pyrometer reads 840°C. The peephole is then carefully opened for cone observation to monitor the temperature. Only cones 012 and 010 should be allowed to melt, the

[7] Pyrometric cones are made of specific formulae of refractory and fluxing materials to measure the effects of both time and temperature, known as 'heat-work'. Different numbered cones are designed to bend, or deform at specific temperatures. See www.ortonceramic.com for more information.

[8] A downdraft kiln does not have an opening in the roof of the kiln, therefore the heat when reaching the roof is directed downwards, into an opening in the kiln floor which directs it to the chimney.

latter should fall at about 887°C. Upon completion of firing, stoke holes are covered to avoid cold drafts from cracking or warping filters near the flame port.

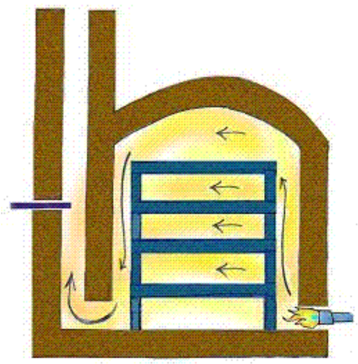


Figure 3-1 Example of Heat Flow in a Down-draft Kiln
(Peterson 2009)

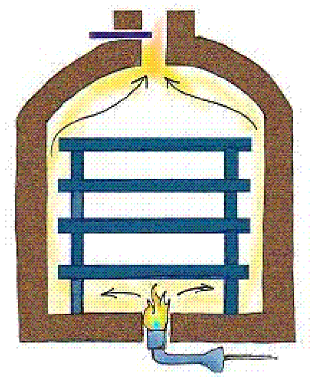


Figure 3-2 Example of Heat Flow in an Up-draft Kiln

IDE, RDIC-C and the Nicaragua factories all fire with wood. However, propane fired kilns can also be used (Nardo 2005). At IDE, after firing is completed, kilns are cooled for 12-24 hours depending on the kiln size and weather conditions. At RDI-C total firing time is about 8-9 hours and the kiln is cooled for an additional 24 hours, and as at IDE, firing time varies depending on the weather conditions and kiln design (Hagan *et al.* 2009). The Nicaragua factory fires for 8-9 hours and allows the kiln to cool over-night before gradually opening the kiln door.

3.4.7 Flow Rate Tests

Photo 3-5 Calibrated "T" Device
(Source unknown)

It is important to soak fired, cooled filters and ensure they are saturated prior to testing their flow rate (Lantagne 2001a). Nederstigt and Lam found that filters soaked for 24 hours prior to testing flow rate have consistent discharge rates. Filters, having been soaked for less time, have inconsistent and slower flow rates (van Halem 2006: A-10). At the factories, filters are soaked for different amounts of time: a minimum of four hours (Rayner 2006), overnight (Rivera 2006), thoroughly (Nardo 2005), 12 hours (IDE 2008), or overnight with a minimum of five hours (Hagan *et al.* 2009). Flow tests at IDE are carried out by filling the filters with water and measuring the amount of water remaining in the filtering element after one hour, using a "calibrated volume-measuring dipstick" (or T-device). IDE's acceptable flow rate is between 2.0-3.0 litres per hour. RDI-C also uses a T-device to measure the water level after one hour; the acceptable flow rate at

RDI-C is 1.5 – 3.0 litres per hour. The Iraq manual suggests timing how long it takes for a measured amount of water to filter through the element or measuring how much water filters out after 15 minutes and multiplying it by four. Their acceptable flow rate is 1.0-2.0 litres per hour. Nicaragua's acceptable flow rate is 1.0-2.5 litres in the first hour and is calculated either by measuring the amount of water which filters through the filter in the first hour or using a T-device to measure the water level in the element after the first hour (Rayner 2006).

3.4.8 Silver Application

As further discussed in Section 3.6, silver is added to improve the microbiological effectiveness of filters. Colloidal silver, a suspension of silver nanoparticles, acts as a disinfectant. Although at a few factories it is added to the filter mix, usually filters are coated with colloidal silver after firing. Silver nitrate is applied to filters instead of colloidal silver at some factories.

Reviewed manuals recommend filters be absolutely dry before colloidal silver application to ensure maximum absorption. Both the inside and outside of the filters should be coated with colloidal silver for increased effectiveness (Lantagne 2001a). At IDE, silver is diluted in 10-20 litres of water and 300 ml of this solution is applied to each filter. The dilution is equivalent to 1 ml of 3.2% colloidal silver solution per 300 ml, 50% of which is applied to the inside and 50% to the outside of the filter. The rim of the filter is not painted.

In Nicaragua, 2 ml of 3.2% colloidal silver is diluted with 300 ml of clean water. Liquid silver is diluted per filter and used immediately to coat first the inside, then the outside of the filter including the bottom. It is also suggested that mixing enough to dip filters rather than painting them might be quicker and more effective if production levels are high (Rayner 2006).

The Iraq manual also recommends painting a dilution of 2ml of 3.2% colloidal silver per 300 ml water. In addition, it suggests that when working with powdered silver a concentrated solution can be mixed by adding 33 grams of silver to 1 litre of water and then 2 ml of this concentrated solution to 300 ml of water per filter for application to the filter element. If dipping, mixing a 220 mg/L strength solution in a large container is recommended.

Rather than using colloidal silver, RDI-C uses 99.8% silver nitrate powder. As tests have found that 30% of the silver nitrate leeches out when first used, it is recommended that users discard water from the first three fillings of the filter (Hagan *et al.* 2009). A concentrate of 1.5 L of deionised water with 100 grams of silver crystals is mixed and further diluted using 100ml of the concentrate per 18 litres of filtered water. In order to protect the diluted silver from oxidation it is stored in sealed 20 litre pots. At RDI-C more silver is applied to the inside (200 ml/47 mg) of the filter than the outside (100 ml/ 23 mg). RDI-C explains that filters are not dipped because of the silver loss due to oxidation, the varying requirements for the inside and outside of the filtering element, and increased drying time. Spraying has also been considered as an application method but has not been implemented due to concern for worker safety and because airborne silver would be wasted (Hagan *et al.* 2009). Currently, colloidal silver is also being added to the filter mixture and fired into filters in the Dominican Republic and Tanzania (Ballantine and Hawkins 2009).

3.4.9 Additional Quality Control

In addition to flow rate testing, the reviewed manuals recommend frequent visual inspections for cracks and deformation. IDE also recommends performing a sound resonance test whereby the filter is tapped and depending on the sound it makes, an experienced potter can tell if it is under-fired and possibly detect internal cracks. A new recommendation by Potters for Peace is a pressure test to detect internal cracks. In this test, the filtering element is submerged in water up to its rim without letting water flow into the filter. If water seeps through the walls of the filter after being submerged for 10 seconds it is an indication of internal cracks and the filtering element should be discarded (Pillars and Diaz 2009).

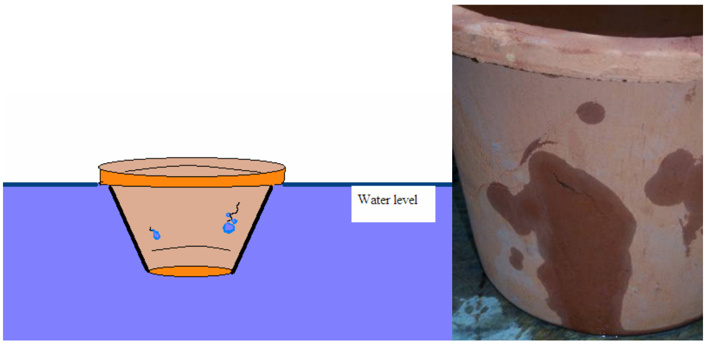


Figure 3-3 Pressure "Crack" Test
(Pillars and Diaz 2009)

3.4.10 Packaging

Although there are various ways of packaging filters, it has been recommended that all filtering elements be dried thoroughly and placed in plastic bags to protect them from getting dirty (Rayner 2006). In Nicaragua, filters are placed in a plastic bag and packaged in a cardboard box protected with newspaper. Taps are placed loose inside the plastic receptacle and instruction and logo stickers are stuck to the outside. IDE packages the filtering element in a box with an instructional booklet and brush included. Prior to packaging, IDE performs a leak test on all taps using a compressed air source, submerging the taps and looking for bubbles. RDI-C has receptacles custom made from food-grade PET. Included in their filter package are a cleaning brush, plastic tap and instruction pamphlet. A fitting ring, which is placed between the plastic receptacle and filtering element to ensure a tight fit, is also included. RDI-C also sells a replacement pack which consists of a filter element, fitting ring, plastic tap, brush, and instruction brochure. These are placed in a cardboard box (with polystyrene on bottom and top) or a carrying basket.

3.5 How Ceramic Pot Filters Work

3.5.1 Introduction

As described in the previous section, each of the filter factories has adapted the general filter making process according to locally available materials and conditions. This local adaptation is one of the advantages which allows this technology to be transferable. In order to understand how variables affect the characteristics and efficacy of the filtering element it is important to understand how the filter works. In this section the literature on physical characteristics of the filtering elements and how some production variables may affect the filters is reviewed, taking into consideration both microbiological effectiveness and user needs.

3.5.2 Physical Characteristics and Mechanisms

During firing, the combustible (burn-out material) added to the filter mix burns out leaving small pores which increase the porosity and hydraulic conductivity of the filtering elements. The pore size is determined by the size and amount of burn-out added to the mixture (Lantagne 2001a), however it has also been linked to the clay content (Oyanedel-Craver and Smith 2007). The pore shape and diameter act as a physical barrier to pathogens, other organic material and turbidity in the influent water. Pore sizes were measured in the lip of a filter from Nicaragua, where saw-dust is used as burn-out material, using a Scanning Electron Microscope (SEM) and were found to range from 0.6 microns to approximately three microns (Lantagne 2001a). The pore sizes of the filters, therefore, were found to be within range of the 1.0 micron goal to screen out *E. coli*. There were also cracks and spaces which measured up to 150 microns and 500 microns respectively, which could be of concern if interconnected; however, this would also likely increase the flow rate beyond the acceptable limit (Lantagne 2001a). Microbiological testing found that three of the four filters tested removed all *E. coli* which suggests the pore size is small enough to screen out *E. coli* in the majority of the filters (Lantagne 2001a). With the application of colloidal silver, all filters removed 100% of the total and thermo-tolerant coliforms (Lantagne 2001a).

The pore sizes were measured on the lip of the filter which was assumed to be the worst-case scenario since it receives the least amount of pressure during the pressing of the filters. A later study, using mercury intrusion porosimetry test, found that pore size distributions and porosities did not vary significantly between the bottom, middle and lip of filters and therefore the manufacturing method should not affect variations in pore sizes (van Halem 2006). The total pore area, which might contribute to increased adsorptive capabilities, has however, been found to vary widely per cm^3 of material (van Halem 2006).

Although average pore size diameter was calculated at 40 microns, filters were successful at removing micro-organisms smaller than the pores (van Halem 2006). Therefore, it was suggested that filters work by additional mechanisms to mechanical screening including sedimentation, diffusion, inertia, turbulence and adsorption. In addition, tortuosity[9] increases total surface area and can encourage these processes (van Halem 2006). Although other mechanisms aid the effectiveness of the filters in removing microbiological contamination, size exclusion has been found to be significant as there is a correlation between pore size and bacteria removal. Filters with smaller pores have a higher removal rate of bacteria (Oyanedel-Craver and Smith 2007).

A correlation has also been found between clay content, pore size and flow rate. In a comparison study of model filters made from different clays, porosities were found to be the same yet the median pore diameter correlated with the clay content and it was found that samples with "relatively uniform and fine-grained particle-size distributions will likely produce filters with better bacteria-removal efficiency, smaller pores, and lower dispersion than comparatively coarse-grained, heterogeneous soils" (Oyanedel-Craver and Smith 2007: 931). The hydraulic conductivity[10] and porosity[11] might also be influenced by predominant clay minerals as the filter model which measured highest in these parameters also had a high kaolinite (a clay mineral) content in the clay (Oyanedel-Craver and Smith 2007).

Filters manufactured in different countries have been found to vary both in porosity and pore size. Measured with mercury intrusion porosimetry, filters from Cambodia had porosity measuring 43%, Ghana 39% and Nicaragua 37%. Pore sizes were measured at: Cambodia 25 microns, Ghana 22 microns, Nicaragua 17 microns (van Halem 2006). The manufacturing details, however, were

[9] The more tortuous (winding or twisting with bends and turns) the filter material is, the longer the path the water must pass through to exit the filter.
[10] Hydraulic conductivity relates to the rate water can move through the filter.
[11] Porosity relates to the volume of void spaces in the filter.

not available for the filters tested. The application of silver also affected the pores by reducing the effective pore size (van Halem 2006). Upon comparing the tortuosity of filters from Cambodia, Ghana and Nicaragua it was found that the filter material from Nicaragua is more tortuous (van Halem 2006). Since tortuosity reflects the actual path the water takes through the filter, it can influence the various mechanisms at work including screening, sedimentation and adsorption. This was supported by evidence of higher removal of Clostridium spores and *E. coli* by the Nicaraguan filters (van Halem 2006).

3.5.3 Flow Rate

The flow rate of a filter is used as a form of quality control as discussed in Section 2.2. Flow rate is an important consideration in filter usefulness since filters need to treat enough drinking water daily for a family at a rate that is convenient for an appropriate pattern of use. In practice, a given flow rate will vary depending upon:

1. the quality of the influent water;
2. the depth of the water in the filtering element (which affects the wetted area and defines the maximum pressure pushing the water through the filter pot);
3. the size of the receptacle in relation to the filtering element;
4. the shape and size of the filtering element;
5. the consistency of the porosity of the filtering element;
6. the pattern of use including the frequency with which the filtering element is filled and the amount of water which is withdrawn (the latter will also be influenced by the height of the tap);

The graph in Figure 3-4 was created from calculations using measurements provided by van Halem for filter geometry and mean discharge rates for the Cambodian filters used in her study (van Halem 2006: pgs. A-13, A-15, Appendix II, Tables 1.5 and 1.9) and the dimensions of a standard 20 litre receptacle (r=15 cm, h=30 cm, vol=21.21 litre); however, receptacle sizes sold with filtering elements vary. The Cambodian filter in this example had a capacity of 9.84 litres and a flow rate of 1 litre in the first hour if filled to the top. The amount of water which can be collected before reaching the bottom of the filtering element is about four litres, at which point the flow rate will reduce if water is not withdrawn from the receptacle. Although the receptacle capacity is about 8 litres taking into account displacement by the filter, the flow will stop at just over six litres with a single filling of the filtering element. The following graph (Figure 3-4) shows the cumulative volume of water that can be filtered with the same filtering element using four possible scenarios.

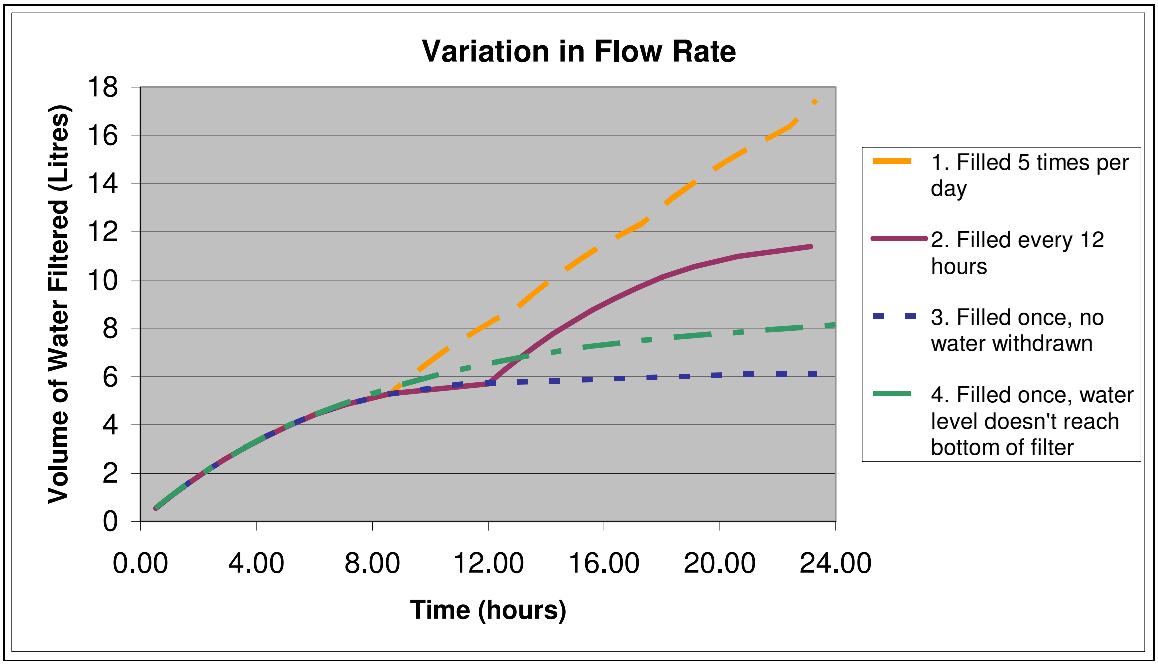


Figure 3-4 Variation in Flow Rate

Scenario 1: The orange line represents the filter being filled, left to filter for 8 hours before being refilled every four hours for the remainder of a 24 hour period. This scenario could represent the situation where the filter is filled last thing in the evening and then four times the subsequent day, with filtered water being withdrawn throughout the day. With this scenario, the filter can produce about 17 litres of drinking water per 24 hours, enough to provide a family of five with an average of three litres of water per person. So this, or a similar pattern of use, is important to obtain the largest amount of drinking water from the filter.

Scenario 2: The purple line represents the filter being filled and left to filter for 12 hours before it is filled again and allowed to filter for another 12 hours. It is assumed that water is withdrawn during the day. This scenario allows 11.5 litres to be treated per day.

Scenario 3: The blue line represents how much water could be filtered if the filtering element is filled and left for 24 hours with no water withdrawn from the receptacle. If water is withdrawn, the flow rate will vary depending on the time and amount of water withdrawn. This scenario allows only 6 litres to be filtered over the 24 hours.

Scenario 4: The green line represents the flow rate if the filtering element is filled and left to filter for 24 hours in a situation where the water level in the receptacle never reaches the bottom of the filter (either due to a larger receptacle or water being withdrawn). This example shows the change in flow rate over time based on the change in water level in the filtering element, without the influence of the water level in the receptacle. In this case, the filter will be capable of treating just over eight litres of water in 24 hours. The average flow rate, if the water level in the filter is kept between 13 and 23 cm is about 0.7 litres per hour.

The flow rate will also vary depending on the quality of the influent water and has been found to reduce considerably due to clogging both in the laboratory (Lantagne 2001a; Fahlin 2003; van Halem 2006) and the field (Lantagne 2001b). Scrubbing of the filtering elements has been found to rejuvenate the flow rate in filters (Lantagne 2001a) and has been incorporated into operation and maintenance instructions for filter use. Van Halem (2006) found that after 12 weeks of use in the laboratory, filters had flow rates of less than 0.5 litres per hour, which would not be sufficient to meet a family's drinking water needs. Although scrubbing temporarily increased flow rates, filters did not return to their original flow rate and even with scrubbing, flow rates continually diminished (van Halem 2006). Fahlin (2003) found that clogging impeded his research into the hydraulic conductivity of filters. However, in some field investigations users have reported that filters provided enough water for additional uses (Roberts 2004) and only 5% of filter disuse was attributed to unsatisfactory flow rates (Brown and Sobsey 2006).

In a study to see if flow rate could be increased without sacrificing the bacteriological removal efficacy of filters, filters were made with either increased burn-out material (rice husk) or increased laterite (thought to be effective against viruses). Flow rates were successfully increased to up to 10 l/hr and 8 l/hr respectively. During the six month testing period no significant difference was measured in *E. coli* removal between the filters with higher flow rates and lower flow rates. Filters with and without silver nitrate impregnation did differ significantly in their ability to remove *E. coli,* however. Filters with silver had nearly twice as high mean log reduction value (LRV)[12] of *E. coli.* This study concluded that although future research is necessary to investigate long-term effects, increasing the flow rate does not affect the micro-biological efficacy of the filters *(Bloem et al. 2009)*.

In contrast, another study where filters were manufactured with increased flow rates by a) increasing burn-out material and b) altering the type of burn-out material, found that beyond a flow rate of approximately 1.7 l/hr, consistent total coliform reduction begins to drop below 99%

[12] Log reduction value (LRV) represents the microbial removal efficiency, where LRV of 4, expressed as a percentage would be 99.99%.

