EVALUATING THE TECHNICAL PERFORMANCE AND SOCIAL ACCEPTABILITY OF KEG-SHAPED CERAMIC WATER FILTERS IN NORTHERN GHANA

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ABSTRACT

The Kosim Water Keg (KWK) is a new ceramic water filter designed have faster filtration rates and integrate better with consumers' water habits. The design seals together two ceramic pot filters (CPFs) to form a keg shape. The keg is submerged in raw water stored in any water vessel, and water is cleaned as it filters into the keg interior, and a siphon extracts the filtered water. The purpose of this thesis is to construct prototype KWKs and test them for bacterial removal, turbidity removal, filtration rate, and siphoning rate. A preliminary consumer study is also included.

Eight KWKs were constructed and tested in Tamale, Ghana in January 2011. From January 18th to 25th, the KWKs were tested using dugout water, a common surface water source in Northern Ghana. The KWKs constructed from Ceramica Tamakloe (CT) filters removed 91.9% of total coliforms and 96.0% of *E. coli* colonies. The control CT CPFs removed 98.5% of total coliforms and 99.4% of *E. coli* colonies. KWK turbidity removal averaged 58%, which was lower than the 78% removal achieved by the CPFs. Filtration rates for the KWKs were 9 to 11 liters in the first hour compared to 2 to 3 liters for the CPFs. Water siphons out of the KWKs at 0.59 liters per minute for the first 3 liters, whereas the CPF's spigot averaged 1.42 liters per minute for the first three liters.

Five households tried KWKs in their homes, and responses were positive, with households particularly liking that the KWK provided clean water, kept filtered water cool, and worked inside their existing water vessels. They disliked the slow speed of the siphon mechanism.

The KWK is a promising product that merits further research. Longer term testing should 1) evaluate product durability; 2) develop a filter cleaning regime; and 3) conduct a more thorough household study. The existing construction design works, but further improvements could be made to the sealant method, the siphon removal mechanism, and the restraint system used to install the KWK.

Keywords: household water treatment, ceramic filtration, safe water storage, field testing

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

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The MIT student Ghana team was a constant source of support and entertainment during the trip. Particular thanks to the three members of MIT's Chi Phi fraternity – Mitch Westwood, Stephen Hendel, and Zach Dearing – who traveled to Ghana with the team and were always available to help out where needed, including spending an entire day sieving rice husks. Claudia Espinoza, who traveled to Ghana previously to work on the water filter, also provided me with invaluable advice regarding her experience working on the KWK and the pitfalls to avoid.

The Ghanaian staff members of Pure Home Water were also major contributors to the success of my project, particularly Amuda Abdul-Rashid who faithfully followed up with the households participating in my survey.

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ACRONYMS

CAWST - Centre for Affordable Water and Sanitation Technology

CDC – Centers for Disease Control and Prevention

CPF – Ceramic Pot Filter

CT Filter – Ceramica Tamakloe Filter (pot-shaped ceramic filter)

CWS – Community Water Solutions

GHS – Ghanaian Cedi (1 GHS = US$0.66)

HWTS – Household Water Treatment System

IDE – International Development Enterprises

JMP - Joint Monitoring Program for Water Supply and Sanitation

KWK – Kosim Water Keg

MDG – Millennium Development Goals

MF – Membrane Filtration

MPN – Most Probable Number (for bacterial test results)

NGO – Non-Governmental Organization

NTU - Nephelometric Turbidity Unit (a measurement of turbidity)

PATH – Program for Appropriate Technology in Health

PFP – Potters for Peace

PHW – Pure Home Water

QT – Quanti-Tray™ (bacterial measurement test)

TNTC – Too Numerous To Count (for bacterial test results)

UNDP – United Nations Development Programme

UNICEF – United Nations Children's Fund

WHO – World Health Organization

DEFINITION OF TERMS

Several very similar ceramic products are referenced in this report. For clarity, below are definitions for how these terms will be used.

CT Filter – These are the pot-shaped ceramic filters produced by Ceramica Tamakloe Ltd in Accra, Ghana. They come only in the traditional, flat-bottomed flowerpot shape.

Kosim Filter – These are the ceramic filters produced by Pure Home Water in Tamale, Ghana. "Kosim" is the brand name used by PHW. These filters have either a flat or paraboloid bottom, depending on the press used.

