Hemispheric Ceramic Pot Filter Evaluation and Quality Assurance Program in Northern Ghana

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ABSTRACT

Pure Home Water (PHW) is a non-profit based in Ghana that seeks to bring safe drinking water to those most in need in Northern Ghana through the production, sale, and distribution of ceramic pot filters (CPF) and other water, sanitation and hygiene innovations. This thesis documents the improvement of the performance of PHW's CPF in three areas; flow rate, bacteria removal, and strength. This thesis also documents the improvement of the PHW filter factory's quality assurance program primarily through the discovery of more efficient quality control measures. Of particular importance is the quality control measure known as the "First Drip Test" which accurately predicts both a CPF's flow rate and bacteria removal effectiveness. Two other tests, the "Bubble Test" and a tortuosity representation, were also found to be accurate quality control measures. In the production of CPFs, it was found that the percentage of combustible by mass, in this case rice husk, is the primary factor in determining both the flow rate characteristics and strength characteristics of the CPF. The flow rate increases linearly as the percentage of combustible used in the CPF composition increases. The strength decreases as the percentage of combustible used increases.

Thesis Supervisor: Susan Murcott
Title: Senior Lecturer of Civil and Environmental Engineering

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Before all others: my King, Jesus Christ. His grace was sufficient.

Thank you Susan for all your indefatigable effort and for this great opportunity and experience I have gained through your work.

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1.0 Introduction

1.1 Water in the World

According to WHO/UNICEF (2012) 778 million people in the world do not have access to improved sources of drinking water. An improved supply of drinking water is defined as "a household connection, or access to a public stand pipe, a protected well or spring, a borehole, or a sample of rainwater collection." The definition requires that at least twenty liters per person per day are available within one kilometer of a person's home. However, the reality of the situation is much worse, due to how an improved drinking water source is defined. The definition does not take into account whether the supply is regular or intermittent. If there is water available only a part of the year, as occurs in locations with wet and dry seasons, then this cannot count as an improved water supply, as it is not available. Additionally, the definition does not take into account the safety of the water, which is vital to a person's health. It also does not count hand pumps that are in disrepair. It is possible that an improved source as defined above could still contain the presence of fecal matter. For example, according to the United Nations Statistics Division (2010), 82% of Ghanaians have access to an improved drinking water supply. However, this number is most likely much lower than stated due to the discrepancies in the definition.

1.2 The Ceramic Pot Filter

The ceramic pot filter (CPF) is an adequate technology in providing safe drinking water and safe storage. However, it is not the silver bullet in household water treatment and storage (HWTS) products as the context in which a technology is placed is vital to its success. It comes in many shapes, from flowerpot to parabolic to hemispheric, and is made of clay and a combustible material, typically sawdust or rice husk. The combustible incinerates when the CPF is fired in the kiln, leaving small pores which give the CPF its filtering ability. Both materials are acquired locally, and the filters are made locally as well. The local availability and production are two features that enable self-reliance in the filter manufacturing process. The filters go through a process of mixing, molding, drying, firing, and drying once again, after which a coating of colloidal silver is painted on each filter. In some instances the filter is dipped in colloidal silver. The silver acts a disinfectant. Each CPF is placed in a plastic or clay receptacle with lid and spigot included. This is a vital piece of the CPF insofar as it provides a safe storage environment for treated water.

1.3 History of the Ceramic Pot Filter

The ceramic water filter was first invented in 1982 by Fernando Mazariegos in Guatemala. He produced a 50 page manual in which the filter is called "the artisan filter for potable water" (as translated from the Spanish). The manual describes how to build a mixer, kiln, and the filter itself. USAID provided funding for the first filter factory which was built in Ecuador in the 1980s. Mazariegos helped in this process. During this time, technical issues with the filter arose, so Ron Rivera was first introduced to the filter when he came to sort out the issues on this project. Ron Rivera was later hired as the Nicaragua in-country supervisor for Potters for Peace (Lantagne, 2001a). When Potters for Peace decided they wanted to further pursue the application of this filter technology, Ron Rivera, along with Manny Hernandez, and others, played key roles in disseminating it to other countries. Today there are 35 filter factories in 18 countries (Rayner, 2009). The 36th factory, built by Pure Home Water (PHW) in 2010-2011, is the site of this author's research. MIT faculty, students, and alumni, including Susan Murcott, Rebecca Huang, and Danielle Lantagne, were among the first to undertake scientific studies of the CPF with Ron Rivera at the Potters for Peace Factory in Managua, Nicaragua. These studies helped to spark interest in the filter by other researchers.

1.4 Pure Home Water

PHW is located in Tamale, Ghana and is a registered non-profit in Ghana. PHW was founded in 2005 by Susan Murcott, a Senior Lecturer at MIT's Department of Civil and Environmental Engineering. PHW's intention is to serve the 900,000 people in northern Ghana who currently use an unimproved drinking water source (Ghana Statistical Survey, 2003). The need for a point-of-use water treatment technology is amplified by the fact that, as of 2011, only 13% of Ghanaians have access to improved sanitation (WHO, 2011a). This fact heightens the need for point-of-use drinking water treatment as can be shown in the research of Eisenberg et al. (2007). Eisenburg speaks of different pathways that can prevent pathogenic microorganisms from infecting humans. These include safe hygiene, safe excreta disposal, safe water storage and handling, and water quality improvements. Eisenberg et al found that water quality improvement is a critical pathway *when* excreta disposal and water storage and handling are performed inadequately as is the case in Northern Ghana. Through many challenges PHW has successfully distributed 17,400 filters serving more than 100,000 people through 2011. In February 2012, PHW began full production at its still growing factory outside Tamale. PHW has a contract with Rotary International through a Future Vision Global Grant, to sell 1,250 subsidized filters to Ghanaians in local villages and to construct an equal number of tippy tap hand washing stations. PHW seeks to grow to address sanitation issues, proper hygiene education, and the potential sale of other (HWTS) products in its future.

1.5 Objectives

The two primary goals of Pure Home Water (PHW) are:

"(1) to provide safe drinking water to those most in need in Northern Ghana and

(2) to become locally and financially self-sustaining."

This study will provide crucial steps toward making these goals a reality. The three primary goals of this study are to:

(1) find the optimum filter composition specific to the factory in Tamale, Ghana,

(2) identify one or multiple simple and cheap indicators for determining ceramic pot filter (CPF) effectiveness in removing harmful pathogens, as will be indicated by total coliform removal, and

(3) devise a quality assurance program for the PHW factory in Tamale, Ghana.

Safe drinking water is vital to health; therefore, the CPF can be thought of as a health product. To that end, every CPF must be tested to ensure proper and adequate performance. Achievement of this study's three goals will help to guarantee that CPFs sold to the public are providing water that is safe to drink.

Secondary goals arise from primary goal number two. Identifying one or more indicators for filtering effectiveness in removing total coliform will shed light on how the filter actually works. These secondary goals include:

(1) maximizing flow rate and

(2) maximizing filtering effectiveness in removing harmful pathogens, as will be indicated by total coliform removal

In the best case scenario, better understanding of the porosity and tortuosity of the filter will contribute to the process of determining the optimal pore size. When these filtering mechanisms are understood, the CPF composition can be changed to maximize flow rate and filtering effectiveness.

A new CPF design has just begun to be manufactured at the PHW factory in Tamale, Ghana as of November 2011 when the first of two new hydraulic presses, together with hemispheric molds came on line. Thus, tertiary goals of this study include:

(1) an evaluation of the new hemispheric CPF and

(2) creation of necessary aids to the hemispheric design, e.g. T-device, fact sheet, quality assurance testing setup, etc.

Although total coliform has been shown to be a poor indicator bacteria of safe water (Levy et al, 2012), total coliform is considered a valuable indicator of treatment system performance (WHO, 2011b). In this research total coliform is not used as indicator bacteria of safe water, but as an indicator of treatment system performance.

2.0 Literature Review

Potters for Peace originally recommended a flow rate of 1-2 L/hr so that the painted or impregnated silver nanoparticles would be in contact with the water for long enough to disinfect pathogens. Ron Rivera, who played a key role in disseminating the ceramic pot filter (along with Manny Hernandez), determined a necessary contact time of 60 minutes to filter two liters of water based on the Microdyn application directions (Lantagne, 2001). Stemming from this assumption, it was recommended that CPFs with flow rates higher than 2 L/hr should be discarded. However, several studies, including Kleiman (2011) and Bloem (2009) have shown that there is no correlation between flow rate and filtering effectiveness. This holds up to a certain flow rate, which remains unknown, after which filtering effectiveness diminishes. However, flow rate remains central to the quality control and quality assurance process in ceramic pot filter factories around the world. Sixteen of 18 factories surveyed test the flow rate of every single filter produced (Rayner, 2009). This is likely because it is thought that flow rate can still shed light on the uniformity of manufacturing and production (Rayner, 2009). Meanwhile, several studies, (van Halem, 2006 and Kleiman, 2011) have recommended finding a better indicator for bacteria removal than flow rate. Kleiman (2011) recommends that additional research be conducted to determine the relationship between flow rate and filtering effectiveness both with and without silver applied.

2.1 Pure Home Water Research

Two MIT Master of Engineering theses by Miller (2010) and Kleiman (2011) provided important steps towards establishing a ceramic filter factory in Tamale, Ghana. Miller (2010) performed a 12 week study and reached conclusions on the design of the filter based on several performance categories. Miller found that a sawdust combustible removed *E. coli* better than a rice husk combustible; however, rice husk removed total coliform better than sawdust. He found flow rate increases with a high percentage of combustible by mass, when the combustible is unsifted, and when rice husk rather than sawdust is used. From these conclusions he recommended to PHW that two filter compositions (or "recipes") out of the many different compositions be further tested before marketing and full scale production. Kleiman provided the "design and construction of an underground water storage system" (2011) to fill the factory's water needs. She also improved the quality control process, which brought PHW one step closer to the full production level.

2.2 Recent Research

The following two studies by Gensburger (2011) and Kallman (2011) were both published in 2011 and, when compared side by side, produce some interesting results as well as further questions.

Gensburger (2011) conducted a study with the objective of increasing flow rate without compromising strength of the filter or filtering effectiveness. Gensburger confirmed the results of earlier studies (Bloem, 2009) as well some generally agreed upon speculations about how the filter works. She confirmed that:

- increasing the quantity of rice husk increases the flow rate,
- there is no relationship between *E. coli* removal and flow rate, either with or without silver. (This finding holds up to 25 L/hr. But it must also be pointed out that Gensburger used the constant head method to measure flow rate which will give a greater than actual flow rate),
- increasing the percentage of combustible, from the range of 23.8% to 31.1%, does not reduce bacteria removal efficacy (either with or without silver),
- the application of silver increases the removal of *E. coli*, and finally,
- a smaller combustible particle size leads to better removal efficiency because smaller pores are produced in the filter.

Kallman et al. (2011) found that:

- as the amount of combustible used decreases the percentage of pores less than 1 um increases. (This follows intuition because as the amount of combustible used decreases there is a smaller chance of clumping, and clumping would increase the pore size),
- for filters without silver as the amount of combustible used increases, the *E. coli* removal decreases. (This, they say, is because "the main mechanism for bacteria removal in ceramic filters is retention of the cell in small pores" (p. 5)),
- for filters with silver, the higher the percentage of combustible, 17% combustible in her study, removed the most *E. coli* compared to filters with 4% and 9% combustible. (This, the authors say, is because the higher amount of combustible creates a higher porosity which creates more surface area for the silver nanoparticles to adsorb to), and finally
- sorption and/or size exclusion is the main mechanism for removing bacteria when silver is not applied.

The seeming contradiction between the Gensburger and Kallman results can perhaps be reconciled in one aspect of filter manufacturing and production. It is possible that Gensburger obtained her results when clay and combustible are very well mixed while Kallman obtained her results when clay and combustible are not mixed as well. This would explain differing results when the amount of combustible is increased for filters without silver. Because as the amount of combustible is increased in Gensburger's study, there was no decrease in bacteria removal while in Kallman's study the increase in combustible did lead to a decrease in bacteria removal. Indeed, this might be the correct explanation, as Gensburger used a mixer because her research was performed at a more advanced facility than Kallman. Another important difference must also be noted. Gensburger used rice husk while Kallman used sawdust as a combustible. It is apparent from Miller's study in 2010 that the types of combustible cannot be thought of as equivalent. A comparison of these two studies raises two questions. 1. How does clay and combustible mixing affect bacteria removal performance? 2. Why do different types of combustibles produce different bacteria removal performance?

Bloem et al (2009) found that filters with silver had a better flow rate after an extended period (2500 L of water passed through each filter) than filters without silver because the filters without silver had formed a biofilm. They also found that bacteria removal is not dependent on flow rate. Virus removal (MS2 bacteriophages were used) was low for filters with and without silver. The mean viral Log Removal Value (LRV) was around 0.5.

Van Halem (2006) puts forth important theories on the potential mechanisms of filtration in the CPF. Based on her mercury intrusion porosimetry results, the dominant pore size is from 14 μm to 23 μm. Bacteria is much smaller than this, and its size depends on its shape. Spherical is 0.5 μm to 1 μm. Cylindrical is 0.5 μm to 1 μm wide and 1.5 μm to 3 μm long. Helical is 0.5 μm to 5 μm wide and 6 μm to 15 μm long (Tchobanoglous, 1991). So Van Halem concludes that mechanisms other than screening are playing a major role in removing bacteria. Van Halem lists other possible mechanisms such as sedimentation, diffusion, turbulence, inertia, and adsorption. Van Halem postulates that the tortuosity of the filtering element explains why these other mechanisms play a role in removing bacteria. More specifically, she says an increased tortuosity enhances the effects of the aforementioned mechanisms. She also found that filters with silver applied have a smaller porosity than filters without silver applied, as the silver fills the pores less than 1 um in diameter.

Plappally et al (2010) found that a change in water chemistry with time is imminent. Plappally et al found that the difference in alkalinity of the influent water and filtrate is predicted by a variety of factors including temperature, electrical conductivity, and change in turbidity.

2.3 Ceramic Pot Filter Efficacy in the Field

The most compelling evidence for the usefulness of the CPF comes from Brown et al (2008) in "the first randomized, controlled trial of locally produced ceramic water filters for point of use drinking water treatment." They found a 49% reduction in diarrheal disease when the CPF is used. The study included a total of 1,196 people in a rural village in Cambodia. Previously, Brown (2007) found that the CPF reduced diarrheal disease by about 40%. He also concluded that "the filters maintained effectiveness over long periods, up to 44 months in field use" (p. iv). Closely linked to this finding, Brown determined that bacteria removal effectiveness did not decrease with time, as one might suspect (p. 220). This evidence establishes that the current filter replacement time of 1 to 2 years, as stated by Rayner (2009), can be increased. The extended life of the CPF adds to its usefulness as an effective technology for treating drinking water.

Further recommendation of the CPF was given by Hunter (2009) when he conducted a meta-analysis of "28 separate studies of randomized controlled trials of HWT with 39 intervention arms . . . included in the analysis" (p. 8991). Seven of the 39 data sets were of ceramic filters. Hunter found that "ceramic filters are the most effective form of HWT in the long term" (p.8991). The other forms of HWT analyzed in this study included chlorination with safe storage, combined coagulant-chlorine disinfection system, SODIS, and the biosand filter.

A study by Brown and Clasen (2012) found that household water treatment will be effective only if it has a high adherence level from its users. Brown and Clasen state that "A decline in adherence from 100% to 90% reduces predicted health gains by up to 96%, with sharpest declines when pre-treatment water quality is of higher risk." This startling fact stresses just how important a high adherence rate is.

The hardest part of creating a self-sustaining filter factory is having a successful commercial market. The Safe Water Project at PATH, Program for Appropriate Technology in

Health, puts it bluntly, “In most cases, HWTS products are a hard sell” (2012, p.11). PATH describes many techniques to overcome this challenge. Some of these techniques that PATH recommends include interpersonal communication to gain a consumer’s trust, interactive product demonstrations, and advertising messages that focus not only on health benefits, but also on aspirational desires. As the challenge to bring people clean water continues, these insights and lessons will be much needed.

3.0 Methods

All research was performed in Tamale, Ghana from January 4 to January 24th, 2012. This is during the dry season in Ghana, so there was no rain, and during the annual harmattan (dust storms that occur annually from December to March) the average daytime temperature was 90 degrees Fahrenheit. In total, 145 filters were tested, all of which had been manufactured at the PHW factory. Of these 145 filters, 35 different compositions were manufactured. The composition of each filter can be found in Table 3-1 below. The raw data collected for these filters is located in Appendix A. A total of nine different tests that will be described in the following sections were performed during this study. However, not every filter underwent every test due to breakage (20 filters), limited time and limited supplies. 31 filters underwent every test.

Table 3-1: Tested Filter Compositions

Gbalahi Clay (kg)	Wayamba Clay (kg)	Grog (kg)	Rice Husk (kg)	# of Filters Tested
20	6.7	0	3.3	5
18	4.5	0	7.5	3
18	6	0	7	4
18	5	0	7	3
18	12	0	8	3
18	5	2	7	7
18	5	3	7	5
16	4	0	10	6
16	10	5	7	4
16	0	2	5	5
14	0	3	5	5
13	8	0	8	6
13	0	0	3	1
13	0	1	4	1
12	4	0	2.5	4
12	4	0	3	4
12	4	0	3.5	4
12	4	0	4	3
12	4	3	4	5
12	4	0	2.5	4
12	4	0	3	3
12	4	0	4	4
12	4	3	5	4
12	4	0	2.5	4
12	4	0	3	5
12	4	0	4	3
12	4	3	5	5
11.25	11.25	0	7.5	5
11.2	11.2	0	8	3
11	0	2	3	3
11	0	0	4	10
11	0	1	4	8
11	0	3	4	2
11	0	3	3	1
0	13	0	3	3

3.1 Factory Setting

The PHW factory is located next to the small village of Taha. The factory floor layout is currently divided into three sections:

1. clay and combustible storage and mixing and pressing,
2. firing and CPF drying and storage, and
3. quality control.

The quality control section served as the testing location for nine different tests: turbidity, turbidity tube, porosity, bubble test, flow rate, first drip test, qualitative strength inspection, and thickness and carbon layer inspection. The nine tests were performed by the author of this study, with assistance from Abdul-Karim Alale, who is an employee of PHW, and Kellie Courtney, who is an MIT senior chemical engineering major also working under Susan Murcott. In Figure 3-1, the quality control section makes up a third of the factory located on the far right of the picture.

Figure 3-1: Pure Home Water Factory

Figure 3-2: Soak Tank

Figure 3-3: Quality Control Factory Section

3.2 Lab Setting

The PHW lab is located in the PHW office/house which is located about 1.5 miles from downtown Tamale. All testing of microbiological sample analysis was performed at this location. The sampling of the filtrate water from CPFs without silver applied was performed at the factory while the sampling of the filtrate water from CPFs with silver applied was performed on the PHW house front porch. In the middle center of Figure 3-4, the QuantiTray Sealer can be seen. Also, on the right of the picture, a part of the incubator used is visible.

Figure 3-4: Pure Home Water Laboratory

3.3 Turbidity Test Method

Turbidity was tested using a Hach 2100P Turbidimeter as seen in Figure 3-5.

Figure 3-5: Hach 2100P Turbidimeter

The following describes the turbidity testing procedure:

1. Soak filter for 24 hours in soak tank located at PHW factory.
2. Suspended filter on test rack with string/rope "basket" (see Figure 3-17) so that filtrate can be collected.
3. Collect influent water from the Taha dugout, as seen in Figure 3-22.
4. Place one drop of oil on each 10mL glass test vial and rub with soft cloth to remove scratches from vial.
5. Place approximately 3L in each CPF.
6. Allow 1L of water to filter through CPF before collecting filtrate water.
7. Collect filtrate directly into 10mL vial appropriate for the turbidimeter.
8. Collect a sample of influent water in a 10mL vial appropriate for the turbidimeter.
9. Place sample jar in turbidimeter while lining up vial arrow with specified turbidimeter arrow for correct orientation.
10. Test samples.
11. Record results in units of N.T.U. (Nephelometric Turbidity Units).
12. Calculate the percent turbidity reduction using Equation 3-1:

Equation 3-1: $$\%\ NTU\ Reduction = \frac{Influent\ NTU - Effluent\ NTU}{Influent\ NTU} \times 100$$

The turbidimeter was calibrated in Ghana before use by means of the in-device program. Figure 4 shows each of the four HACH manufactured standards used for calibrating the turbidimeter, 0 NTU, 20 NTU, 100 NTU, and 800 NTU.

Figure 3-6: Turbidimeter Calibration Standards

3.4 Turbidity Tube Test Method

This test was performed using a DelAgua Turbidity Tube at the same time turbidity testing occurred with the HACH Turbidimeter. After a sample for the turbidimeter was collected, the following procedure was performed:

1. Place 1L plastic beaker under filtrate "drip location" of CPF.
2. Collect 300 mL of filtrate water.
3. Pour a small amount of water into DelAgua turbidity tube, wait for bubbles to clear, and then look directly down. If bull's eye on bottom of tube is still visible, repeat the process.
4. Once the bull's eye on bottom is just past the limit of visibility, read the numbers along the side of tube.
5. Record result in units of T.U. (Turbidity Units). It is important to note the results are on a log scale, as can be seen in Figure 3-9.
6. Take a sample of the influent water and record its TU value as well.
7. Calculate the percent turbidity reduction using Equation 3-2:

Equation 3-2: $$\%\,TU\ Reduction = \frac{Influent\ TU - Effluent\ TU}{Influent\ TU} \times 100$$

Figures 3-7, 3-8, 3-9, and 3-10 provide visual aids to the turbidity tube testing process.