(Klarman 2009). These filters were made at a factory which aims to leave a carbon residual within the walls of the filter, which differs from the filters used in other studies. This could have an impact on the results and appeared to have an influence on both the flow rates of the filters and the turbidity of the effluent water, the latter was considerably higher during the first week of the study and the flow rates of several of the filters in this study actually doubled during the five week testing period (Klarman 2009).

Filters manufactured using a larger screen size to sieve the sawdust showed no significant difference in flow rates (Klarman 2009). At the RDI-C factory, however, filter mix ratios are adjusted to achieve acceptable flow rate ranges according to the particle size of the rice husks received, adding more rice husk to the mixture if it is observed to be smaller (Hagan *et al.* 2009) indicating a relationship between burn-out particle size and flow rate. In addition, using different burn-out materials, even when sifted to the same screen size, can increase the flow rate but also reduces total coliform removal efficiency. This emphasises the need to develop a new ratio when changing the burn-out material (Klarman 2009).

3.6 Silver

3.6.1 Introduction

Lantange (2001a) provides an overview of silver and its historical and present day use in other fields as well as in ceramic water filters and concludes that although the mechanisms of bacterial inactivation are complicated, silver application does improve the effectiveness of the filters. The amount of silver measured in effluent water was below USEPA (United States Environmental Protection Agency) and WHO guideline values for silver (0.1mg/L), and therefore does not pose a risk to human health (Lantagne 2001a; Lantagne 2001b). In agreement with this, other studies have found that silver contributes to the microbiological removal effectiveness (van Halem 2006; Oyanedel-Craver and Smith 2007) and the amount of silver in the effluent water does not exceed WHO guidelines (Oyanedel-Craver and Smith 2007). In addition it has been observed that the silver inhibits biological growth from forming on the filters and in the receptacles (van Halem 2006; Bloem *et al.* 2009). It has been concluded that the mechanism by which silver improves filter performance is by disinfection (Oyanedel-Craver and Smith 2007).

Investigations into the hydraulic properties of pot filters have been inconclusive (Fahlin 2003). However, using a bromide tracer breakthrough test, it was estimated that water remains in the pores of filters for 50 minutes, which, depending on the thickness of the silver layer, should provide sufficient contact time to inactivate bacteria (Fahlin 2003). It remains unknown how deeply silver penetrates into the filter walls and it has been suggested that biological growth can occur and result in clogging and reduced flow rate if some pores remain un-lined with silver (Fahlin 2003).

3.6.2 Application Methods

As mentioned in Section 3.4.8, silver is currently being applied by three different methods and two types of silver are being used. A colloidal silver solution is either painted on, elements are dipped in a silver solution, or colloidal silver is integrated into the filter mix prior to pressing and firing the filters. Some factories paint a silver nitrate solution on the filters instead of colloidal silver.

Investigations into the effectiveness of different colloidal silver application methods have found that colloidal silver should be applied to both the inside and outside of the filter for effective microbiological reduction (Lantagne 2001a). Although it has been recommended that filters be dipped rather than painted with colloidal silver to ensure the full path of water flow through the filter is coated (Fahlin 2003), it has since been concluded that the quantity of colloidal silver applied is more important than the application method (Oyanedel-Craver and Smith 2007). Although it has been suggested that silver could reduce total pore area and adsorptive surface area (van Halem 2006), tracer experiments post-colloidal silver application did not suggest this (Oyanedel-Craver and Smith 2007).

Microbiological efficacy of filters in the field with silver nitrate painted on were found to be comparable to filters with no silver nitrate applied (Brown 2007). Filters produced with a high flow rate, however, found that microbiological efficacy improved after the application of silver nitrate (Bloem *et al.* 2009). Filters produced with colloidal silver fired into the filters have been found to be effective at removing *E. coli* and total coliforms (Lantagne, Klarman *et al.* 2009).

The choice of indicator bacteria should be considered when testing for microbiological efficacy as many tests are carried out using *E. coli* and one study found no difference between filters with and without colloidal silver application at removing Clostridium spores (van Halem 2006). Clostridium spores are a gram positive bacteria, and are not sensitive to colloidal silver.

3.7 Virus Removal

Virus removal remains a challenge with ceramic filters due to the small sizes of viruses and because silver is not effective against viruses. It has also been found that the LRV of MS2 bacteriophages is slightly reduced in filters with colloidal silver and therefore it has been suggested that colloidal silver application does not have a positive effect on virus removal. However, filters have not been found to be effective at removing MS2 bacteriophages in filters with or without colloidal silver (van Halem 2006).

RDI-C adds laterite, an iron-oxide rich compound, to their filter mix as it is thought to provide additional viral binding sites (Hagan *et al.* 2009), however, although a 1-2 $\log_{10}$ reduction (90-99%) in MS2 was documented, no significant difference was found between filters with or without laterite (Brown 2007). Likewise, in a recent study (Bloem *et al.* 2009) filters made with increased laterite (which also increased the flow rate) did not show improved removal efficiencies, as the mean LRV was less than 0.5 for all of the filters tested, with or without laterite. Filters with laterite were also heavier and more porous (Bloem *et al.* 2009), which might affect breakage and user acceptability.

3.8 Metallic Compounds

Some metallic compounds have been found to leech from filters. Both aluminium and silver were below WHO guidelines as well as barium, copper, manganese and silicon. Filters were found to retain zinc (van Halem 2006). Arsenic was found in the effluent water above the provisional WHO guideline of 10 µg/L. The amount is worrying, but decreased from 200 µg/L to a mean of 17 µg/L after 12 weeks.

3.9 Summary

Ceramic filters have shown to be effective in both the field and laboratory at improving water quality. Although filtered water in the field does not always meet WHO drinking water quality guidelines of 0 *E. coli* per 100/ml sample, water quality is significantly improved. Post contamination is a possible explanation for why in some cases effluent water has a negative LRV. Filters seem to work well after several years in use; however there might be a decline in effectiveness with time. In the laboratory, five-year old filters from the field were found to reduce in effectiveness after several batches of heavily spiked *E. coli* were passed through the filters and some *E. coli* passed through the filter. In addition, with time, filters appear to loose their ability to retain colloidal silver (Bielefeldt *et al.* 2009).

Although self-reported diarrhoea is considered by some a subjective and unreliable indicator (Schmidt and Cairncross 2009), filter users report significantly fewer cases of diarrhoea and additional benefits from other health related advantages. Drinking water is not the only transmission route for diarrhoea causing pathogens and filter users might also have a higher degree of health and hygiene awareness. Although the primary association with continued use was the amount of time in the field, it is also correlated with user investment, health and hygiene awareness and other aspects (Brown and Sobsey 2006).

Production procedures vary from country to country, as do the filters. Filters from different countries vary in porosity, pore size, tortuosity and other characteristics (van Halem 2006); however, production details have not been available for the filters studied in order to compare and speculate on the influences. Clay content has been found to influence both the flow rate and porosity (Oyanedel-Craver and Smith 2007).

Although in the field, filter users do not cite insufficient water as being a primary cause for disuse, flow rates measured in the laboratory would not provide sufficient drinking water for a family. Efforts to increase the flow rate without sacrificing the microbiological removal efficiency have had different findings, with one study concluding that flow rates could be successfully raised to 8-10 l/hr while maintaining microbiological efficacy (Bloem *et al.* 2009), and another that beyond 1.7 l/hr total coliform reduction begins to drop to below 99% (Klarman 2009).

4 Methodology

4.1 Introduction

The aim of this project was to identify the various filter factories worldwide and to survey and document existing production practices to provide data that will help the Ceramics Filter Manufacturing Working Group make appropriate manufacturing recommendations, which are expected to help filter factories improve the quality of filters being produced. In order to achieve this aim and answer the research questions listed in Section 1.10, a list of filter factories was compiled, a survey was prepared and results were analysed as described below. A literature review was carried out on field studies, documented production processes and investigations into the physical properties of ceramic pot filters. In addition, the Ceramics Filter Manufacturing Working Group held bi-monthly conference calls during which different aspects of filter production were discussed. In Section 6.2, how the methodology was followed is discussed.

4.2 Sample Group

The selection criterion for participating in this study was that factories must be currently producing filters on a full-time, part-time or per-order basis. Contact information was collected from representatives of Potters for Peace, Potters without Borders, Filter Pure, and others who have worked with various filter projects including members of the Ceramics Filter Manufacturing Working Group for all known, currently producing filter factories. All filter factories meeting the criterion with contact information available were contacted with an initial e-mail introducing them to the objectives of this project and inviting them to participate. The invitation e-mail was translated into Spanish by the author and proof-read by a native Spanish speaker. The invitation included a request to provide updated contact information if no longer involved with the factory or in filter production.

4.3 Data Collection Methodology

It has been recommended that in choosing a data collection method both the nature of the investigation and the characteristics of the study population should be taken into consideration (Kumar 1999). In order to obtain information on current practices in ceramic water filter production both questionnaires and interviews were considered. Because of the geographical dispersion of filter factories it was logistically not possible within the timeframe of this project to visit each one; however this did not exclude the possibility of carrying out telephone interviews. In contrast to interviews, some of the disadvantages of questionnaires, as Kumar (1999) highlights, are that they typically have a low response rate, do not allow for clarification of questions and cannot be supplemented with additional information (i.e. observation). Conversely, they also allow the recipient time to think about the answers and allow for the possibility of consulting others. In this study, these were considered advantages because they could lead to providing more complete information. Since the advantages of interviews and both the advantages and disadvantages of questionnaires were deemed important to the author, it was decided that both questionnaires and interviews should be carried out despite the time-consuming nature of interviews (Kumar 1999). Furthermore, the extent to which participants in the study would have reliable access to a computer and the internet or be available for a telephone interview was unknown. Additional barriers, such as language, were also recognised as a possibility. In addition, the author wanted to ensure that as many questions as possible were understood and that as many questions as possible were answered. Interviews also allowed the author to invite the participant to expand upon interesting or different manufacturing practices.

After receiving a positive response to the initial invitation, representatives were sent a questionnaire by e-mail and given the option to complete and return it and schedule a follow-up call to review the questionnaire, or to simply review it for its content and participate in a telephone interview in which the author would fill out the questionnaire during the call. The survey was sent to those who expressed interest in participating and follow-up e-mails were sent to those who did not reply.

4.4 Survey Design

An outline 'mind-map' (see Figure 2-4) was prepared detailing ceramic water filter production procedures including known variables in the manufacturing process. Several production manuals were reviewed and compared to the outline to include all known variables. It was reviewed by members of the Ceramics Filter Manufacturing Working Group and feedback was incorporated into the outline.

The survey was developed based on this 'mind-map' (Figure 2-4). Questions which addressed each of the variables were formulated. A selection of both quantitative and qualitative questions was used in order to not only capture quantitative details of filter production, but also to develop an understanding of the experiences of each of the factories. Quantitative questions addressed typical manufacturing procedures. Qualitative questions of each phase of production encouraged participants to discuss past and current challenges, successes and dead-ends, as well as to allow them to discuss aspects of production in their facility which might not have been addressed in the questionnaire.

The survey was reviewed and modified according to suggestions and feedback from members of the Ceramics Filter Manufacturing Working Group and Potters for Peace. A pilot interview with a filter factory representative was carried out to check timing, flow and appropriateness of questions. Recommended modifications were made to the survey where appropriate. The survey was translated into Spanish by the author and reviewed by a native Spanish speaker. Corrections to Spanish grammar and vocabulary were incorporated where appropriate.

4.5 Survey Implementation

Structured interviews guided by the questionnaire were carried out in either Spanish or English. Interviews lasted between 1-2 hours. Not all participants were available or willing to participate in a telephone interview. In these cases, participants filled out the questionnaire and returned it by e-mail. In some cases, where a factory representative either temporarily or regularly did not have access to e-mail, a phone line, or there was a language barrier, an intermediary brought the questionnaire to the factory for the representative to complete, transferred the data to the computer and forwarded it to the author.

4.6 Limitations

Several areas for bias existed. Firstly, self-selecting bias may have influenced who responded to the invitation. Those who filled out the survey after saying they would respond might have had certain characteristics in common which may indicate a 'self-selecting bias' (Kumar 1999). Those characteristics might relate to the amount of time the factory has been running, their ability to fill out the survey well, the amount of contact they have had with other organizations and projects, the relative success of the factory, current challenges or current circumstances.

Secondly, 'social desirability' responding, whereby the respondent's answer is biased to show the respondent in a desirable light (Sapsford and Jupp 1996), may have occurred. In addition, there is often a discrepancy between what people say they do, think they should do and actually do. These will be of concern in any self-reporting research method. In addition, it must also be acknowledged that what actually happens in the factory might be different from what owners or managers see. Although quality control of a health tool is of utmost importance, comparing what people think they should be doing with recommended practices is valuable in itself, especially where de-centralised production does not always ensure that new developments regarding best practice have been communicated to all facilities.

Thirdly, where interviews were carried out, interviewer bias is also a risk. Although prompting was essential, it may have introduced bias (Sapsford and Jupp 1996). However, this might be balanced with the advantage of ensuring that participants answer as many questions as possible, understand the questions and also provided the opportunity to request elaboration on novel production methods.

Lastly, although an attempt was made to interview production managers, this was not always possible due to language barriers, organizational structures or other reasons. Participants available for interview had different roles in relation to the filter enterprises and some representatives were not intimately involved in production. Participants included production managers, owners, directors, exclusive distributors, etc. with varying levels of involvement in the details of production (see section 5.3). As a result, despite combining both interview and questionnaire data collection methods, not all questions were answered by all participants. In some cases this was because some factories wished their production details to remain confidential, but also because some participants did not know the answer to every question. Although it was suggested that such information be researched and provided at a later date, and subsequently solicited via e-mail. In many cases, it was not supplied within the timeframe of this project. This resulted in some questions remaining unanswered and may have also resulted in some misinformation regarding actual procedures in the factory which complicates cross-survey comparison. Although where possible and within permissible timeframes, an attempt was made to acquire missing information or confirm suspect information. Where information was missing, it was noted in the appropriate section. The lack of knowledge is in itself significant within the context of this research and is discussed in Section 6.

4.7 Data Analysis

Information from each of the questionnaires was translated where necessary, and transferred to a master Microsoft Excel spreadsheet per participant (as opposed to against each variable) for analysis. In this way, any perceived discrepancies in the answers from one factory could be identified and checked for accuracy. Once all data had been transferred to the spreadsheet, quantitative data was reviewed. A close reading of the qualitative data was carried out to identify patterns, similarities and differences and to establish categories. General categories of interest were established and data pertaining to each category was grouped and analysed for presentation in the results section of this report.

5 Results

5.1 Introduction

In this section results from the survey are presented. A total of 35 operational filter factories were identified in 18 countries, 25 of which participated in the survey (71%). Eight of the factories are in Myanmar and supported by one organisation. Since many of their production procedures are standardised, they were often counted as one factory. Where their characteristics or practices vary, they were counted individually. In the following sections (n=) refers to the number of respondents who answered a particular question; when underlined (<u>n=</u>) indicates that the Myanmar factories were counted as individual factories rather than as one. Results are cross-referenced to the corresponding questions in the survey (Appendix 5) and answers in the data sheets (Appendix 6) according to the following codes: Background Information: QBG 1-29, Materials and Processing: QMP 1-72, Filter Production: QFP 1-80, Quality Control: QQC 1-34, and Delivery: QD 1-21. Filter factories are referred to according to the codes displayed in Table 5-1.

Figure 5-1 Filter Factory Locations
(Source: Google Maps)

5.2 Survey Distribution

A list of 31 filter factories (counting Myanmar as one) was generated in conjunction with the Ceramics Filter Manufacturing Working Group. Thirty-one factories in 20 countries thought to be currently producing filters on a full-time, part-time or on a per-order basis were sent an e-mail describing the project and inviting them to participate (see Appendix 2). Twenty-seven factory representatives (n=31, 87%) responded positively to the initial e-mail, two (6%) did not respond (Iraq, a different Myanmar factory), one (3%) declined participation (Ghana), and one (3%) did not meet the criteria as they are no longer producing filters (Senegal). After willingness to participate was confirmed, the questionnaire was e-mailed (see Appendix 5) along with a request to set a date and time for an interview.

5.3 Study Participants and General Characteristics

Of the 27 factories who agreed to participate, nine (33%) did not respond to the survey. Of the 18 participants (n=27, 67%), six respondents (n=18, 33%) filled out the questionnaire and returned it via e-mail, eight (44%) were filled out by the author during a telephone interview and four (22%) both participated in an interview and completed the questionnaire. No respondents were excluded from the survey. However, as mentioned earlier, often the eight Myanmar factories were counted as one.

Of the 25 total participants (n=25, QBG11-12), nine (36%) factories were set up with technical assistance from Potters for Peace, two (8%) Potters without Borders, two (8%) Filter Pure, one (4%) AFA Guatemala, eight (32%) Thirst Aid, one (4%) American Red Cross, and one (4%) RDI-C & Potters for Peace. Participating factories have been producing filters since 2001, 16 of which (n=24, 67%) have been set up since 2007 (QBG13-14). Table 5-1 includes details of participating factories, reference codes, the organisation which provided technical assistance, the year production started and the level of production.

Table 5-1 Participating Factories

Code	Country	Organization	Year Started	Production
Benin	Benin	Potters without Borders	2007	Part Time
Cam-1	Cambodia-IDE	Potters for Peace	2001	Full Time
Cam-2	Cambodia-RDI	RDI-C	2003	Full Time
Colombia	Colombia	Potters for Peace	2007	Full Time
DR	Dominican Republic	Filter Pure	2006	Part Time
Guate-1	Guatemala- Antigua	AFA Guatemala	2004	Full Time
Guate-2	Guatemala- San Mateo	Potters for Peace	2005	Part Time
Indo-1	Indonesia- Bali	Potters for Peace	2007	On Order
Indo-2	Indonesia- Bandung	RDIC & Potters for Peace	2005	Full Time
MM-1	Myanmar- Twante	Thirst-Aid	2008	Full Time
MM-2	Myanmar- Twante	Thirst-Aid	2007	Full Time
MM-3	Myanmar- Twante	Thirst-Aid	2009	Full Time
MM-4	Myanmar- Twante	Thirst-Aid	2009	Full Time
MM-5	Myanmar-Yangon	Thirst-Aid	2008	Full Time
MM-6	Myanmar- Pathein	Thirst-Aid	2008	Full Time
MM-7	Myanmar- Yangon	Thirst-Aid	2006	Full Time
MM-8	Myanmar- Sagaing	Thirst-Aid	2009	Part Time
Nica-1	Nicaragua- San Marcos	Potters for Peace	1998	Full Time
Nica-2	Nicaragua-Ciudad Sandino	Potters for Peace	xx	Part Time
Nigeria	Nigeria	Potters for Peace	2008	Full Time
SL-1	Sri Lanka- Kelanya	Potters for Peace	2007	Full Time
SL-2	Sri Lanka- Matara	American Red Cross	2008	Full Time
Tanz-1	Tanzania- Arusha	Filter Pure	2009	Full Time
Tanz-2	Tanzania- Tabora	Potters for Peace	2007	On Order
Yemen	Yemen	Potters without Borders	2008	Full Time

Of 25 participants (n=21, QBG-3), seven surveys (33%) were completed by directors/general managers, eight (38%) by owners, three (14%) by supervisors/production managers, two (10%) by administrators and one (5%) by a legal representative. Information for SL-1 was provided by a representative of a formerly supporting organisation since the current factory contact person was not available.

Monthly production (QBG18) ranges from 45 filters per month to 4480 filters per month, averaging 1500 filters per month (n=25). Figure 5-2 details the current level of production at each factory.