Kosim Water Keg (or "Keg" or "KWK") – This refers to the keg design being research in this report. The "Kosim" portion comes from its affiliation with PHW.

Raw water – Water from any source (improved or unimproved) that has not passed through the filter.

Ceramic Pot Filters (CPF) – This term will refer to all ceramic pot filters systems produced by Pure Home Water or any of the other 36 ceramic filter factories around the world. Any system where water flows through the ceramic pot filter and is stored in a separate safe storage container is considered a "ceramic pot filter."

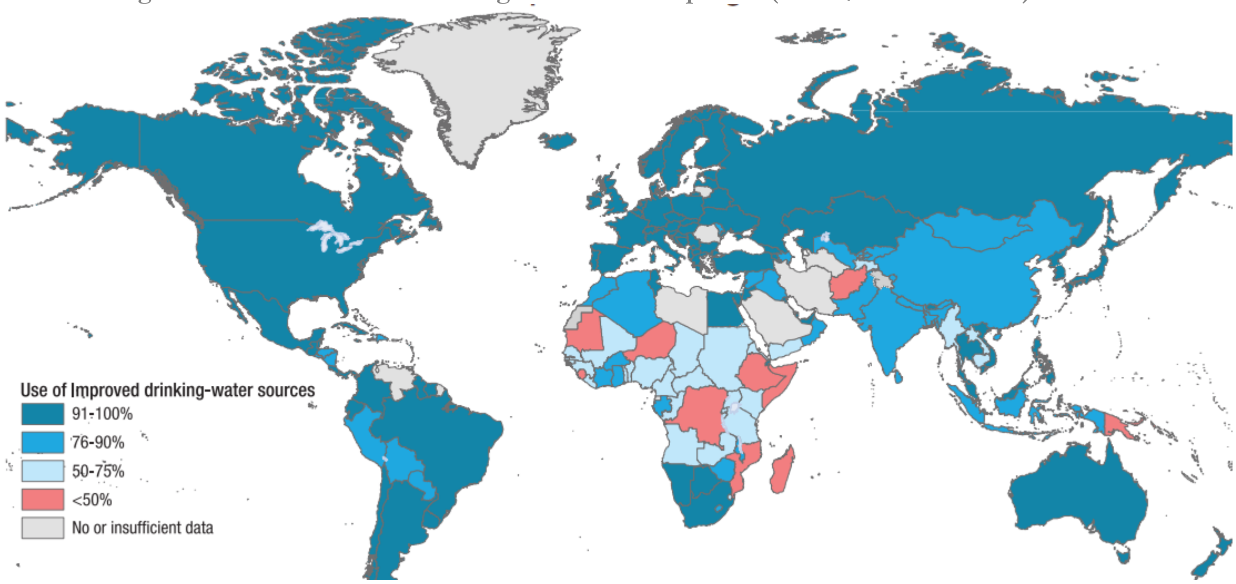
Vessel – Any reference to a "water vessel" or "ceramic vessel" will be referencing the ceramic containers used for water storage, and in which the KWKs are submerged. For clarity, the term "ceramic pot" will never be used refer to the water storage containers.

1 INTRODUCTION

1.1 GLOBAL WATER CONDITION

Globally, 884 million people (13% of the world's population) lack access to improved water sources, and 37% of those people are concentrated in Sub-Saharan Africa. In addition to regional variation, there is a significant disparity between urban and rural population's access to improved water - 84% of the population without improved water live in rural areas (WHO/UNICEF 2010). The effect of this unclean water can be measured in disease and mortality. According to the World Health Organization's (WHO) Water Sanitation and Health group, 1.6 million people die annually from diarrheal diseases due to unsafe water and poor sanitation. Ninety percent of these deaths are in children under the age of five. One hundred thirty-three million people have intestinal infections, and another 160 million people get schistosomiasis annually.