Figure 3-7: Karim pours sample into turbidity tube

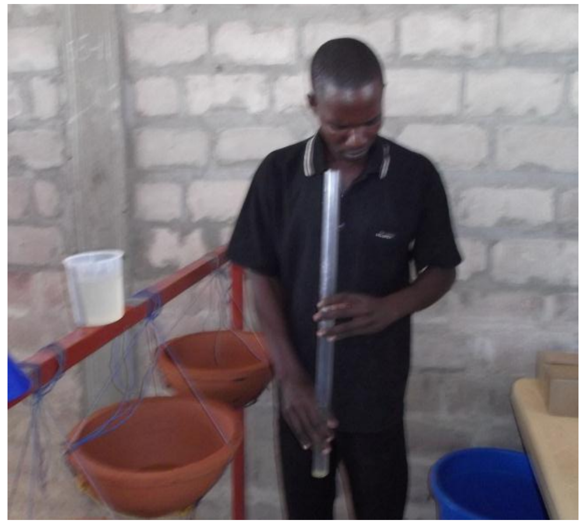

Figure 3-8: Karim undergoing the iterative testing process

Figure 3-9: Karim reading the TU

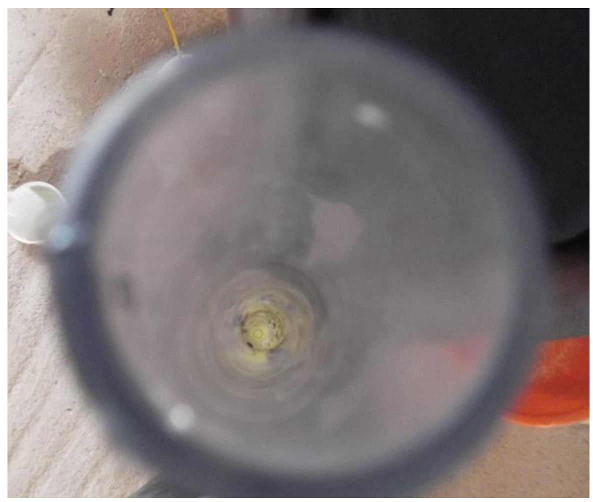

Figure 3-10: Yellow bottom and black circle, which is called a bulls eye, is visible at bottom of tube (no water present)

3.5 Porosity Test Method

The following test method follows ASTM Standard C373-88 and gives the apparent porosity. It is termed "apparent" because porosity is determined by mass, not volume, by using the assumption that one cubic centimeter of water weighs one gram. The procedure is described accordingly:

1. A Cen-Tech 70 Lb/32 Kg Digital Postal Scale was used as seen in Figure 3-11. Its capacity is 32 kg and its readability is 1.0 g. Scale is placed on level sturdy surface. In this instance, the scale is placed on plywood which is placed on a concrete floor. Tare scale and measure in SI units.
2. Measure dry mass of filter using scale. This is ideally done before water is ever introduced to the post-fired filter. This helps to maintain uniformity in the testing process as some of the very fine particles of a filter tend to crumble and rub off. Introducing water to the filter exacerbates this problem.
3. Soak filter for 24 hours in soak tank making sure the filter remains completely submerged as seen in Figure 3-12. Handle filters with caution as some of the weakest compositions are prone to break after extended soaking.
4. Place prepared PVC "stand" (Figure 3-13) and "basket" (Figure 3-14) in soak tank and place scale and plywood on stand but under the top part of the basket so that the upper basket square can be placed on the scale as seen in Figure 3-15.

Figure 3-11: Cen-Tech 70 Lb/32 Kg Digital Postal Scale on plywood and concrete surface

Figure 3-12: Soak Tank with Filters

5. The mass of the basket is resting entirely on the scale at this point (this includes the portions in and out of the water). So the scale can be tared to zero.
6. Place filter on the lower submerged square of the basket as seen in Figure 3-16
7. Measure the filter's mass underwater.
8. Remove filter from water and wait to weigh again until drips of water no longer fall from the filter.
9. Remove scale from stand and place again in the location where dry mass was measured. Tare scale and measure in SI units.

10. Measure saturated mass of filter.
11. Use Equation 3-3 (from ASTM Standard C373-88) to determine apparent porosity of the filter:

Equation 3-3: $$Apparent\ Porosity = n = \frac{m_{saturated} - m_{dry}}{m_{saturated} - m_{underwater}}$$

Where,

$m_{saturated}$ = mass of filter when saturated
m_{dry} = mass of filter when dry
$m_{underwater}$ = mass of filter saturated when weighed underwater

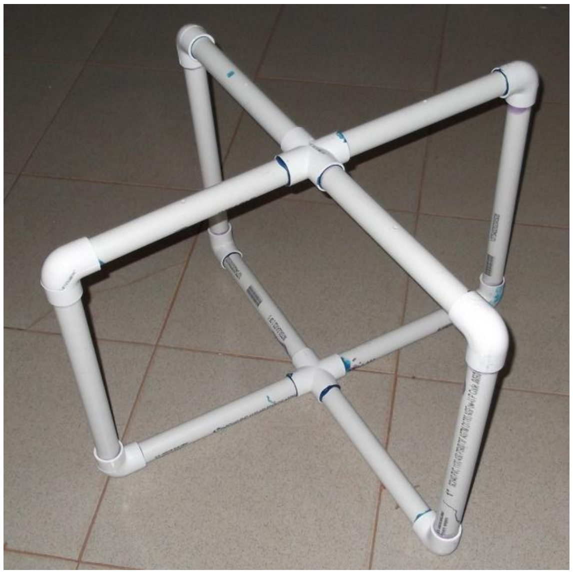

Figure 3-13: PVC Pipe “Stand” for Apparent Porosity Test

Figure 3-14: PVC Pipe “Basket” for Apparent Porosity Test

Figure 3-15: Porosity Test Apparatus

Figure 3-16: Porosity Test Apparatus with Filter

3.6 Pressure or “Bubble Test” Method

The pressure or bubble test is an ingenious test previously developed to determine if a filter has cracks or pores that are too large (Rayner, 2009, p. 116). The process is described:

1. Soak filters for 24 hours in soak tank making sure the filter remains completely submerged as seen in Figure 3-12.
2. Remove filter from water and then submerge filter with lip facing down so that a pocket of air is created in the filter. Care should be taken to ensure the filter is level when being submerged; otherwise water can enter the air pocket and give potentially false results.
3. Once the filter is entirely submerged, wait for five seconds.
    a. If no stream of bubbles is escaping the filter, the filter passes, P.
    b. If a small stream of bubbles escapes the filter, the filter is marked as having little bubbles, LB.
    c. If a large stream of bubbles escapes the filter, the filter fails, F.
4. All filters that are classified as LB or F should be discarded and broken to ensure they are not used.

3.7 Flow Rate Test Methods

Two types of methods for testing the flow rate are presented here. The first method is called the “collection” method and the second as the “T-device” method. It should be noted that the collection method is more accurate than the T-device method as it is an actual measurement of volume and time whereas the T-device method (although it is a measure of distance) is dependent on the filter maintaining a proper shape. These two methods can be conducted concurrently and this was done for the entirety of this research.

Collection Method Test Procedure:

1. Soak filter for 24 hours in soak tank making sure the filter remains completely submerged as seen in Figure 3-12. Handle filters with caution as they are prone to break after extended soaking.
2. Place filters in string “basket” which hangs from a metal rack as seen in Figures 3-17 and 3-18.
3. Fill filters to the top of the filter lip ensuring that filter is level (this is easier to do when water level is near the top of the filter lip so that you can tell which way the filter is slanting).
4. Place 1 L beaker or graduated cylinder underneath filter to catch filtrate water.
5. Whenever the 1 L container is full, empty it and put it back in place to collect water. Keep a tally for the number of times the container is emptied.
6. Start stopwatch to record time.
7. After 15 minutes measure the amount of water that has collected in the receptacle.
8. After 30 minutes measure the amount of water that has collected in the receptacle.
9. After 60 minutes measure the amount of water that has collected in the receptacle (the 60 minute recording was not performed during this study due to time constraints).
10. Record Results.

Use Equation 3-4 to calculate flow rate: $Q = \frac{V}{t}$

Where,

Q = flow rate
V = volume of water collected
t = time to collect V

Figure 3-17: Flow Rate Test (both the collection method and T-device method are shown)

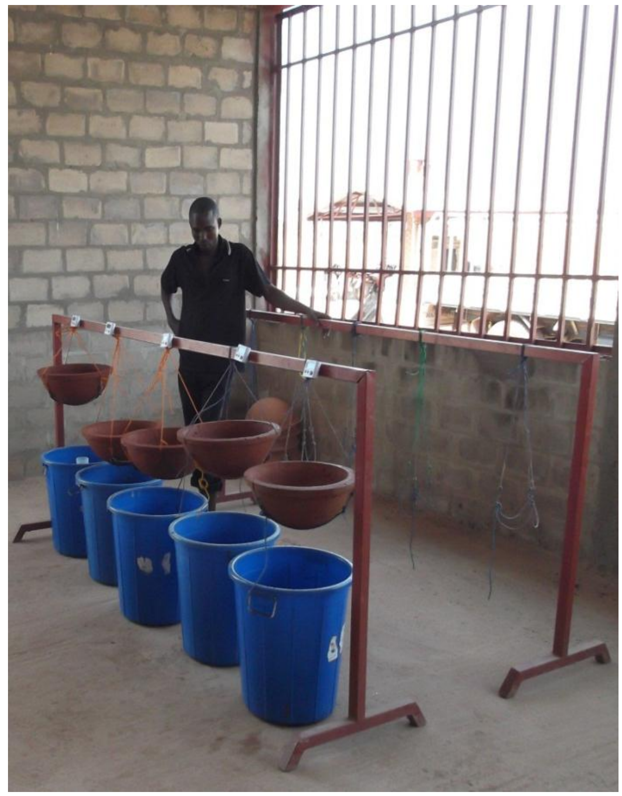

Figure 3-18: Flow Rate Test Setup with metal racks

T-Device Method Test Procedure:

1. Soak filter for 24 hours in soak tank making sure the filter remains completely submerged as seen in Figure 3-12. Handle filters with caution as they are prone to break after extended soaking.
2. Place filters in string "basket" which hangs from a metal rack as seen in Figures 3-17 and 3-18.
3. Fill filters to the top of the filter lip ensuring that filter is level (this is easier to do when water level is near the top of the filter lip so that you can tell which way the filter is slanting).
4. Start stopwatch to record time.
5. After 15 minutes use calibrated T-device to measure drop in water height.
6. After 30 minutes use calibrated T-device to measure drop in water height.

7. After 60 minutes use calibrated T-device to measure drop in water height.
8. Record Results.
9. Use Equation 3-4 to calculate flow rate (In this case Q is the measured drop in water height and t is the experiment time length).

3.8 T-Device Calibration

The T-device, as seen in Figure 3-17 and 3-20, must calibrated for each specific filter mold. This is because each filter mold used by different factories varies in size and shape. Equations for the calibration of each of the general filter shapes (e.g. flowerpot, parabolic, hemisphere) can be found. Miller (2010) performs such calculations for the flowerpot and parabolic filter shapes. The appropriate unique parameters to each filter can then be used (e.g. for the hemisphere, the radius is the only unique parameter needed). What follows is the calculus for finding the equation needed to calibrate a hemispheric filter T-device:

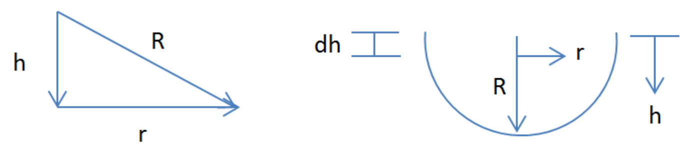

Figure 3-19: Hemispheric CPF Modeling

Equation 3-5: $h^2 + r^2 = R^2$

Equation 3-6: $r^2 = R^2 - h^2$

Equation 3-7: $V = \int_0^h \pi r^2 dh = \int_0^h \pi(R^2 - h^2)dh = \int_0^h \pi R^2 dh - \int_0^h \pi h^2 dh = \pi R^2 h - \frac{\pi h^3}{3}$

Equation 3-8: $V = \pi h\left(R^2 - \frac{h^2}{3}\right)$

Where,

R = radius of the filter
V = volume of water that has exited the filter
h = distance the water level has dropped in the filter
r = radius of the filter as h increases
dh = infinitesimal distance the water level has dropped in the filter

Figure 3-20: T-Device for the Hemispheric CPF

Using Equation 3-8, the radius of the filter, and desired volumes, one can mark off heights on the T-device. The design schematic of the concrete hemisphere PHW filter is shown in Figure 3-21. After correcting for 6% clay shrinkage during firing, the radius should be 16.8 cm.

Equation 3-9: $$7.05\ in \times \frac{2.54\ cm}{1\ in} \times 0.94 = 16.8\ cm$$

The measured inner radius of the concrete hemisphere CPF is actually 17.2 cm. Table 3-2 shows the volume of water that has exited the filter and its corresponding distance down the T-device from the datum, 0 L. The values in the right hand column have been rounded to the nearest mm due to loss of measuring accuracy beyond that point. The measured radius has been used for these calculations, as opposed to the design schematic radius.

Table 3-2: T-Device Calibration

Volume of water that has exited the filter (L)	Distance from 0 L for corresponding marker (cm)
1	1.1
2	2.2
3	3.3
4	4.4
5	5.6
6	6.8
7	8.1
8	9.6
9	11.3
10	13.6

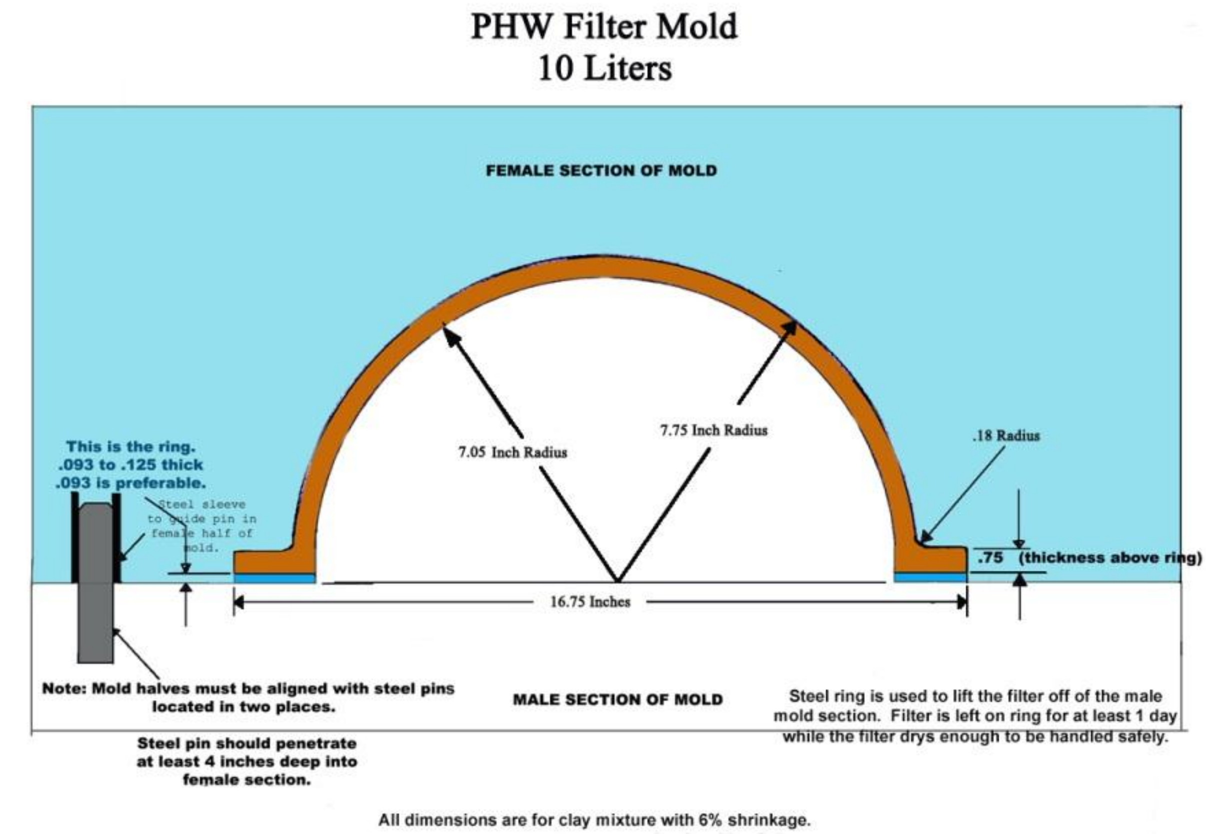

Figure 3-21: Pure Home Water Mold Design Schematic

3.9 "First Drip Test" Test Method

The First Drip Test was invented by the author together with another MIT Masters student, Amelia Servi, with help in the procedure details from Karim Alale. We officially named this test "First Drip." As will be shown later in this study, the first drip test holds promise as a substitute to more tedious and time consuming tests. Its explanation and procedure follows:

1. Once filters have been cooled, removed from the kiln, dusted off, and weighed dry for porosity testing, they are placed in the string "basket" hanging from a metal rack that is also used for flow rate testing. It is vital that the filters do not get wet at all.
2. Prepare 1L of water in a beaker or graduated cylinder for every filter to be tested.
3. Prepare timer as needed.
4. Pour the 1L of water into filter while simultaneously starting timer.
5. When first drip of filtrate leaves the filter stop timer.

6. Remember to push holding ropes underneath filter to the side as much as possible, because if a rope is directly underneath the filter it will saturate thereby increasing the first drip time and will give inaccurate results!
7. Record results.

3.10 Tortuosity Test Method

The method for testing tortuosity was not perfected and therefore not used in this study. However, it is important to show the method as parts of its equations and reasoning will be used later in this study. Equation 3-10 gives the Darcy velocity, as known in Darcy's Law, which represents the flow through a porous media with a certain cross-sectional area. This cross-sectional area is the total area of the pipe, or in this case the filter, not just the area available for water to flow through. Equation 3-11 uses the porosity to determine the pore velocity, or the actual velocity of a molecule of water flowing through the porous media. As the Darcy velocity is not directly measurable, the combination of Equations 3-10 and 3-11 yield the pore velocity which can be calculated from measurable quantities Q, A, and n. Equation 3-12 is the combination of Equations 3-10 and 3-11. Equation 3-13 characterizes the distance of the actual travel path a molecule of water would take through the porous media. This value must not be thought of as an exact distance because in reality there are millions of potential travel paths of varying lengths. The new variable, travel time, introduced can be measured according to the tracer dye test procedure described below. Equation 3-14 defines tortuosity as the actual travel path over the straight line travel path. This indicates that a higher value means a more tortuous path.

Equation 3-10: $$q = \frac{Q}{A}$$

Where,

Q = flow rate
A = cross-sectional area
q = Darcy velocity

Equation 3-11: $$v = \frac{q}{n}$$

Where,

v = pore velocity
n = porosity

The two equations above can be combined to form,

Equation 3-12: $$v = \frac{Q}{A \times n}$$

Equation 3-13: $$L_e = vt$$

Where,

L_e = actual travel path
t = travel time

Equation 3-14: $$\tau = \frac{L_e}{L_o}$$

Where,

τ = tortuosity
L_o = thickness (straight line travel path)

The three equations above can be combined to create a new equation for tortuosity,

Equation 3-15: $$\tau = \frac{Q \times t}{L_o \times A \times n}$$

The test method for determining the tracer dye time is as follows:

1. Soak filter for 24 hours in soak tank.
2. Suspend filter with string/rope underneath the entirety of the filter lip so that outflow from the bottom of the filter is visible.
3. Measure 1L of water and mix in 10 drops of food coloring to produce highly colored water.
4. Pour in prepared liter of dyed water and start stopwatch.
5. Record time it takes for dyed water to first breakthrough the whole filter wall in significant concentration. Significant concentration means that the filtrate is almost the same color and intensity as the influent water. (Trying to quantify the concentration for breakthrough time would require more technology than is wanted for simple tests in the factory setting, thus the test was abandoned).
6. Rinse out filter by allowing 10L to flow through it.
7. Use equation 3-15 to determine tortuosity.

3.11 Bacteria Removal Test Method

To determine how effectively each CPF removed bacteria from the water it treated, the IDEXX Quanti-Tray/2000 test was used. The conduct of this test occurred in two stages, at the factory and in the lab. The in-lab stage follows the procedure described by IDEXX, which can be found on their website, http://www.idexx.com/view/xhtml/en_us/water/quanti-tray.jsf. The procedural steps conducted at the PHW factory are as follows:

1. Collect influent water from desired source. In this study, water was collected from the Taha Dugout, a small watering hole near the PHW factory and named after the adjacent village of Taha. This source was chosen because of its high bacteria count and because this is representative of the quality of water that PHW's target market of CPF users typically drink. Figure 3-22 shows the collection method and Figure 3-23 gives a visual indication of the source's turbidity.