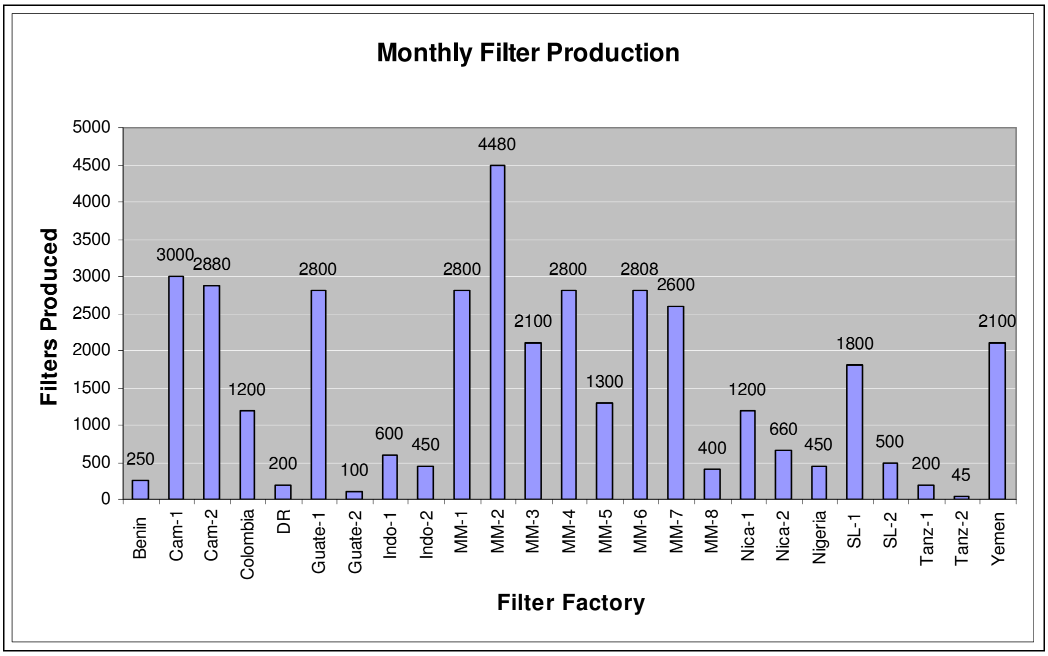


Figure 5-2 Monthly Filter Production

Total production for all participating filter factories is over 37,700 filters per month. Nine factories (36%) produce 500 filters or fewer per month, two factories (8%) produce between 500 and 1,000 filters per month, four factories (16%) produce between 1,000 and 2,000 filters per month, nine factories (36%) produce 2,000-3,000 filters per month and one factory (4%) produces more than 3,000 filters per month.

Complete filter units are sold for (n=24, QBG21-22) an average wholesale price of U$15.71 ranging from U$7.50-35.00. Average retail price is U$16.68 (n=23), ranging from U$8.00-35.00. For just the replacement element, wholesale prices average U$7.78 and range from U$3.00-25.00; retail prices average U$8.60 and range from U$4.00-25.00. See Figure 5-3 for retail price details per factory.

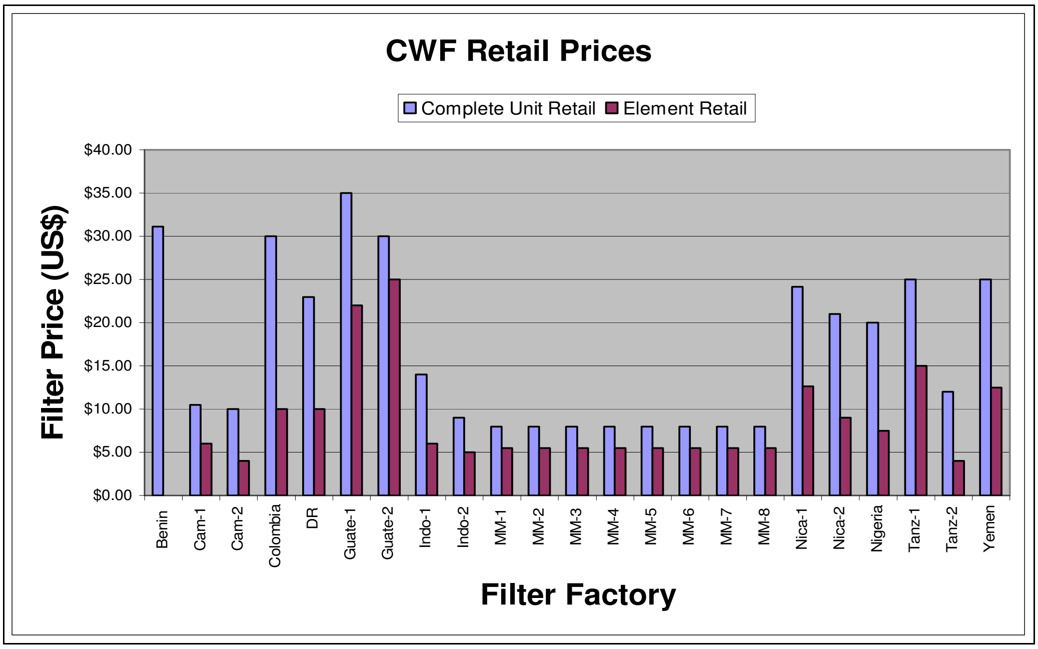


Figure 5-3 CWF Retail Prices

Fifteen factories (n=24, 62%) sell more than 50% of their filters to non-governmental organisations (NGOs) or international non-governmental organisations (INGOs). Six factories (25%) sell 50-100% of their filters to the public. One factory (MM-8) sells 90% of their filters to the government. Filters manufactured at SL-2 are sold exclusively to the Sri Lankan Red Cross (QBG23-24).

5.4 Factory Set-Up

5.4.1 Equipment

Photo 5-1 Pug Mill
(Thirst-Aid 2009b)

Equipment (QMP1) varies per factory. Only the Yemen factory (n=25, 4%) does not have an electric mill and therefore pulverises clay manually. Fifteen factories (60%) have mortar mixers. Thirteen factories (52%) have pug-mills including the eight Myanmar factories, Colombia, DR, Nica-1 and both of the Sri Lanka (SL-1, SL-2) factories. Three factories (12%) have manual presses while 24 (96%) have hydraulic presses (numbers add to more than 100% because some have both). Only three factories (12%) have air compressors and seven (28%) have pottery wheels. Not all equipment at the factories is used for filter production, however. In Table 5-2, type and number of equipment in each factory are displayed.

Table 5-2 Factory Equipment

Country	Hammer Mill	Mortar mixer	Pug Mill	Manual Press	Hydraulic Press	Air Compressor	Pottery Wheel	Kilns
Benin	1	1	0	0	1	0	0	1
Cam-1	2	2	0	1	2	1	0	7
Cam-2	1	2	0	0	1	0	3	5
Colombia	1	0	1	0	1	0	0	1
DR	2	1	1	0	1	0	3	3
Guate-1	1	1	0	0	1	1	1	2
Guate-2	0	1	0	0	1	0	0	1
Indo-1	1	0	0	0	1	2	1	2
Indo-2	2	1	0	2	0	0	2	1
MM-1	1	1	1	0	1	0	0	3
MM-2	1	1	1	0	2	0	0	5
MM-3	1	1	1	0	1	0	0	3
MM-4	1	1	1	0	1	0	0	3
MM-5	1	0	1	0	2	0	0	3
MM-6	1	0	1	0	2	0	0	4
MM-7	1	1	1	0	3	0	0	2
MM-8	1	0	1	0	1	0	0	2
Nica-1	2	0	1	1	1	0	0	6
Nica-2	1	0	0	0	1	0	0	1
Nigeria	1	0	0	0	1	0	0	1
SL-1	1	2	1	0	1	0	0	1
SL-2	1	3	3	0	2	0	0	5
Tanz-1	1	1	0	0	1	0	2	3
Tanz-2	1	0	0	0	1	0	1	1
Yemen	0	0	0	0	1	0	0	1
Number of factories that have:								
None	2	10	12	22	1	22	18	0
One	19	11	12	2	18	2	3	9
Two	4	3	0	1	5	1	2	4
Three	0	1	1	0	1	0	2	6

5.4.2 Water

Source water (QMP31-37) is used in filter production and for flow rate testing. Fourteen factories (n=18, 78%) consider their water source reliable, one factory (6%) considers it somewhat reliable and three facilities (17%) do not, two of which have intermittent piped supply and one which has their water trucked in. Eight factories (n=18, 44%) have 24-hr piped municipal supply, others rely upon intermittent supply (1, 6%), water being trucked in (2, 12%), or alternative sources including ground or rainwater (3, 17%). Four factories use a combination of sources (22%).

Source water has been tested for arsenic at three factories (n=16, 19%). No arsenic was detected at any of the eight Myanmar factories, 0 ppb in the groundwater at Cam-1, and "not much" at Tanz-2. The eight Myanmar factories are currently testing source water for heavy metals, however results are not yet available. SL-2 has tested for faecal coliform, total coliform and ferrous compounds, the latter, is present in the dry season. Cam-2, Guate-2 and Indo-2 have had their source water tested, but details were not available. Tanz-2 has also tested for sodium and fluoride. The remaining 10 factories (63%) have not tested their source water or do not know if it has been tested.

5.4.3 Electricity

Eight factories (n=24, 33%) get 100% of their electrical supply from the grid. Three (13%) do not use electricity in production (Indo-2, Guate-1 and Yemen). Six factories (25%) rely upon a generator (Cam-2, MM-1, MM-2, MM-3, MM-4 and MM-6) and the rest (7, 30%) rely upon both the grid and a generator for their power supply (QMP2). Energy is a big expense in Nigeria, so effort is made to do most things manually.

5.5 Materials

5.5.1 Clay

Clay sources (n=17, QMP7) are those typically used by local potters (6, 35%). Reported criteria for selecting clay are quality (6, 35%), plasticity (5, 30%), proximity of the mine (4, 24%), and the colour of the clay (1, 6%). Three factories (18%) reported exploring various mines before finding a clay that worked. Five factories (30%) mentioned having identified reliable clay sources, however, the Yemen factory finds getting clay of a consistent quality challenging because there is no clay mine per se, as clay is collected from excavations at construction sites and this leads to inconsistencies. The Colombia factory reported that if clay is not chosen carefully, it can result in a failure rate of over 20%. Three factories (18%) mentioned experimenting with clay. At Cam-1 and Indo-2, clay is tested for plasticity and prototypes are test fired and evaluated for cracking, breaking, firing temperature and filtration rates. In Nigeria, university students evaluate suitability in a laboratory by testing for shrinkage, ease of use, firing temperature, filtration and materials composition. Seventeen factories (n=18, QMP8-14) receive their clay directly from the mine and process it themselves (94%). Cam-2 receives their clay pre-formed into bricks. Two factories (Benin and SL-2, 11%) blend three clays with different characteristics.

Sixteen factories (n=17, 94%) mill their clay and 15 factories (n=18, 83%), sieve their clay. The clay sieve sizes (n=11) range from 9 to 80 mesh using Tyler Equivalent[13] (see Appendix 3 for Tyler Mesh chart). Four factories (n=11, 36%) use between 9-16 mesh, three factories (27%) use between 21-

[13] Tyler mesh size can be determined by counting the number of openings per linear inch which controls the particle size of material passed through the sieve

30 mesh and four factories (36%) report using between 60-80 mesh sieves. Figure 5-4 below shows the clay mesh sizes being used.

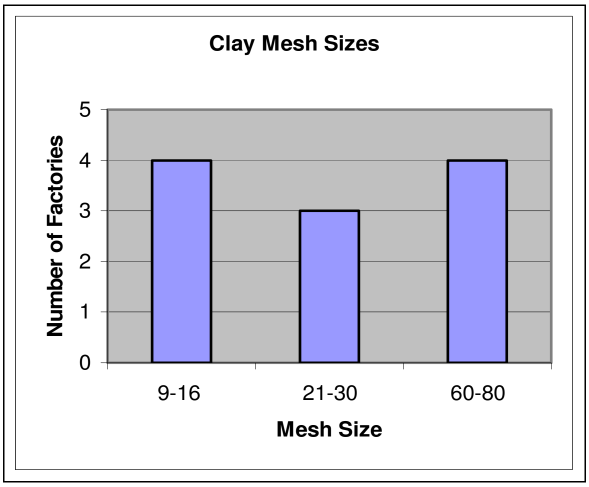


Figure 5-4 Clay Mesh Sizes

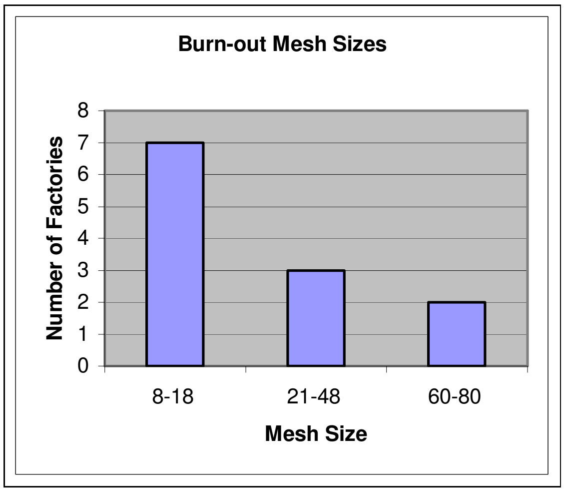


Figure 5-5 Burn-out Mesh Sizes

5.5.2 Burn-out Material

Seven factories (n=18, 39%, QMP 19-26) use rice husks and 10 use sawdust (56%). The Benin factory (5%) uses a combination of sawdust and peanut shells in their mixture. Of those using sawdust (n=10), three (30%) always use pine, one (10%) always uses guanacaste (Nica-2), one (10%) always uses pine and gravellea (Tanz-1), one (10%) predominantly uses oak (Nigeria), and four (40%) use what is available. One factory (DR) found that when using sawdust from oak in their filter mixture it left an oily residue and resulted in a reduced flow rate.

Seven factories (n=18, 39%) mill their own burn-out materials and 15 (n= 17, 88%) sieve it. Mesh sizes for sieving combustible material (n=12) range from 8-18 mesh (7, 58%), 21-48 mesh (3, 25%), and 60-80 mesh (2, 17%). Indo-2 uses two sieve sizes to eliminate both the larger and finer particles. Cam-1 and Indo-2 use different mills for clay and burn-out material. Burn-out sieve size ranges are detailed above in Figure 5-5 above.

Hammer mill or grinder blades are sharpened (n=11, QMP27) monthly, every two months (3, 27%) every 6 months to a year (3, 27%), every 2,000 kilos of clay (1, 9%) or as needed or don't know (4, 36%). The Dominican Republic (DR) factory reported that sharpening the hammer mill blades helps achieve a finer particle size of burn-out material. The Nigeria factory has successfully used a kitchen blender to increase yield from sawdust and as an alternative, SL-2 uses a chilli grinder for milling rice husks.

The Myanmar factories had difficulties working with rice husks initially since the high silica content in the outer rice husks tended to block the pores; however, they have had success using only the inner rice husks. Indo-2 found that using sawdust as a burn-out material increased shrinkage too much yet Cam-1 expressed a preference for sawdust if it were more readily available since the filters would be smoother and nicer looking.

5.5.3 Additional Materials

Two factories, DR and Tanz-1 (n=18, 11%, QMP62-67), add colloidal silver diluted in water to their dry mix. Cam-2 adds laterite[14] and others include grog[15] (Indo-2) or sand (Guate-1) in their regular formulae. Guate-2 sometimes adds grog from bricks which did not fire well. SL-2 has experimented with adding grog, however, they found that it reduced shrinkage to the extent the filter elements would not fit in the receptacles.

5.6 Mixing

Where rice husks are used (n=7, QFP1-8), six factories (n=6, 100%) report measuring materials by weight. Ratios vary between 76:24 to 90:10, clay to rice husk. Table 5-3 lists filter mixture ratios where rice husks are used.

Table 5-3 Clay-Rice Husk Mixture

Country	Clay Mesh	Burn-out Mesh	Burn-out type	Measured by	Ratio Clay (%)	Ratio Burnable (%)	Ratio Other (%)	Other material
Cam-1	n/a	16	Rice Husk	Weight	76	24		
Cam-2	don't know	don't know	Rice Husk	Weight	75	20	5	Laterite
Indo-1	12	12	Rice Husk	Weight	90	10		
Indo-2	n/a	don’t know	Rice Husk	Weight	84.5	10	5.5	Grog/failed filters
MM-All	30	16	Rice Husk	Weight	88	12		
SL-1	80	60*	Rice Husk	blank	blank	blank		
SL-2	80	18	Rice Husk	Weight	87	13		

***this might be an error**

[14] Laterite is thought to provide additional viral binding sites.
[15] Grog is ground up fired clay

Clay to sawdust ratios (n=10), when mixed by weight (n=6, 60%) range between 75:25 to 95:5, clay to sawdust. When mixed by volume (n=4, 40%), however, the ratio ranges from 53:47 to 50:50 clay to sawdust. The Benin factory includes both sawdust and peanut husks in their filter mix. In Table 5-4 mixture ratios where sawdust is used are presented.

Table 5-4 Clay-Sawdust Mixture

Country	Clay Mesh	Burn-out Mesh	Burn-out	Measured by:	Ratio Clay (%)	Ratio Burn out (%)	Ratio Other (%)	Other
Colombia	21	21	Saw dust	Weight	84.4	15.6		
Guate-1	10	10	Saw dust	Weight	Private	Private	Private	Sand
Nica-1	n/a	8	Saw dust	Weight	93.8	6.25		
Nica-2	80	80*	Saw dust	Weight	85.7	14.3		
Tanz-2	Mosq. net	Mosq. net	Saw dust	Weight	75	25		
Yemen	9 or 16	9 or 16	Saw dust	Weight	95	5		
DR	60	48	Saw dust	Volume	53	47	Private	Silver
Guate-2	don't know	don't know	Saw dust	Volume	blank	blank		
Nigeria	blank	don't know	Saw dust	Volume	50	50		
Tanz-1	25	30	Saw dust	Volume	53	47	Private	Silver
Benin	16	don't know	Saw dust	Both	63.6	19.2	16.16	Peanut

***this might be an error, 8 mesh is more likely.**

Mixing times (QFP9, 10) vary greatly with dry mixing (n=20) lasting for between five minutes and one hour (avg=13, stdev=12). Wet mixing times (n=21) range between 5 and 45 minutes (avg=15, stdev=9). Mixing times are detailed in Table 5-5, Table 5-7 and Table 5-6.

Table 5-5 Mixing Times (all manual)

Non electric mixer or by hand		
Filter Factory	Time Dry (min)	Time Wet (min)
MM-2	10	20
MM-5	5	5
MM-6	20	15
MM-8	10	15
Nica-2	10	10
Tanz-2	15	15

Table 5-7 Mixing Times (manual/electric)

Non-electric dry and electric wet		
Filter Factory	Time Dry (min)	Time Wet (min)
Guate-1	blank	30
Indo-2	60	15
MM-1	10	20
MM-3	20	20
MM-4	10	15
MM7	10	15

Table 5-6 Mixing Times (all electric)

Electric Mixer - Both		
Filter Factory	Time Dry (min)	Time Wet (min)
Benin	10	10
Cam-1	8	8
Cam-2	10	10
Colombia	10	10
DR	5	10
Indo-1	10	10
Nica-1	0	45*
SL-1	5	6
SL-2	8	as needed
Tanz-1	5	10

* due to the type of mixer, clay and burn-out material are not mixed prior to adding water.

At Indo-2, dry materials are mixed for one hour manually as they have found that when mixed for less than 50 minutes, flow rates become inconsistent. In Nigeria, the mixing process takes half a day, where ingredients are mixed manually on the ground and then pounded in a mortar and pestle. At Nica-2, because of the type of mixer, dry ingredients are not mixed in advance of adding water.

Photo 5-2 Mixing Dry Materials in a Drum Mixer, Myanmar
(Thirst-Aid 2009b)

Photo 5-3 Mixing in a Mortar Mixer, Nicaragua
(Rayner 2006)

Photo 5-4 Manual Mixing, adding water to filter mixture, Colombia
(Asopafin 2009)

Fifteen factories (n=18, 83%, QFP11,12) wedge the clay before pressing. The Nigeria factory also pounds the mixture using a mortar and pestle. Only the Myanmar factories use pug mills. They started using non de-airing pug mills in all of the Myanmar factories after finding that their use resulted in much stronger filters.

Eight factories (n=16, QFP14,15) always press filters the same day the mix is made and do not reprocess dried mixture (Guate-1, Guate-2, Indo-1, Indo-2, MM-all, Nica-1, Nigeria, Tanz-2). Three factories (19%) sometimes or normally leave the mixture overnight, but do not reprocess dried mixture (Benin, Cam-1, Cam-2). One factory (6%) presses the same day but will also reprocess dried mixture (Yemen). Four factories (25%) use mixture prepared the day before and will reprocess dried mixture (Nica-2, SL-2, Tanz-1, DR). Two of these factories (DR and Tanz-1) include silver in the mixture which makes it expensive to waste.

Three factories (n=16, 19%, QFP5-8) do not adjust their formula (Benin, Cam-1, Nica-2). Guate-2 (6%) adjusts their formula regularly, and twelve (75%) adjust their formula as needed. Reasons given for adjusting the formula include clay quality (31%, Guate-1, Nigeria, Tanz-2, Yemen, DR), flow rate (13%, Cam-2, DR), variation in rice husk (6%, MM-all), the weather (13%, Tanz-2, Indo-2), or a quality control issue (6%, DR). At Indo-2 three distinct mixes are prepared daily to make filters suited to different heights in the kiln and small adjustments are made to the formula after every firing.