Figure 1 Percent Access to Improved Water Source By Country
Source: "Progress on Sanitation and Drinking Water – 2010 Update" (WHO/UNICEF 2010)



In recognition of the toll that unclean water takes on populations, access to clean water is included in the UN Millennium Development Goal 7 to "Ensure Environmental Sustainability." Target 7c is to "Reduce by half the proportion of people without sustainable access to safe drinking water and basic sanitation," by 2015 (UNDP 2011). If this goal is reached, 470,000 lives would be saved each year, and globally, people would gain 320 million days without sickness (WHO "Health" 2011). Progress is measured by the proportion of people with an "improved drinking water source." An "improved water source" is defined as a household connection, standpipe, borehole, protected hand-dug well, protected spring, or rainwater catchment. Users who access water only through unprotected dug wells, unprotected springs, vendor water, bottled water[1], or tanker trucks of water are not considered to have sustainable access to an "improved water source." Practically, this means

[1] Bottled water and tanker trucks, while often clean sources of water, are not considered to be sustainable

that people with access to an improved source may still not have access to an uncontaminated source, since this UN definition does not address any specific microbial contaminant level or treatment standard. The WHO, who together with UNICEF monitors progress towards meeting the MDG under the Joint Monitoring Program (JMP) for Water Supply and Sanitation, defines "access to clean water" more narrowly to require the water to have "microbial, chemical, and physical characteristics that meet WHO guidelines or national standards on drinking water quality" (WHO "Health" 2011). They additionally define "sustainable access" as requiring the water to be within 1 kilometer of the user's home and provide 20 liters per person per day (see Table 1 below for details).

Table 1 Summary of Requirements for Water Service Level to Promote Health
Source: Domestic Water Quantity, Service Level and Health (Howard 2003).

Service level	**Access measure**	*Needs met*	**Level of health concern**
No access (quantity collected often below 5 l/c/d)	More than 1000m or 30 minutes total collection time	Consumption – cannot be assured Hygiene – not possible (unless practised at source)	Very high
Basic access (average quantity unlikely to exceed 20 l/c/d)	Between 100 and 1000m or 5 to 30 minutes total collection time	Consumption – should be assured Hygiene – handwashing and basic food hygiene possible; laundry/ bathing difficult to assure unless carried out at source	High
Intermediate access (average quantity about 50 l/c/d)	Water delivered through one tap on-plot (or within 100m or 5 minutes total collection time	Consumption – assured Hygiene – all basic personal and food hygiene assured; laundry and bathing should also be assured	Low
Optimal access (average quantity 100 l/c/d and above)	Water supplied through multiple taps continuously	Consumption – all needs met Hygiene – all needs should be met	Very low

Water borne diseases are caused by a combination of poor water quality, poor water access, poor sanitation, and poor hygiene practices. Table 2 on the left from UNICEF estimates the impact each type of intervention has on reducing diarrhea cases. Projects improving water quality or hygiene practices have the largest impact on diarrheal rates, but health based interventions need to consider all four categories to fully address the disease burden in developing countries.

Table 2 Percent Reduction in Diarrheal Diseases by Water/Sanitation Intervention Source: UNICEF Handbook on Water Quality (2008)

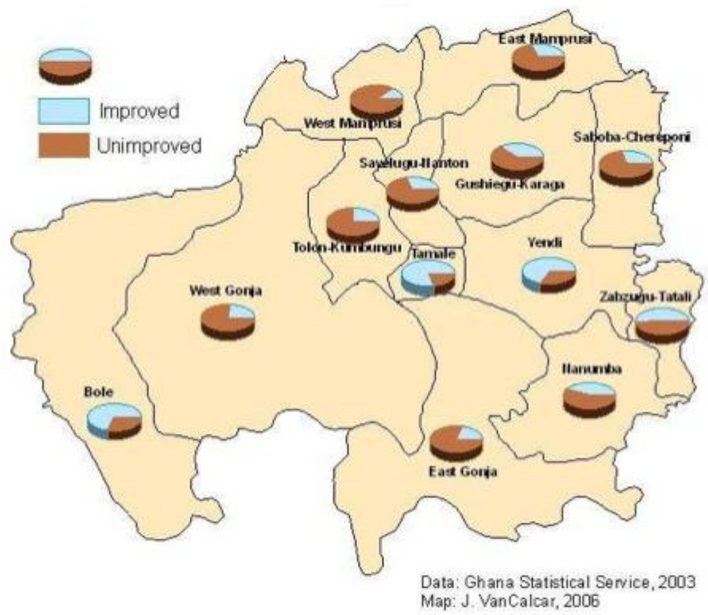
Intervention	**% Reduction**
Sanitation	24
Hygiene	42
Water Quantity	23
Water Quality	39