Figure 3-22: Kellie fills a jerry can with water from the Taha Dugout

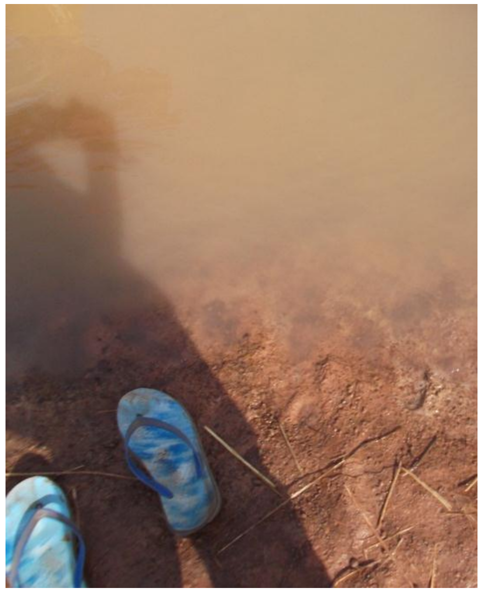

Figure 3-23: Extremely turbid water in the Taha Dugout

2. A plastic bucket with a square hole cut out of it is placed on top of another plastic bucket which is used as a stand. The CPF is then placed in the top plastic bucket. Such a setup can be seen in Figure 3-24. In this study 10 CPF were tested concurrently with the setup seen in Figure 3-25.
3. Sweep and clean testing area to avoid environmental contamination. Testing area in this study was inside the PHW factory. However, because the design of the factory is open air to allow cooling and because testing occurred during the harmattan season, the space was susceptible to a considerable amount of dust.
4. The person performing the study should wash their hands throughout the experimental procedure, especially when coming into contact with the filtrate. In this study hand sanitizer was used due to its convenience.
5. Wash bucket that contains the CPF (transparent bucket in Figure 3-24) with soap and water before testing to avoid environmental contamination.

Figure 3-24: Filter Test Setup

Figure 3-25: The microbiological "laboratory" at the factory

6. Scrub CPF with brush in a basin of clean water so that any bacterial contamination caused by the environmental surroundings may be removed (no soap or chlorine of any kind should be used because residual chlorine or soap may be left in the filter which would skew bacteriological results).
7. Pre label 100 mL Whirlpak bags with filter identification number, date, and time.
8. Wash small cups (which hold Whirlpak sterile sample bags upright under dripping filters) with soap and water equal to the number bucket setups used (as seen in Figure 3-25).
9. Place labeled Whirlpak bag into clean cup and wipe edges of the cup lip as well as the top of the unopened Whirlpak bag with alcohol swab.
10. Stir influent water and then pour 3L of influent water into each CPF being tested.
11. Open Whirlpak bag and place the cup which contains the Whirlpak bag in the transparent bucket. Adjust the cup as necessary so that the Whirlpak bag catches the filtrate drip stream from the CPF.

Figure 3-26: Cooling and storage of filtrate samples before taking back to the lab for testing

12. Once 100mL has been collected, remove cup and whirl closed the Whirlpak bag. Place securely closed filtrate sample in cooler (as seen in Figure 3-26) for transportation to lab.
13. Collect a well-mixed sample of the influent water in a Whirlpak bag for testing as well.

3.12 Qualitative Strength Inspection

A MIT Master of Engineering Thesis (Watters, 2010) has quantitatively studied bending strength of certain previous filter compositions made at the PHW factory. Although quantitative strength tests were not performed during this study, qualitative strength inspection and observation was one of the vital tests for choosing the best filter composition. The series of observations used for determining the qualitative strength of each CPF are categorized below:

1. How stiff and sturdy a CPF felt when handling it dry.
2. Whether the fired clay tended to crumble off or not when CPF was handled (crumbling signified a weaker CPF).
3. When a saturated CPF was placed in the flow rate testing setup, three ropes diverged downward from the metal rack to support the CPF, as seen previously in Figure 3-17. These three ropes happened to place a strong force in the three points where they came into contact with the CPF. This unintentional strength test showed how far the rope would "dig" into the CPF. The exceptionally weak CPFs broke in this state.
4. How stiff and sturdy a CPF felt when handling it saturated.
5. How often CPFs of the same composition broke when handling saturated.

Using this set of observations, each CPF composition was categorized relative to the other compositions using this scale: very weak, weak, fair, moderate, strong, very strong.

3.13 Thickness and Carbon Layer Inspection

Approximately three to five CPFs from each firing were cut open to measure their thickness, examine the uniformity in thickness, (which tells how evenly they are being pressed), the presence or absence of a carbon layer, and if present, the thickness of the carbon layer. Photo evidence of one CPF from each firing was also documented. In categorizing this data according to firings, we assumed that the sample of CPFs tested during that specific firing represented all CPFs fired at the same time and pressed on the same day. This is a simplifying assumption given our knowledge of different temperature cold and hot spots within the kiln. However, it is our best guess in representing the varied conditions from one firing to the next.

Figure 3-27: A CPF cut in half by saw

3.14 Silver Application

Once the filters were tested, they were transported back to the PHW house and office where they were painted with colloidal silver. PHW buys 75% colloidal silver from Argenol Labs in Spain. The PHW practice for applying colloidal silver solution to a CPF is detailed below in two stages: stock solution preparation and solution application.

Stock Solution Preparation (2.83%, 28333 mg of silver / L of water)

1. Wear gloves, lab coat, face mask, and protective glasses while undergoing this procedure
2. Place metal weighing dish on a balance accurate to 0.01 grams. Tare balance
3. Using a spatula place 4.72g in metal weighing dish on balance
4. Measure 125 mL of tap water using a graduated cylinder. Mix measured amount of silver with tap water. Stock solution can be seen in Figure 3-28, along with metal weighing dish and spatula
5. When finished using stock solution seal in an opaque, airtight bottle in a dark cabinet

This amount of stock solution is enough to paint 42 CPFs, which is approximately the number of accepted CPFs PHW currently expects to produce each week at the factory. Should this number change, Equation 3-18 shows the necessary adjustments in amount of silver powder to be used to make the stock solution. Equation 3-19 is a more general form of equation 3-18, should the silver application concentration be altered. Equation 3-20 provides the amount of water in milliliters that will be needed to create the stock solution for a given number of filters to be painted.

Equation 3-18: $grams\ of\ powder\ silver = 0.1133\ \times\ \#\ of\ filters\ to\ be\ painted$

Equation 3-19: $grams\ of\ powder\ silver = \frac{stock\ solution\ concentration\ in \frac{mg}{L} \times .003 \times \#\ of\ filters\ to\ be\ painted}{1000 \times\ silver\ content\ \%}$

Equation 3-20: $mL\ of\ water = 3\ \times \#\ of\ filters\ to\ be\ painted$

Figure 3-28: Stock solution, spatula, and metal weighing dish used for creating colloidal silver application solution

Figure 3-29: Application solution and paint brush

Application Solution Preparation and Painting Process (0.021%, 212.5 mg/L of silver/L of water)

1. Using a syringe, extract 3 mL from the stock solution and mix thoroughly into 400 mL of water. This is the application solution to be used for one CPF.
2. If more than one CPF is to be painted, dilution of the stock solution can be scaled up. During this study 9mL of stock solution was placed in 1200 mL of tap water in a plastic water bottle (Figure 3-29) which is enough to paint three CPFs.
3. A silver painting setup was established before painting begins. It is advisable for the setting to be in a clean location microbiologically speaking. It is also important that the setting does not allow colloidal silver into the surrounding environment. The silver painting setting at PHW is located temporarily on its front porch as seen in Figure 3-30. It is being relocated to inside the PHW house/office. Black plastic lining was used to prevent the transport of silver (Figure 3-30 and 3-31).
4. Using a paintbrush, as seen in Figure 3-29, apply the application solution to the CPF.
    a. Starting on the inside surface of the filter, the brush stroke should move from the lip of the CPF to the center, and back to the lip. Dip the brush in the solution after every "down and back" stroke. Repeat this step to paint the entirety of the inside surface of the CPF. The first 100 mL is to be used in this manner.
    b. Flip the CPF over, and repeat process for the outside surface of the CPF. Except this time, the brush stroke should move from the top center of the CPF down to the lip, and back again, as seen in Figure 10. Dip the brush in the solution after every "down and back" stroke. Repeat this step to paint the entirety of the outside surface of the CPF. The second 100 mL is to be used in this manner.
    c. Flip the CPF over again to paint the inside surface once again. Use the third 100 mL to perform this step.
    d. Use 50 mL to paint the lip of the CPF.
    e. Use the final 50 mL to paint the outside surface of the CPF again.
5. The CPF must dry for at least 24 hours before packing and shipping, as seen in Figure 3-32.

Figure 3-30: The silver application location and setup

Figure 3-31: Karim painting a CPF with colloidal silver

When 400 mL of application solution at 0.021% is applied to each filter, there will be 85 mg of colloidal silver in each CPF. This is more than is suggested in the Best Practices Manual (Rayner, 2009) because the hemispheric CPF has a larger surface area than most ceramic filters manufactured elsewhere.

Figure 3-32: Newly painted CPFs drying

3.15 Filter Manufacturing Method

The PHW method for manufacturing CPFs is illustrated in pictures and briefly described below. A detailed description has previously been given by Miller and Watters (2010). This method follows the guidelines first established and published by Potters for Peace, (http://s189535770.onlinehome.us/pottersforpeace/?page_id=125), but with modifications based on guidance and innovations provided by Manny Hernandez and Curt and Cathy Bradner (ThristAid).

Initially, the raw materials are collected and brought to the PHW factory. The clay is mined from the neighboring village of Gbalahi and the rice husk is retrieved from a rice mill down the road. PHW uses two types of clay, Gbalahi and Wayamba. They are both named after the local villages from which the clay is obtained.

Figure 3-33: Piles of Clay at the PHW Factory

Figure 3-34: Rice husk used by PHW

Next, the clay is ground into finer particles with a mortar and pestle using local methods. Women from the nearby village of Taha can be seen performing this process in Figure 3-35.

After this, the correct amount of clay, rice husk, and water is weighed according to the intended composition.

Figure 3-35: Taha women grounding clay

Figure 3-36: Abraham weighing water

After weighing, the clay and rice husk is mixed for five minutes to ensure it is completely mixed. Water is then added and mixed in as well. Clumps of the “mixture” are formed that will comprise each CPF.

Figure 3-37: John and Alhassan mixing clay and rice husk

Figure 3-38: Clumps of clay, rice husk, and water ready to be pressed

The hydraulic press, powered by a diesel generator, is prepared by placing a wet plastic bag over the male mold and then a wooden annulus is placed over that, as seen in Figure 3-39. The clump of clay/rice husk mixture is placed on the prepared press.

Figure 3-39: The hemispheric hydraulic press with plastic bag and wooden annulus

Figure 3-40: Abraham placing the clump of clay, rice husk "mixture" on the male mold

Another wet plastic bag is placed on the clump clay, rice husk mixture to prevent sticking to the female mold and the filter is pressed hydraulically. The excess clay is removed with a wet wooden knife and used for the next CPF.

Figure 3-41: Abraham pressing a CPF

Figure 3-42: John and Alhassan removing the excess clay from the CPF

The pressed CPF is lifted and carried by its wooden annulus to a rack to dry. The plastic bags are removed and are then cleaned with water and the pressing process is repeated until all of the clay, rice husk mixture has been used. Figure 3-43 shows, in order, a newly pressed filter, a dry but unfired filter, and a newly fired filter.

Figure 3-43: the CPF at three stages of production

The CPF must dry for at least four days or else it will warp and crack when fired in the kiln. The four day drying timing is appropriate for the nine month dry season from September to May in Ghana. The drying time will be considerably increased during the wet season (but we don't yet have that experience). After drying, 32 CPFs are stacked in the kiln, as seen in (Figure 3-44) and a three cone set of pyrometric cones (012, 011, and 010) are placed in two specific locations in the kiln. Pyrometric cones measure a value called heat-work which is comprised of both how high the temperature in the kiln is and the amount of time at those elevated temperatures. The opening in the kiln (Figure 3-44) is closed up with brick and clay and the following day the CPFs are fired for approximately 10 hours with a maximum temperature around 850 degrees centigrade. The day after firing, once CPFs have cooled, they are removed and ash is brushed off of their surfaces. At this point CPFs are handed over for a variety of quality control tests to ensure their efficacy.

Figure 3-44: CPFs stacked eight high in the kiln

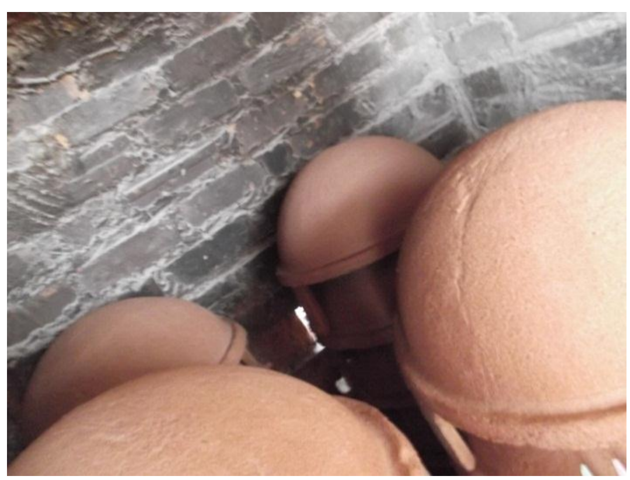

Figure 3-45: Four stacks of CPFs fit in the kiln

Figure 3-46: The kiln in action

3.16 Statistical Methods

Minitab 15 was used to perform all statistical analysis in this research. All graphs titled *fitted line plot* and all outlined statistical tables originate from analysis performed in Minitab 15. Four different types of statistical tests were performed. These include simple regression, multiple regression (both linear and non-linear), ordinal logistic regression, and upper-tailed 2-sample Student's t-tests. Interpretation of the tests is provided in Chapters 5-7. All tests were performed at a 95% confidence interval.

4.0 Choosing the Best Filter Composition

The first goal of this research was to find the optimum filter composition specific to the factory in Tamale, Ghana. The CPF has three technical performance measures by which it must function properly: 1) filtering effectiveness in removing the selected bacterial indicator, total coliform, 2) strength, and 3) flow rate. Therefore, these three performance measures serve as the evaluation criteria for determining which filter composition is indeed optimal. Removing pathogenic microorganisms is important as they often cause life threatening diarrheal diseases (Gerba, 2005). Strength is an important parameter because the CPFs are vulnerable to breakage in the household and in transit. Periodically filters must be removed from their plastic container to be scrubbed. Scrubbing removes particles from the CPF pores which increases the flow rate. Even when trained, users don't always understand how to properly handle the CPF. So making the CPF as strong as possible will decrease the chance of it being broken by the average user, as will proper education and training. The flow rate is the final important evaluation criterion because the CPF must supply a sufficient quantity of water to the family who uses it. In Ghana, the average family size is 12.5 (Green, 2008). It has been found that a person needs 7.5 L of water each day (Howard & Bartram, 2003). Therefore, an average family in Ghana ideally needs 94 L of safe water each day. If the CPF is filtering 16 hours a day, then its flow rate must be 5.9 L/hr. This fact has motivated this research to improve the flow rate of the CPF design so that it can safely provide a larger volume of water on a daily basis.

4.1 Prior Composition Research

Choosing the best CPF composition specific to the PHW factory was accomplished by building on the work of several different researchers and consultants. For the PHW factory, research starts with the work of Reed Miller, and is documented in his Master of Engineering thesis (2010). The next steps were made by the consultants Curt and Cathy Bradner, whose work is documented in the Master of Engineering thesis of Shanti Kleiman (2011). After this, Jim Niquette, PHW Board Member, continued to search for the best composition. Filters from the Bradners and Jim Niquette were used in this research, in addition to newly created compositions. By building off the work of this past research, the author was able to improve on the CPF composition for PHW.

4.2 Performance Criteria 1: Bacteria Removal Filtering Effectiveness

Nine different production variables were tested to see if they played a role in determining how well a CPF removed total coliform bacteria. The nine production variables include the following:

- Percent of rice husk used in the composition mix,
- Percent of Gbalahi clay used in the composition mix,
- Percent of Wayamba clay used in the composition mix,
- Percent of grog used in the composition mix,

- Percent of Gbalahi clay used out of the total clay in the composition mix (this is the percentage of Gbalahi clay used when the total clay used includes both Gbalahi and Wayamba clay. It differs from the second variable because rice husk is excluded when calculating the percentage),
- Duration CPFs were fired in the kiln,
- Maximum temperature the kiln reached,
- Duration of the soak time (which represents the amount of time the kiln's temperature was above 700 degrees Celsius), and
- Dry mass of the CPF after it has been fired.

The results (Figures 4-1 to 4-9) showed that, in a simple regression test, none of these production variables predict how well a CPF removed total coliform bacteria, total coliform removal being the response variable. In all cases the percentage of response variable variation, R-squared, was very low indicating that the model did not fit the data.

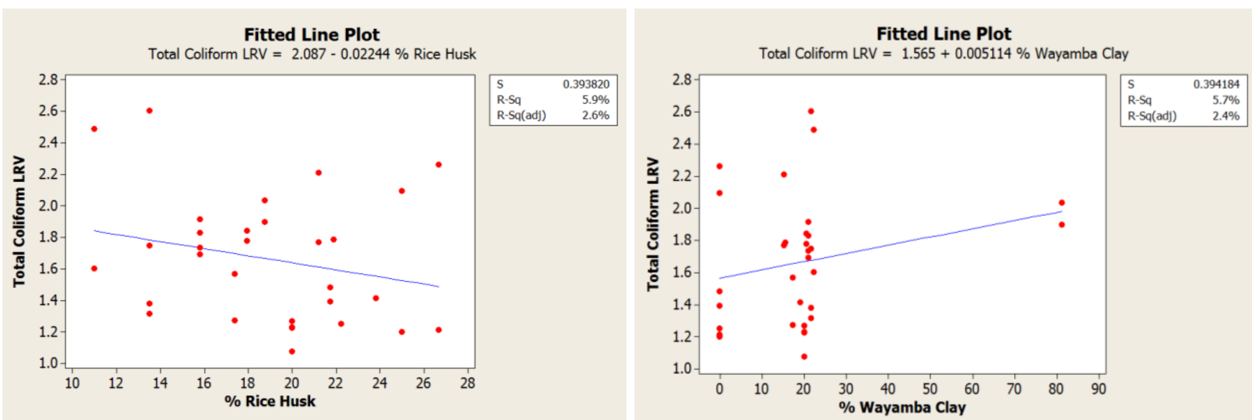

Figure 4-1 & 4-2: Total Coliform LRV vs. Percent Rice Husk and Total Coliform LRV vs. Percent Wayamba Clay

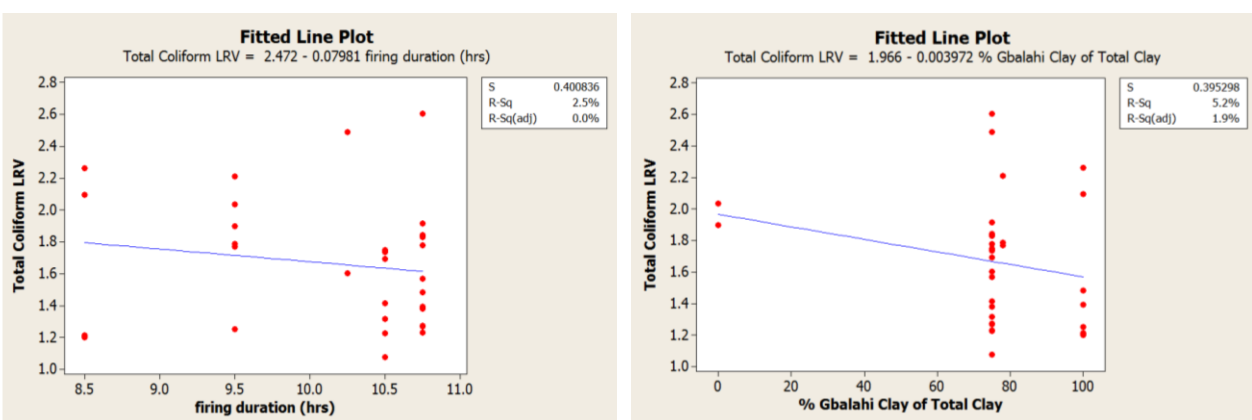

Figure 4-3 & 4-4: Total Coliform LRV vs. Firing Duration and Total Coliform LRV vs. Percent Gbalahi Clay of Total Clay

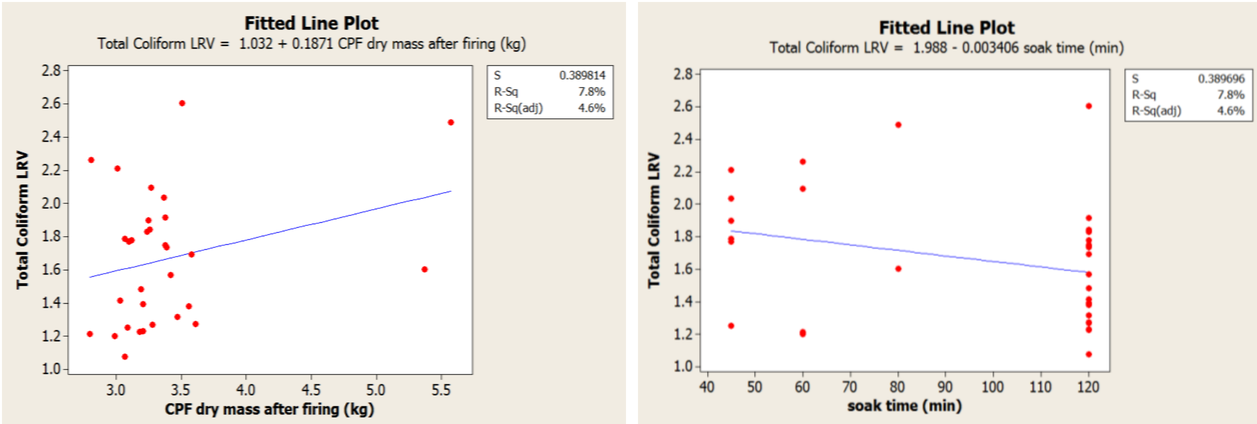

Figure 4-5 & 4-6: Total Coliform LRV vs. CPF Dry Mass After Firing and Total Coliform LRV vs. Soak Time

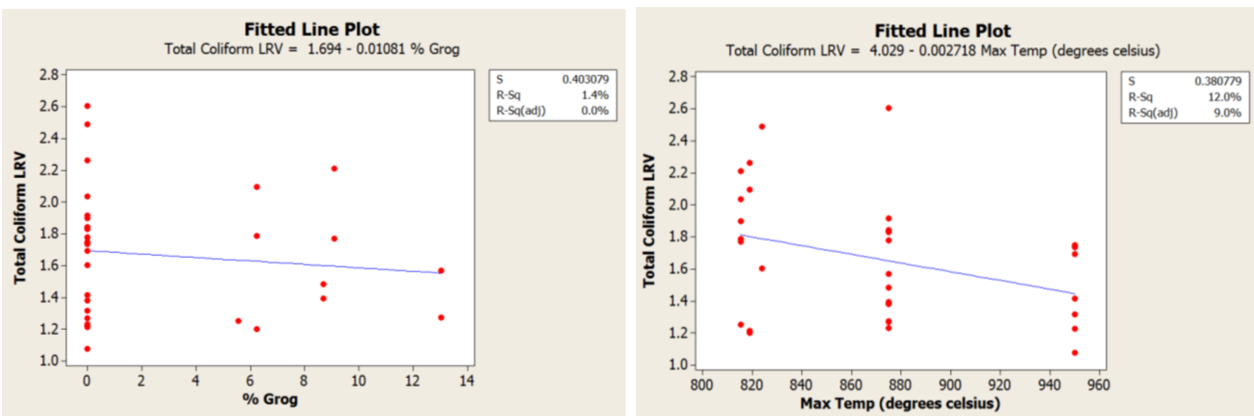

Figure 4-7 & 4-8: Total Coliform LRV vs. Percent Grog and Total Coliform LRV vs. Max Temp

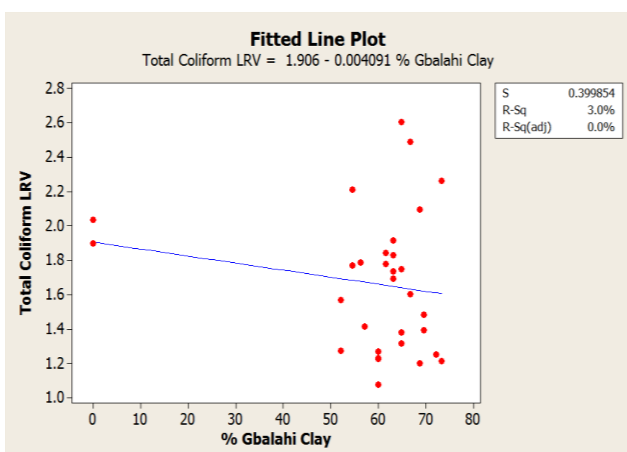

Figure 4-9: Total Coliform LRV vs. Percent Gbalahi Clay

Next, a multiple regression analysis was performed, to account for any chance that total coliform bacteria removal is predicted by a combination of these nine production variables. Table 4-1 shows that the multiple regression model also does not fit the data. The p-value in the Analysis of Variance (ANOVA) Table (0.300) shows that the model estimated by the regression procedure is not statistically significant at an α-level of 0.05. The p-values for the estimated coefficients are greater than 0.05, indicating that they are not related to total coliform removal at an α-level of 0.05.