5.7 Forming Filter Elements

In Rabinal, Guatemala, filters are still being made on the potter’s wheel and sold through AFA Guatemala (Guate-1). Otherwise, all factories (n=18), including Guate-1, press filters using a press with moulds.

5.7.1 Presses

Seventeen factories (n=18, 94%) use a hydraulic press (QFP19-20). At Indo-2, the non-hydraulic press works with a system of weights and pulleys. All presses were made locally except for one imported from Cambodia (SL-2), one from Holland (Indo-1), one from Nicaragua (Guate-2) and one portable press from Nicaragua (Nigeria). Photo 5-5, Photo 5-6, Photo 5-7, and Photo 5-8 show different presses with moulds made from different materials.

Photo 5-5 Filter Press with aluminium mould, Indo-2
(Pelita 2009)

Photo 5-6 Filter Press with cast-iron mould, Cam-1
(IDECambodia 2009)

Photo 5-7 Filter Press with wood mould, Myanmar
(Thirst-Aid 2009b)

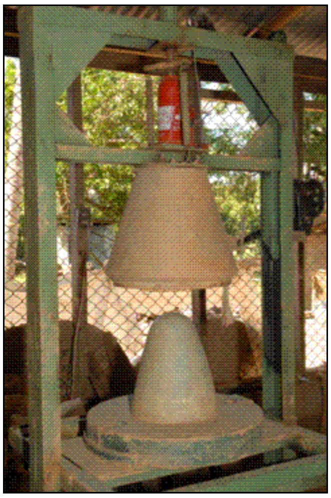


Photo 5-8 Filter Press with cement mould, DR
(FilterPure 2009)

5.7.2 Moulds

Three mould designs are currently being used (n=25, QFP25-27). Fifteen (60%) factories use flat-bottomed moulds based on the original hand-thrown design. The eight (32%) Myanmar factories use a semi-circle round bottomed mould and the two Filter Pure factories (8%, DR, Tanz-1) use an oblong, round-bottomed mould. Flat bottomed moulds are made out of aluminium (12, 80%) or cast iron (3, 20%). Both of the Filter Pure (100%) moulds are made out of cement. In Myanmar, moulds are made out of cast iron, steel, aluminium or are carved from teak wood. Table 5-8 shows where moulds were made, mould material, filter dimensions, filter capacity and clay quantity. Reported filter wall thickness ranges from 1-3 cm. Filter dimensions should be considered approximate as shrinkage and firing time will affect the final filter size. Although the survey requested finished filter size, some participants may have provided mould dimensions. In addition, filter capacities for the five factories whose moulds were made in Nicaragua range from seven to nine litres. This difference might be more than can be accounted for by shrinkage.

Table 5-8 Mould and Filter Sizes

Country	Made in:	Material:	Filter Height (cm)	Filter Diam. (cm)	Walls Thick (cm)	Capacity (litres)	Quantity in press (kg)
Benin	blank	Aluminium	24	32	0.1*	8	8
Cam-1	Cambodia	Cast-iron	24	33.5	1.7	10	9
Cam-2	Cambodia	Aluminium	blank	blank	blank	11	8
Colombia	blank	Aluminium	blank	blank	blank	blank	8
DR	Dominican Republic	Cement	28	28	1.6	6	5.4
Guate-1	Guatemala	Aluminium	23	32	blank	7	don't know
Guate-2	blank	Aluminium	28**	30.5**	2	11**	blank
Indo-1	Nicaragua	Aluminium	25	32	1.5	9	8.4
Indo-2	Indonesia	Aluminium	blank	blank	1.8	8	5.7
MM-All	Myanmar	Cast iron, Carved teak, Steel or Aluminium	blank	blank	1.4	10	7
Nica-1	Managua	Aluminium	23.5	32	1	8	7.3
Nica-2	Nicaragua	Aluminium	22.5	31	blank	7	5
Nigeria	Nicaragua	Aluminium	blank	blank	blank	blank	blank
SL-1	Cambodia	Cast Iron	14*	blank	3	10	10.5
SL-2	Cambodia	Cast Iron	23	32	2.5	8	10
Tanz-1	Tanzania	Cement	29	33	2.1	8	8
Tanz-2	Nicaragua	Aluminium	blank	blank	0.5*	7	3*
Yemen	Nicaragua	Aluminium	blank	blank	blank	7	9
*this information does not appear to be accurate							
**calcualated from answers provided in inches and US gallons.							

All of the filter factories (n=17, QFP36-38) expressed satisfaction with their mould release. Thirteen factories (n=18, 72%) use plastic bags to prevent the clay from sticking to the mould. The Myanmar factories brush vegetable oil on plastic bags to prevent the clay from sticking to the plastic bags. Four other factories use lubricant including coconut oil (3, 17%: SL-1, SL-2, Indo-2) and palm oil (6%, Colombia). Cam-1 is testing different oils to replace plastic bags to reduce the need to smooth crease lines caused by the plastic bags when pressing. They are currently experimenting with coconut, vegetable and fish oil, but have found that vegetable oil did not work because the mould is not polished. Cam-2 reported having experimented with oils, but did not find it as effective as plastic bags. SL-2 mentioned that coconut oil did not work with the aluminium mould; however after switching to a cast iron mould it worked. DR reported that thin plastic bags last for 50 pressings; however Nigeria reported that plastic bags are not an insignificant expense. Nica-1 doubles the bags for pressing.

5.8 Trimming

All factories (n=18, 100%, QFP32-34,43-44) stamp their filters with a lot number and eight (n=16, 50%) also stamp them with a logo. All but SL-1 and Tanz-2 (n=18, 89%) touch up or trim filters after pressing. SL-2, Benin, Yemen, MM-all, Guate-2, and Tanz-1 only touch up the lip of the filters and do not touch the inside or outside of the filter. Of those that trim their filters (n=10), eight trim the bottom of the filter, all smooth the sides and two roughen the sides as necessary (Guate-1, Nica-1).

5.9 Drying

Drying times vary depending on the season and weather conditions (humidity, sun, wind). Drying times (n=24, QFP45-48) average seven days in the dry season (min 3, max 21) and 13 in the wet season (min 4, max 45). Figure 5-6 shows drying time ranges.

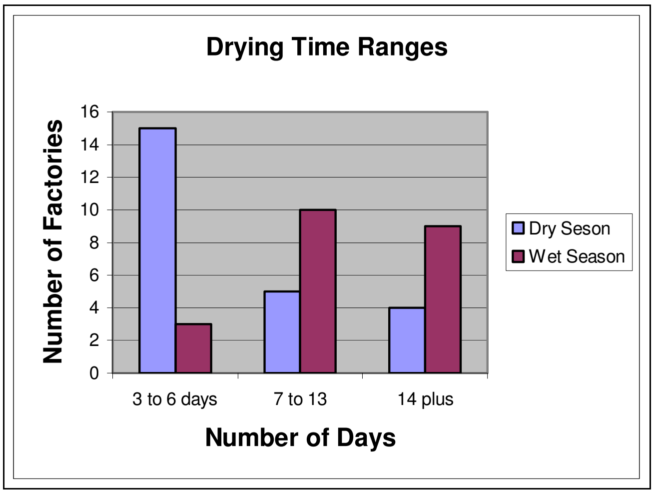


Figure 5-6 Drying Time Ranges

Cam-1, Cam-2, Colombia, DR, Guate-2, Indo-2, Nigeria and SL-2 mentioned drying time as a challenge (n=18, 44%). Mould, which can develop on wet clay, was reported as a problem since the mould marks do not fire out (Cam-1), in response, production during the wet season is decreased by 15% and increased in the dry season. Indo-2 dries filters on rolling racks and relocates them to near the kiln so the warmth accelerates the drying process. Myanmar factories have increased storage space for the filters to dry during the rainy season. Two factories (11%) sometimes artificially dry their filters. In Nigeria, locally made convection ovens can dry filters in two hours; however filters are usually left to dry naturally. SL-2 has converted a large kiln into a drying room and warms it to 45°C for two days using leftover charcoal from previous firings. Nica-1 and Nica-2 resolve the problem of insects burrowing into the clay (beetles) by covering filters with plastic bags. Figure 5-7 illustrates drying times during the wet and dry seasons at each of the filter factories.

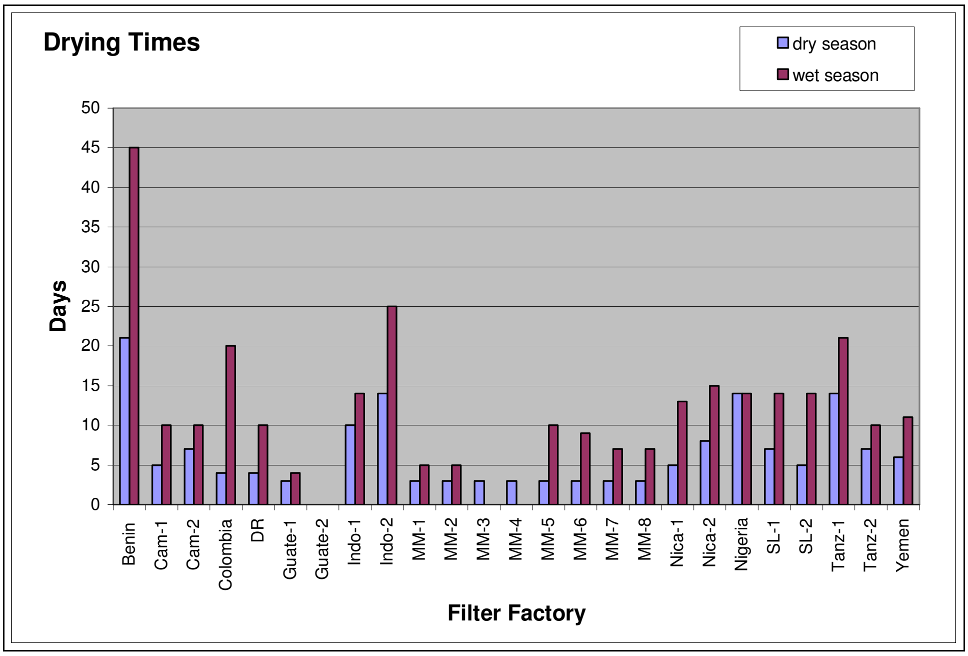


Figure 5-7 Drying Times

5.10 Firing

5.10.1 Kilns

Photo 5-9 Mani Kiln
(Hernandez 2006)

Factories (n=24, QMP1, QFP56-7) have between one and seven kilns with an average of 2.75 kilns. Kiln capacity used in production (n=18) ranges from 40 to 200 filters with an average of 86 filters per kiln. Kiln types vary between factories. Eight factories (n=18, 44%) have Mani Kilns (downdraft), which hold 50 filters. In addition, Cam-2, DR and the Myanmar factories (17%) have Mani Arch Top kilns which hold between 70-200 filters. Six factories have updraft kilns (33%) with capacities ranging from 40 to 150 filters, SL-2 has another type of downdraft kiln which holds 100 filters and Yemen has a propane fired kiln with a 98 filter capacity (see Figure 3-1 and Figure 3-2 for diagrams of heat-flow in down-draft and up-draft kilns). Six factories (n=18, 33%, QFP58) stack filters directly on top of each other and twelve (67%) use clay spacers to avoid carbon marks on the filters. Both Tanz-1 and DR factories (n=16, 13%) aim to leave a carbon residual inside the filter walls, whereas the others (14, 88%) do not. For five factories (28%), production is limited by the number of kilns and the amount of time it takes to fire and cool the kilns (Cam-2, Guate-2, Indo-1, Indo-2 and Nigeria). Kiln details are presented in Table 5-9.

Table 5-9 Kilns

Country	#Kilns	Sizes	Type	Capacity	Fuel
Benin	blank	blank	Updraft	150	Oil
Cam-1	7	1.9 m^3	Mani	50	Wood
Cam-2	5	90 filters	Mani, Mani Arch, Other DD	90	Wood
Colombia	1	2.5x2.5x3.0m	Updraft	125	Wood
DR	3	5x3x4H ft?	Mani Arch	200	Wood
Guate-1	2	100 filters each	Updraft	100	Wood
Guate-2	1	45 filters	Updraft	40	Wood
Indo-1	2	75 filters each	Mani	75	Wood
Indo-2	1	150 filters	Updraft	150	Wood
MM-all	2 to 5	blank	Mani & Mani Arch	54/72	Wood
Nica-1	6	1.4 m^3	Mani	50	Wood
Nica-2	1	50 filters	Mani	50	Wood
Nigeria	1	standard Mani	Mani	50	Wood
SL-1	1	80 filters	Updraft	80	Wood
SL-2	5	Some are huge for tile making	Other Down draft	100	Wood
Tanz-1	3	1 m^3 & 1.5 m^3	Mani & others	50, 30, 5	Wood, Propane
Tanz-2	1	50 filters	blank	50	Wood
Yemen	1	4.5 m^3	Other	98	Propane

5.10.2 Fuel

Fifteen factories fire with wood (n=18, 83%, QFP61). Tanz-1 fires to 600°C with wood, then switches to propane for the last two hours. The Yemen factory fires exclusively with propane and the Benin factory fires with oil.

Photo 5-10 Filters Stacked for Firing, Myanmar
(Thirst-Aid 2009b)

Photo 5-11 Kiln being Fired, Cam-1
(IDECambodia 2009)

Photo 5-12 Kiln and Fired Filters, Yemen
(SilverFilterCompany 2009)

Several factories have experimented with different fuel sources. Cam-1 tested with rice husks and a blower system. Although it worked, kilns are fired with wood since it is available. Cam-2 reported that the cost of experimenting with alternative fuel sources is high. They tried injecting rice husks but they didn't burn properly, produced a lot of ash and the cost of electricity made it too expensive. They also tried firing with compressed fuel logs but the machines weren't durable enough. Myanmar did not have success firing with rice husks. They did however fire with oil successfully but it was too expensive.

Photo 5-13 Experimenting with Alternative Fuel Sources, Colombia (sawdust and coffee husks)
(Rivera 2008)

The Nigeria factory commented that normal firewood does not reach peak temperatures, and therefore dense wood must be used. The quantity of wood required for a firing will vary depending on the type and dryness of the wood and the kiln efficiency and size. The Colombia factory reported using an average 600 kg of wood to fire a 125 filter capacity updraft kiln for 5-6 hours. In Nicaragua, an estimated 200 kg of wood is used to fire a 50 filter Mani Kiln for 8-9 hours (Rayner 2006). When using propane, using several smaller canisters helps maintain pressure, as reported by the Yemen factory.

5.10.3 Measuring Temperature

Target temperatures range from 700°C to 980°C and average 870°C (QFP62-66). Temperature is monitored visually and measured with pyrometers and/or pyrometric cones. Thirteen factories (n=18, 72%) use pyrometers to measure the temperature in the kilns and nine factories (50%) use cones (see Section 3.4.6 for more information on pyrometric cones). Four factories (n=18, 22%) use both. In addition, six factories (33%) report estimating temperature visually (see Section 3.4.6 and Appendix 4), however at the Nigeria factory, estimating temperature visually did not work.

Of those that use cones (n=9), three use only one cone (Cam-1, Guate-1 and Nica-2), two use three cones of the same number in different places in the kiln (Nigeria, Tanz-1), three (Cam-2, MM-all, Guate-2) use two cones of different numbers and one (Nica-1) uses three cones of different numbers. At Indo-1, temperature is measured with a pyrometer at six different locations in the kiln. Some have reported difficulties acquiring pyrometers or cones in country (Indo-2, SL-2). With that being said, factories (n=17) feel they always (8, 44%), almost always (7, 41%) or usually (2, 12%), follow their firing schedule, meeting desired temperature grades and soak times (FPQ65). At least three factories (17%) mentioned that successful firings lie in the skill and experience of the kiln master. In Table 5-10, details on firing practices are presented including firing times (QFP67) which range from six to 14 hours. Kiln cooling times (QFP68) range from 12-24 hours.

Table 5-10 Firing Practices

Country	Fuel	Pyro-meter	Cones	Visual	Number of Cones	Cone numbers	Target Temp °C	Frequency Achieved	Fire Time (hrs)
Cam-2	Wood	x	x		2	012, 014	866	Always	10 to 12
MM-all	Wood	x	x	x	2	09, 010	900	Almost Always	6 to 7
Nigeria	Wood	x	x		3	06	900	Almost Always	10 to 12
Tanz-1	Wood & Propane	x	x	x	3	012	880-900	Always	8
Cam-1	Wood		x		1	014	830	Always	12
Guate-1	Wood		x	x	varies	012	private	blank	private
Guate-2	Wood		x		2	014, 012	847	Almost Always	11
Nica-1	Wood		x		3	010,012,014	886	Always	8
Nica-2	Wood		x	x	1	012	830	Almost Always	8
Benin	Oil	x			n/a	n/a	900	Almost Always	12
Colombia	Wood	x			n/a	n/a	900	Usually	6
DR	Wood	x		x	n/a	n/a	980	Always	12
Indo-1	Wood	x			n/a	n/a	900	Always	8.5
Indo-2	Wood	x		x	n/a	n/a	832	Always	10 to 14
SL-1	Wood	x			n/a	n/a	800	Almost Always	15
SL-2	Wood	x			n/a	n/a	800	Almost Always	10 to 11
Tanz-2	Wood	x			n/a	n/a	700-920	Usually	6 to 8
Yemen	Propane	x			n/a	n/a	880	Always	11

Figure 5-8 shows the percentage of filters which crack per kiln-load at each of the factories. All of the factories reported that these rates are consistent except for Benin, Guate-2, Nica-1, Nica-2, SL-2 and Tanz-1. SL-1 does not know if these rates are consistent.

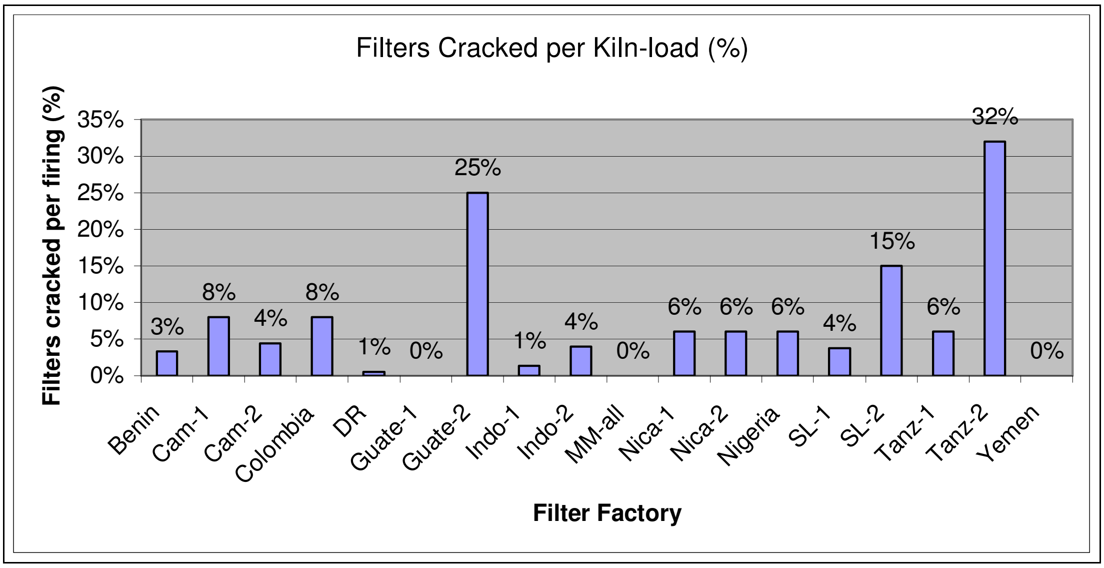


Figure 5-8 Filters Cracked per Kiln-load (%)

5.11 Silver

5.11.1 Silver Types

Two forms of silver are currently being used (n=18, QMP38-58), colloidal silver (15, 83%) and silver nitrate (3, 17%). MM-all is included in both sums, since they currently use both. Tanz-2 does not use either, but rather Katadyn tablets made of a sodium silver chloride complex with 0.1% silver ions and 2.5% Sodium dichloroisocyanurante. Colloidal silver is being used in liquid (n=15, 7, 47%) and powdered (10, 67%) form, Guate-2 and Benin use both. Silver nitrate is used in powdered form (n=3, 100%). Filters are either dipped in (n=18, 10, 56%) or painted with a silver solution (6, 33%) or silver is added to the filter mixture and fired into the filter pots (2, 11%).