1.2 GHANA WATER AND HEALTH INDICATORS

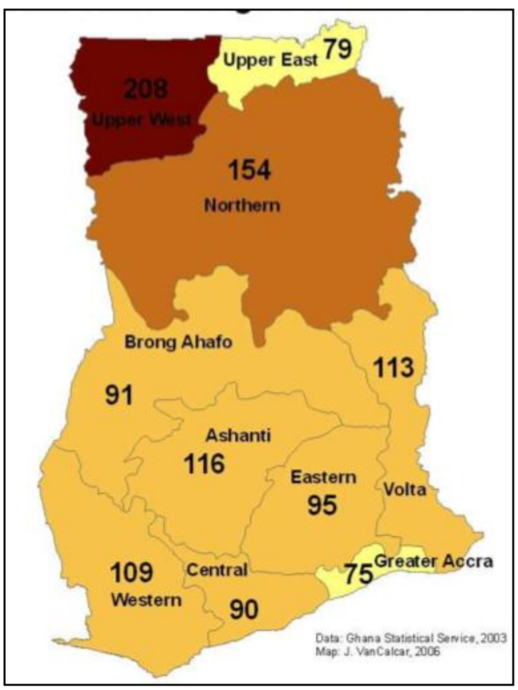
Northern Ghana, where this project is located, suffers from a severe lack of improved water sources. Figure 2 pictorially demonstrates the percentage of improved versus unimproved sources in the different districts of Northern Ghana based on data from the Ghana Statistical Services in 2000. Taking populations from the 2000 census, this translates to 1 million people lacking access to improved sources out of a total population of 1.8 million (VanCalcar 2004).

Coverage follows the global trend of varying in quality for urban versus rural communities. Ghana Statistical Services compared predominately urban Tamale to more rural Savelugu in 2004. Tamale, which was 67% urban, provided 80% of its population with improved water sources, and 79% of households used a tap or standpipe at least part of the time. Savelugu, which was only 35% urban, provided 30% of households with improved water sources. Only 10% had access to a standpipe or tap and 65% used a dam or surface water (VanCalcar 2004).

Figure 2 Percent Access to Improved Water Source By Region in Northern Ghana
Source: VanCalcar 2004



In recent years, Ghana has reportedly made great strides towards meeting the MDGs. The JMP 2008 estimate for Ghanaians without access to an improved water source is only 18% (10% of urban households and 26% of rural households). Over 11 million people have gained access to an improved water source between 1990 and 2008 (WHO/UNICEF 2010).



Lack of access to improved water is important because poor water quality increases the spread of dangerous diseases. These waterborne pathogens include cholera, typhoid, hepatitis, and guinea worm. In Ghana, poor health and sanitation results in the death of 111 children before the age of five for every 1,000 live births (VanCalcar 2004). Diarrhea accounts for 12 percent of all deaths of Ghanaian children under five, many of which could be prevented with improvements to water treatment, sanitation and hygiene (WHO 2006). Figure 3 to the left demonstrates the severity of this problem, especially in the Northern and Upper West Regions of Ghana where the mortality rate for children under five is 154 and 208 per 1,000 births respectively (VanCalcar 2004).

Figure 3 Mortality Rates for Children Under Five Years of Age Per 1,000 Births
Source: VanCalcar 2004