Table 4-1: Multiple Regression- Total Coliform LRV vs. Nine Production Variables

Predictor	Coef	SE Coef	T	P
Constant	9.957	9.208	1.08	0.291
% Rice Husk	-0.04529	0.04445	-1.02	0.319
% Gbalahi Clay	0.01833	0.03027	0.61	0.551
% Wayamba Clay	-0.02421	0.08822	-0.27	0.786
% Gbalahi Clay of Total Clay	-0.03472	0.08708	-0.40	0.694
firing duration (hrs)	-0.1999	0.2706	-0.74	0.468
soak time (min)	0.001813	0.007109	0.26	0.801
Max Temp (degrees celsius)	-0.003765	0.002663	-1.41	0.171
CPF dry mass after firing (kg)	-0.0841	0.2043	-0.41	0.685

S = 0.384600   R-Sq = 31.9%   R-Sq(adj) = 7.1%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	8	1.5238	0.1905	1.29	0.300
Residual Error	22	3.2542	0.1479		
Total	30	4.7779			

While regression showed no relation between total coliform bacteria removal and percent rice husk, two different 2-sample Student's t-tests were performed to see if rice husk percentages lower than a given value did produce higher total coliform bacteria removal. In the first 2-sample t-test the percentage of rice husk chosen as the dividing line was 20%. The null hypothesis assumes the difference between the two populations is 0. Table 4-2 below shows that the p-value (0.03) is less than an α -level of 0.05 which means the null hypothesis is rejected. The upper-tailed alternate hypothesis can then be accepted, which says that the total coliform removal for CPFs made with less than 20% rice husk is higher than that for CPFs made with 20% rice husk or more than 20% rice husk.

Table 4-2: 2-Sample Student's t-test: Total Coliform LRV for given Rice Husk Percentages

Two-sample T for % rice husk < 20% vs % rice husk > or = to 20%

	N	Mean	StDev	SE Mean
% rice husk < 20%	16	1.794	0.365	0.091
% rice husk > or = to 20	15	1.525	0.398	0.10

Difference = mu (% rice husk < 20%) - mu (% rice husk > or = to 20%)
Estimate for difference: 0.269
95% lower bound for difference: 0.035
T-Test of difference = 0 (vs >): T-Value = 1.96 P-Value = 0.030 DF = 28

In the second 2-sample t-test the percentage of rice husk chosen as the dividing line was 17%. The null hypothesis assumes the difference between the two populations is 0. Table 4-3 below shows that the p-value (0.068) is more than an alpha-level of 0.05 which means the null hypothesis is probably true. This means that for CPFs made with less than 17% rice husk the total coliform removal is probably equal to CPFs made with 17% rice husk or more than 17% rice husk.

Table 4-3: 2-Sample Student's t-test: Total Coliform LRV for given Rice Husk Percentages

```
Two-sample T for % rice husk < 17% vs % rice husk > or = to 17%

                           N   Mean  StDev  SE Mean
% rice husk < 17%         10  1.831  0.421     0.13
% rice husk > or = to 17  21  1.585  0.372    0.081


Difference = mu (% rice husk < 17%) - mu (% rice husk > or = to 17%)
Estimate for difference:  0.246
95% lower bound for difference:  -0.027
T-Test of difference = 0 (vs >): T-Value = 1.58  P-Value = 0.068  DF = 15
```

Confusion arises from the results of these two t-tests because it is generally thought that a decrease in the amount of rice husk used would increase the total coliform removal. However, the analysis shows that such a relationship does not exist in this case. A possible explanation for this is uneven mixing of clay and rice husk which creates a greater chance for the clumping of rice husk.

There are at least two other production variables that could affect the bacteria removal; however, they were not tested in this study. The first of these variables is how thoroughly the clay and rice husk were mixed. As discussed in chapter two, it is thought that clay and rice husk that are more thoroughly mixed will better remove bacteria because smaller pores are produced in the filter. Smaller pores are produced in the filter because less clumping of rice husk occurs. The second undocumented production variable is the distribution of the rice husk particle sizes. Future research into these production variables might show that they affect the total coliform removal.

4.3 Performance Criteria 2: Flow Rate

The nine production variables were again analyzed to see which, if any, affect the flow rate of a CPF. It was found that five of the production variables, percent Gbalahi clay, percent Wayamba clay, percent grog, percent Gbalahi clay of total clay (excludes rice husk), and maximum firing temperature, did not predict the flow rate. The percentage of response variable variation, R-squared, was very low for all five variables (Figures 4-10 to 4-14), exhibiting that each model did not fit the data.

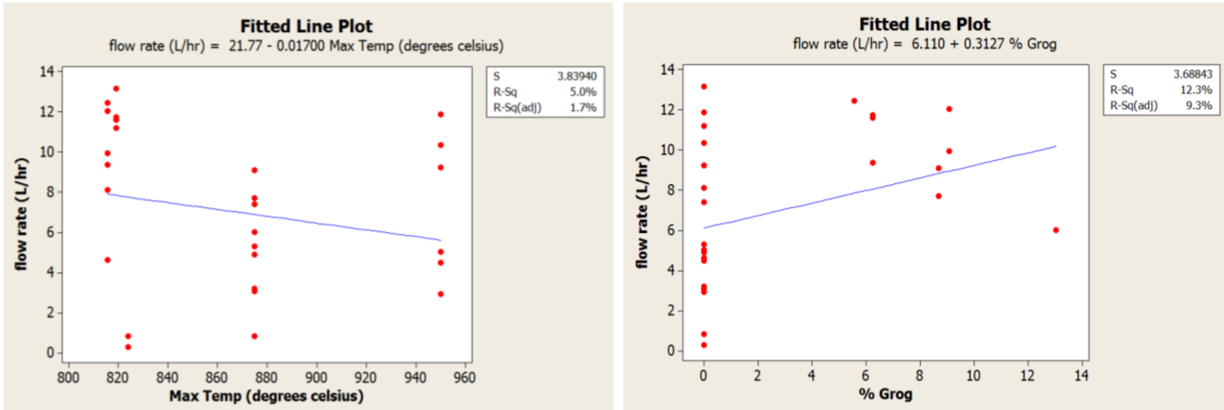

Figure 4-10 & 4-11: Flow Rate vs. Max Temp and Flow Rate vs. Percent Grog

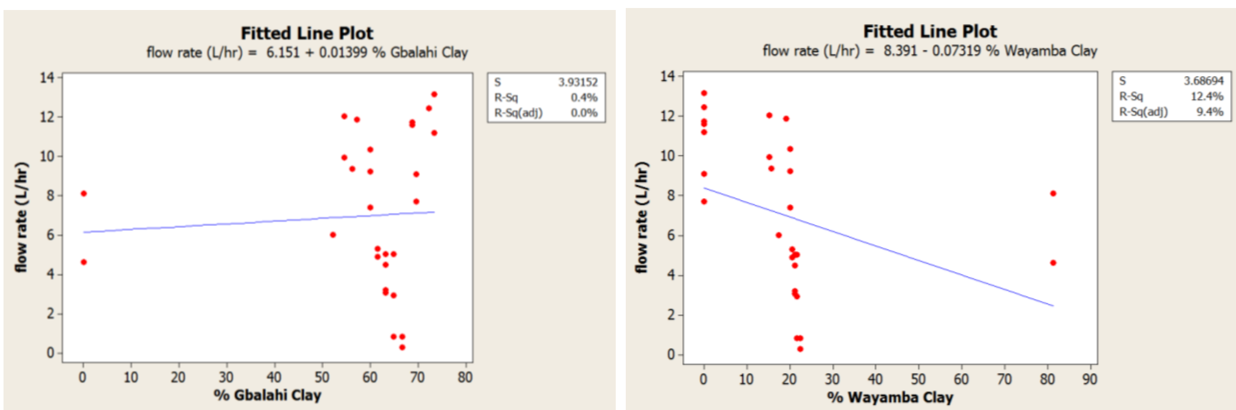

Figure 4-12 & 4-13: Flow Rate vs. Percent Gbalahi Clay and Flow Rate vs. Percent Wayamba Clay

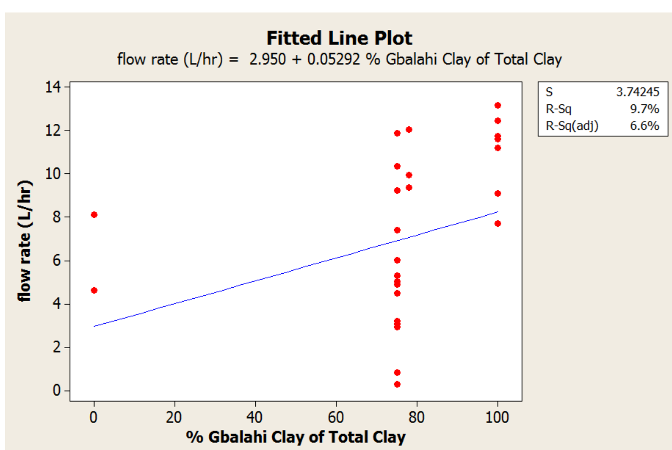

Figure 4-14: Flow Rate vs. Percent Gbalahi Clay of Total Clay

However, it was found that the other four variables played some role in determining the flow rate. In Table 4-4, the p-value in the Analysis of Variance (0.000), at an α-level of .05, indicates that the relationship between flow rate and dry mass after firing is statistically significant. Additionally, the percentage of response variable variation, R-squared value, shows that dry mass after firing explains 59.5% of the variance in flow rate, signifying that the model weakly fits the data (Figure 4-15).

Table 4-4: Simple Regression and Analysis of Variance for Flow Rate vs. Dry Mass After Firing

```
The regression equation is
flow rate (L/hr) = 50.32 - 13.26 CPF dry mass
after firing (kg)


S = 2.28736   R-Sq = 60.9%   R-Sq(adj) = 59.5%


Analysis of Variance

Source       DF       SS       MS      F      P
Regression    1  220.434  220.434  42.13  0.000
Error        27  141.265    5.232
Total        28  361.698
```

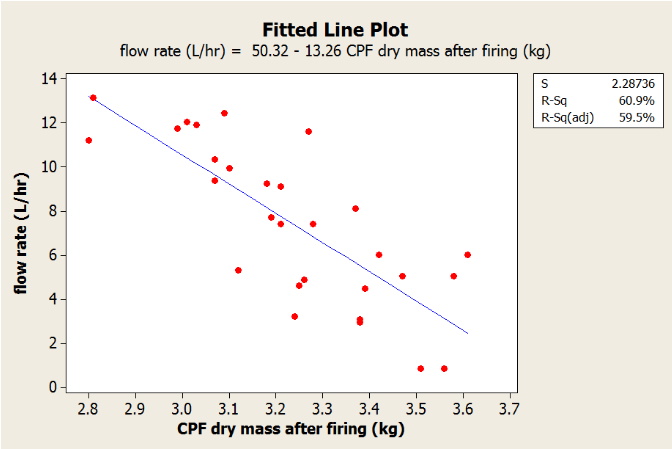

Figure 4-15: Flow Rate vs. CPF Dry Mass After Firing

However, the dry mass after firing is itself dependent on the percent of rice husk used in the composition (Figure 4-16). This is because the higher the percentage of rice husk, the higher the loss of mass will be for the CPF during firing.

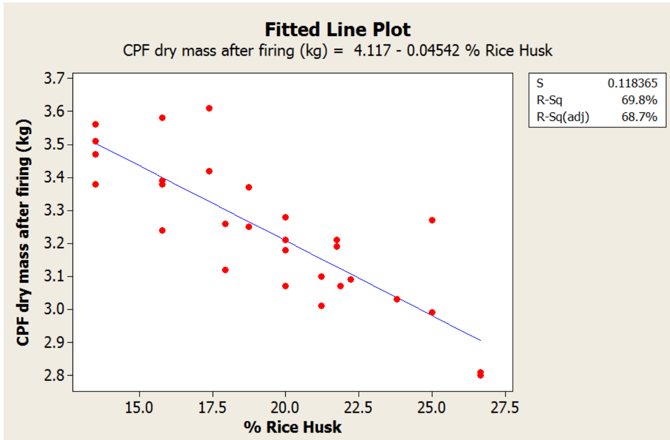

Figure 4-16: CPF Dry Mass After Firing vs. Percent Rice Husk

So the primary production variable that affects flow rate is percent rice husk used. In Table 4-5, the p-value in the Analysis of Variance (0.000), at an alpha-level of .05, indicates that the relationship between flow rate and percent rice husk is statistically significant. Additionally, the R-squared value shows that dry mass after firing explains 86.1% of the variance in flow rate, signifying that the model fits the data (Figure 4-17).

Table 4-5: Simple Regression and ANOVA for Flow Rate vs. Percent Rice Husk

```
The regression equation is
flow rate (L/hr) = - 8.794 + 0.8364 % Rice Husk


S = 1.44416   R-Sq = 86.6%   R-Sq(adj) = 86.1%


Analysis of Variance

Source      DF       SS       MS       F      P
Regression   1  389.420  389.420  186.72  0.000
Error       29   60.482    2.086
Total       30  449.902
```

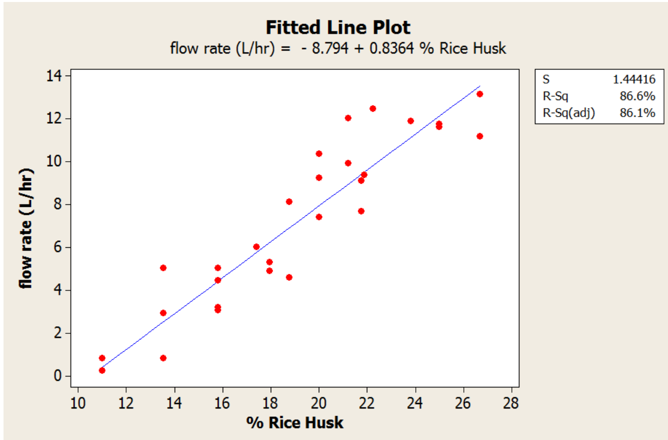

Figure 4-17: Flow Rate vs. Percent Rice Husk

The flow rate-percent rice husk relationship explains the flow rate mechanism. As the percentage of rice husk used increases, the flow rate increases because the porous volume in the CPF is increasing. A larger porous volume allows more water to flow through the CPF in a given time.

The final two production variables have a possibility of affecting flow rate. However, the R-squared values for both of these, firing duration and firing soak time, imply a very weak correlation at best (Figure 4-18 & 4-19). These correlations indicate that a decrease in firing time, whether it is total time or time above 700 degrees centigrade, would produce a faster flow rate. No conclusions can be drawn from this, rather it is recommended that additional research focus specifically on the firing process.

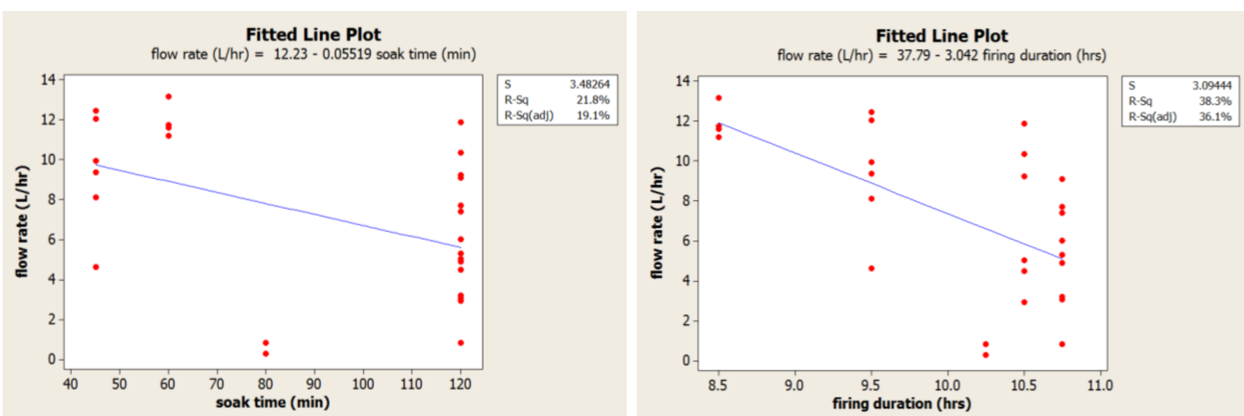

Figure 4-18 & 4-19: Flow Rate vs. Soak Time and Flow Rate vs. Firing Duration

A 2-sample Student's t-test was performed to see the effect of firing temperature on flow rate. The two samples had nearly identical firing durations (10.5 to 10.75 hours), and identical soak times (120 minutes). In addition, the samples were composed of CPFs with nearly identical compositions (Table 4-6). Compositions are notated in kilograms as follows: Gbalahi clay-

Wayamba clay-grog-rice husk. The first sample had compositions of 12-4-0-2.5, 12-4-0-3, 12-4-0-3.5, 12-4-0-4, and 12-4-3-4 (n=15). The second sample had compositions of 12-4-0-2.5, 12-4-0-3, 12-4-0-4, and 12-4-0-5 (n=22). The only difference was the maximum firing temperature. The first sample maximum firing temperature was 875 degrees centigrade. The second sample maximum firing temperature was 950 degrees centigrade.

Table 4-6: Composition Comparison for a 2-sample Student's t-test

Composition	# of CPFs		Composition	# of CPFs
12-4-0-2.5	3		12-4-0-2.5	5
12-4-0-3	4		12-4-0-3	7
12-4-0-3.5	3		12-4-0-4	4
12-4-0-4	3		12-4-0-5	6
12-4-3-4	2			
Total	15		Total	22

Table 4-7: 2-Sample Student's t-test for 950 Degrees Centigrade vs. 875 Degrees Centigrade

```
                          N  Mean  StDev  SE Mean
950 degrees centigrade   22  4.97   2.20     0.47
875 degrees centigrade   15  2.94   1.66     0.43


Difference = mu (950 degrees centigrade) - mu (875 degrees centigrade)
Estimate for difference:  2.033
95% lower bound for difference:  0.957
T-Test of difference = 0 (vs >): T-Value = 3.20  P-Value = 0.002  DF = 34
```

The null hypothesis assumes the difference between the two population means is 0. That is, the null hypothesis says the difference in flow rate between the 950 degree centigrade sample and the 875 degree centigrade sample is 0. Table 4-7 above shows that the p-value (0.002) is less than an alpha-level of 0.01 which means the null hypothesis is rejected. The upper-tailed alternate hypothesis can then be accepted, which says the flow rate for CPFs fired at 950 degrees centigrade is greater than the flow rate for CPFs fired at 875 degrees centigrade. Therefore, we can say that for this set of compositions, the higher firing temperature of 950 degrees centigrade gives a higher flow rate.