Silver Nitrate, used at Cam-2, MM-all and Indo-2, is purchased in country imported from either China or Germany. Colloidal silver is imported from Germany (Reickerman - Spraylat) or Spain (Argenol Labs – Collargol or Argenyl) in both powdered and liquid forms. In addition, Guate-2 is using silver from USA and one factory wished to keep the information confidential. None of the factories make their own colloidal silver. Indo-2 purchases silver nitrate in small packets from a local reseller; the source and ppm therefore, are not confirmed.

5.11.2 Water Quality

Silver is diluted using a variety of water qualities (n=15) including water purified by reverse osmosis (1, 7%), groundwater (3, 20%), filtered groundwater (1, 7%), municipal water (3, 20%), municipal water without chlorine (1, 7%), deionised water (2, 13%), distilled water (1, 7%) potable water (2, 13%) and untreated surface water (1, 7%). The factories which use silver nitrate, which are included in the above counts, use water purified by reverse osmosis (MM-all), and deionised water (Indo-2, Cam-2).

5.11.3 Silver Application Methods and Concentrations

Silver (n=18) is dipped (10, 56%), painted on (6, 33%) or fired into the filters (2, 11%). Cam-1 does not paint the rim of the filters with silver. Table 5-11 details the concentration and dilution of colloidal silver when applied by painting.

Table 5-11 Colloidal Silver Applied by Painting

Colloidal Silver Applied by Painting									
Country	Silver from:	Company	Form	Concen-tration (%)	PPM	Silver Solution (ml)	Water (ml)	Diluted Solution (PPM)	Amount in Filter (mg)
Cam-1	Spain	Argenol Labs	Liquid	3.2	32000	1	300	107	32
SL-1	Spain	Argenol Labs	Liquid	3.2	32000	2	300	213	64
SL-2	Spain	Argenol Labs	Liquid	3.2	32000	2	300	213	64
Nica-1	Spain	Argenol Labs	Powder	3.2*	32000	2	300	213	64*
MM-all	Germany	Reickerman-Spraylat	Liquid	3.2	32000	3	333	288	96
*Reports using powdered silver, Argenol Labs only sells powdered silver to the filter factories of concentrations between 70-75%, therefore, it is likely Nica-1 prepares a silver concentrate which is further diluted according to the above specifications.									

Table 5-12 details the concentration and amount of colloidal silver applied by dipping.

Table 5-12 Colloidal Silver Applied by Dipping

Colloidal Silver Applied by Dipping								
Country	Silver from:	Company	Form	Concen-tration (%)	PPM	Silver (grams)	water (ml)	Silver solution (PPM)
Benin	Spain	Argenol Labs	Liquid/Powder	4	40000	14	40000	14*
Colombia	Spain	Argenol Labs	Powder	75	750000	70	250000	210
Indo-1	Spain	Argenol Labs	Powder	75	750000	20	1000**	1500
Yemen	Spain	Argenol Labs	Powder	75	750000	14	40000	263
* If silver is purchased from Argenol Labs in powder form as reported, then it is between 70-75%. Using 75% silver would result in the diluted solution being 263 PPM. If these figures are for the 3.2% solution from Argenol Labs, then the PPM of the diluted solution would be 11.								
** This might be a typographical error. Confirmation was not possible.								

Tanz-2 dips filters in a solution made from dissolving five tablets of Katadyn Micropur Forte, a sodium silver chloride complex with 0.1% silver ions and 2.5% Sodium dichloroisocyanurante in seven litres of water. Guate-1 paints their filters with a dilution of liquid colloidal silver mixed with distilled water, but wished to maintain the quantity and dilution private. Guate-2 uses liquid colloidal silver from USA, of an unknown concentration, diluted with tap water and applied by painting it on. Tanz-1 and DR fire colloidal silver into their filters, however, the amount used is confidential. They also paint colloidal silver onto fired filters to prevent post-contamination.

The Myanmar factories, Indo-2 and Cam-2 paint a silver nitrate solution on each filter. Myanmar mixes 50 grams of silver nitrate per litre of water, which makes a 32,000 parts per million (ppm) solution. This is provided to each factory for a week's supply of concentrated solution. At the factory, this concentrated solution is further diluted to make a 250 ppm solution for application to the filters, the same dilution as used with colloidal silver. Cam-2 adds 100 grams of 99.8% silver nitrate to 1500 ml of water to make a concentrate; 100 ml of this concentrate is then mixed with 18 litres of water which is enough to coat 60 filtering elements. Each element is coated with 300 ml, 200 ml on the inside and 100 ml on the outside. At Indo-2, 0.5 grams (ppm unknown) is added to 400 ml of water which is painted onto each filter.

5.11.4 Silver Sensitivities

Silver is affected both by UV exposure and oxidation. Eight factories (n=14, 57%) mention storing silver in conditions protecting it from UV light and/or in a black or dark container. Five (36%) store it in the original or a sealed plastic container. Diluted silver is used immediately at eight factories (n=11, 73%). Cam-1 and SL-1 (18%) mentioned storing diluted silver for one to two months, both of which dip their filters. MM-all (9%) store a concentrated solution of silver nitrate (for dilution at the factory) for one week.

5.12 Quality Control

Quality control takes place throughout the filter production process. It can be categorised into inspection (visual, auditory and crack test), flow rate, and bacteriological testing. In Myanmar, 3rd party inspections are performed on a random selection of 5% of all filters sold to NGOs. If any filters fail inspection, the entire shipment is held up until the issue is resolved.

5.12.1 Visual Inspections

Visual Inspections (QQC17-18) take place throughout the production process at all factories (n=17, 100%). Eight factories (n=15, 53%) perform visual inspections before firing, flow rate testing, silver application and packaging. Others, inspect filters visually before and during flow rate testing and before silver application (Cam-1), before firing and before packaging (DR), after firing (Guate-1), before packaging (Guate-2), before firing and before the flow test (Nica-1), before firing and before silver application (Nigeria), before firing and after firing (Tanz-1), and before firing (Tanz-2). Workers look for cracks (n=16, 15, 94%), deformity (9, 56%), defects or irregularities (8, 50%), and uniformity of colour (3, 19%). Numbers add up to more than 100% due to multiple answers.

At the Indo-2 factory, two people are dedicated to quality control inspections. A magnifying glass is used to find defects which are marked with chalk. Defective filters are then compared and analysed to see if causes can be diagnosed. These procedures have been implemented to emphasise and reinforce the importance of filter inspection and quality control.

5.12.2 Auditory Inspections

The sound a fired filter makes when knocked or tapped can indicate complete firing and sometimes internal cracks. Auditory inspections are always performed (n=15, 47%, QQC20) at seven factories including MM-all, DR, Guate-1, Nica-2, Nica-2, Benin and Nigeria factories, usually at four factories (27%) including Colombia, Indo-1, Indo-2, Yemen, and sometimes at three factories (20%) including Cam-2, SR-2, Tanz-1. At Cam-1, auditory inspections are performed on ten filters per month.

5.12.3 Pressure (Crack) Tests

Pressure “crack” tests consist of submerging a filtering element in water only up to its rim and holding it for about 10 seconds to see if any water appears on the inside of the element indicating a crack (see Section 3.4.9). They are performed (n=15, QQC19) always at Benin, Cam-2, Indo-1, Nica-1 and Nica-2 and MM-all factories. DR and Nigeria sometimes perform crack tests; however seven factories (47%) do not perform crack tests. MM-all performs crack tests on all filters, however they submerge the filters rim down and look for air bubbles in the water, an indication of large pores, spaces or cracks.

5.12.4 Flow Rate Testing

Photo 5-14 Soaking Filters
(Rayner 2006)

All filter factories but two perform flow rate tests on 100% of their filters (n=18, 89%, QQC1-9). DR performs flow tests on 8% of their filters and Tanz-1 on 4%. Likewise, all factories but three soak their filters (83%, DR, Tanz-1, Guate-2). Five factories soak their filters for 24 hours prior to testing the flow rate (Benin, Indo-1, Nigeria, SL-1, SL-2, 28%). MM-all and Nica-2 soak their filters for 12 hours (11%), Cam-1 for 6-12 hrs (6%), Guate-1 soaks filters “until saturated” (6%) and the rest (6 factories, 33%) soak filters for two to eight hours.

Eight factories (n=18, 44%) test the flow rate by placing the filtering element in a bucket and measuring the amount of water which filters through after an hour. Tanz-1 measures the amount of water which passes through the filter after half an hour. Eight factories use a T-device to measure the water level in the filtering element after an hour (44%). SL-1 has a different method to measure the flow rate, but did not describe it.

Factory established acceptable flow rates range from 1.0 to 3.0 litres minimum and 2.0 to 5.0 litres maximum, in the first hour. The Myanmar factories report that filters (10 L capacity) with a maximum flow rate of 4.5 litres in the first hour consistently pass microbiological tests. Figure 5-9 shows the flow rate range each factory has established and the capacity (L) of their filtering elements.

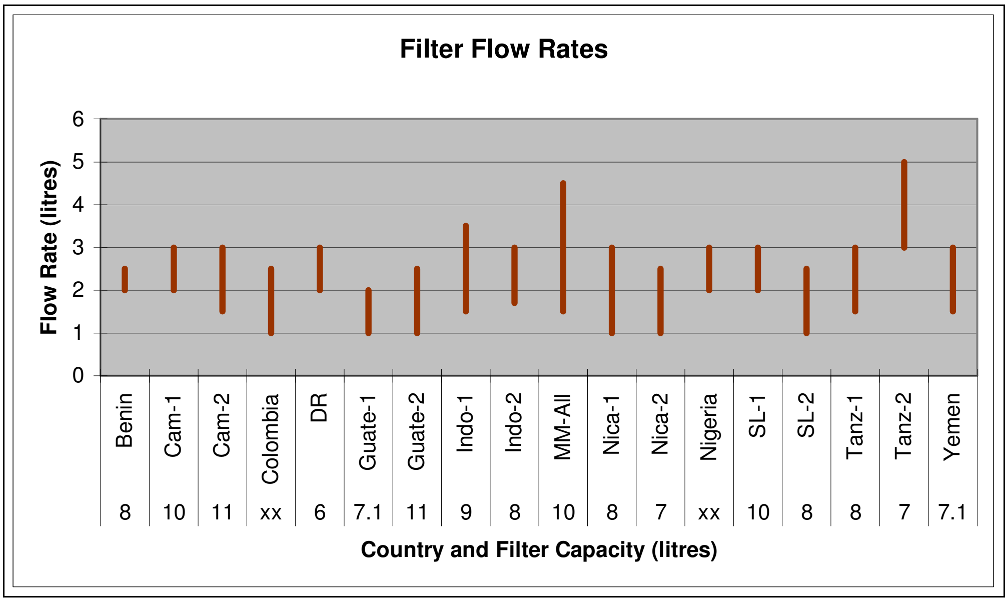


Figure 5-9 Flow Rate Ranges

Water used for soaking and flow rate testing (n=14, QQC10) is mostly disposed of on the ground (8, 57%). At four factories the water is continuously reused (Indo-1, Nica-1, Cam-2 and Colombia). At the Myanmar factories and Indo-2 the flow test water is re-used but the water used to soak the filters is discarded. Guate-1 is located on an ecological coffee plantation and follow established water disposal regulations. At SL-2 the water must be disposed of daily due to the threat of mosquitoes. Other factories (Cam-1, Guate-1, Indo-2, Tanz-2) also dispose of water used for soaking filters every day (36%). Nigeria, Nica-2 and Indo-1 change the water between every 10 days and two months depending on the condition of the water (21%). At Cam-2 there is no set protocol.

5.12.5 Bacteriological Testing

Thirteen factories report carrying out bacteriological testing regularly (n=18, 72%, QQC12-16). The quantity of filters that are regularly tested ranges from 0.2-15% (n=8). In addition, four factories (22%) also reported having carried out microbiological tests on filters (Nica-1, Nica-2, SL-1, Yemen). Nine factories (50%) test their filters at the factory, 14 factories (78%) use laboratories and six factories (33%) use both. These numbers add up to more than 100% due to multiple answers. None of the respondents provided the data set regarding acceptable ranges for test results. In DR, no changes in production procedures are allowed without first being confirmed by microbiological testing. Information on microbiological testing is presented in Table 5-13.

Table 5-13 Filter Effluent Testing

Country	Regular Testing	Quantity (%)	Factory	Lab	Turbidity	pH	TC	TTC	Fluoride	Silver	Arsenic	Comments
Guate-1	yes	blank	x	x	F/L	F/L	F/L	F/L	F/L	F/L	F/L	Based on quality control manuals.
Indo-1	yes	15%	x			F	F	F				
Indo-2	yes	2%		x		L	L	L	L	L	L	Two filters per week chosen randomly. Monthly: effluent water from 5-10 filters in the field is tested.
Benin	yes	blank		x	L	L	L		L	L	L	blank
DR	yes	8%		x		L	L					Effluent water is also tested from two filters in use every two months.
Cam-1	yes	0.2%	x	x			L			F		Microbiological tests carried out in lab. Field kit is used to confirm silver application.
MM-All	yes	1%		x			L					
Tanz-1	yes	4%	x	x			F/L					4% from each firing tested at factory, 4% from every other firing tested in lab.
Cam-2	yes	blank		x								Water quality index and primary chemical contaminants are tested for on a random sample monthly.
Guate-2	yes	blank		x								
Nigeria	yes	10%	x	x								Hach tests in factory. Two or three samples (in nine months) tested in lab for *E. coli* and chemical analysis.
SL-2	yes	2%	x	x								Presence/Absence Hydrogen Sulfide kit in factory and some samples to lab.
Tanz-2	yes	blank		x								
Nica-1	no	blank		x			L	L				Also tests for streptococcus & *E. coli.*
SL-1	no	blank	x	x			F/L	F/L		F/L	F/L	
Yemen	no	blank	x				F					Hach tests from time to time. Clients conduct complete tests.
Colombia	no	blank										Others have tested the filters.
Nica-2	no	blank	x									

Key: F= in factory testing, L= laboratory testing

5.12.6 Failed Filters

Ten factories (n=15, 67%) reported that they do not reprocess greenware (dried but not yet fired) filters which do not pass quality control (QFP15). They are destroyed and thrown away (MM-all, Cam-2, Colombia, Guate-1, Nica-1, Nigeria), soaked and used to close the kiln door (Cam-1), or used as road fill (Indo-2). Five factories reported reprocessing greenware (QFP15, DR, Nica-2, SL-2, Tanz-1, and Yemen). When asked what is done with greenware which fails quality control (QQC24), Tanz-2 also reported reprocessing it (n=15, 40%). Four factories mentioned re-milling the dried filter mixture prior to re-hydrating it (Nica-2, SL-2, Tanz-1, and Tanz-2).

When asked if factories would patch a filter before firing (n=13, QQC22), one factory (8%) said sometimes and 12 factories (92%) said no. Two answers from written surveys in Spanish were omitted from the results because, upon reflection, the question was worded in such a way that it could have been interpreted as referring to trimming the filter rather than patching a dried-and-ready-to-fire filter.

Six factories do not ever re-fire filters (n=16, 38%, QQC23). Of the ten that do (63%), seven (n=10, 70%) do so to increase the flow rate, one if it is under fired (which can result in a low flow rate), one rarely re-fires filters, and DR will re-fire a filter only if there is concern that it has been exposed to contamination. Indo-2 has an 80% success rate at increasing the flow rate when re-firing filters. However, if filters have a 1.2-1.3 litre per hour flow rate, a second firing will increase the flow rate beyond their maximum allowable flow rate.

When fired filters do not pass quality control (n=16, QQC25) they are stored (SL-2), not used (Nica-2), used as flower pots by the owner (Nica-1), or destroyed (12, 75%). MM-all drill a hole in the bottom or break them to use for road-fill. At Indo-2, they are ground and added to mortar mix to repair kilns with, ground to use in filter mixture, or used to fill in cracks in the road. At DR, where silver is fired into the filter, broken pieces of filters are placed in the recipient to provide residual protection in filtered water. At Tanz-1, filters are occasionally milled and added to filter mixture. At Cam-2, destroyed filters are collected by local people and used to fill potholes.

5.12.7 Filter Logs

All factories keep filter logs (n=18, 100%, QQC29,30). Thirteen keep them always (72%), Benin, Colombia and DR, usually (17%) and Nica-2 and Cam-2 keep them sometimes (11%). Sixteen factories provided details regarding which information is recorded on their filter logs which is presented in Table 5-14.

Table 5-14 Filter Log Details

Country	Date made	Filter #	Lot #	Flow rate	Discard date	Discard reason	Date sold	Buyer Info.	Other
Cam-1	x	x	x	x					monthly account of number of filters sold
Guate-1	x	x	x	x			x	x	operator, conditions, materials/where from
Guate-2							x		
Indo-1	x	x	x	x	x	x	x	x	filter weight, drying time, kiln temp, visual faults
Indo-2	x	x	x	x	x	x	x	x	payments
MM-All	x	x	x	x			x	x	
Nica-1	x	x	x	x					dates cs applied, packaged, time and date of firing
Nigeria	x	x	x	x	x			x	
SL-1	x	x		x	x			x	
SL-2	x	x	x	x	x	x*			formula for batch
Tanz-1			x	x		x			number of filters fired, micro bio test results
Tanz-2	x	x	x	x		x	x	x	
Yemen	x	x	x	x					
Benin	x								
Colombia		x	x	x					
DR	x	x		x*			x		Bacteria testing results

*information is sometimes recorded

Indo-1 has implemented Statistical Process Control (SPC) procedures whereby all process parameters such as filter weight, drying time, kiln temperatures (6 positions), visual faults and filtration rates are documented. Firing curves, filtration rate distributions, and diagrams are created for data analysis.

Table 5-15 shows how many factories log which information throughout the production process. In addition, seven factories log additional information which is presented in Table 5-14 above.

Table 5-15 Filter Log Items

Information recorded:	Date made	Filter #	Lot #	Flow rate	Date discard	Reason discard	Date sold	Buyer info.
n=16	13 (81%)	13 (81%)	12 (75%)	14 (88%)	5 (31%)	5 (31%)	7 (44%)	7 (44%)

5.12.8 Failure Rates

The average total failure rate (n=15, QQC31) is 12% (range 2-27%, stdev 8). Table 5-16 shows failure rate percentages for each of the factories. Cam-2 reported a less than 10% failure rate.

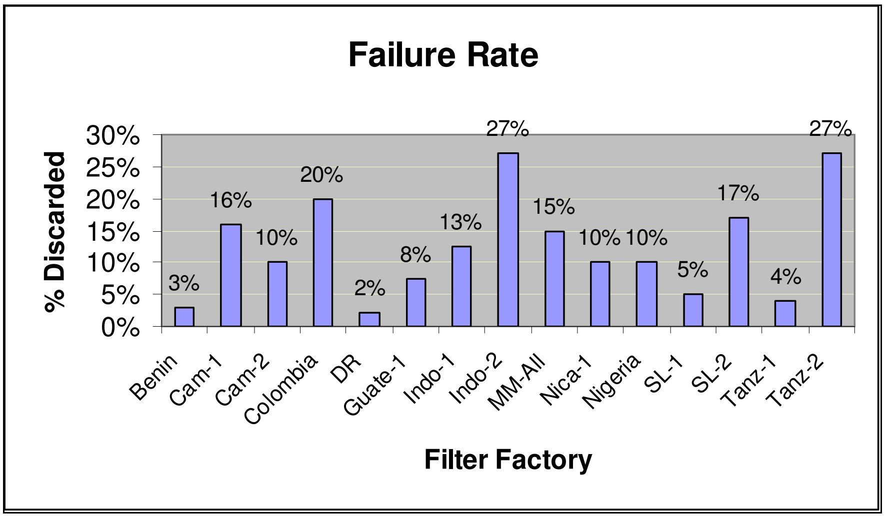


Table 5-16 Failure Rates

Ten factories (n=10) provided failure rate percentages per phase of production. Factories reported between 0-5% do not pass visual inspections, between 0-2% do not pass auditory inspections and between 0-17% do not pass flow rate tests (average 6%, stdev 5.3). Between 0-7% of filters are damaged during firing (average 2%, stdev 2.4), 0-1% from accidents and 0-1% during drying. The average failure rate for these ten factories is 9%, ranging from 2-20% (stdev 6.2). Flow rate testing is the primary reason for filters not passing quality control for seven of these 10 factories. Only Benin, DR and Tanz-1 have higher discard rates for other reasons. It should be noted that DR and Tanz-1 do not perform flow rate tests on all of their filters.