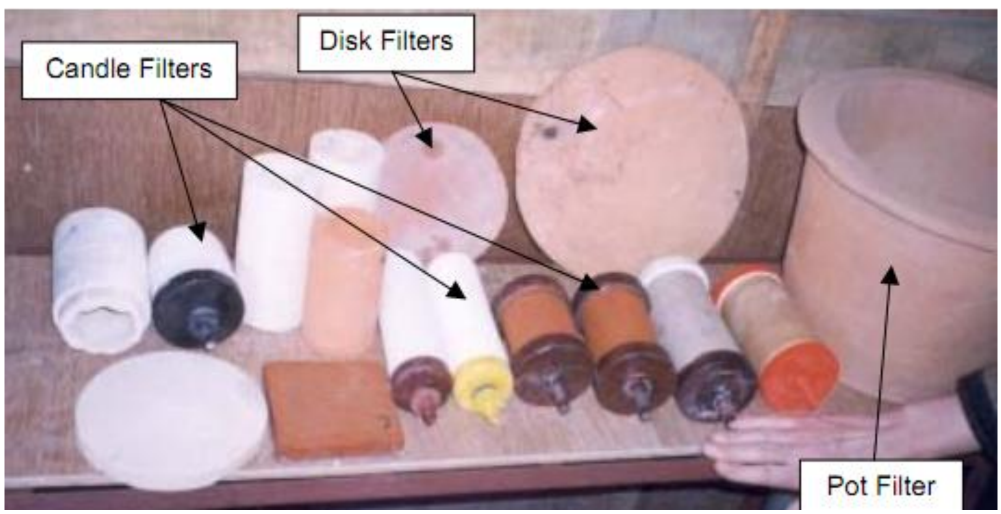
When considering the volume of clean water a household water treatment system would need to produce to improve this situation, one needs to consider local household sizes. Households in rural Ghana typically consist of multiple stand alone structures in an enclosed compound. A study by Vanessa Green in 2008 found the average household size in rural areas to be 13 people and in urban areas to be 12 people. A 2005 survey by Rachel Peletz and a 2006 survey by Sophie Johnson similarly found the average household size in rural areas to be 12 people, but they found urban household size to be 6. This difference is likely due to Green focusing on low-income urban households, which are typically larger than middle-income households (Green 2008).

Figure 4 Photo of a Typical Household in Rural Ghana

1.3 Ceramic Water Filters

Ceramic filters are an established way to remove bacteria, protozoa, guinea worm, and turbidity from water. According to the WHO, ceramic and carbon filtration can achieve a 2 to 6 log removal of bacteria, depending on the pore size and chemical coatings. They do not tend to be as effective

Figure 5 Examples of Different Types of Ceramic Filters
Source: Dies 2003



against viruses. At best, they can remove 1 to 4 logs of viruses, but low end filters, particularly ceramic pot filters, are not typically advertised to be able to remove any viruses. Against protozoa, ceramic filters are very effective and can typically remove 4 to 6 logs (WHO *Guidelines* 2008). Ceramic filters work by having water filter through tiny pores in the ceramic wall. Pathogens and particulates get trapped in the pores. Additives, such as silver, are sometimes added to the ceramic to further kill bacteria. A variety of shapes and designs exist using the same basic principle of mechanical filtration, but ceramic filters are all prone to a few specific problems:

1. Unlike chlorine, there is no residual purification with ceramic filtration. If filtered water is stored in a contaminated container, it can quickly regress to its previous level of contamination.

2. The filters themselves must also be carefully kept clean and free of bacterial growth to prevent contamination of the water during filtration.
3. Ceramic filters usually filter slowly, because pores need to be sized small enough to prevent the passage of pathogens. To stay low-cost, water is forced through the filters only by the water pressure of unfiltered water stored above the filter. These two factors combine into slow filtration rates.

Four of the most popular design configurations are discussed below. Candle filters consist of small, cylindrical ceramic filters that are submerged in contaminated water. Water filters into the candle filter and then flows down into a separate clean storage container beneath the candle filter. Siphon filters add a siphon suction force to the candle filter design to increase the filtration rate. Ceramic pot filters are shaped like flower pots[2]; water is poured into the pot and filters through it into a clean storage container below. Finally, disk filters place a circle of porous clay, essentially the bottom of the ceramic pot filter, between two water storage containers. Water is poured into the top container and filters through the disk into the lower container. This design has only been implemented in three countries in a limited extent.

1.3.1 Candle Filter

Figure 6 (left) Schematic of a Candle Filter
(right) Photo of an Actual Candle Filter System
Source: (left) http://www.purifiers.co.za/productinfo/12l-home-units/stainless-steel-home-unit.htm
(right)http://ces.iisc.ernet.in/energy/water/paper/drinkingwater/simplemethods/filtration.html

To use, candle filters are submerged in the raw water. This water filters to the interior of the filter tube. The filter's bottom feeds into a separate clean storage container where the filtered water is stored until the users wants it. The filtering element itself is made of kaolin clay or diatomaceous earth, and is typically small, with a height of 4 to 10 inches and diameters of 2 to 2.5 inches. Multiple filtering elements can be submerged in the same container to increase filtering rates. Candle filters sometimes contain activated carbon or silver coatings to kill pathogens and prevent bacterial growth on the filter. In 2005, Amber Franz, an MIT graduate student, studied five candle filter brands, and found that one contained only activated carbon, one had only a silver coating, one had neither and two had both (Franz 2005).