4.4 Performance Criteria 3: Strength

Eight of the nine production variables were analyzed for a third time to see which ones affect the strength of a CPF. As explained in Section 4.3, the variable dry mass after firing is dependent on percent rice husk. As described in Section 3.12 of the methods, the strength of each CPF was categorized qualitatively. Therefore, in the analysis of the strength, ordinal logistic regression was used. Ordinal logistic regression is based on having predictor variables with three or more values with a natural ordering. In this case those predictor variables are very weak, weak, fair, moderate, strong, and very strong. They suggest a natural ordering of increasing strength. Two ordinal logistic regression tests were performed to split up the two primary aspects of production variables, physical components and firing technique.

Table 4-8 shows that the predictors percent grog, percent Gbalahi clay, and percent Gbalahi clay of total clay (percent Wayamba clay is implicit due to percentages adding up to 100%) have p-values higher than an α-level of 0.05. There is insufficient evidence to conclude that the predictors mentioned immediately above have an effect on strength. However, the p-value for percent rice husk (0.007) is less than an alpha-level of 0.05 which means there is sufficient evidence to conclude that percent rice husk affects strength. The positive coefficient, and an odds ratio that is greater than one indicates that a higher percentage of rice husk used in a composition tends to be associated with lower CPF strength. The p-value for the Pearson test (0.993) and the p-value for the deviance test (1.00) signify that there is insufficient evidence to claim that the model does not fit the data adequately.

In the second ordinal logistic regression analysis, Table 4-9 shows the three firing production variables, duration, maximum temperature, or soak time, have p-values higher than an α-level of 0.05. There is insufficient evidence to conclude that the predictors mentioned immediately above have an effect upon strength. The p-value for the Pearson test (1.00) and the p-value for the deviance test (1.00) signify that there is insufficient evidence to claim that the model does not fit the data adequately.

Table 4-8: Ordinal Logistic Regression: Strength vs. Four Materials Production Variables

Response Information

Variable	Value	Count
strength	1	4
	3	6
	4	5
	5	6
	6	10
	Total	31

Logistic Regression Table

Predictor	Coef	SE Coef	Z	P	Odds Ratio	95% CI Lower
Const(1)	-66.1312	24.4363	-2.71	0.007		
Const(2)	-61.1258	23.4174	-2.61	0.009		
Const(3)	-50.8755	20.8324	-2.44	0.015		
Const(4)	-34.5455	16.7947	-2.06	0.040		
% Grog	0.745646	0.676501	1.10	0.270	2.11	0.56
% Rice Husk	3.37285	1.25134	2.70	0.007	29.16	2.51
% Gbalahi Clay	-0.847263	0.844251	-1.00	0.316	0.43	0.08
% Gbalahi Clay of Total Clay	0.401637	0.635162	0.63	0.527	1.49	0.43

Predictor	Upper
Const(1)	
Const(2)	
Const(3)	
Const(4)	
% Grog	7.94
% Rice Husk	338.82
% Gbalahi Clay	2.24
% Gbalahi Clay of Total Clay	5.19

Log-Likelihood = -7.177

Test that all slopes are zero: G = 82.314, DF = 4, P-Value = 0.000

Goodness-of-Fit Tests

Method	Chi-Square	DF	P
Pearson	27.3951	48	0.993
Deviance	14.3545	48	1.000

Measures of Association:

(Between the Response Variable and Predicted Probabilities)

Pairs	Number	Percent	Summary Measures	
Concordant	371	99.2	Somers' D	0.98
Discordant	3	0.8	Goodman-Kruskal Gamma	0.98
Ties	0	0.0	Kendall's Tau-a	0.79
Total	374	100.0		

Table 4-9: Ordinal Logistic Regression: Strength vs. Three Firing Production Variables

```
Response Information

Variable  Value  Count
strength  1          4
          3          6
          4          5
          5          6
          6         10
          Total     31

Logistic Regression Table
                                                                              95%
                                                                               CI
Predictor                        Coef  SE Coef      Z      P   Odds Ratio  Lower
Const(1)                      9805.51   305886   0.03  0.974
Const(2)                      11086.0   321225   0.03  0.972
Const(3)                      11113.3   194949   0.06  0.955
Const(4)                      11114.7   194949   0.06  0.955
firing duration (hrs)        -959.051  25009.5  -0.04  0.969         0.00   0.00
soak time (min)               16.7071  2424.47   0.01  0.995  18021499.80   0.00
Max Temp (degrees celsius)  -3.21037  83.3650  -0.04  0.969         0.04   0.00

Predictor                          Upper
Const(1)
Const(2)
Const(3)
Const(4)
firing duration (hrs)                  *
soak time (min)                        *
Max Temp (degrees celsius)  3.69357E+69

Log-Likelihood = -19.879
Test that all slopes are zero: G = 56.912, DF = 3, P-Value = 0.000

Goodness-of-Fit Tests

Method    Chi-Square  DF      P
Pearson    0.0105110  13  1.000
Deviance   0.0105241  13  1.000

Measures of Association:
(Between the Response Variable and Predicted Probabilities)

Pairs        Number  Percent  Summary Measures
Concordant      296     79.1  Somers' D              0.75
Discordant       16      4.3  Goodman-Kruskal Gamma  0.90
Ties             62     16.6  Kendall's Tau-a        0.60
Total           374    100.0
```

4.5 Final Composition Decision

The final composition decision was made by picking from 12 possible compositions presented in Table 4-10. A meeting was conducted with the following people taking part in the decision making process, Susan Murcott (PHW founder), John Adams (PHW factory manager), Abdul-Karim Alale (PHW quality control manager), Kellie Courtney (MIT undergraduate), and the author of this research. Surprisingly, everyone picked one of two compositions without previously discussing which option they would pick. The compositions chosen were the highlighted row and the row immediately above it, which were very similar to each other. Currently, the highlighted composition, 12-4-0-4 fired at a higher temperature, is being produced. John and Karim are Ghanaians from the Northern Region. It was crucial to include them in the testing process, analysis, and decision making for two reasons. First, because they are the people who are actually going to make the filters. Second, participatory learning and research is vital to knowledge transfer and project understanding. It also helps bridge language or other barriers that may exist in cross-cultural projects.

Table 4-10: PHW Final Composition Selection Options

Recipe Components (kg)				Fired at Higher Temp.	Sieved Rice Husk	Flow Rate (L/hr)	Bacteria LRV (without silver)	Bacteria LRV (with silver)	Turbidity Removal %	Bubble Test (% Pass)	Strength
Gbalahi Clay	Wayamba Clay	Grog	Rice Husk								
0	13	0	3	no	no	6.4	2	2.7	76	67 (2/3)	fair
13	0	1	4	no	no	12.5	1.3	3.1	57	100 (1/1)	fair
18	5	2	7	no	no	10.1	1.6	2.7	67	58 (4/7)	fair
18	5	3	7	no	no	11.8	2	3.2	81	40 (2/5)	fair
16	0	2	5	no	no	8.5	1.4	2.8	53	100 (5/5)	moderate
12	4	0	4	no	no	7	1.3	2.7	55	100 (3/3)	strong
12	4	0	3	yes	no	6.7	1.7	-	91	100 (3/3)	very strong
12	4	0	4	yes	no	9.6	1.2	-	92	75 (3/4)	strong
12	4	0	5	yes	no	10.9	1.4	-	61	50 (2/4)	moderate
12	4	0	3	yes	yes	4.3	1.7	-	71	80 (4/5)	very strong
12	4	0	4	yes	yes	9.6	1.1	-	60	50 (2/4)	strong
12	4	0	5	yes	yes	9.5	1.5	-	59	75 (3/4)	moderate

As seen in Section 4.2, optimizing for filter effectiveness in removing bacteria could not be achieved; therefore, using this parameter to choose the best composition was based on a case by case analysis of a CPFs total coliform log removal value (LRV). Table 4-10 above shows that LRVs were fairly consistent, and when the LRVs for CPFs with silver applied are accounted for, the variation decreases. So, in choosing the best composition, it was decided that all LRVs displayed in Table 4-10 would be sufficient. It is expected that the chosen composition 12-4-0-4 will have a LRV (with silver applied) of 2.6.

PHW is seeking to increase the flow rate as much as possible without sacrificing bacterial and turbidity removal performance because the typical unimproved surface water that is filtered in northern Ghana is very turbid (greater than 100 NTU). This means the filter can quickly clog if the flow rate is not high enough. PHW wants to increase the flow rate to better serve their customers who complained that the older versions did not produce enough treated water in a day for their families. Schools also benefit from higher flow rates. As was seen in Section 4.3, to increase the flow rate one must increase the percentage of rice husk used in the composition and increase the maximum firing temperature. However, as the percentage of rice husk increases, the strength of the CPF decreases. To find the best composition one must balance these two technical requirements. Composition 12-4-0-4 was chosen because it is an excellent balance. It was qualitatively deemed “strong” and produced a flow rate of 9.6 L/hr.

There are two additional technical parameters in Table 4-10 that were not mentioned in the three primary performance criteria of flow rate, filter effectiveness in removing total coliform, and strength. These two parameters are percent turbidity removal and percent of CPFs that pass the bubble test. The percent turbidity removal is a secondary indicator for determining water quality. Turbidity is also a measure of how aesthetically pleasing the filtrate will be to the user; therefore, it was included as a factor. Additionally, the percent of CPFs that pass the bubble test indicate the manufacturability of a certain composition. If a given composition always passes the bubble test, then it says that that specific composition can consistently be manufactured without producing cracks or excessively large pores in each individual CPF. This is important because any factory would want a high CPF acceptance rate. For these two parameters, composition 12-4-0-4 was chosen for having the highest turbidity removal of all compositions shown on Table 4-10 and for having an adequate manufacturability percentage based on the bubble test, 75%, for a sample size of four. Although this sample size is not statistically significant, this is the best result due to study limitations.

The chosen composition is by no means permanent. Rather, it is our best guess based on what we have learned to date. It is hoped that with additional testing and research, the current composition continues to be improved. The next recommended step is to study more closely how sifting and more thoroughly mixing the rice husk varies LRV, flow rate, and strength.

5.0 Identifying a Quality Control Measure for Ceramic Pot Filter Efficacy

This chapter addresses the second goal of this research; to identify one or multiple simple and low-cost quality control (QC) measures for determining ceramic pot filter effectiveness in removing harmful pathogens, as indicated by total coliform removal. Nine different tests were performed to examine if the characteristic each test was measuring would accurately indicate total coliform removal. If such a quality control measure or set of quality control measures is found, it will save both money and time in the quality control process because microbiological testing is both expensive and time consuming.

5.1 Tests that Fail as a Quality Control Measure

First, six QC tests that failed are shown below. Those tests that failed to indicate a relationship were dry mass of the CPF, percent absorption, percent turbidity reduction by either the turbidimeter or turbidity tube methods of measurement, porosity, and flow rate. In each case the percentage of response variable variation, R-squared, was very low for the fitted line plot (simple linear regression) exhibiting that the model did not fit the data, as shown in Figures 5-1 to 5-6. While these and other figures shown only a test for linear regression, different forms of non-linear regression also did not fir the data. The results of non-linear regression analysis are not shown here.

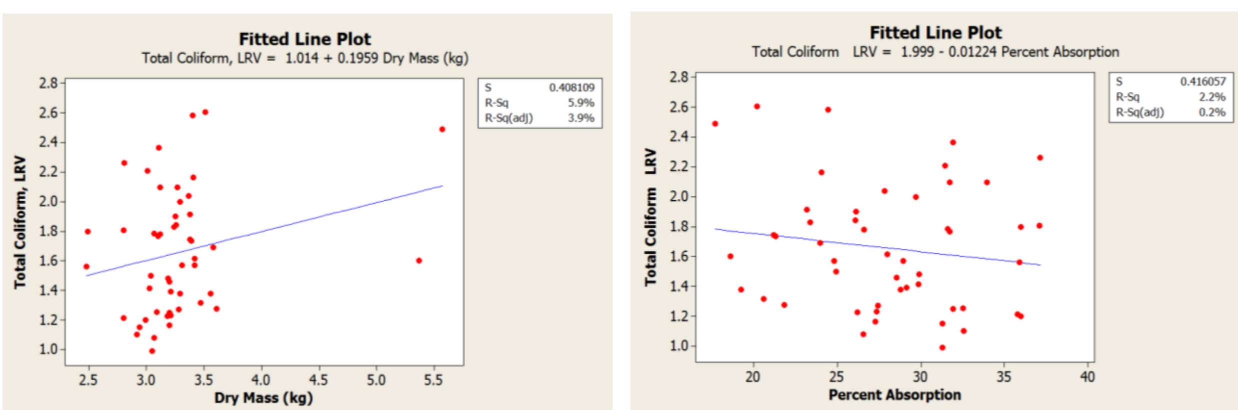

Figure 5-1 & 5-2: Total Coliform LRV vs. Dry Mass and Total Coliform LRV vs. Percent Absorption

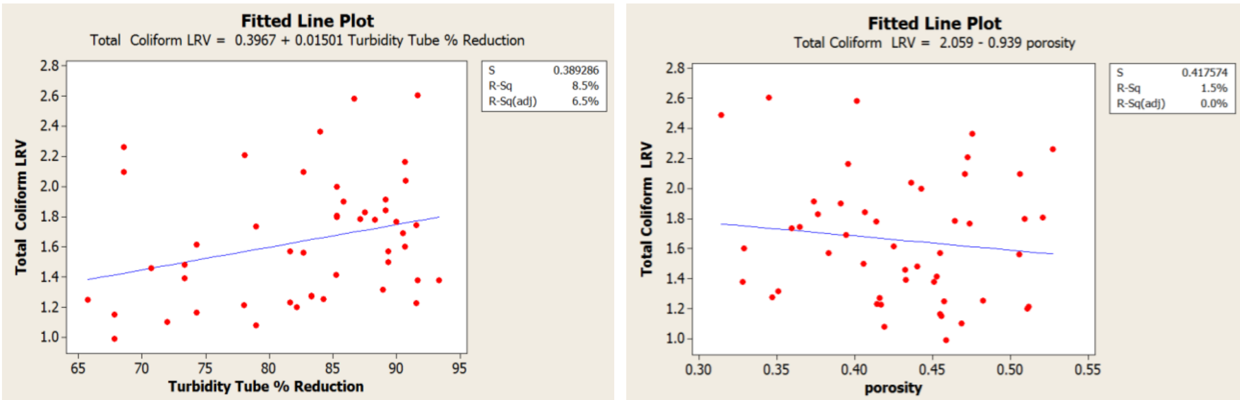

Figure 5-3 & 5-4: Total Coliform LRV vs. Turbidity Tube Percent Reduction and Total Coliform LRV vs. Porosity

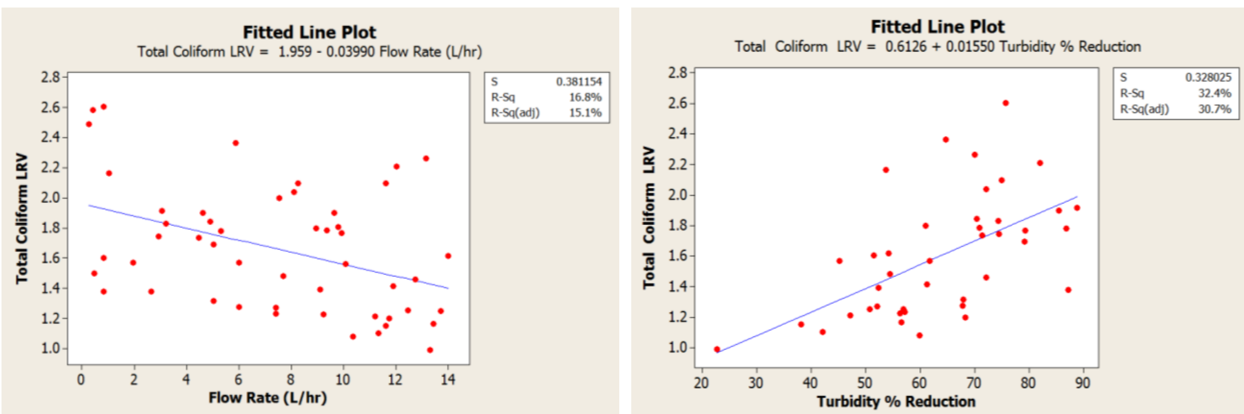

Figure 5-5 & 5-6: Total Coliform LRV vs. Flow Rate and Total Coliform LRV vs. Turbidity Percent Reduction

5.2 Bubble Test Confirmed as a Quality Control Measure for Total Coliform Removal

The first test that was a successful QC test for total coliform removal was the Bubble Test. A 2-sample Student's t-test was performed to see if CPFs that passed the Bubble Test had a higher total coliform bacteria removal than did CPFs that failed the Bubble Test. The null hypothesis states that the difference in total coliform removal between the two populations (CPFs that pass the Bubble Test and CPFs that fail the Bubble Test) is zero. Table 5-1 below shows that the p-value (0.003) is less than an alpha-level of 0.01 which means the null hypothesis is rejected. There is a low probability that the populations are equal. The upper-tailed alternate hypothesis can then be accepted, which says that the total coliform removal for CPFs that passed the Bubble Test have a higher total coliform bacteria removal than did CPFs that failed the Bubble Test. Therefore, the Bubble Test is recommended for use in the Quality Assurance program.

Table 5-1: 2 Sample Student's t-test: Total Coliform LRV for Passing or Failing the Bubble Test

```
Two-sample T for PASS Bubble Test vs FAIL Bubble Test

                   N   Mean  StDev  SE Mean
PASS Bubble Test  50  1.661  0.414    0.058
FAIL Bubble Test  14  1.307  0.372    0.099

Difference = mu (PASS Bubble Test) - mu (FAIL Bubble Test)
Estimate for difference:  0.354
95% lower bound for difference:  0.156
T-Test of difference = 0 (vs >): T-Value = 3.07  P-Value = 0.003  DF = 22
```

5.3 First Drip Test as a Quality Control Measure for Total Coliform Removal

The second test that was a successful QC test for total coliform removal is the "First Drip Test", as described in Section 3.9. In Figure 5-7 the R-squared value shows that the First Drip Time explains 70.9% of the variance in total coliform removal, signifying that the model fits the data. The total coliform removal and First Drip Time are both represented logarithmically in Figure 5-7 for the purpose of representing it linearly. In Table 5-2, the p-value in the Analysis of Variance (0.000), at an alpha-level of 0.05, indicates that the relationship between total coliform LRV and First Drip Time is statistically significant.

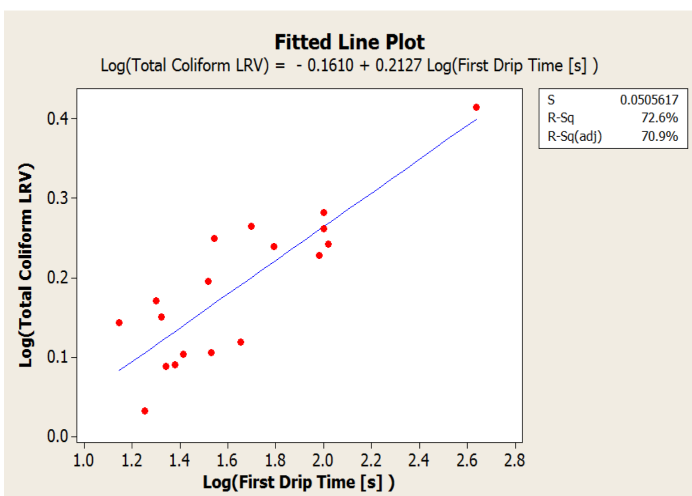

Figure 5-7: Log(Total Coliform LRV) vs. Log(First Drip Time)

Table 5-2: Regression Analysis: Log(Total Coliform LRV) versus Log(First Drip Time [s])

```
The regression equation is
Log(Total Coliform LRV) = - 0.1610 + 0.2127 Log(First Drip Time [s] )

S = 0.0505617   R-Sq = 72.6%   R-Sq(adj) = 70.9%

Analysis of Variance

Source      DF        SS        MS      F      P
Regression   1  0.108404  0.108404  42.40  0.000
Error       16  0.040904  0.002556
Total       17  0.149308
```

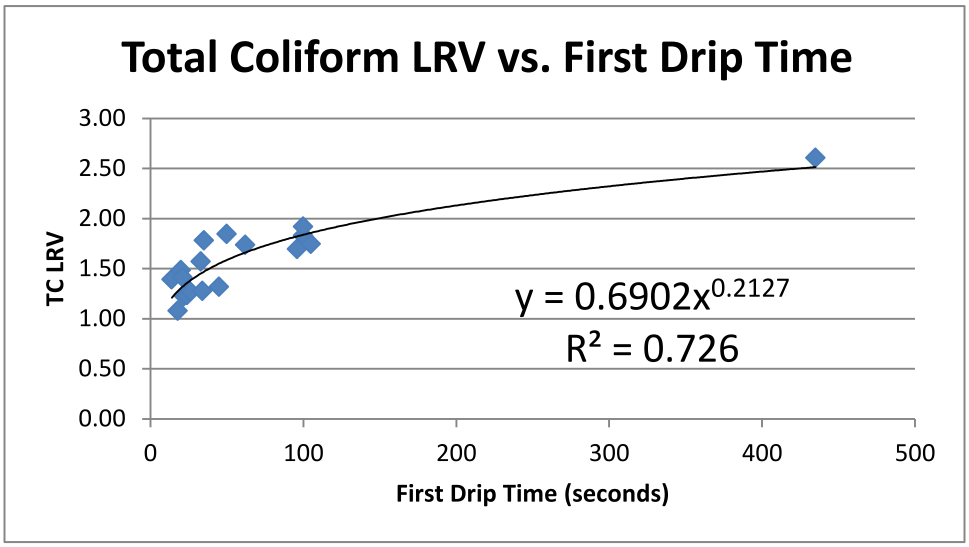

Figure 5-8: Total Coliform LRV vs. First Drip Time

Figure 5-8 shows that the actual relationship between total coliform removal and First Drip Time follows a power curve according to the following equation:

Equation 5-1: $$TC\ LRV = 0.6902 \times First\ Drip\ Time^{0.2127}$$

This equation allows one to accept the CPFs that reach a minimum desired level of total coliform removal. For example, if one desired to accept CPFs that had a minimum total coliform LRV of 2, then 2 would be plugged into the left hand side of equation 5-1. First Drip Time could then be solved for, giving an answer in seconds. In this example, the minimum First Drip Time would be 149 seconds. This means all filters with a First Drip Time faster than 149 seconds do not pass the test because their total coliform LRV will be lower than 2. Table 5-3 gives some possible desired total coliform LRVs and their corresponding minimum First Drip Times in seconds.