Some factories did not provide percentages associated with discard rates, but rather, indicated at which stages more losses occur. Cam-2 discards most filters due to them not passing visual inspection, flow rate testing and from firing. Indo-2 looses some to visual and auditory inspections, more to flow rate testing, and about 5% to firing. Both Tanz-2 and SL-2 loose most filters to flow rate and firing. At least 7% of the filters fail flow rate testing at the Yemen factory, but their total failure rate varies depending on the quality of their clay. The Nigeria factory reported that initially failure rate was as high as 50%, mainly at the pressing and firing stages, however they have now managed to reduce it to 10%.

5.13 Materials & Packaging

5.13.1 Receptacles

All factories (n=18, 100%, QD1-9) sell filtering elements with plastic receptacles, in addition, the Myanmar factories, Nica-2 and Guate-1 (n=18, 17%) also sell clay receptacles. SL-2 is experimenting with clay receptacles. Clay receptacles supplied by the Myanmar factories are coated with colloidal silver. According to Thirst-Aid, men really like the clay receptacles because they keep the water cool, women, however, find them heavy and difficult to clean. Nine factories (n=15, 60%) commission the manufacture of plastic receptacles. All of the factories package their filters with a plastic tap; five (n=9, 56%) sell filters with the tap attached. Cam-1 reported that metal taps had a higher failure rate than plastic ones. No factories include an extra tap or cloth pre-filters. All factories provide cleaning instructions (n=18, 100%), 16 (89%) include a brochure or sticker and two (11%) have instructions printed directly on the receptacle (DR, Nigeria). Five factories include a cleaning brush (MM-all, SL-1, SL-2, Yemen, Cam-2). In addition, Cam-2 provides a fitting ring which is placed between the receptacle and filtering element and helps to protect the filtering element against damage.

5.13.2 Packaging

Eight factories (n=17, 47%, QD10-13) regularly package the filtering element in a plastic bag. Eight factories (47%) package the filter elements individually in cardboard boxes, three with newspaper (Nica-1, Nica-2, SL-1), one with Styrofoam (Indo-1), one with shredded paper (SL-2), one with waste rubber and straw (MM-7) and two with no padding (Cam-1, Guate-1). Three sell them in the receptacle (Indo-2, Nigeria, Tanz-2). Five vary the packaging depending on whether filters are being sold individually or in bulk. Benin, Cam-2 and seven Myanmar factories also package elements in locally made baskets. One of the Myanmar factories recently switched to cardboard boxes (MM-7) and although NGO's think they look nicer and are easier to stack, they are not as practical as they get soggy when wet and don't get re-used like the baskets do.

Photo 5-15 Packaged Filters, Myanmar (Thirst-Aid 2009b)

Photo 5-16 Packaging Filters, Nicaragua (Rayner 2006)

Photo 5-17 Packaging Filters, Honduras (Hernandez 2009)

Four factories (n=18, 22%) stack filters when transporting multiple units. Indo-1 stacks them two high with Styrofoam padding and a maximum of six per crate, MM-all stack six together with straw or waste rubber between them and DR and Tanz-1 stack five filters with cardboard separators between them.

Factories have varying success with packaging for transport. The Myanmar factories ship an extra 5% to compensate for possible breakage; however they have found that fewer than 2% break. They manufacture semi-circle shaped filters and package them stacked with straw and rubber padding in crates. Tanz-1 reported that all filters distributed nationally reach their destination without breaking. Yemen has not had problems with breakages. Cam-1 reported that by buying cardboard boxes the same size as the filter element, the element does not move and therefore doesn't break. For export; however, larger boxes are used and filters are paded with Styrofoam.

In contrast, three factories reported having issues with breakage during transportation. Tanz-2 reported that as many as 15 of 35 (42%) have broken during transport. Indo-2 have found that even when packaging with newspaper and bubble wrap in a crate, that during transport they get lots of breakages due to the condition of the roads. For the DR, breakage rates are high when shipping by air or UPS (United Parcel Service).

5.13.3 Operation and Maintenance

Cleaning frequency (n=16, QD15-17) is recommended weekly (4, 25%), every two weeks (3, 19%), monthly (6, 38%), every three months (1, 6%), or as needed based on water quality or filter performance (7, 44%), numbers add up to greater than 100% due to multiple answers. Two recommend washing hands first (Colombia & SL-2, 13%). Cleaning procedures recommend using filtered, boiled or chlorinated water (5, 31%) scrubbing with a brush (9, 56%) or wiping with a cloth or sponge (3, 19%). Five recommend using soap on the receptacle but not the element itself (31%). One says to not use bleach or cleaning products (Nigeria, 6%). Four specify to not touch the outside of the filtering element (25%). Cam-2 recommends air-drying the filter completely before re-filling it. The DR factory, where silver is fired into the filters, recommends using 1-2 tablespoons of chlorine bleach to wash the receptacle and element every 1-2 weeks, and an intensive cleaning every three months whereby the element should be boiled for five minutes at a rolling boil.

Photo 5-18 Cleaning Instructions, Colombia
(Asopafin 2009)

Replacement recommendations range from 1 to 5 years (n=15). Eight factories (53%) recommend replacement every 1-2 years. Four factories (27%) recommend replacement every 2-4 years. Two factories (13%) recommend replacement every five years, unless it breaks before then (DR, Tanz-1). The Myanmar factories recommend replacement when the element cracks or breaks.

5.14 Health and Safety

5.14.1 Materials Processing

When processing clay (n=16, 100%, QMP16-17), factory workers use dust masks or some sort of nose and mouth covering. Eight (50%) use them always six (38%) use them almost always and two (13%) usually. In addition, six (38%) wear gloves, five (31%) use goggles or glasses, one requires that workers wear closed toe shoes, one uses ear protection and at Cam-2, a fan is used to blow the clay dust away. For processing burn-out material (n=15, QMP28-29), 14 (93%) use face masks, four (27%) use goggles, two (13%) use ear protection and two (13%) wear gloves. One factory reported that no health and safety precautions are taken while processing burn-out material due to a lack of industrial health and safety guidelines. Ten (67%) reported that the health and safety measures reported above are always carried out while processing burn-out material, four (27%) almost always and one (7%) usually.

5.14.2 Mixing and Pressing

While mixing filter mixture and pressing filters (n=12, QFP28-29), eight factories (67%) report wearing masks, three (25%) wear goggles, three (25%) wear gloves and three (25%) reported taking very few or no health and safety precautions. In addition, at SL-2, helmets are worn while mixing. At Cam-1, the press has an automatic stop system and the mixer has a pulley system installed to prevent injuries. At Cam-2, shoes are required, fans blow and the press is located at a distance from other factory movements. Eight (67%) reported always taking these precautions, two (17%) almost always and two (17%) usually. Four factories (n=14, 29%) reported minor accidents, three of which specified hand or finger injuries.

5.14.3 Firing

Six (n=14, 43%, FP75-76) factories use gloves, five (36%) use face masks, three (21%) reported using goggles or glasses and three (21%) do not have specified health and safely precautions. At Cam-1 workers found that gloves didn't work and therefore use a cloth instead. At Indo-2 they also wear headbands and a wet t-shirt. Two (14%) recommend not touching hot stuff. Participants reported that recommended health and safety precautions are always (7, 50%), almost always (3, 21%) or usually (1, 7%) carried out. In Nigeria, supplements and vitamins are provided for the kiln masters and firing days are rotated to allow workers to recover between firings.

5.14.4 Silver

Of the 15 factories that work with powdered silver (n=11, QMP59-60), all use gloves (100%), four (36%) wear face masks and four (36%) use eye protection. Seven (64%) reported always taking these health and safety measures, three (27%) almost always and one (9%) usually.

Of the seven factories working with liquid silver (n=5, numbers do not add up to 100% because three factories work with both liquid and powdered silver) three (60%) wear gloves, two (40%) wear face masks one (20%) wears aprons and one (20%) does not take any health and safety precautions. At one factory the workers did not like wearing gloves and so they no longer do. Three (60%) reported that they always, one (20%) almost always and one (20%) never, take health and safety precautions when working with liquid silver.

6 Analysis and Discussion

6.1 Introduction

The aim of this project was to identify the various filter factories worldwide and to survey and document existing production practices to provide data that will help the Ceramics Filter Manufacturing Working Group make appropriate manufacturing recommendations, which are expected to help filter factories improve the quality of filters being produced. In order to do this, filter factories were contacted and participating factories either filled out a questionnaire, were interviewed, or both. In addition, a literature review was carried out to learn about the effectiveness of filters in the field and to compare variation between current production procedure manuals. Also, published findings from laboratory studies which have evaluated filter characteristics and their effects on the efficacy of the filters were reviewed. In this section the findings from these results are discussed and lessons learned, recommendations where production guidelines are needed, and suggestions for future research are presented.

Photo 6-1 Filters, DR-1
(FilterPure 2009)

Photo 6-2 Filter, Myanmar
(Thirst-Aid 2009b)

Photo 6-3 Filter, Indo-2
(Pelita 2009)

One of the challenges of comparing production procedures and standardising the production process is bridging the art of working with clay with the manufacturing of a health tool. In many cases quantitative information was not available and even when available, not always comparable due the relationships between variables. Variations in production are inevitable not only between factories in different countries, but also depending upon the season, at the same factory. Although this might pose a challenge in establishing best practice guidelines, there are areas where guidelines for ranges can be promoted and areas where diversion from protocol should be avoided.

6.2 Methodology

6.2.1 Survey

Although the author had hoped to carry out telephone interviews with each participating factory, some preferred to submit a completed survey electronically. The distribution of the survey provided participants with this option. In addition, it allowed for consultation and the collection of additional information as needed.

Few participants returned information on costing and some declined to share this information. Therefore costing was dropped from the results. Factories have different methods of calculating costs and therefore it was perhaps a burdensome aspect of the questionnaire. In addition, the costing information was requested on a different excel worksheet which might have been overlooked by some.

Although the usefulness of this project relied upon comprehensive production procedures being collected, and many did not seem to mind the length, the questionnaire for some participants might have been too long. The questionnaire was designed with the intention of drawing out as many characteristics as possible and therefore contained many questions which in retrospect could have been omitted. It was unknown at the time; however, which questions would be superfluous. There were also topics for which additional questions could have been added or more specific.

6.2.2 Reliability of Data

Due to the comprehensive nature of the questionnaire and that the participants in this study varied in their roles at each factory, it is not surprising that every participant was not able to answer every question. The accuracy of the data provided, as a result, was sometimes questionable. Answers which in the author's opinion were not likely were either omitted from the results or it was noted that their accuracy was questionable. The majority were mentioned in the results, however, because there is value in knowing which questions were more difficult to answer. Self-reporting bias probably occurred, however in the author's opinion, participants answered questions honestly within the scope of their knowledge.

The production of ceramic pot filters has typically been promoted as an "open source" technology; however some factories chose to withhold proprietary information which complicates the comparison of results. Data withheld included the amount and concentration of silver, costing information, and filter mixture formula.

6.3 Discussion of Results

In the following sections research questions one and two are addressed. Research question one was answered with data collected from the survey, and research question three was answered with findings from the literature review. The following section compares findings from both the survey and the literature review.

Research question 1: What are the current production procedures at the various ceramic water filter factories?

Research question 3: What is known about some of the manufacturing variables which affect the microbiological efficacy of the filters?

6.3.1 Materials and Processing

6.3.1.1 Clay

Photo 6-4 Clay Mine in the Rainy Season (IDECambodia 2009)

Clay plays an important role in filter quality. A correlation has been found between clay content, flow rate and pore size (Oyanedel-Craver and Smith 2007). Although at least five factories (n= 17, 30%) mentioned having identified reliable clay sources, both the Yemen and Colombia factories mentioned the effects and challenges of inconsistent clay qualities on filter production.

Experienced potters choose appropriate clay to meet their outcome objectives which include a workable clay body with appropriate plasticity, shrinkage rate, and that will fire at the desired temperature. There are however, other characteristics which cannot be identified by sight and feel, such as the materials composition. The mineral composition of clay might play an important role in the hydraulic conductivity and porosity of filters (Oyanedel-Craver and Smith 2007). Although the source of arsenic is unknown, it has been has been found in effluent water from filters made in Ghana, Cambodia and Nicaragua (van Halem 2006).

Clay is milled and sieved to remove impurities, such as sand or organic material. Sixteen factories mill their clay (n=17, 94%) and 15 factories (n=18, 83%) sieve their clay, however three do not sieve their clay. Sieve sizes for clay vary between 9 and 80 mesh (see Appendix 3 for mesh sizing chart). Although the mesh size used will be somewhat dependent upon the availability of sieves sizes in each country, it is recommended that guidelines be established to indicate an appropriate range for sieve sizes and that filter factories follow these guidelines. The option for wet processing of clay should also be explored and promoted where sufficient water supply is available to reduce health risks associated with working with dry clay. In addition, methods for improving clay quality would be helpful for some factories.

6.3.1.2 Burn-out Material

The effects of different burn-out types have not been evaluated. The DR factory reported a lack of success with oak as it not only left an oily residue on the fired filter, but also resulted in a reduced flow rate. Ten factories use sawdust (n=18, 56%) from different woods including pine, guanacaste, gravella, oak, a mixture, or depending on availability. Although some factories use sawdust of a specific type, using sawdust from a variety of wood types will likely affect the consistency of the filters being made. Seven factories (39%) use rice husks and one uses a combination of sawdust and peanut shells. MM-all reported a large variation in rice husk qualities which can affect the outcome of the filters. Although filters made with either sawdust or rice husk have been evaluated in the field and the laboratory for microbiological efficacy, the effects of different burn-out materials, including sawdust varieties, on filters has not been evaluated.

The burn-out material is thought to play a significant role in creating the pores within the filter; therefore both particle size and consistency of particle size are likely to be important. Although 15 (n=16) factories sieve their burn-out material, only 12 (80%) indicated the mesh size. Although the 60 and 80 mesh sizes reported by two participants are likely to be mistakes, even when eliminated from the results, the remaining mesh range of 8-48 is wide. Only one factory sieves with two screens to separate out both the finer and larger particles. At RDI-C (Cam-2), the amount of burn-out added to the mixture varies depending on the size of the rice husk to achieve the desired flow rate (Hagan *et al.* 2009). However, in an attempt to make faster flowing filters, sawdust screened to a larger particle size showed no significant difference in flow rate (Klarman 2009). Factories use flow rate as an indicator of filter efficacy and although the relationships between burn-out size, pore size, hydraulic conductivity and microbiological efficacy require further investigation, guidelines can be established with regards to burn-out material processing.

6.3.1.3 Source Water

The influence of source water quality (both microbiological and chemical) which is used in production and for flow rate testing has not been investigated. Ten factories (n=16, 62%) either have not tested or do not know if their source water has been tested.

6.3.1.4 Formula

Filter mixture ratios are established by trial and error until the desired flow rate is reached. Prototypes are then tested for microbiological removal efficacy. The plasticity of the clay (Rivera 2006) and the size of the burn-out material (Hagan *et al.* 2009) will influence the quantity of burn-out material added to achieve the desired flow rate. Mix ratios are calculated either by weight or volume. Where rice husks are used, formula is measured by weight (n=6, 100%) and the percentage of rice husks added to the mixture ranges from 10 to 24%. Where sawdust is used (n=10), 60% measure by weight, and 40% by volume. Percentage of sawdust ranges from 5-15.6% by weight or 47-53% by volume. Where both sawdust and peanut shells are used (n=1), ingredients were reported to be measured by both weight and volume and they make up 35% of the mixture (see Section 5.6). Thirst-Aid (Myanmar) pointed out that humidity can affect the weight of rice husks enough that the filter mixture must sometimes be adjusted accordingly. Settling and particle size might also affect precise measuring when burn-out material is measured by volume.

The only study comparing burn-out types found that using the same screen size but different burn-out materials affected both the flow rate and microbiological efficacy (Klarman 2009), therefore different mix ratios will apply depending on burnout type. The relationships between type of burn-out, amount of burn-out material, clay characteristics, particle size and burn-out type require further evaluation relative to pore size, structure, porosity, tortuosity and hydraulic conductivity.

Once a formula has been established, the rigidity to which it is adhered to also varies. Nineteen percent (n=16) do not adjust their formula, however 6% adjust it regularly and 75% as needed. At the DR factory, no adjustments to the formula are allowed without being supported by bacteriological testing. However, at the Myanmar factory that produces the best quality filters and has the lowest failure rate of the Myanmar factories, minor modifications to the formula are made regularly depending on the quality and humidity of the rice husks. Thirty-one percent (31%) of the factories surveyed modify their formula depending on the quality of the clay. In uncontrolled environments, where climatic control is not an option, small adjustments to the mix might not have major impacts on filter quality. Two of the problems with uncontrolled modifications to the filter mixture formula are that 1) if not accompanied by regular bacteriological testing, flow rate will be used as a sole indicator of filter efficacy 2) it can result in the output being only as good as the operator and different operators might adjust the formula differently, thereby affecting the consistency of the product. Prohibiting formula modification might be unrealistic, however, and could adversely affect filter quality and inhibit the accurate documentation of daily production procedures which can aid in troubleshooting and filter evaluations.

Mixing times vary between 5-20 minutes dry - except for Indo-2 where dry ingredients are hand mixed for 60 minutes in order to achieve specified flow rates and in Nigeria, where the mixing process takes half a day. Wet mixing times range from 6-30 minutes. Mixing, particularly dry mixing, is considered important to achieve an even distribution of burn-out material which possibly affects pore distribution (Lantagne 2001a).

Eighty-three percent (n=18) of the factories work the clay by wedging (like kneading dough), thumping or thrusting the clay mixture onto a hard surface before adding it to the press. This aids in removing air-bubbles and in homogenising the mixture. In Nigeria it is pounded in a mortar and pestle and all of the Myanmar factories use pug-mills because they have found that it resulted in stronger filters. Investigation into the advantages of working or pounding the clay and/or using a pug-mill on the filter mixture prior to pressing is recommended in Section 6.4.3.

Although discouraged by Potters for Peace, eight factories (n=16, 50%) leave filter mixture overnight before pressing and/or reprocess dried mixture, however the effects of either on filter quality have not been evaluated. Ten factories (n=25) do not have mixers and two do not have hammer mills and few have air compressors. Three factories do not use electricity in production and the cost of energy might also be prohibitive in some areas (Nigeria, Cambodia). These are important considerations when making recommendations. Section 5.4.1 has a chart of filter factories and their equipment.

6.3.2 Pressing and Drying

Mould designs and sizes vary. Filter capacity ranges from six to 11 litres and wall thickness ranges from one to three centimetres. There are three mould shapes including the flat-bottomed original design (n=25, 60%), 32% use a semi-circle round-bottomed mould and 8% use an oblong, round-bottomed mould. All factories press their filters, although in Rabinal, Guatemala, filters are still made on the potter's wheel and sold through Guate-1. Filter design, including wall thickness, filter capacity and surface area are likely to have an effect on filter functionality. In addition, round bottomed filters have an extra advantage that they cannot be placed on a dirty countertop possibly preventing one pathway of contamination. In addition, they might be stronger.

All participants (n=17, 100%) expressed satisfaction with their mould release. Plastic bags are used by 72% (n=18) and 23% are successfully using lubricant (e.g. coconut or palm oil) in place of plastic bags. An evaluation of the effects of using different lubricants as a mould release is recommended since if adverse effects are not found, replacing plastic bags would be environmentally friendly, cost effective and reduce or eliminate trimming and touching up filtering elements. In addition, it would reduce the handling of freshly pressed filters which might disrupt internal pore structures. The mould material might, however, influence the suitability of using certain oils as one factory commented that they had success with coconut oil only after switching from an aluminium to a cast iron mould.

Drying times in the wet season pose a problem for at least eight factories (n=18, 39%) and although some have modified production levels or increased shelving to allow for longer storage during the wet season, others have introduced quick drying methods (see Section 5.9). Whereas exceptionally quick or uneven drying will lead to obvious deformation and cracking, the possibility also exists of internal and invisible cracks forming in the absence of obvious deformation. The initial drying phase is particularly important; therefore suggestions for artificial drying methods and guidelines including methods to quantitatively measure sufficient dryness prior to using artificial drying methods are recommended.

6.3.3 Kilns and Firing

Firing is an important part of the filter making process and can affect the consistency and quality of the filters produced. A kiln which is heated or cooled too quickly can cause cracking and deformation. Uneven heat distribution within the kiln might lead to some filters from the same kiln load being over-fired while others are under-fired. Under-firing or over-firing will affect the quality and often, the filtration rate of the filter.