Franz tested five commercial brands of candle filters in Kenya and again in Boston, MA. Using local river water in Kenya, she found a 2 to 5 log reduction (99 to 99.999% percent removal) in both total coliforms and *E. coli*. (The Kenyan raw water had coliforms concentrations of 78,000 to

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[2] Not all Ceramic Pot Filters have flat bottoms. Some are shaped in half-hemispheres and others have paraboloid bottoms. They are all sized to hold 7 to 9 liters.

1,600,000 CFU/100mL and *E. coli* concentrations of 24,000 to 1,200,000 CFU/100 mL, calculated from diluted samples). When using the less contaminated Charles River water (total coliforms 1,400 to 6,100 CFU/100 mL and *E. coli* concentrations of 140 to 550 CFU/100 mL), log removal ranged from 1 to 3 for both total coliforms and *E. coli* (Franz 2005). However, these results come from filters used in lab-like conditions. She did not perform tests on candle filters in use in actual homes to determine filters performance over time under normal maintenance. While up to 6 log removal can occur when being used by trained personnel, a 2 log removal is more typically when used by normal users in their home. A 2003 Bolivian study found that candle filters being used by actual people in their homes resulted in a 63% reduction in diarrheal diseases over six months. 88% of users were consistently using them during this time period (Brown 2003).

Franz measured the turbidity reduction from candle filters, and she found that the filters could remove 96.6 to 99.3% of the turbidity, and that all the filters were able to reduce the turbidity below 1 NTU. (The source water had turbidities ranging from 15 to 21 NTU.) When filtering the less turbid Charles River water (1.8 to 8.4 NTU) from Boston, the candle filters consistently brought the turbidity to below 0.6 NTU (Franz 2005).

Franz found that the flow rates for the candle filter ranged from 0.035 liters per hour to 0.454 liters per hour. When the filters were left alone for twenty hours (without refilling the raw water) filtration rates typically decreased by a 50 to 75% compared flow rates in the first three hours. For example the AquaMaster candle filter had a filtration rate of 0.144 liters per hour over the first three hours, but over twenty hours, this dropped to 0.042 liters per hour. Franz attributed this decrease to a combination of clogging in the filter and the lower water pressure due to a drop in the raw water height (Franz 2005).

Prices for candle filters range from US$2 (in South America) to US$40 (in the UK). The filter performance varied between filter brands, and there is a quality difference associated with the price change (Franz 2005). The Bolivian study referenced earlier found that after 9 months, 20% of households had stopped using the candle filters when they broke, and the families did not have an easy and affordable way to replace the filter (Brown 2003).

1.3.2 Siphon Filter

The siphon filter uses the same candle filter element but adds a siphon to provide a suction force to

Figure 7 (a) Schematic of a Siphon Filter **(b) Photos of Siphon Filters**
Source: (a) http://washtech.wordpress.com/category/topics/water-supply/water-treatment/
(b) http://www.campinghikingwaterfilters.tk/hot-deals-katadyn-siphon-filter/

increase filtration rates. To use, the filter is placed in a raw water vessel elevated 28 inches above the clean water storage container. This height difference powers the siphon, which creates a vacuum inside of the filter that pulls raw water through the filter. The filter element has pore sizes from 0.1 to 10 micrometers to mechanically filter out pathogens and is usually impregnated with silver to kill bacteria and prevent growth on the filter. A cloth around the filter acts as a pre-filter to reduce clogging of the ceramic element. To clean the filter, the rubber bulb on the tubing can be squeezed to provide the pressure to backwash the filter. When this fails, scrubbing is used to remove trapped particles. However, studies by Delft University and MIT have found that users consistently fail to remember the proper cleaning technique and did not understand the backwashing mechanism (Ziff 2009).

Basic Water Needs Foundation, a Dutch NGO, developed the siphon filter design. Testing in a Dutch laboratory found that the filter could remove log 4.4 to 5.5 of *E. coli* bacteria over a lifespan of 7,000 liters of water. Virus removal has not been tested, but based on filter pore size, it is expected that the filter will not remove viruses. Sara Ziff, an MIT graduate student, field tested siphon filters installed in 24 households in Northern Ghana. She took 48 water samples of the filtered water, and found an overall reduction in total coliforms of 90.7% (1.0 log reduction) and of *E. coli* by 94.1% (1.2 log reduction). However, six water samples were dropped from this average because they showed an increase in contamination of the filtered water relative to the source water. This was attributed to recontamination of the water in the "clean" water storage container (Ziff 2009).