Table 5-3: Total Coliform LRV and Corresponding First Drip Time

Desired Total Coliform LRV	Corresponding First Drip Time (s)
1	6
1.25	16
1.5	38
1.75	79
2	149
2.25	259

At first glance, the farthest point on the right in Figure 5-8 would appear to be an outlier. However, it is not an outlier for two reasons. First, the data point was collected from a filter with 13% rice husk. This was one of the lowest percentages of rice husk tried when testing various compositions. It follows that the lower the percentage of rice husk used the longer the First Drip Time will be. This is because the filter will be less porous (see Section 7.4) which makes it harder for water to pass through the filter. The second reason this data point is not an outlier is because another filter with the identical composition to the one in question did not have a First Drip at all (within the context of the First Drip test). This means there is an imaginary point even farther to the right on the graph, further securing the reliability of the trend.

The correlation between total coliform removal and first drip time also helps to explain the filtering mechanisms of the CPF. The test shows that a slower drip time gives a higher total coliform removal because a slower drip time implies stronger capillary forces withholding the flow of water. Stronger capillary forces imply smaller pore sizes because as the length of the interface (pore size) decreases the capillary force increases (see equation 5-3). The smaller pore sizes more readily screen, adsorb, or contain bacteria in their pores. This means it is important to have small pore sizes in CPFs to remove bacteria.

5.4 First Drip Test as a Quality Control Measure for Flow Rate

The First Drip Time was also found to be an accurate indicator for flow rate. In Figure 5-9 the R-squared value shows that the First Drip Time explains 92.4% of the variance in flow rate, signifying that the model fits the data. The flow rate and First Drip Time are both represented logarithmically in Figure 5-9 for the purpose of representing the correlation linearly. In Table 5-4, the p-value in the Analysis of Variance (0.000), at an α-level of 0.05, indicates that the relationship between flow rate and First Drip Time is statistically significant.

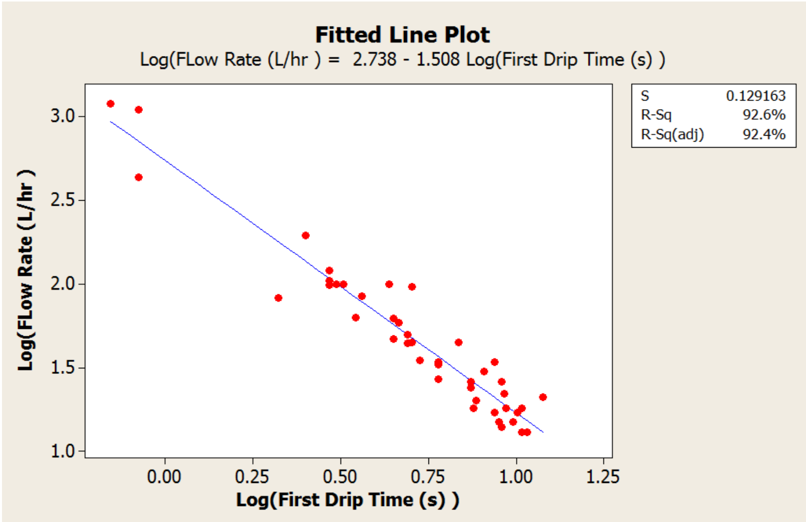

Figure 5-9: Log(Flow Rate) vs. Log(First Drip Time)

Table 5-4: Regression Analysis: Log(Flow Rate (L/hr)) versus Log(First Drip Time (s))

```
The regression equation is
Log(Flow Rate (L/hr ) = 2.738 - 1.508 Log(First Drip Time (s) )

S = 0.129163   R-Sq = 92.6%   R-Sq(adj) = 92.4%

Analysis of Variance
Source      DF       SS       MS       F      P
Regression   1  8.52626  8.52626  511.08  0.000
Error       41  0.68400  0.01668
Total       42  9.21026
```

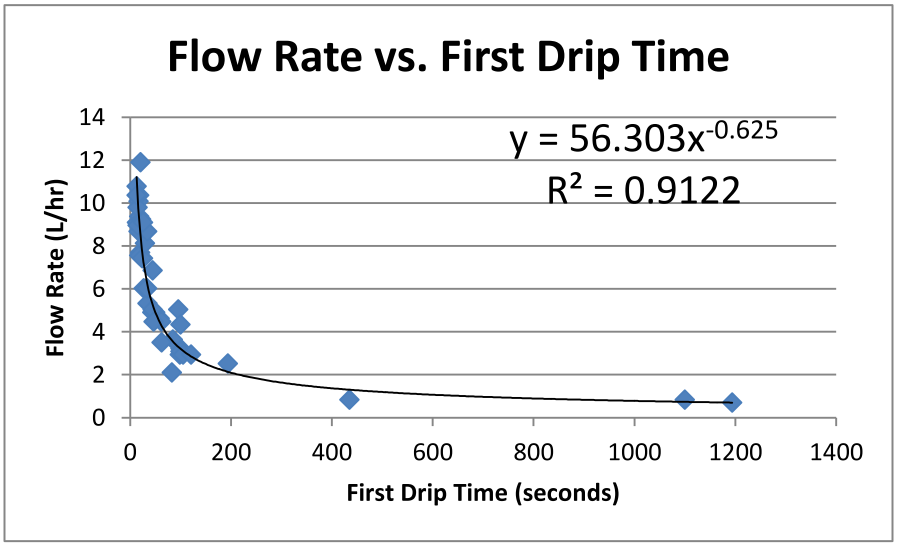

Figure 5-10: Flow Rate vs. First Drip Time

Figure 5-10 shows that the actual relationship between flow rate and First Drip Time follows a power curve according to the following equation:

Equation 5-2: $$Flow\ Rate = 56.303 \times First\ Drip\ Time^{-0.625}$$

Equation 5-2 allows one to accept the CPFs that reach a minimum desired flow rate. For example, if one desired to accept CPFs that had a minimum flow rate of 6 L/hr, then 6 would be plugged into the left hand side of equation 5-2. First Drip Time could then be solved for, giving an answer in seconds. In this example the maximum First Drip Time would be 36 seconds. This means all filters with a first drip time slower than 36 seconds do not pass the test because their flow rate will be less than 6 L/hr. Table 5-5 gives some possible desired flow rates and their corresponding maximum first drip times in seconds.

Table 5-5: Flow Rate and Corresponding First Drip Time

Desired Flow Rate (L/hr)	Corresponding First Drip Time (s)
2	209
3	109
4	69
5	48
6	36
7	28
8	23

The correlation between flow rate and First Drip Time also accurately reflects the Young-Laplace equation for capillary pressure (Equation 5-3). For the CPF, the surface tension and wetting angle are assumed to remain constant. This means the capillary pressure is inversely proportionate to the length of the capillary interface, or pore size. When capillary pressure is graphed versus pore size, such a relationship should produce an asymptotic graph, as it does in Figure 5-10. Flow rate is a reflection of capillary pressure because a higher pressure gradient will create a faster flow rate. It can then be concluded (as it was in the previous section) that First Drip Time varies based on average pore size. Therefore, a smaller pore size implies a slower flow.

Equation 5-3: $$\Delta p = \frac{2\gamma cos\theta}{a}$$ Young-Laplace Equation for Capillary Pressure

Where,

Δp = capillary pressure

γ = surface tension

θ = wetting angle of the liquid on the surface

a = length of the capillary interface

As the First Drip Test can be performed more quickly than the flow rate test, it can help save time in the quality control process, if substituted in its place.

5.5 T-Device Method as a Flow Rate Indicator for the Collection Method

Of the two test methods for determining flow rate the collection method is more accurate as it directly measures the volume of filtrate in a specified time period. The T-device method relies on the assumption that each CPF will be exactly shaped as a hemisphere. As each CPF is never perfectly molded, there can be error in this method. However, the following assessments show that the T-device method is quite accurate. As the T-device test method is performed faster than the collection method, it can substitute for the collection method. The assessments below also show that both the 30 minute test and 15 minute test for the T-device can be used. As a side note, this also means the PHW mold is working very uniformly because the assumption that each CPF is shaped exactly as a hemisphere holds true.

In Figure 5-11 the R-squared value shows that the collection method explains 97.2% of the variance in the T-device method for a 30 minute testing time, signifying that the model fits the data. In Table 5-6, the p-value in the Analysis of Variance (0.000), at an alpha-level of 0.05, indicates that the relationship between the collection method and the T-device method is statistically significant.

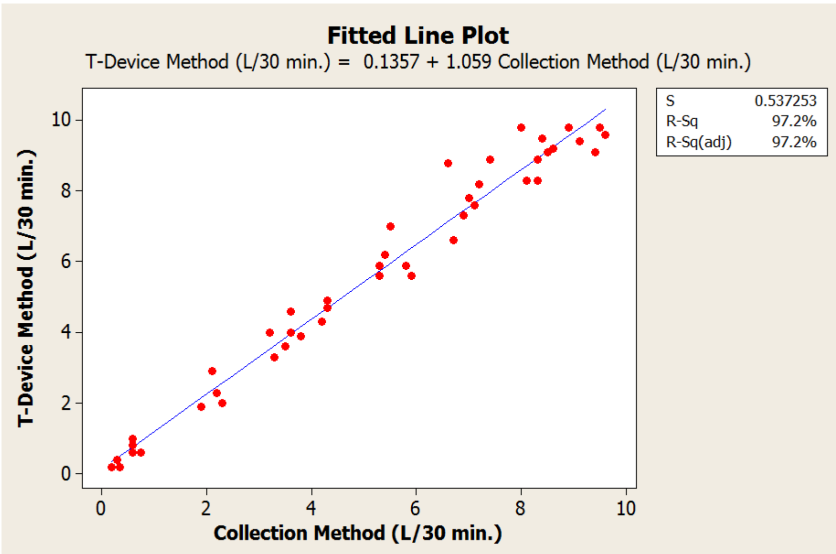

Figure 5-11: T-Device Method vs. Collection Method (30 min)

Table 5-6: Regression Analysis: T-Device Method (L/30 min) vs. Collection Method (L/30 min)

```
The regression equation is
T-Device Method (L/30 min.) = 0.1357 + 1.059 Collection Method (L/30 min.)

S = 0.537253   R-Sq = 97.2%   R-Sq(adj) = 97.2%

Analysis of Variance
Source      DF       SS       MS        F      P
Regression   1  437.885  437.885  1517.06  0.000
Error       43   12.412    0.289
Total       44  450.296
```

In Figure 5-12, the R-squared value shows that the collection method explains 95.7% of the variance in T-device method for a 15 minute testing time, signifying that the model fits the data. In Table 5-7, the p-value in the Analysis of Variance (0.000), at an alpha-level of 0.05, indicates that the relationship between the collection method and the T-device method is statistically significant.

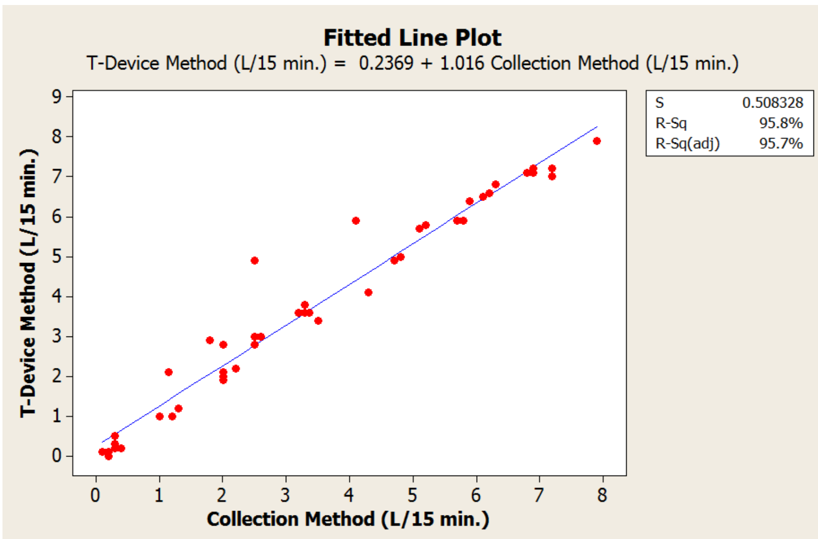

Figure 5-12: T-Device Method vs. Collection Method (15 min)

Table 5-7: Regression Analysis: T-Device Method (L/15 min) vs. Collection Method (L/15 min)

```
The regression equation is
T-Device Method (L/15 min.) = 0.2369 + 1.016 Collection Method (L/15 min.)

S = 0.508328   R-Sq = 95.8%   R-Sq(adj) = 95.7%

Analysis of Variance
Source      DF       SS       MS       F      P
Regression   1  250.828  250.828  970.71  0.000
Error       43   11.111    0.258
Total       44  261.939
```

5.6 Tortuosity Representation as a Quality Control Measure for Total Coliform Removal

A third and final indicator for total coliform removal is a representation of tortuosity. As described in Section 3.10, flow rate, porosity, First Drip Time, and thickness can be used to calculate tortuosity. Multiple regression was performed with three of these factors, thickness was excluded as all CPFs tested were of equal thickness, to find the best correlation to total coliform removal.

In Table 5-8 the R-squared value shows that the regression equation formed explains 85.2% of the variance in total coliform removal, signifying that the model fits the data. Also in Table 5-8, the p-value in the Analysis of Variance (0.000), at an alpha-level of 0.05, indicates that the relationship between the regression equation and the total coliform removal is statistically significant. When examining the regression equation, one can deduce that a faster flow rate signifies a lower tortuosity which produces a lower LRV. A greater porosity signifies a higher tortuosity which produces a higher LRV. A longer First Drip Time signifies a higher tortuosity which produces a higher LRV.

This test would provide a more accurate representation of total coliform removal than would the first drip test by itself. However, the tortuosity representation requires one to perform three tests on every CPF. The choice between accuracy and time spent is a decision that affects the factory's level and degree of quality control.

Table 5-8: Regression Analysis: Total Coliform LRV vs. Flow Rate, Porosity, And First Drip Time

```
The regression equation is
Total Coliform LRV = - 0.058 - 0.110 Flow Rate (L/hr) + 5.53 Porosity
                     + 0.00197 First Drip Time (s)

Predictor                 Coef    SE Coef      T      P
Constant               -0.0583     0.5774  -0.10  0.921
Flow Rate (L/hr)      -0.10989    0.02202  -4.99  0.000
Porosity                 5.527      1.668   3.31  0.005
First Drip Time (s)  0.0019687  0.0004649   4.23  0.001

S = 0.138463   R-Sq = 87.6%   R-Sq(adj) = 85.2%

Analysis of Variance
Source          DF       SS       MS      F      P
Regression       3  2.03739  0.67913  35.42  0.000
Residual Error  15  0.28758  0.01917
Total           18  2.32497


Source               DF   Seq SS
Flow Rate (L/hr)      1  1.48131
Porosity              1  0.21226
First Drip Time (s)   1  0.34382
```

6.0 Devising a Quality Assurance Program for PHW

According to the American Society for Quality (2012), Quality Assurance is defined as "the planned and systematic activities implemented in a quality system so that quality requirements for a product or service will be fulfilled." The American Society for Quality (2012) define Quality Control as "the observation techniques and activities used to fulfill requirements for quality." In this chapter a Quality Assurance Program for the PHW factory in Tamale, Ghana will be proposed based on the experience of Curt and Cathy Bradner (ThristAid), results from extensive filter testing and analysis, observations made in the factory in January 2012, and relationships developed with the Ghanaian factory workers. This analysis will only be for the quality control tests in order to limit scope. In order to complete a comprehensive QA plan, best practices involving clay, combustibles, pressing, firing, storage, packaging and transport will be omitted.

The Quality Assurance/Quality Control program is important because it acts as the bridge which transfers the technical benefits to the people who need that benefit. That is, Ghanaians need filters that effectively remove pathogens, will not break, and provide a sufficient amount of water for their family's daily needs.

6.1 Quality Assurance Process, Schedule, and Responsibilities

The following describes the QA process for the PHW hemisphere filters:

1. Remove filters from kiln, dust off ash, and place on factory drying rack.

2. Break and discard any misshapen filters in the designated filter disposal site.

3. Follow the First Drip Test procedure as found in Section 3.9.

4. Record results in Table 6-1 using each filter's ID.

5. Place filters in soak tank,

6. Follow the Bubble Test procedure as found in Section 3.6. Record results in Table 6-1.

7. All filters that have passed the Bubble Test should be examined according to their First Drip test results. As explained in Section 5.3 and Section 5.4, the First Drip Test will provide upper and lower bounds for accepting filters. If a filter exceeds the upper bound that means its flow rate is too slow. If a filter falls below the lower bound that means its total coliform removal is too low. In either case, the filter should be broken and discarded.

8. All filters that fail the Bubble Test should be broken and discarded in the designated disposal site.

9. Place all filters that have passed both the First Drip test and the Bubble test on racks and move racks to the "clean section" (Section 1) which is the laboratory silver application and inventory section (Figure 6-1). (Note: this section of the factory is currently under construction and is planned to be completed by January 2013).

10. Apply silver to filters according to the methods introduced in Section 3.14.

11. Select two filters from each batch for bacteriological tests (From 2011-present, total coliform/E. *coli* IDEXX QuantiTray has been used as the bacterial indicator for bacteria removal performance. Beginning in June 2012 we will substitute a new lower cost H_2S MPN test).

12. Perform bacterial test and record result in Table 6-1.

13. At the end of each month, fill out Table 6-2.

Table 6-1: Pure Home Water – Quality Control Test Results

Filter ID	First Drip Time (seconds)	Bubble Test (P/LB/F)	Bacterial Indicator Test (LRV)	Filter Fate (to sale/destroyed)
e.g. 4-11-1	34	Pass	2.3	To sale

Table 6-2: Pure Home Water – Monthly Filter Production

# of Filters:	Total	Remarks
Manufactured	e.g. 400	
Rejected Before Firing	e.g. 30	
Rejected During Testing	e.g. 100	
To be Painted with Silver and Sold	e.g. 270	

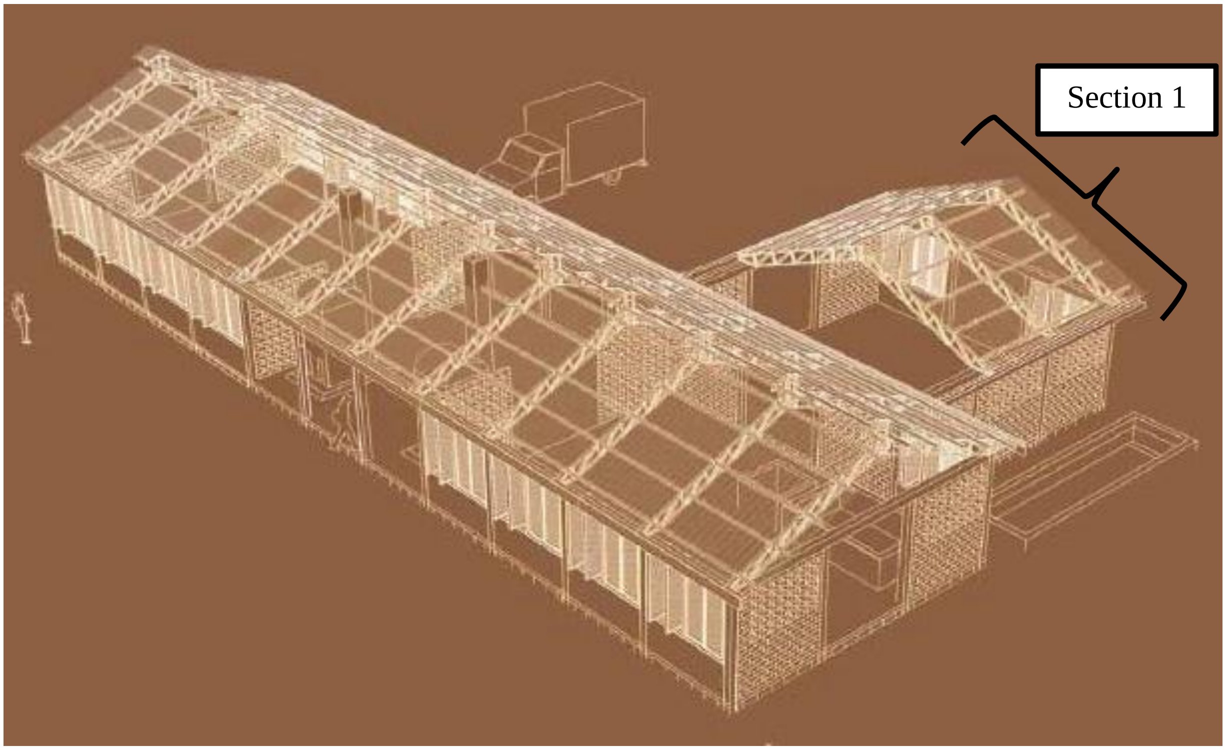

Figure 6-1: Plan Layout of the PHW Factory (credit: Chris de Vries)

The following provides the schedule of the trained QA/QC PHW employee:

Table 6-3: Quality Control Test Schedule

<table>
<tr><th>Time/day</th><th>Monday</th><th>Tuesday</th><th>Wednesday</th><th>Thursday</th><th>Friday</th></tr>
<tr><td>9AM-12PM</td><td>First Drip Test (Batch 1)</td><td>First Drip Test (Batch 2)</td><td>Microbiological Testing</td><td rowspan="2">Office Work</td><td rowspan="2">Apply Silver</td></tr>
<tr><td>1PM-4PM</td><td>Apply Silver</td><td>Bubble Test (Batch 1)</td><td>Bubble Test (Batch 2)</td></tr>
</table>

Each week at the PHW factory two batches of filters are fired in the kiln. While the kiln firing schedule does not match the schedule in Table 6-3, it is not necessary to immediately perform the First Drip Test the day the filters come out of the kiln. This way, the QC schedule can be repeated uniformly each week regardless of when filters come out of the kiln. So the first batch that was fired the previous week can undergo the First Drip Test on Monday morning. As each batch currently contains 32 filters, that allows approximately six minutes to test each filter, which is feasible. The first batch is then Bubble Tested on Tuesday afternoon, which allows 24 hours for the filters to soak and reach saturation. This schedule is used for the second batch except it is shifted one day so that it is performed on Tuesday and Wednesday instead of Monday and Tuesday. Wednesday morning is set aside for microbiological testing of two filters from each batch. Limited bacteriological testing will ensure the First Drip test is correctly identifying filters that should be discarded. On Thursday several tasks need to be performed at the PHW office. This includes data entry for Table 6-1 and Table 6-2, emailing all data to PHW Manager, and accounting tasks. On all of Friday and Monday afternoon, all filters that have passed both the Bubble Test and First Drip test are painted with colloidal silver. If it is assumed that 50% of all filters can be sold, then 32 filters need to be painted each week. This allows approximately 17 minutes to paint each filter, which again is feasible. In reality, the filters painted on Monday will be filters from the previous week that were not painted on the previous Friday.