Kiln capacities range from 40-200 filters and 83% (n=18) fire with wood. Kiln size and other characteristics influence fuel efficiency. In Colombia, about 600 kg of wood is used to fire 125 filters. This survey did not include a question about the source of wood, however at least one factory commented that it might not be from legal cutting. Although alternative fuel sources have been experimented with, and successful in some cases, apart from the Benin factory which fires their kiln with oil, none of the factories are currently firing with alternative fuels (see Section 5.10.1). This calls attention to the need to not only encourage the use of alternative sources, but also evaluate optimal kiln size and design for maximum efficiency to reduce the amount of fuel required for firing.

All factories (n=18, 100%) use either a pyrometer or cones as temperature guides while firing. Orton[16] recommends using a three-cone system (a guide cone, firing cone and guard cone), the first cone will fall when reaching close to the temperature, the second when the temperature has been achieved and the last if the desired temperature has been exceeded, only one factory reported using this three cone method. Three factories use two cone numbers and five factories use one cone number. Temperatures can vary within a kiln and therefore it is also recommended that cone packs (of three cones) be placed at varying heights in the kiln. Only one factory does this, but with only one cone number. At Indo-1, temperature is monitored with a pyrometer at six different locations in the kiln. At Indo-2, the temperature in the kiln varies enough that not only are different formulae used for filters to be placed at different heights in the kiln, but also "place-holder" filters often occupy the bottom row in the kiln.

Experienced potters can interpret the temperature of the clay during firing by its colour (see Appendix 4) and at least three factories (17%) mentioned that successful firing is dependent upon the kiln master's experience and 85% (n=17) feel that they always or almost always follow their temperature grades and soak (hold) times and most factories (11, 61%, n=18) report consistent firing results. The use of pyrometric cones and pyrometers can aid in measuring temperature at various locations in the kiln and in troubleshooting. The acquisition of cones and pyrometers is difficult in some countries, however.

6.3.4 Silver

Respondents found it difficult to answer questions pertaining to the strength and dilution of colloidal silver applied to filters. Information was provided by nine factories that use colloidal silver (n=15, 60%). The silver concentration in diluted solutions ranges from 14- 1500 ppm. Should the two extremes be excluded as errors, silver concentrations still range from 107 to 288 ppm. Filters are either dipped or painted with silver, although each has its advantages and

[16] See http://www.ortonceramic.com/pyrometrics/industrial/cones.shtml for more information.

disadvantages, the quantity of silver applied has been found to be more important than the application method (Oyanedel-Craver and Smith 2007).

Although colloidal silver has been found to improve the microbiological effectiveness of filters (Lantagne 2001a; van Halem 2006; Oyanedel-Craver and Smith 2007), silver nitrate is also being used by three factories. Filters with and without the application of silver nitrate were found to be comparable in their microbiological removal efficiency in the field (Brown 2007), however filters made with high flow rates did improve in effectiveness after the application of silver nitrate in the laboratory (Bloem *et al.* 2009). Little is known about the amount of time silver nitrate will remain in the filter, leeching and the effects of influent water on the effectiveness.

One factory dilutes and dips filters in a Katadyn water disinfection product (see Section 5.11.3). No indication of evaluation of the application of this product to ceramic filters was provided. It is not recommended that alternative products be used with out prior evaluation.

6.3.5 Quality Control

All factories (n=17) carry out visual inspections at varying times in the production process and one uses a magnifying glass. Auditory inspections (see Section 5.12.2) are always performed at only 47% of the factories. Although qualitative, this is an important check to check if the filter has been properly fired and can indicate the presence of internal cracks. Promotion of the pressure "crack" test is recent (see Section 5.12.3) and therefore it is not surprising that 47% do not perform this test. Many participants had not heard of this test. This shows a need for communication amongst the decentralised production facilities. Two factories aim to leave a carbon residual in the walls of the filters; the effect of this has not been evaluated.

Since bacteriological testing can be expensive and in many places access to a laboratory is limited, it is not regularly carried out by all factories (see Section 5.12.5). Instead, along with regular visual inspections, flow rate testing is used as a primary indicator of filter quality. Flow rate can be an indicator of internal cracks or defects, potential contact time with silver and the ability of the filter to produce sufficient water quantity. Filters discarded due to unacceptable flow rates range from 0-17% (average 6%, stdev 5.3). Flow rate tests are carried out by all factories; however, only 89% carry them out on all filters. In addition, soaking filters prior to flow rate testing is important for reliable results (Lantagne 2001a), although the amount of time required to ensure saturation might vary per factory, Nederstigt and Lam (2005) found that after 24 hours of soaking time filtration rates became constant. If soaked for less than 24 hours, filters had lower flow rates (van Halem 2006: A-10). Only five factories (n=18, 28%) soak their filters in water for 24 hours prior to flow rate testing. One factory reported soaking their filters until saturated, however, it was not explained how saturation is determined.

Maximum flow rate ranges vary from 1 litre to 5 litres per hour. Flow rate has been found to diminish with use both in the laboratory (Lantagne 2001a; Fahlin 2003; van Halem 2006) and in the field (Lantagne 2001b) due to clogging of the pores. In addition, the hydraulic head influences the flow rate; therefore the flow rate will slow as the filter empties. Although a minimum flow rate of one litre in the first hour should provide enough drinking water for a family of five if filled four to five times a day, clogging might slow the filtration rate beyond acceptable limits. In addition the size of the receptacle in relation to the filter size and shape and pattern of use will affect how much and how quickly water can be collected as once the water level in the receptacle reaches the bottom of the filter, the flow rate will be affected (see section 3.5.3).

Studies have been carried out to measure the effectiveness of filters with increased flow rates. One concluded that effectiveness of microbiological removal began to decrease below 99% after 1.7 l/hr (Klarman 2009); the other found there was no significant difference in microbiological efficacy between filters reaching a flow rate of up to an 8-10 l/hr and slower filters *(Bloem et al. 2009).* Filters in these two studies were produced in the Dominican Republic and Cambodia respectively, and therefore mould shape and size and production methods varied.

6.3.6 Microbiological Testing

Respondents had difficulty answering questions regarding which microbiological tests are carried out on their filters. Thirteen factories (n=18, 72%) responded that microbiological tests are carried out regularly on between 0.2-15% (average 5%) of their filters. No factories provided information on acceptable ranges and few provided bacteriological test results. Microbiological testing can be expensive and confusing. Not all factories have access to a local, certified laboratory. There is a need for guidance on field kits available, how they work, the variety of indicator organisms, frequency and percentage of filters that should be tested either at the factory and/or at an independent, qualified laboratory.

6.3.7 Filter Logs and Failure Rates

Filter logs that are used to hold records of all filters are filled out 'always' or 'usually' by 16 factories (89%). Between 12-14 factories (57-88%) record the date made, filter number, lot number and flow rate. One factory reported recording the operator, conditions, and origin of materials and one factory collects information including filter weight, drying time, kiln temperature, visual faults and filtration rates. Firing curves, filtration rate distributions and diagrams are created with this data for analysis. Maintenance of production logs can aid factories in increasing efficiency and troubleshooting and can useful for researchers investigating filter characteristics, especially in the absence of strict adherence to production protocol.

Failure rates vary widely between 2% and 27% with five factories (n=15, 33%) having a failure rate of greater than 15%. Tanz-2 reported that 32% of their filters consistently crack during firing, which is inconsistent with their overall failure rate of 24-30%. More consistent manufacturing practices should lead to a more consistent product including using materials of consistent quality, having good manufacturing methods and consistent manufacturing practices. In addition, which quality control tests are carried out and the rejection criteria might affect the failure rate. For example, auditory inspections are carried out by only 47% of the factories and only 40% always carry out pressure "crack" tests (6, n=15). In addition, some rejection criteria can be subjective, for example filter discolouration and deformation.

Although only four factories record the reason for rejection on a log, 14 factories document flow rates. Flow rate is the number one reason for rejecting filters at 7 of the 10 factories who reported percent loss per quality control criterion. Two of the three factories who reported other reasons do not perform flow rate tests on 100% of their filters. Interestingly, the third factory, Benin, performs flow rate testing on 100% of their filters and has the smallest flow rate range of all the factories, accepting only filters which filter between 2 and 2.5 litres in the first hour. They usually keep a filter log but record only the date made.

Since many variables can influence a filter failing a given quality control inspection, the phase in production which led to a defective filter can sometimes be difficult to determine. For example, a filter could crack during firing; however, although the cause could be from heating or cooling the kiln too quickly it could also be due to a number of other causes including but not limited to materials characteristics, or the filter drying too quickly or unevenly.

6.3.8 Health and Safety

Health and safety risks can include both injury and long-term health risks. Four factories reported minor injuries to hands and fingers. Although no factories reported back injuries, the use of proper lifting techniques and ergonomic work conditions are important to minimise such risks. Proper safety goggles (for example welders goggles) should be used to protect eyes from damage which can be caused from looking into the kiln at hot temperatures to check cones or the colour of the clay.

Silicosis is a long term health risk associated with the inhalation of crystalline silica dust found in clay. It is an irreversible lung disease and can progress even when exposure has stopped. It is therefore important that health and safety measures while processing clay are strictly enforced and wet processing of clay should be adopted where possible. Because airborne particles can travel, even nearby workers not directly involved in clay processing may be exposed to the silica dust. Although face masks are part of the health and safety guidelines while processing clay for all factories who responded to this question (n=16), only 50% reported that they are always used. Other measures can be taken, including careful selection of equipment location and properly securing collection bags to hammer mills to minimise dust output. Appropriate health and safety precautions in other areas, including the handling of powdered silver and processing burn-out material should be reviewed and strictly enforced. Preventative measures should be taken not only while processing these materials but also during cleaning, since dry brushing can cause settled particles to become airborne, water should be used while cleaning.

6.4 Lessons Learned, Recommendations and Further Research

6.4.1 Introduction

The analysis of the literature review and survey results suggests seven key lessons learned which contribute towards answering research question two and provide the basis for the recommendations in Section 6.4.3 and recommendations for future research (Question 4) in Section 6.4.4. Research questions two and four are presented below, followed by the key lessons learned.

Research question 2: What are some of the lessons learned and where are recommendations needed in the production process?

Research question 4: Where is further research needed in order to make recommendations for standardisation or best practice?

6.4.2 Lessons Learned

Little is known about how the many variables in filter production influence filter quality.

There are a lot of variables in filter production (see Figure 2-4) and there are few studies characterising the effects of these variables. Additional research is needed in many areas in order to refine recommendations for best practice (see 6.4.4).

Production practices are not consistent and are not well documented.

There is variation in filter production both within and between factories. Filters produced in different factories have been found to have different characteristics. Although some variation in daily production might be inevitable, the documentation and analysis of daily production practices can aid in increasing production efficiency and troubleshooting. In addition, investigations into filter characteristics and effectiveness could benefit from having production details available.

Guidelines for diluting silver are needed.

Respondents found it difficult to answer questions regarding the amount and concentration of silver applied to filters. Based on the information reported, silver application is not consistent. Although further research is still needed regarding the effects of different types of silver, application methods, and concentration on the efficacy of the filters, clear information about silver concentrations and corresponding dilution formulae need to be made available to the factories.

Microbiological testing guidelines are needed.

Factories provided little information regarding what tests are carried out and acceptable water quality parameters. Microbiological testing of filters is inconsistent between factories. Eight factories reported testing 0.2-15% of their filters regularly. Guidelines for the percentage of filters which should be tested, frequency of testing, and what should be tested for are not available. Although the availability of a local, certified laboratory may vary depending on the factory location, with training, in-house testing could be implemented to complement laboratory testing.

Flow rate testing procedures are not standardised.

Flow rate testing is used as a primary indicator of filter efficacy; however factories do not follow a standard procedure. Lantange (2001a) noted that it is important to soak filters until they are saturated prior to flow rate testing to obtain consistent results. Nederstigt and Lam found that the flow rate of filters became consistent after a 24 hour soaking period (van Halem 2006). Only five filter factories soak their filters for 24 hours prior to flow rate testing and three factories do not soak their filters prior to testing flow rates. Although the soaking time required to achieve saturation may vary from factory to factory, it is important that filters are saturated prior to flow rate testing to ensure consistent flow rate measurements.

Health and Safety precautions are not strictly adhered to.

Although all factories reported using dust masks or some sort of nose and mouth covering while processing raw materials, these precautions are not strictly adhered to or enforced as only eight factories reported always using face masks. While mixing materials, only eight factories report using face masks. In order to reduce occupational health risks, appropriate preventative measures need to be outlined and enforced for various aspects of production, but particularly when working with clay, burn-out material and powdered silver.

Factories could benefit from sharing experiences.

This survey was to gain overall understanding of the production practices in each factory. Factories were asked about current and previous challenges, solutions and what they have tried in the past but did not work. Although many participants provided valuable information which is reported throughout Section 5 and Section 6, the length of the survey likely influenced the amount of detail some participants provided. What works at one factory might not work for another, however; many participants expressed interest in sharing their experiences and learning from others.

6.4.3 Recommendations

6.4.3.1 Materials

- Although potters are competent in identifying appropriate clay sources, guidelines for the identification of and simple methods for evaluating clay characteristics and improving the quality of clay would be useful for factories.
- When possible, clay should be analysed for characteristics and materials composition both when using a different source and when clay quality changes.
- Recommendations on an appropriate mesh size range for clay processing should be made and adopted, although this might be limited by availability of sieve sizes in each country.

- Wet processing techniques and guidelines should be developed and implemented where there is sufficient water for this process as wet processing can reduce adverse health impacts on workers compared with dry processing.
- Recommendations for appropriate burn-out mesh size ranges, per burn-out type, should be made and adopted. Availability of sieve sizes in each country may vary.

6.4.3.2 Production

- A list of recommended production variables for factories to document which will aid in troubleshooting and filter research needs to be developed. Sample logs could be distributed along with guidelines for the analysis of data collected. Documentation of production procedures should be adopted into regular practice.
- Acceptable ranges of divergence from an established formula and guidelines for appropriate microbiological testing to support changes in formula need to be developed.
- Further investigation into the advantages of processing filter mixture through pug-mills, along with alternative methods of achieving similar results should be considered as this may lead to improved filter quality and durability.
- Guidelines which describe options for artificial drying methods and methods to quantitatively measure sufficient dryness prior to using artificial drying techniques should be developed.
- Further experimentation with alternative fuel sources should be promoted. The sharing of experiences between factories might aid in developing successful techniques.
- Kiln designs should be evaluated for efficiency, including optimal kiln size. This can reduce fuel consumption and aid in more evenly fired and consistent filtering elements. Options will need to consider different production levels.
- The use of pyrometers and pyrometric cones for monitoring firing temperatures should be promoted.
- Clear guidelines on silver concentrations, dilution formulae and application methods need to be developed.

6.4.3.3 Quality Control

- A simple test to check the soaking time required to achieve saturation prior to flow rate testing should be developed and adopted. This would also give an indication of the porosity of the filter elements.
- There is a need for guidance on low-cost, user-friendly field kits available for water testing and instructions on their use. In addition, recommended frequency and percentage of filters that should be tested both at the factory and at independent laboratories is needed.

6.4.4 Recommended Research

- Evaluation of clay bodies, the effects of materials composition and pore structures on fired filter strength and microbiological efficacy.
- The effects of chemicals, heavy metals and other inorganic contaminants in production water and/or clay on effluent water from fired filtering elements and how they might be influenced by different firing temperatures.
- The effects of different burn-out materials, quantity, particle size and consistency of particle size on filter pore size and structure, total pore area, porosity, hydraulic conductivity and microbiological effectiveness including the strength of the filter and the quality of the effluent water.
- Determine the effects of leaving filter mix for extended periods of time prior to pressing and the effects of re-processing dry mixture.
- Determine if using oils as a mould release influences firing, leaves a residual on the fired filter or effects the absorption of silver.
- Evaluation of the variables which can be modified to increase flow rates without jeopardising the microbiological efficacy of filters (with and without silver application) and how the pore structure, microbiological efficacy and durability of filters are affected.
- Determine the influence of filter design including shape, diameter, depth, height, capacity and wall thickness on microbiological effectiveness and end-user considerations such as flow-rate, post-contamination and durability of the filter.

- Evaluate the effects of leaving a carbon residual within the walls of the filtering elements on microbiological effectiveness, total pore area, pore structure, and effluent water quality.
- Evaluate the effectiveness of different silver types (colloidal and nitrate) on microbial deactivation, the amount found in effluent water and the length of time it lasts in the filter. Determine optimum quantity, concentration, and application methods for each.
- Evaluate the effects of influent water characteristics and time on the leaching of silver from the filter and filter effectiveness and whether it varies for colloidal silver versus silver nitrate.
- Investigations into the wearing away of filter walls during the life span of a filter and how it affects the filter's microbiological efficacy, silver retention ability and useful life. Determine evidence-based recommended replacement guidelines.

7 Conclusions and Recommendations

Household water treatment and safe storage systems (HWTS) are gaining attention as affordable and effective means of improving water quality in the home resulting in reduced mortality and morbidity from infectious diarrhoea. Locally produced ceramic water filters are one form of HWTS which have shown promising results at improving the microbiological quality of water in the home. They are affordable, easy to use and acceptable to users. Currently, there are at least 35 filter factories operating in 18 countries, and several more are being established. One of the advantages of this technology is that it is transferable; however maintaining quality control in decentralised production remains unaddressed. This project is an important first step in addressing this need.

The aim of this project was to identify the various filter factories worldwide and to survey and document existing production practices to provide data that will help the Ceramics Filter Manufacturing Working Group make appropriate manufacturing recommendations, which are expected to help filter factories improve the quality of filters being produced. Research questions addressed were:

1) What are the current production procedures at the various ceramic water filter factories?
2) What are some of the lessons learned and where are recommendations needed in the production process?
3) What is known about some of the manufacturing variables which affect the microbiological efficacy of the filters?
4) Where is further research needed in order to make recommendations for standardisation or best practice?

These questions were addressed by carrying out a literature review (Section 3) on relevant published and unpublished documents (Question 3), developing a list of filter factories currently in operation and designing, distributing and carrying out a survey of production practices at all participating filter factories, the results of which are presented in Section 5 (answering Question 1). The analysis of the information compiled addressed questions two and four and are discussed in Section 6.

One of the limitations of this study was that participants were not always familiar with the intricacies of production. This led to many questions being left unanswered and some may have been answered incorrectly, even though the distribution of the survey allowed participants the opportunity to gather missing information. The survey was long, however, and this may have influenced their attention to detail.

One of the challenges of comparing production procedures and making recommendations for best practice is bridging the art of working with clay with the manufacturing of a health tool. Filters are not made in controlled environments, and materials of consistent quality are not always available. The weather can affect the humidity of materials. Clay coming from different sources, or even from different levels of the same mine, will vary in characteristics. Ceramic Filter Pot technology was designed for filters to be produced by local artisans and therefore, with a certain level of tolerance for variation. The challenge is in identifying where and how much variance is acceptable in the production of a locally-produced, cost-effective, microbiologically-effective, and user-friendly HWTS. The analysis of the findings in Section 6 led to the recommendations and further research needs presented in Sections 6.4.3 and 6.4.4, which are summarised below.

Recommendations for the development and implementation of guidelines for production are summarised below:

- Identification and evaluation of clay characteristics and methods for improving clay quality.
- Appropriate mesh size ranges for sieving both clay and burn-out materials.
- Techniques for the wet processing of clay as an alternative to dry processing.
- Acceptable ranges of divergence from an established formula, beyond which microbiological testing of filters should confirm efficacy.
- Acceptable quick drying options and guidelines for appropriate use.
- The use of pyrometers and pyrometric cones in monitoring kiln temperature.
- Silver types, concentrations and dilution guidelines.
- How to measure the time required to achieve saturation of filtering elements prior to testing the flow rate.
- Minimum and ideal frequencies and percentages of filters that should be tested for microbiological effectiveness in the factory and/or in the laboratory and which field kits are available and how they work.

Additional recommendations include:

- Developing a list of important production variables to be recorded throughout the production process that will aid both factories and researchers, the creation of sample templates, and the adoption of production documentation by factories.
- Further experimentation and evaluation of the effects of using pug-mills on filter durability and quality.
- Further experimentation with alternative fuel sources.
- Continuing evaluation of kiln design, efficiency, including optimal kiln size.