Basic Water Needs determined the flow rate for the siphon filter to be between 3 and 5 liters per hour, which compares quite favorably to the 0.5 liters per hour that the candle filter achieves. Testing by Ziff in Cambridge found an average flow rate of 4 liters per hour when the upper raw water container was kept 15 inches above the lower clean water storage container. This rate increased to 7 liters per hour when the containers were separated by 28 inches (Ziff 2009).

The filter system sells for US$8 to $12, and the ceramic filter element alone costs US$3 to $4. The system is designed to last for five years, and the ceramic filter will work for 7,000 to 10,000 liters of water. For a family of six using 7.5 liters of water per person per day, the filter would need to be replaced every five to seven months (Ziff 2009). Filter life is reduced when dealing with highly turbid waters, such as is often seen in Ghanaian surface water.

1.3.3 Ceramic Pot Filters

The third main type of ceramic filter, and the one most commonly associated with NGO work, is the ceramic pot filter. The design consists of a porous clay pot impregnated with silver and suspended over a clean storage container. Dirty water is poured into the clay filter and then trickles through it into the clean storage container below. A tap at the bottom of the clean water storage container releases the filtered water. Filters are cleaned by scrubbing the ceramic pot with a stiff brush whenever the flow rate slows down to an unacceptable level or the filter visibly has a layer of particulates inside of it.

Figure 8 (left) Schematic of Ceramic Pot Filter
(right) Photo of Ceramic Pot Filter
Source:(left)http://blogs.princeton.edu/chm333/f2006/water/05_international_issues/03_inexpensive_and_sustainable_forms_of_water_puri/04_filtration/
(right) http://www.pottersforpeace.org/

The filter was originally tested and developed by Dr. Fernando Mazariegos in Guatemala in 1982. Ron Rivera standardized and disseminated the design through the non-profit organization Potters For Peace. The pots are produced by mixing clay and tiny combustible materials, such as saw dust or rice husks, in a pre-determined ration (usually 60% clay and 40% combustible). These factories typically use local clay, and the precise clay ratio varies based on local clay properties and combustible type. During firing, the combustible material burns out, which leaves tiny, tortuous pathways through the clay. The fired pot is coated, or painted, with colloidal silver, which has anti-microbial properties. Purification is through two methods. First, the water is mechanically filtered as it moves through the clay, and secondly, the colloidal silver inactivates waterborne pathogens. Over 36 factories around the world are currently producing ceramic pot filters (Rayner 2009).

Lab testing shows that colloidal silver pots can have nearly 3 log removal of bacteria, but field testing results are not as good. Lab testing in 2007 by Jill Baumgartner, et al measured a 99.4% removal of total coliforms and 99.8% removal of *E. coli*. When the filters were overfilled, however, removal was nearly halved, likely due to water leaking into the safe storage container where the ceramic filter meets the container (Baumgartner et al, 2007). Lantagne's field study used presence/absence tests and found that 53% of homes tested negative for *E. coli* after filtering and only 6% tested negative for total coliforms (with a sample size of 24 filters). She noted that homes with positive tests for *E. coli* seemed dirtier compared to households testing negative, and so these homes may have had trouble maintaining their filters. Selective quantitative testing (sample size of 7 homes) revealed that all of the households had more total coliforms and some households had more

E. coli in their filtered water than their source water. This was likely due to contamination of the safe water container (Lantagne 2001). Regarding how bacterial reduction translates into health affects, a study in Cambodia found that use of ceramic pot filters in households reduced diarrheal disease rates by 46% (Sobsey 2008).