The responsibilities that are required of the QC employee are based on the process and schedule sections directly above. They must perform steps 1-9 in the process section individually as well as perform bacteriological testing, and the necessary data entry and analysis work.

The following provides some additional comments for the QA program:

- Soak Tank: Large amounts of dust gets into the soak tank. Also, mosquito larvae grow in the soak tank if it is not diligently covered while not in use. So it is essential to cover the soak tank whenever possible.

- Data Recording: QA data recording must be standardized. It is recommended that Table 6-1 be used for the field data sheet. Table 6-2 also must be filled out monthly. A large number of these sheets should be bound together and one sheet should be used for each batch of filters from the kiln. Completely filling out and detailing any problems on each sheet must be stressed during training.

- Communication among Staff: The results of the quality control tests must be relayed by the QA/QC staff back to the filter production staff. Creating this line of communication will do two things:
    1. Instill a sense of pride in their work among the filter production staff.
    2. Help the filter production staff see problems with how the filters are turning out (if problems like uneven pressing, firing, or mixing occur) and enable them to look for a solution.

6.2 Quality Assurance Training Method

There are two overarching themes that guide the training for the QA program. Both of them arise from the experience of consultants Curt and Cathy Bradner, whose work for PHW is documented in the Master of Engineering thesis of Shanti Kleiman (2011).

Staff Participation and Leadership Training:

1. "Engage the staff from the very beginning, working together in the process of trial and error as part of training. In this way, leadership is being transferred from the start" Kleiman (p. 62, 2011)

2. "Bradner finds that when manufacturers and their employees understand that they are making a public health product, adding another level of responsibility to their consumers, greater attention to quality is cultivated." Kleiman (p. 64, 2011)

Based on the first overarching theme, it is very important that the staff is taught through a hands on approach. Additionally, based on observational experience, the staff will learn best by repetition of tasks. To this end, we recommend letting the staff attempt all the tasks while overseeing their work. If they are incorrectly doing something or forget a step, it is important to correct it. Cultivating this attention to detail can be accomplished through the second overarching theme and through giving simple visual explanations as to why a certain step or task is important.

Once a staff member has fully learned their duties and has a general understanding of the reason for each task and step, they can be trusted to perform their job with excellence. They will gain a greater understanding of why what they do is important and will begin to understand how their job relates to the jobs of other staff members.

6.3 Generalization of the Quality Assurance Program for Application to Other Factories

We welcome other ceramic pot filter factories around the world in borrowing and applying relevant parts of this program that they feel would benefit their own factory production. Additionally, if other factories are being started, this experience and documentation may be able to help jumpstart their own Quality Assurance/Quality Control Program. At the same time, we recognize that the results found in this research and the methods developed by PHW may not necessarily be transferrable to other factory locations (Bradners, 2011). It is up to the factory managers to adjust the procedures and methods to best fit their own setting.

The most useful part of this program that other factories may want to adopt is the dual use of the Bubble Test and First Drip Test as quality control measures because they are performed quickly, simply, with low-cost, and encompass all the necessary testing required. That is, they can indicate flow rate, total coliform removal, and if any cracks or large holes are present. It is our hope that the ability to test CPFs quickly, simply, with low-cost, and thoroughly will be beneficial to the success of factories around the world.

7.0 Additional Results

This chapter looks into additional findings about the CPF that were not covered in previous chapters.

7.1 How Tortuosity Affects Total Coliform Removal

In Section 5.6, it was shown, using multiple regression, how a representation of tortuosity accurately indicated total coliform removal. This did not mean a higher tortuosity signifies a higher total coliform removal. It was simply a correlation between the two. However the following assessment does hope to show that a higher tortuosity causes a higher total coliform removal.

In Figure 7-1, the percentage of response variable variation, R-squared value, shows that tortuosity explains 40.3% of the variance in flow rate, signifying that the model very weakly fits the data. In Table 7-1, the p-value in the Analysis of Variance (0.002), at an alpha-level of 0.05, indicates that the relationship between total coliform LRV and tortuosity is statistically significant. This does not mean tortuosity is highly correlated to total coliform removal. It simply says the correlation given is most likely correct. The issue remains, as to whether an R-squared value of 40.3% can be trusted as an accurate correlation. If it can be trusted, then an increase in tortuosity means an increase in total coliform removal. However, we don't conclude that this is the case. Additional research is needed on this specific topic.

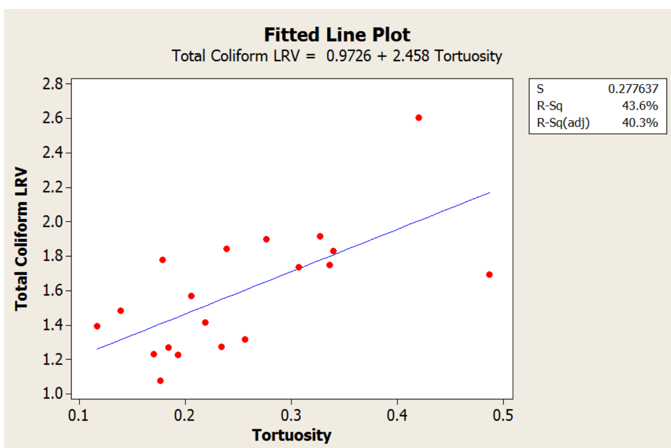

Figure 7-1: Total Coliform LRV vs. Tortuosity

Table 7-1: Regression Analysis: Total Coliform LRV versus Tortuosity

```
The regression equation is
Total Coliform LRV = 0.9726 + 2.458 Tortuosity

S = 0.277637   R-Sq = 43.6%   R-Sq(adj) = 40.3%

Analysis of Variance
Source        DF        SS        MS      F       P
Regression     1   1.01457   1.01457  13.16   0.002
Error         17   1.31040   0.07708
Total         18   2.32497
```

7.2 How Carbon Layer Affects Total Coliform Removal

A 2 sample Student's t-test was performed to examine whether the presence of a carbon layer in the CPF provides a higher total coliform removal than if a carbon layer is absent. The null hypothesis assumes the difference in total coliform LRV between the two populations is 0, the populations being CPFs with a carbon layer and CPFs without a carbon layer. Table 7-2 below shows that the p-value (0.506) is greater than an alpha-level of 0.05 which means the null hypothesis is accepted. The presence or absence of a carbon layer makes no difference to the total coliform LRV.

Table 7-2: 2 Sample Student's t-test: TC LRV for Carbon Layer Present and Absent

```
Two-sample T for Carbon Layer Present vs Carbon Layer Absent

                        N   Mean  StDev  SE Mean
Carbon Layer Present   21  1.693  0.462     0.10
Carbon Layer Absent    22  1.695  0.399    0.085

Difference = mu (Carbon Layer Present) - mu (Carbon Layer Absent)
Estimate for difference:  -0.002
95% lower bound for difference:  -0.224
T-Test of difference = 0 (vs >): T-Value = -0.02  P-Value = 0.506  DF = 39
```

7.3 How CPF Wall Thickness Affects Flow Rate and Total Coliform Removal

It was hypothesized that a thicker CPF wall would increase the total coliform removal because the water has more contact with the CPF and therefore pathogens have a greater chance of being removed from the water passing through. It was also hypothesized that a thicker wall would decrease the flow rate because the water has a greater number of pores to "push" its way through. However, both of these hypotheses prove inconclusive with the results shown in Figure 7-2 and Figure 7-3.

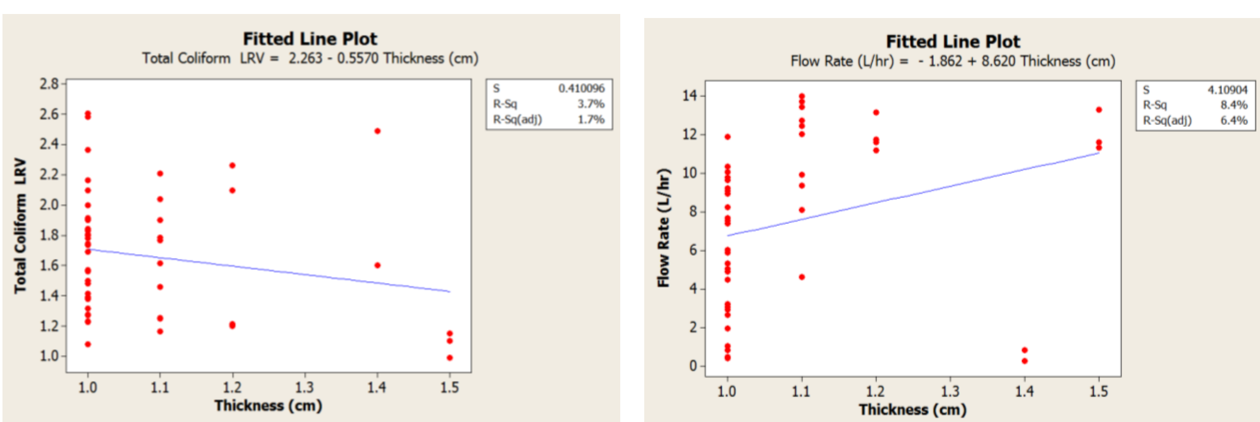

Figure 7-2 & 7-3: Total Coliform LRV vs. Thickness and Flow Rate vs. Thickness

7.4 The Relationship among Flow Rate, Porosity, and Percentage of Combustible

In Section 4.3 it was found that as the percentage of rice husk used in a CPF increased the flow rate of the CPF increased. That graph is replicated below in Figure 7-4. Also shown in Figure 7-5 is the correlation between porosity and percent rice husk. As the percentage of rice husk used increases, the porosity also increases. In Table 7-3 and Table 7-4, the p-value in both cases in the Analysis of Variance (0.000), at an α-level of 0.05, indicates that the relationship between porosity versus percent rice husk and between flow rate versus percent rice husk are statistically significant. In Figure 7-6 as the porosity increases the flow rate increases. It is not the percentage of rice husk used that directly increases the flow rate, it is an increase in porosity that increases flow rate. That is because a greater porosity provides more openings for the water to flow through. The porosity (and not the flow rate) is directly affected by the percentage of rice husk used because more rice husk creates the chance for more pores in the CPF. It can be concluded that the percentage of rice husk used indirectly affects the flow rate.

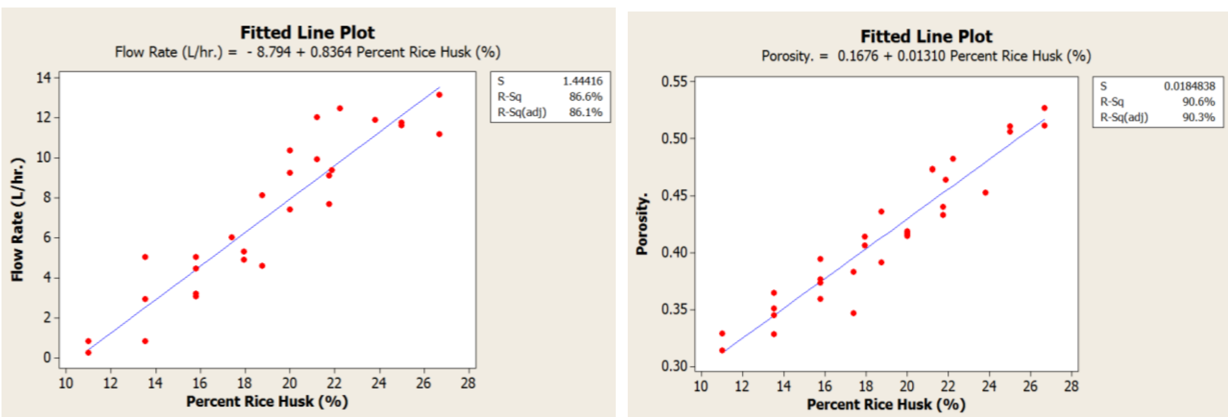

Figure 7-4 & 7-5: Porosity vs. Percent Rice Husk and Flow Rate vs. Percent Rice Husk

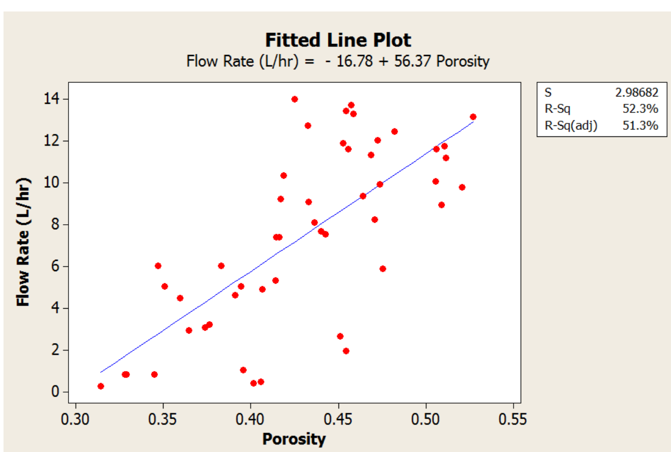

Figure 7-6: Flow Rate vs. Porosity

Table 7-3: Regression Analysis: Flow Rate (L/hr) versus Porosity

```
The regression equation is
Flow Rate (L/hr) = - 16.78 + 56.37 Porosity

S = 2.98682   R-Sq = 52.3%   R-Sq(adj) = 51.3%

Analysis of Variance
Source      DF       SS       MS      F      P
Regression   1  460.073  460.073  51.57  0.000
Error       47  419.291    8.921
Total       48  879.364
```

Table 7-4: Regression Analysis: Porosity versus Percent Rice Husk

```
The regression equation is
Porosity = 0.2477 + 0.008495 Percent Rice Husk

S = 0.0299010   R-Sq = 71.0%   R-Sq(adj) = 70.4%

Analysis of Variance
Source      DF        SS        MS       F      P
Regression   1  0.102778  0.102778  114.96  0.000
Error       47  0.042021  0.000894
Total       48  0.144800
```

8.0 Conclusions & Recommendations

This nine month research project, including three weeks of field research, draws several conclusions beneficial to Pure Home Water's goals of providing safe drinking water to those most in need in Northern Ghana and becoming a locally and financially self-sustaining organization. The three primary goals of this study were accomplished:

(1) The best filter composition to date specific to the factory in Tamale, Ghana was found (see Table 4-9) and is currently being used to make 1,250 filters under the Rotary International, Future Vision Global Grant, the PHW factory's first large order.

Table 8-1: Chosen Filter Composition

Gbalahi Clay (kg)	Wayamba Clay (kg)	Rice Husk (kg)
14	4	4

Table 8-2: Chosen Filter Performance

Flow Rate (L/hr)	LRV without Silver	Expected LRV with Silver	Turbidity Removal (Percent)	Manufacturability (Percent Pass)
6-10	1.2	2.7	92	75

(2) Two simple and low-cost quality control measures, the First Drip Test and the tortuosity representation (see Section 5.3 and Section 5.6), were developed to determine ceramic pot filter effectiveness in removing harmful pathogens, as is indicated by total coliform removal.

The equation to screen the acceptance/rejection of CPFs which reach a desired minimum level of total coliform removal is:

$$TC\ LRV = 0.6902 \times First\ Drip\ Time^{0.2127}$$

The equation to screen the acceptance/rejection of CPFs which reach a desired minimum flow rate is:

$$Flow\ Rate = 56.303 \times First\ Drip\ Time^{-0.625}$$

(3) A Quality Assurance Program has been developed and presented here (Chapter 6) for the PHW factory in Tamale, Ghana

One of the two secondary goals was achieved. That is, the flow rate was maximized, but maximizing the total coliform removal was not achieved.

What follows is a summary of research results followed by recommendations for future research that we think is important to successfully making CPFs. Finally, recommendations are given to PHW on how to best implement the findings of this research.

8.1 Summary of Research Results

- The primary production variable that affects flow rate is percentage of rice husk used in making the CPF. As the percentage of rice husk used increases, the flow rate increases because the porous volume in the CPF is increasing.

- A secondary production variable that affects flow rate is maximum firing temperature. As the maximum firing temperature increases, up to 950 degrees Celsius, the flow rate increases.

- The primary production variable that affects strength is percentage of rice husk used in making the CPF. As the percentage of rice husk used increases, the strength decreases because the CPF structure is compromised as less and less clay is used.

- The Bubble Test is a good quality control measure. The total coliform removal for CPFs that passed the bubble test has a higher total coliform bacteria removal than did CPFs that failed the bubble test.

- The First Drip Test is a good quality control measure. An increase in First Drip Time means an increase in total coliform removal (according to a power curve). The correlation between total coliform removal and First Drip Time also helps to explain the filtering mechanisms of the CPF. The test shows that a slower First Drip Time gives a higher total coliform removal because a slower drip time implies stronger capillary forces withholding the flow of water. Stronger capillary forces imply smaller pore sizes because as the length of the interface (pore size) decreases the capillary force increases (see equation 5-3). The smaller pore sizes more readily screen, adsorb, or contain bacteria in their pores. This means it is important to have small pore sizes in CPFs to remove bacteria.

- The First Drip Test was also found to be a good quality control measure to substitute for the flow rate test. As the first drip time increases, the flow rate decreases (according to a power curve). The correlation between flow rate and first drip time also accurately reflects the Young-Laplace equation for capillary pressure (Equation 5-3). For the CPF, the surface tension and wetting angle are assumed to remain constant. This means the capillary pressure is inversely proportional to the length of the capillary interface, or pore size. When capillary pressure is graphed versus pore size, such a relationship should produce an asymptotic graph, as it does in Figure 5-10. Flow rate is a reflection of capillary pressure because a higher pressure gradient will create a faster flow rate. It can then be concluded (as it was in the previous section) that first drip time varies based on average pore size. Therefore, a smaller pore size implies a slower flow.

- A third and final quality control measure for total coliform removal is a representation of tortuosity. As described in Section 3.10, flow rate, porosity, first drip time, and thickness can be used to calculate tortuosity. Multiple regression was performed with three of these factors, thickness was excluded as all CPFs tested were of equal thickness, to find the best correlation equation to total coliform removal.

- The presence or absence of a carbon layer makes no difference to the total coliform LRV. Based on the testing conducted during January 2012 more research is needed on this topic.

- This research was unsuccessful in finding which production variable, if any, affects total coliform removal

8.2 Research Recommendations

Eleven areas of research on the CPF are recommended:

1. How thoroughly the clay and rice husk are mixed and how that affects total coliform removal.

2. How the distribution of the rice husk particle sizes affects total coliform removal.

3. How tortuosity affects total coliform removal.

4. How kiln variables (maximum temperature, firing duration, and soak time) affect total coliform removal.

5. How soak time in the kiln affects flow rate.

6. How firing duration affects flow rate.

7. How the distribution of the rice husk particle sizes affect flow rate.

8. What production variables determine the manufacturability of a given CPF composition? That is, what determines how well a certain composition's CPFs pass the Bubble Test?

9. How does the carbon layer affect filter durability/longevity .

10. How the carbon layer affects the removal of contaminants such as metals, pesticides, longevity, and taste/odor.

11. How the total coliform removal and flow rate are affected over long term consistent use.

8.3 Recommendations to Pure Home Water

The first recommendation for PHW is to use the Quality Assurance/Quality Control Program outlined in Chapter 6 and to refine this plan in the months ahead. We specifically recommend using only the Bubble Test and First Drip Test as the quality control measures because they are performed quickly, simply, with low cost, and encompass all the necessary testing required. That is, they can indicate flow rate, total coliform removal, and if any cracks or large holes are present. As the production at PHW increases with time, the ability to test CPFs quickly, simply, and thoroughly at low cost will be critical to the factory's success.