Further research is needed in the following areas:

- Evaluation of clay bodies for materials compositions and effects of pore structures on fired filter strength, breakage rates and microbiological efficacy.
- The effects of chemicals, heavy metals and other inorganic contaminants in water and/or clay on effluent water from filter elements and effects of different firing temperatures.
- The effects of different burn-out materials with regards to quantity and particle size on filter pore size and structure, total pore area, porosity, hydraulic conductivity and microbiological effectiveness including the strength of the filter and the quality of the effluent water.
- Determine the effects of leaving filter mix for extended periods of time prior to pressing and the effects of re-processing dry mixture.
- The influence of oils as a mould release on firing and possible residual effects on the filter, or on the absorption of silver.
- Identification of which variables can be modified to increase flow rates without jeopardising the microbiological efficacy and how the pore structures, microbiological effectiveness and durability of the filter are affected.
- The influences of filter design including shape, diameter, depth, height, capacity and wall thickness on the microbiological effectiveness and durability, including end-user considerations such as flow-rate and post-contamination.
- The effects of leaving a carbon residual within the walls of the filtering elements on microbiological effectiveness, total pore area, pore structure, and effluent water quality.

- The effectiveness of different silver types (colloidal and nitrate), concentration/dilutions, and application methods on microbial deactivation, amounts in effluent water and the length of time it lasts in the filter.
- How water influent quality affects silver leaching from the filter, filter effectiveness and lifespan of the filter whether it is different for colloidal silver versus silver nitrate
- The change in wall thickness during the life span of a filter, and how it affects microbiological efficacy, silver retention and useful life. Determine evidence-based recommended replacement guidelines.

8 Glossary

Daily Adjusted Life Years (DALYs): are used to evaluate and prioritise public health concerns. They represent a sum of the number of years lost by premature mortality and the number of years of healthy life lost due to less than full health or disability.

Greenware: refers to wares which are dry and ready to fire, therefore dry filter pots which have not yet been fired.

Goethite: see Laterite.

Grog: ground up fired clay. It is often added to clay to reduce plasticity.

Hydraulic conductivity: the rate water can move through a medium, in this case a filter.

Laterite: a soil layer consisting of several minerals including goethite, an iron-oxide. Laterite and goethite are used interchangeably in this document. Laterite is thought to provide additional viral binding sites. It also increases the flow rate and the weight of the filters.

Log Reduction Value (LRV): represents the microbial removal efficiency, where LRV of 4, expressed as a percentage, would be 99.99%.

Mani Kiln: a down-draft kiln designed by Manny Hernandez, based on the Minnesota Flat-top kiln. A down-draft Kiln does not have an opening in the roof of the kiln, therefore the heat when reaching the roof is directed downwards, into an opening in the kiln floor which directs it to the chimney.

Mesh size: represents how many openings there are per linear inch in a screen or sieve using the Tyler Mesh Equivalent. This controls the particle size of material passed through a sieve.

Porosity: relates to the volume of void spaces in the filter.

Pug mill: a machine typically used in pottery to mix and extrude wet clay. It helps to create a homogenous mixture and reduce air bubbles; reducing the need for wedging.

Pyrometric cones: are made of specific formulae of refractory and fluxing materials to measure the effects of both time and temperature, known as 'heat-work'. Different numbered cones are designed to bend, or deform at specific temperatures. See www.ortonceramic.com for more information.

SODIS: Solar Water Disinfection. A process whereby plastic PET bottles are filled with water and placed in the sun for a number of hours. Solar UV-A radiation and temperature inactivate pathogens.

Tortuosity: describes the path water takes through the filter walls. A more tortuous filter material will have a more winding or twisting path with bends and turns, increasing the distance water must travel to exit the filter.

Tyler Equivalent or Tyler Mesh size: see Mesh size.

Wedge: a pottery term for working clay to homogenise the material and remove air bubbles; it can be compared to kneading bread dough.

9 References

AFA (1995) *Contra la morbilidad infantil: Filtros artesanales y educación.* Instituto de Investigaciones Económicas y sociales (IDIES): Guatemala.

Asopafin (2009). Colombia**:** Photograph provided by Asopafin, Colombia in response to questionnaire.

Ballantine, L. and Hawkins, T. (2009) *FilterPure Employs New Standards for Fabricating and Distributing CWF*. International Ceramic Pot Filter Workshop. Atlanta, GA, USA.

Bielefeldt, A.R., Kowalski, K. and Summers, R.S. (2009) *(In Press) Bacterial treatment effectiveness of point-of-use ceramic water filters*. Water Research (2009). doi: 10,1016/j.w.watres.2009.04.047.

Bloem, S.C., van Halem, D., Sampson, M.L., Huoy, L.S. and Heijman, B. (2009) *Silver Impregnated Ceramic Pot Filter: Flow Rate versus the Removal Efficiency of Pathogens*. International Ceramic Pot Filter Workshop. Atlanta, GA, USA.

Brown, J. (2007) *Effectiveness of ceramic filtration for drinking water treatment in Cambodia*. Unpublished Thesis, University of North Carolina.

Brown, J. and Sobsey, M. (2006) *Independent Appraisal of Ceramic Water Filtration Interventions in Cambodia.* Submitted to UNICEF:

Brown, J., Sobsey, M.D. and Loomis, D. (2008) Local Drinking Water FIlters Reduce Diarrheal Disease in Cambodia: A Randomized, Controlled Trial of the Ceramic Water Purifier. *Am. J. Trop. Med. Hyg.* 79(3): 394-400.

Campbell, E. (2005) *Study on Life Span of Ceramic Filter Colloidal Silver Pot Shaped (CSP) Model.* Managua, Nicaragua.

CFMWG (2009) *Minimum Standards for Local Manufacturing of Ceramic Filters for Water Treatment.* The Ceramics Filter Manufacturing Working Group: Atlanta, GA, USA.

Clasen, T., Robert, I., Rabie, T., Schmidt, W. and Cairncross, S. (2006) *Interventions to improve water quality for preventing diarrhoea*. Cochrane Database of Systematic Reviews 2006. 3**:** 104.

Fahlin, C.J. (2003) *Hydraulic Properties Investigation of the Potters For Peace Colloidal Silver Impregnated, Ceramic Filter*. Unpublished Thesis, University of Colorado at Boulder, Boulder, CO, USA.

FilterPure (2009). Dominican Republic**:** Photograph provided by FilterPure in response to questionnaire.

Hagan, J.M., Harley, N., Pointing, D., Sampson, M., Smith, K. and Soam, V. (2009) *Resource Development International - Cambodia Ceramic Water Filter Handbook-, Version 1.1.* Phnom Penh, Cambodia.

Hernandez, M. (2006) *Kiln Building*. ETHOS Conference Presentation. Kirkland, WA, USA.

Hernandez, M. (2009). Professor of Art. Northern Illinois University**:** Illustrations and photgraphs provided by Manny Hernandez.

Howard, G. and Bartram, J. (2003) *Domestic Water Quantity, Service Level and Health.* World Health Organization: Geneva.

HWTSNetwork (2009) *Network Bulletin*. The International Network to Promote Household Water Treatment and Safe Storage, World Health Organization. Issue 3.

ICAITI (1980) *Identification and Evaluation of Design Alternatives for a Low Cost Domestic Filter for Drinking Water.* Central American Institute of Industrial Technology (ICAITI): Guatemala.

IDE (2008) *IDE Ceramic Water Purifier Production Manual.* International Development Enterprises (IDE): Cambodia.

IDECambodia (2009)**:** Photographs provided by IDE Cambodia in response to the questionnaire.

Johnson, S.M., Peletz, R.L. and Murcott, S. (2008) *Results from household ceramic filter evaluation in northern Ghana*. Access to Sanitation and Safe Water: Global Partnerships and Local Actions. 33rd WEDC International Conference, Accra, Ghana.

Klarman, M. (2009) *Investigation of Ceramic Pot Filter Design Variables*. Unpublished Thesis, Emory University, Rollins School of Public Health, USA.

Kumar, R. (1999) *Research methodology: A step-by-step guide for beginners*. Sage.

Lantagne, D., Klarman, M., Mayer, A., Preston, K., Napotnik, J. and Jellison, K. (2009) Effect of production variables on microbiological removal in locally-produced ceramic filters for household water treatment. *International Journal of Environmental Health Research*.

Lantagne, D., Meierhofer, R., Allgood, G., McGuigan, K.G. and Quick, R. (2009) Comment on "Point of Use Household Drinking Water Filtration: A Practical, Effective Solution for Providing Sustained Access to Safe Drinking Water in the Developing World". *Environ. Sci. Technol.* 43(3): 968-969.

Lantagne, D.S. (2001a) *Investigation of the Potters for Peace Colloidal Silver Impregnated Ceramic Filter Report 1: Intrinsic Effectiveness.* Alethia Environmental: Allston, MA, USA.

Lantagne, D.S. (2001b) *Investigation of the Potters for Peace Colloidal Silver Impregnated Ceramic Filter Report 2: Field Investigations.* Alethia Environmental: Allston, MA, USA.

Nardo, R. (2005) *Factory Startup Manual: For the Production of Ceramic Water Filters*. Unpublished

Oyanedel-Craver, V. and Smith, J. (2007) Sustainable colloidal-silver-impregnated ceramic filter for point-of-use water treatment. *Environmental science & technology* 42(3): 927-933.

Pelita (2009). Indonesia (Indo-2)**:** Photograph provided by Pelita Indonesia in response to questionnaire.

Peterson, B.E. (2009) *Kiln Types by Construction*.About.com:Pottery. http://pottery.about.com/od/potterykilns/tp/typkilncons.htm. (Accessed 2009).

Pillars, B. and Diaz, R.T. (2009) *Factory Overview; Addressing Recontamination*. International Ceramic Pot Filter Workshop, WEF Disinfection. Atlanta, GA, USA.

PottersforPeace (2009) http://pottersforpeace.org. (Accessed 2009).

Rayner, J. (2006) *Potters for Peace Ceramic Filter Production Manual*. Unpublished

Rivera, R. (2006) *Production of Ceramic/Colloidal Silver (CCS) Water Filters*. Unpublished

Roberts, M. (2004) *Field Test of a Silver-Impregnated Ceramic Water Filter*. People-Centred Approaches to Water and Environmental Sanitation. 30th WEDC International Conference, Vientiane, Lao PDR.

Sapsford, R. and Jupp, V. (1996) *Data collection and analysis*. Sage.

Schmidt, W.P. and Cairncross, S. (2009) Household Water Treatment in Poor Populations: Is There Enough Evidence for Scaling up Now? *Environmental science & technology* 43(4): 986-992.

SilverFilterCompany (2009). Yemen**:** Photographs provided by the Silver Filter Company, Yemen in response to the questionnaire.

Sobsey, M.D. (2002) *Managing water in the home: accelerated health gains from improved water supply.* World Health Organization: Geneva.

Sobsey, M.D., Stauber, C.E., Casanova, L.M., Brown, J.M. and Elliott, M.A. (2008) Point of use household drinking water filtration: A practical, effective solution for providing sustained access to safe drinking water in the developing world. *Environmental science & technology* 42(12): 4261-4267.

Thirst-Aid (2009a) Personal Communication (e-mail correspondence).

Thirst-Aid (2009b)**:** Photograph provided by Thirst-Aid in response to questionnaire.

UN (2009a) *Millenium Development Goals Indicators*.United Nations Statistics Division. http://millenniumindicators.un.org/unsd/mdg/Host.aspx?Content=Indicators/OfficialList.htm. (Accessed July 2009).

UN (2009b) *The Millenium Development Goals Report 2009.* United Nations Department of Economic and Social Affairs (DESA): New York.

UNICEF (2008) *Promotion of Household Water Treatment and Safe Storage in UNICEF WASH Programmes.* United Nations Children's Fund (UNICEF):

UNICEF (2009) *UNICEF - Statistics and monitoring - Millennium Development Goals (MDG) monitoring*. http://www.unicef.org/statistics/index_24304.html. (Accessed June 2009).

van Halem, D. (2006) *Ceramic silver impregnated pot filters for household drinking water treatment in developing countries*. Unpublished Thesis, Delft University of Technology, Netherlands.

WHO (1997) *Guidelines for drinking-water quality, 2nd edition.* World Health Organization: Geneva.

WHO (2006) *Guidelines for drinking-water quality: first addendum to third edition.* World Health Organization:

WHO (2009a) *Burden of disease and cost-effectiveness estimates*. http://www.who.int/water_sanitation_health/diseases/burden/en/index.html. (Accessed August 2009).

WHO (2009b) *Facts and figures: Water, sanitation and hygiene links to health*.WHO. http://www.who.int/water_sanitation_health/publications/factsfigures04/en/. (Accessed June 2009).

WHO (2009c) *Water-related diseases*. http://www.who.int/water_sanitation_health/diseases/diarrhoea/en/. (Accessed 2009).

Wright, J., Gundry, S. and Conroy, R. (2004) Household drinking water in developing countries: a systematic review of microbiological contamination between source and point-of-use. *Tropical Medicine & International Health* 9(1): 106.

10 Appendices

Appendix 1 Ceramics Filter Manufacturing Working Group

Daniele Lantagne, PE	Centers for Disease Control and Prevention
Lisa Ballantine	FilterPure
Joe Brown, PhD	University of Alabama
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Burt Cohen	Potters without Borders
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Tracy Hawkins	FilterPure
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Stephanie Hooker	National Institute of Standards and Technology
Susan Murcott	Massachusetts Institute of Technology
Robert Pillers	Potters for Peace
Justine Rayner	Loughborough University
Mike Stewart	University of Colorado

Appendix 2 Filter Factories Contacted and Participating Factories

	Filter Factories Contacted and Response Rates								
	Country	Code	Location	Organisation	Response to initial e-mail	Filled out questionnaire	Interviewed	Both	Neither
1	**Benin**	**Benin**	Porto Novo	Songhai Centre	Yes	x			
2	**Cambodia**	**Cam-1**	Kampong	IDE Cambodia	Yes		x		
3	**Cambodia**		Prey Veng	Red Cross	Yes				x
4	**Cambodia**	**Cam-2**	Kandal	RDI	Yes		x		
5	**Colombia**	**Colombia**	Ocana	ASOPAFIN	Yes	x			
6	**Colombia**		Pasto	Private	Yes				x
7	**Cuba**		Camaguey	Government	Yes				x
8	**Dominican Republic**	**DR**	Jarabacoa	AguaPure	Yes		x		
9	**Dominican Republic**		Santo Domingo	IDEAC	Yes				x
10	**El Salvador**		Tecoluca, San Vincente	CORDES	Yes				x
11	**Ghana**		Accra, Ghana	Ceramica	No				x
12	**Guatemala**	**Guate-1**	Antigua	AFA	Yes		x		
13	**Guatemala**	**Guate-2**	San Mateo Ixtatan	Fundacion Ixtatan	Yes			x	
14	**Honduras**		Sabana Grande	Private Owner	Yes				x
15	**Indonesia**	**Indo-1**	Tabanan, Bali	BFDW	Yes	x			
16	**Indonesia**	**Indo-2**	Bandung, Java	Pelita Indonesia	Yes		x		
17	**Iraq**		Unknown	US Gov't	No Reply				x
18	**Kenya**		Limuru	Private Owner	Yes				x
19	**Myanmar**	**MM-All**	Eight locations	Thirst-Aid	Yes			x	
20	**Myanmar**		Unknown	Unknown	No Reply				x
21	**Nicaragua**	**Nica-1**	San Marcos	Private Owner	Yes	x			
22	**Nicaragua**	**Nica-2**	Ciudad Sandino	Private Owner	Yes	x			
23	**Nigeria**	**Nigeria**	Abeoku	Private Owner	Yes		x		
24	**Peru**		Chorillos, Lima	Merinsa	Yes				x
25	**Peru**		Urubamba	ProPeru	Yes				x
26	**Senegal**		Ourssogui Matam	Senegal Gov't/ KOICA	No longer producing				x
27	**Sri Lanka**	**SL-1**	Kelanya	SLRCS	Yes	x			
28	**Sri Lanka**	**SL-2**	Matara	Private Owner	Yes		x		
29	**Tanzania**	**Tanz-1**	Arusha	Safe Water Ceramics East Africa (SWCEA)	Yes			x	
30	**Tanzania**	**Tanz-2**	Tabora	Simba Clay	Yes		x		
31	**Yemen**	**Yemen**	Hadda	Private Owner	Yes			x	
	Totals:			n=31	27	6	8	4	13
				n=27	87%	22%	30%	15%	48%

Appendix 3 Tyler Mesh Equivalent

US Sieve Size	Tyler Equivalent	Opening	
		mm	in
-	2½ Mesh	8.00	0.312
-	3 Mesh	6.73	0.265
No. 3½	3½ Mesh	5.66	0.233
No. 4	4 Mesh	4.76	0.187
No. 5	5 Mesh	4.00	0.157
No. 6	6 Mesh	3.36	0.132
No. 7	7 Mesh	2.83	0.111
No. 8	8 Mesh	2.38	0.0937
No.10	9 Mesh	2.00	0.0787
No. 12	10 Mesh	1.68	0.0661
No. 14	12 Mesh	1.41	0.0555
No. 16	14 Mesh	1.19	0.0469
No. 18	16 Mesh	1.00	0.0394
No. 20	20 Mesh	0.841	0.0331
No. 25	24 Mesh	0.707	0.0278
No. 30	28 Mesh	0.595	0.0234
No. 35	32 Mesh	0.500	0.0197
No. 40	35 Mesh	0.420	0.0165
No. 45	42 Mesh	0.354	0.0139
No. 50	48 Mesh	0.297	0.0117
No. 60	60 Mesh	0.250	0.0098
No. 70	65 Mesh	0.210	0.0083
No. 80	80 Mesh	0.177	0.0070
No.100	100 Mesh	0.149	0.0059
No. 120	115 Mesh	0.125	0.0049
No. 140	150 Mesh	0.105	0.0041
No. 170	170 Mesh	0.088	0.0035
No. 200	200 Mesh	0.074	0.0029
No. 230	250 Mesh	0.063	0.0025
No. 270	270 Mesh	0.053	0.0021

Source: Primary author: AZoM.com, http://www.azom.com/details.asp?ArticleID=1417

Appendix 4 Temperature Chart

Temperature Equivalent Chart (when heated at 150° C/hr)

Cone No.	Centigrade	Fahrenheit	Visual Color	Firing Stage
022	600	1112	Dull Red	Dehydration 90% complete
021	614	1137		
020	635	1175		
019	683	1261		
018	717	1322		
017	747	1376		
016	792	1457		
015	804	1479		
014	838	1540		
013	852	1565		
012	884	1623	Cherry Red	
011	894	1641		Most-organic matter now burnt away
010	900	1652		
09	923	1693		
08	955	1751	Orange	
07	984	1803		
06	999	1830		Teracottas mature
05	1046	1914		
04	1060	1940		
03½	1080	1976		
03	1101	2014		
02	1120	2048		
01	1137	2079		Earthenware mature
1	1154	2109	Yellow	
2	1162	2124		
3	1168	2134		
4	1186	2167		
5	1196	2185		
6	1222	2232		
7	1240	2264		
8	1263	2305		
9	1280	2336		
10	1305	2381	White	
11	1315	2399		
12	1326	2419		
13	1346	2455		

Appendix 5 Survey

A copy of the survey in Spanish is available by contacting the author.

The survey was developed from the 'mind map' in Figure 2-4. Each question on the survey is labelled according to the following codes: Background Information: QBG 1-29, Materials and Processing: QMP 1-72, Filter Production: QFP 1-80, Quality Control: QQC 1-34, and Delivery: QD 1-21. Answers from each of the participating factories are presented in the data sheets in (Appendix 6). The question codes are in the top two rows of the data sheets.

Appendix 6 Survey Data

The survey is presented in (Appendix 5). Each question is labelled according to the following codes: Background Information: QBG 1-29, Materials and Processing: QMP 1-72, Filter Production: QFP 1-80, Quality Control: QQC 1-34, and Delivery: QD 1-21. Answers from each of the participating factories are presented in the following data sheets, the question codes can be found in the top two rows. In some cases, where no factories provided information, the columns were deleted from the data sheets (for example, no factories make their own colloidal silver and no participants provided acceptable ranges for microbiological testing results).

Answers to multiple choice and Yes/No questions were recorded using numerical codes. The answer options are abbreviated in parentheses next to the question in the question row (third row from the top). For example question 15 in the Background Information section (QBG15) shows: “Do you produce filters (FT/PT/ORD)”, where FT=Full Time, PT=Part Time and ORD=On Order, the answers are recorded as 1, 2, and 3 respectively. Likewise, for Yes/No questions (Y/N), Yes=1 and No=2. Where “blank” or “xx” appears in the answer, the participant did not answer this question.