The second recommendation for PHW is to continue to improve the current CPF composition. This can be accomplished by increasing the bacteria removal, manufacturability, and strength of the CPF. Increasing bacteria removal will best be accomplished by further researching topics 1-4 in Section 8.2 above. Increasing manufacturability can be accomplished by further researching topic 8 in Section 8.2 above. Because flow rate and strength are inversely related by percentage of rice husk used (i.e. as percent of rice husk used increases flow rate increases and strength decreases), a way to increase strength while maintaining a high flow rate needs to be found. To best accomplish this, further research on topics 5-7 in Section 8.2 above should be carried out.

With successful findings in topics 1-11 and practicing the recommended Quality Assurance/Quality Control program, we hope Pure Home Water will successfully help those most in need in Northern Ghana for years to come.

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Appendix A – Raw Data

Filter Composition (kg)				flow rate (L)				bubble test	dry mass (kg)
Type of Clay			Rice	15 minute		30 minute			
Gbalahi	Wayamba	Grog	Husk	collection	T-device	collection	T-device		
20	6.7	0	3.3	0.3	0.5	0.6	0.8	P	5.37
20	6.7	0	3.3	0.1	0.1	0.2	0.2	P	5.57
18	4.5	0	7.5	3.36	3.6	5.9	5.6	P	3.12
18	4.5	0	7.5	3.3	3.8	5.4	6.2	P	3.29
18	4.5	0	7.5	2.5	2.8	4.2	4.3	P	3.11
11.25	11.25	0	7.5	0.4	0.2	0.75	0.6	P	3.41
11.25	11.25	0	7.5	0.2	0	0.3	0.4	P	3.4
11.25	11.25	0	7.5	0.2	0.1	0.35	0.2	P	3.04
16	4	0	10	5.1	5.7	7.2	8.2	P	2.48
16	4	0	10	4.8	5	7	7.8	P	2.8
16	4	0	10	4		6.4	6.6	P	2.49
16	4	0	10	4.8	5	6.9	7.3	P	
16	10	5	7	1	1	1.9	1.9	P	3.29
16	10	5	7	0.7		1.4	1.8	P	3.31
18	6	0	7	7	7.2	9.4	9.5	F	3.04
18	6	0	7	8.3	8.8	9.7	empty	LB	3.1
18	6	0	7	6.9	7.1	9.1	9.4	P	3.2
11.2	11.2	0	8	9.3	9.2	9.8	empty	P	3.2
11.2	11.2	0	8	9.3	9.3	10.2	empty	F	3.12
18	5	0	7	9	9.9	10.4	empty	F	3.04
18	5	0	7	7.9	7.9	9.6	9.6	P	3.2
18	12	0	8	9.1	9.3	10.2	empty	LB	3.4
18	12	0	8	9.2	9.5	10	empty	P	3.42
13	8	0	8	6.2	6.6	8.3	8.9	P	2.94
13	8	0	8	5.7	5.9	8.1	8.3	P	2.92
13	8	0	8	6.9	7.2	9.5	9.8	P	3.05
11	0	2	3	1.9	2	3.3	3.5	LB	3.55
11	0	2	3	3.5	3.8	5.5	6	LB	3.5
11	0	0	4	5.9	6.4	8	9.8	P	2.8
11	0	0	4	7.2	7.2	9.4	9.1	P	2.81
11	0	1	4	5.8	5.9	8.3	8.3	P	3.27
11	0	1	4	7.2	7	8.4	9.5	P	2.99
13	0	0	3	4.5	4.9	6.5	7	F	3.25
0	13	0	3	3.5	3.4	5.8	5.9	P	3.37
0	13	0	3	5.7	6	7.9	8.1	F	3.25
11	0	3	4	7.4	8.1	9.3	10.1	F	3.12
11	0	3	4	6.3	7.6	8.3	9.9	LB	3.22
11	0	3	3	4.6	4.9	7	7.4	F	3.27
13	0	1	4	6.8	7.1	8.9	9.8	P	3.09
14	0	3	5	5	5.1	7.2	8	LB	3.03
18	5	2	7	4.3	4.1	6.7	6.6	P	3.07
18	5	3	7	6.3	6.8	8.6	9.2	P	3.01
18	5	3	7	4.7	4.9	7.1	7.6	P	3.1
0	13	0	3	2	1.9	3.3	3.3	P	3.25
16	0	2	5	2.5	4.9	5.5	7	P	3.19
16	0	2	5	4.4	6	6.5		P	3.21
12	4	0	2.5	0.3	0.3	0.6	1	P	3.56
12	4	0	2.5	0.3	0.2	0.6	0.6	P	3.51
12	4	0	3	1.3	1.2	2.3	2	P	3.24
12	4	0	3	1.2	1	2.2	2.3	P	3.38
12	4	0	3.5	2.2	2.2	3.8	3.9	P	3.12
12	4	0	3.5	2	2	3.5	3.6	P	3.26
12	4	0	4	3.2	3.6	5.3	5.6	P	3.28
12	4	0	4	3.3	3.6	5.3	5.9	P	3.21
12	4	3	4	2.5	3	4.3	4.7	P	3.61
12	4	3	4	2.6	3	4.3	4.9	P	3.42
12*	4*	0	2.5	1.15	2.1	2.1	2.9	P	3.38
12*	4*	0	3	2	2.1	3.6	4	P	3.58
12*	4*	0	4	4.1	5.9	6.6	8.8	P	3.18
12*	4*	0	5	6.1	6.5	8.5	9.1	P	3.03
12**	4**	0	2.5	2	2.8	3.6	4.6	P	3.47
12**	4**	0	3	1.8	2.9	3.2	4	P	3.39
12**	4**	0	4	5.2	5.8	7.4	8.9	P	3.07
12**	4**	0	5	5.5	6.1	6.6	8.8	LB	2.87

*filters fired at higher temp. **filters fired at higher temp and with sieved RH

Filter Composition (kg)				Turbidity			Turbidity Tube	
Type of Clay				influent	filtrate	Decrease	Decrease	porosity
Gbalahi	Wayamba	Grog	Rice Husk	(NTU)		%	%	
20	6.7	0	3.3	51	25	52	91	0.33
20	6.7	0	3.3					0.31
18	4.5	0	7.5				83	0.47
18	4.5	0	7.5				85	0.44
18	4.5	0	7.5	51.3	18.1	65	84	0.48
11.25	11.25	0	7.5	51.3	23.7	54	91	0.40
11.25	11.25	0	7.5				87	0.40
11.25	11.25	0	7.5				89	0.41
16	4	0	10				83	0.51
16	4	0	10				85	0.52
16	4	0	10	51.3	20	61	85	0.51
16	4	0	10					
16	10	5	7				93	0.45
16	10	5	7	51	28	45	89	0.45
18	6	0	7	66	44	34	70	0.42
18	6	0	7	81	37	54	71	0.42
18	6	0	7	122	34	72	71	0.43
11.2	11.2	0	8	81	40	51	66	0.46
11.2	11.2	0	8	66	50	24	63	0.46
18	5	0	7	66	49	27	62	0.46
18	5	0	7	81	35	57	74	0.45
18	12	0	8	66	43	35	64	0.42
18	12	0	8	81	37	54	74	0.42
13	8	0	8	51	32	38	68	0.46
13	8	0	8	66	38	42	72	0.47
13	8	0	8	51	40	23	68	0.46
11	0	2	3	81	27	66	74	0.47
11	0	2	3	51	19	63	86	0.47
11	0	0	4	66	35	47	78	0.51
11	0	0	4	81	24	70	69	0.53
11	0	1	4	81	20	75	69	0.51
11	0	1	4	51	16	68	82	0.51
13	0	0	3	89	28	69	87	0.44
0	13	0	3	89	25	72	91	0.44
0	13	0	3	89	26	71	89	0.43
11	0	3	4	122	24	80	80	0.50
11	0	3	4	89	35	60	84	0.49
11	0	3	3	89	31	65	84	0.49
13	0	1	4	89	38	57	84	0.48
14	0	3	5	89	31	65	84	0.46
18	5	2	7	89	26	71	87	0.46
18	5	3	7	122	22	82	78	0.47
18	5	3	7	89	18	79	90	0.47
0	13	0	3	97	14	86	86	0.39
16	0	2	5	97	44	54	73	0.44
16	0	2	5	97	46	52	73	0.43
12	4	0	2.5	97	12	87	92	0.33
12	4	0	2.5	97	24	76	92	0.34
12	4	0	3	97	25	74	88	0.38
12	4	0	3	97	11	89	89	0.37
12	4	0	3.5	97	13	87	88	0.41
12	4	0	3.5	97	29	70	89	0.41
12	4	0	4	97	47	52	83	0.42
12	4	0	4	97	42	57	82	0.41
12	4	3	4	97	31	68	83	0.35
12	4	3	4	97	37	62	82	0.38
12*	4*	0	2.5	130	33	75	92	0.36
12*	4*	0	3	130	27	79	91	0.39
12*	4*	0	4	130	57	56	92	0.42
12*	4*	0	5	130	50	61	85	0.45
12**	4**	0	2.5	130	42	68	89	0.35
12**	4**	0	3	130	37	71	79	0.36
12**	4**	0	4	130	52	60	79	0.42
12**	4**	0	5	130	53	59	79	0.44

*filters fired at higher temp. **filters fired at higher temp and with sieved RH

Filter Composition (kg)				time to	QT Total Coliform MPN/100 mL	
Type of Clay				first drop	without silver	with silver
Gbalahi	Wayamba	Grog	Rice Husk	(seconds)	LRV	LRV
20	6.7	0	3.3	no drop	1.60	3.92
20	6.7	0	3.3	no drop	2.49	
18	4.5	0	7.5	no drop	2.10	
18	4.5	0	7.5	no drop	2.00	
18	4.5	0	7.5	no drop	2.36	3.43
11.25	11.25	0	7.5	no drop	2.16	5.06
11.25	11.25	0	7.5		2.58	
11.25	11.25	0	7.5	no drop	1.50	
16	4	0	10	39	1.56	
16	4	0	10	39	1.81	
16	4	0	10	40	1.80	2.83
16	4	0	10	49	1.90	
16	10	5	7	no drop	1.38	
16	10	5	7	no drop	1.57	4.33
18	6	0	7		0.89	
18	6	0	7	17	1.12	
18	6	0	7	31	1.46	2.38
11.2	11.2	0	8	14	1.25	1.80
11.2	11.2	0	8		0.63	
18	5	0	7		0.83	
18	5	0	7	13	1.17	2.45
18	12	0	8		0.94	
18	12	0	8	13	1.62	1.58
13	8	0	8	22	1.15	1.91
13	8	0	8	25	1.10	
13	8	0	8	15	0.99	
11	0	2	3	156	1.55	
11	0	2	3	101	1.72	2.62
11	0	0	4		1.21	
11	0	0	4	22	2.26	
11	0	1	4	36	2.10	
11	0	1	4		1.20	
13	0	0	3	54	1.62	1.75
0	13	0	3	92	2.04	2.72
0	13	0	3	63	1.67	2.89
11	0	3	4	20	1.73	2.49
11	0	3	4	21	1.12	
11	0	3	3	32	1.52	2.45
13	0	1	4	21	1.25	3.11
14	0	3	5	31	1.44	2.79
18	5	2	7	39	1.78	2.70
18	5	3	7	19	2.21	
18	5	3	7	44	1.77	3.17
0	13	0	3	59	1.90	
16	0	2	5	20	1.48	2.82
16	0	2	5	14	1.39	
12	4	0	2.5		1.38	
12	4	0	2.5	435	2.60	3.78
12	4	0	3	100	1.83	
12	4	0	3	100	1.92	2.36
12	4	0	3.5	35	1.78	3.38
12	4	0	3.5	50	1.84	
12	4	0	4	26	1.27	2.69
12	4	0	4	24	1.23	
12	4	3	4	34	1.28	1.71
12	4	3	4	33	1.57	
12*	4*	0	2.5	105	1.75	
12*	4*	0	3	96	1.69	2.71
12*	4*	0	4	22	1.23	
12*	4*	0	5	21	1.41	
12**	4**	0	2.5	45	1.32	
12**	4**	0	3	62	1.74	2.67
12**	4**	0	4	18	1.08	
12**	4**	0	5	14	1.51	

*filters fired at higher temp. **filters fired at higher temp and with sieved RH

Filter Composition (kg)				Rice Husk	Gbalahi	Wayamba	Grog	Gb to W ratio
Type of Clay				Percentage (%)				
Gbalahi	Wayamba	Grog	Rice Husk					
20	6.7	0	3.3	11	67	22	0	3
20	6.7	0	3.3	11	67	22	0	3
18	4.5	0	7.5	25	60	15	0	4
18	4.5	0	7.5	25	60	15	0	4
18	4.5	0	7.5	25	60	15	0	4
11.25	11.25	0	7.5	25	38	38	0	1
11.25	11.25	0	7.5	25	38	38	0	1
11.25	11.25	0	7.5	25	38	38	0	1
16	4	0	10	33	53	13	0	4
16	4	0	10	33	53	13	0	4
16	4	0	10	33	53	13	0	4
16	4	0	10	33	53	13	0	4
16	10	5	7	18	42	26	13	2
16	10	5	7	18	42	26	13	2
18	6	0	7	23	58	19	0	3
18	6	0	7	23	58	19	0	3
18	6	0	7	23	58	19	0	3
11.2	11.2	0	8	26	37	37	0	1
11.2	11.2	0	8	26	37	37	0	1
18	5	0	7	23	60	17	0	4
18	5	0	7	23	60	17	0	4
18	12	0	8	21	47	32	0	2
18	12	0	8	21	47	32	0	2
13	8	0	8	28	45	28	0	2
13	8	0	8	28	45	28	0	2
13	8	0	8	28	45	28	0	2
11	0	2	3	19	69	0	13	#DIV/0!
11	0	2	3	19	69	0	13	#DIV/0!
11	0	0	4	27	73	0	0	#DIV/0!
11	0	0	4	27	73	0	0	#DIV/0!
11	0	1	4	25	69	0	6	#DIV/0!
11	0	1	4	25	69	0	6	#DIV/0!
13	0	0	3	19	81	0	0	#DIV/0!
0	13	0	3	19	0	81	0	0
0	13	0	3	19	0	81	0	0
11	0	3	4	22	61	0	17	#DIV/0!
11	0	3	4	22	61	0	17	#DIV/0!
11	0	3	3	18	65	0	18	#DIV/0!
13	0	1	4	22	72	0	6	#DIV/0!
14	0	3	5	23	64	0	14	#DIV/0!
18	5	2	7	22	56	16	6	4
18	5	3	7	21	55	15	9	4
18	5	3	7	21	55	15	9	4
0	13	0	3	19	0	81	0	0
16	0	2	5	22	70	0	9	#DIV/0!
16	0	2	5	22	70	0	9	#DIV/0!
12	4	0	2.5	14	65	22	0	3
12	4	0	2.5	14	65	22	0	3
12	4	0	3	16	63	21	0	3
12	4	0	3	16	63	21	0	3
12	4	0	3.5	18	62	21	0	3
12	4	0	3.5	18	62	21	0	3
12	4	0	4	20	60	20	0	3
12	4	0	4	20	60	20	0	3
12	4	3	4	17	52	17	13	3
12	4	3	4	17	52	17	13	3
12*	4*	0	2.5	14	65	22	0	3
12*	4*	0	3	16	63	21	0	3
12*	4*	0	4	20	60	20	0	3
12*	4*	0	5	24	57	19	0	3
12**	4**	0	2.5	14	65	22	0	3
12**	4**	0	3	16	63	21	0	3
12**	4**	0	4	20	60	20	0	3
12**	4**	0	5	24	57	19	0	3

*filters fired at higher temp. **filters fired at higher temp and with sieved RH

Appendix B – CPF Fact Sheet

Kosim Ceramic Pot Filter

Household Water Treatment and Safe Storage (HWTS)

Pure Home Water - Product Technical Specification Sheet

By Mary Kay Jackson and Susan Murcott (March 2011)

And revised by Matthew Miller (May 2012)

Technology

Brief description of the technology, including supplies needed.

The *Kosim* filter is a ceramic pot filter manufactured in Ghana. The filter unit consists of a fired clay pot filter element, a plastic bucket storage unit, a tap, and a cover lid. The only other supplies needed are a brush used for cleaning the filter element and soap and filtered water used to clean the storage unit. Pure Home Water produces the filters at its factory in Tamale, Ghana and sells the Kosim filter with a laminated pictorial instruction sheet, one Aquatab for initial cleaning, and a brush.

The *Kosim* filter element comes in the shape of a hemisphere. The volume of the hemispheric-pot filter is 10L. These filters are made from red clay and wood saw-dust or rice-husk which gets mixed, pressed in a hydraulic press and fired in a kiln. The surfaces inside and out are treated with 1 cc of 3.2% colloidal silver in 300ml of water. Tests on a filter element produced in Ghana indicate that the pore size of the filter element is on the order of 40 µm (42.63 µm). [1] The filter elements are made in Ghana.

The filter element sits atop a HDPE plastic storage receptacle with a total volume of 40 liters and a water storage volume of approximately 30 liters. The storage receptacle has a ring that sits on top of it to hold the filter element. The filter element and storage receptacle are then covered by an HDPE lid. The storage receptacles and lids are made in Ghana.

The storage receptacle is fitted at the bottom with a plastic tap to allow filtered water to be removed from the storage receptacle for use. The tap comes in two forms: a tabbed, spring loaded valve or a quarter-turn ball valve. The spigots are sourced outside Ghana from one of several suppliers.

What contaminants does it remove?

Water quality tests conducted in January 2012 assessed the effectiveness of the *Kosim* filters in the lab. [2] Results for bacterial tests and for turbidity are summarized below in Table. The percent removals are for paired samples from households with filters.

Table 1: IDEXX QuantiTray Water Quality Tests (n=24)

Indicator	Source Water	Filtered Water	Percent Removal
Average E. *coli* CFU/100mL	2852.65	7.26	99.7
Average Total Coliform CFU/100mL	46515	217.55	99.5

How does it remove contaminants?

Particles, bacteria, guinea worm Cyclops and protozoa are removed by physical straining, and also by other mechanisms including sedimentation, adsorption, diffusion, inertia, and turbulence. The filter element is treated with colloidal silver which may act as a bactericide and viricide.

Capacity (flow or volume)

The clean filter rate is 6.0 to 10.0 liters/hour. Each filter is individually tested at the Pure Home Water factory. If a filter does not meet this flow rate requirement at the time of production, it is destroyed. As a filter element is fouled, the flow rate diminishes, but flow rate is recovered upon cleaning of the filter.

[1] Mahin, Tom, "Review of Thesis "Ceramic silver impregnated pot filters for household drinking water treatment in developing countries" by Doris van Halem", Memorandum to Susan Murcott, 3 Jan. 2007.

[2] Miller, Matthew, "Hemispheric Ceramic Pot Filter Evaluation and Quality Assurance Program in Northern Ghana", Master of Engineering Thesis, Massachusetts Institute of Technology, 11 May 2012.

Replacement period

The filter element should be replaced every three years. Replacement is indicated by a reduction in the recovery rate of filtration upon cleaning, or upon breakage of the filter element. The plastic buckets have a life of 10 years or more. The tap is highly durable, but if necessary, can be replaced due to breakage or fatigue failure.

Cost of technology per unit

Capital: GH¢ 40.00 - 60.00 including filter and appurtenances. (Price range depends on transportation, training, monitoring and service levels).
O&M: GH¢ 25 for filter element replacement, GH¢ 6 for tap replacement
Exchange Rate: US$1.00 = GH¢1.85 (April 2012)

Operation and Maintenance

1. Settle turbid water in a storage vessel before filling the ceramic pot.
2. Keep the ceramic pot filled to the top. This will improve filtration rate.
3. Clean filter with brush provided when flow rate becomes too slow.
4. Clean storage unit with soap and filtered water if necessary. Disinfect with chlorine bleach, iodine or boiling water after cleaning.

Advantages

- Easy to use
- Water tastes good.
- Keeps water fresh.
- The ceramic filter element helps keep the water cool.
- Ceramic pots are culturally acceptable, as clay pots are traditionally used for water storage
- Locally produced
- Clarifies turbid water and makes it look clear and clean
- Water is collected directly from storage receptacle for use
- Equipped with a spigot to prevent recontamination
- Ceramic pores are smaller than the size of protozoa and guinea worm Cyclops
- Ceramic pore structure filters out majority of bacteria
- Colloidal silver in the pores inhibits the growth of biofilms
- One-time purchase provides 3 to 5 years of drinking water for a household
- Inexpensive
- Can be used year round and at all times of day

Disadvantages

- Highly turbid water can reduce the flow rate to unacceptable levels.
- Filter element is fragile and easily broken.
- Spigots from some manufacturers are subject to fatigue failure.
- Requires regular maintenance
- Fuel required for filter element production
- Filter must be replaced over time

Organization's Name and Contact Info

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Measurements of the Qualiplast bucket and the *Kosim* Ceramic Pot Filter Element

Qualiplast (new *Kosim* bucket)
Diameter of lid = 16"
Inner diameter of the top of the bucket = 14 5/8"
Outer diameter of the top of the bucket = 15 7/8"
Height = 20"

Aluminum Mold

Female Mold
Mold radius = 7.5"
Fillet radius = 0.18"
Thickness above ring = 1.05"
Filter wall thickness = 0.87"

Male Mold
Ring thickness = 0.093"
Mold radius = 6.8"
Diameter = 16.6"

Concrete Mold

Female Mold
Mold radius = 7.75"
Fillet radius = 0.18"
Thickness above ring = 0.75"
Filter wall thickness = 0.87"

Male Mold
Ring thickness = 0.093"
Mold radius = 7.05"
Diameter = 16.75"