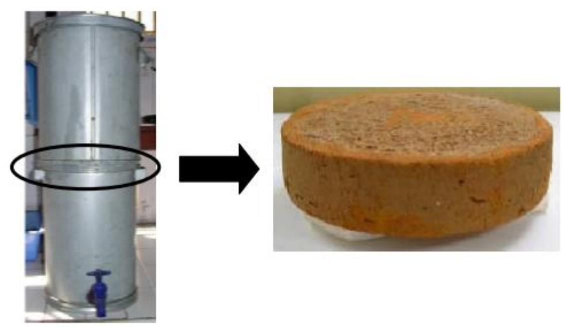
Quality controls among ceramic water filter factories can be uneven. Ceramic pot filters are usually checked for quality by testing their 1 hour filtration rate, which is targeted to be between 1.5 and 3 liters per hour (Hagan 2009). Lantagne's field testing measured a lower average flow rate of 0.98 liters per hour (with a range of 0.13 to 3.5 liters per hour) (Lantagne 2001).

The ceramic pot filters produced by Pure Home Water, the partner organization for this study, currently cost GHS 18 (US$12) to make, exclusive of marketing and overhead costs, with the ceramic element alone costing GHS 6 (US$4). Globally, ceramic pot filters are sold for US$8 to $12 (Heierli 2008). The ceramic filter element is expected to last two to three years before needing to be replaced. In Cambodia, ceramic pot filter usage dropped by 2% per month, and two thirds of this was due to either the ceramic filter or the spigot breaking (Sobsey 2008).

1.3.4 Disk filter

Disk filters are similar to the traditional pot filters, but the filter element is reduced to just the bottom circle which is held between two container. Raw water is poured into the top container, and it then filters down into the bottom container. This system makes shipping the filtering element easier since it is more compact and able to stack. However, the disk filter is not well documented or wide spread and has only been implemented in India, Nepal, and Cuba. Robert Dies, a MIT graduate student, included disk filters in his research of existing water treatment methods in Nepal in 2003. Flow rates varied from 1 to 11 liters per hour, with an average of 3 liters per hour. Total coliforms removal ranged from 93 to 99.99%, and turbidity removed was 99%. He reports that a disk filter produced in India costs US$3.50 (in 2002), and that the filter element alone costs US$0.49 (Dies 2003).

Figure 9 Photo of Ceramic Disk Filter
Source: Dies 2003



1.4 PURE HOME WATER FACTORY

Pure Home Water (PHW) is a non-profit organization in Northern Ghana based in Tamale, the regional capitol. Its mission is to provide safe drinking water by marketing and selling household water treatment systems (HWTS). Susan Murcott, a Senior Lecturer at MIT, founded PHW in 2006 with a US$150,000 grant from the Hilton Foundation. PHW's goal is to be financially self-sustaining through the sale of low cost HWTS, and they did not originally promote any single treatment technique as being preferable. They wanted to educate consumers about the importance of water treatment, the pros and cons of available methods, and provide consumers with a range of products from which they could choose to purchase the system which best met their individual needs (Murcott 2011).

1.4.1 Early Product Diversity

Murcott hired two Ghanaian engineers as PHW sales representatives. During this first year, PHW promoted safe water storage, ceramic pot filters, candle filters, biosand filters, and SODIS.

1.4.1.1 Safe Water System

The Safe Water System (SWS) was developed by the Centers for Disease Control and Prevention (CDC) as a cheap and simple point of use treatment option. This treatment approach consists of providing people with safe storage containers, defined as closed containers that supply water through a tap (so that people's hands and utensils are not going into the water), and chlorine to treat the water. There is also an education component that promotes good hygiene practices and safe handling of food and water (CDC 2008). This system does not work well in turbid water (greater than 0.1 NTU) (WHO *Guidelines* 2008), which is why PHW initially began its promotion by only emphasizing the safe storage container.

1.4.1.2 Ceramic Pot Filters

Ceramica Tamakloe Filtron filters (CT Filters) from Ceramica Tamakloe Ltd. are ceramic pot filters produced in Accra, Ghana. The factory was founded in 2004 with training from Potters for Peace and the Practica Foundation. The ceramic pots measure 10 inches deep with a 12.2 inch diameter with a raw water capacity of 9.8 liters. Measurements by Claire Mattelet, an MIT graduate student, determined that filtering rates were 1.06 liters/hour, and that 99.5% of total coliforms were removed, measured with membrane filtration. No *E. coli* were detected in the source water she measured with membrane filtration, but separate testing by her with 3M Petrifilm, a less sensitive test, on water with *E. coli* found that the CT filters removed 100% *E. coli* (Mattelet 2006). Testing done on CT filters by the author in January 2011 found the flow rates to be between 1.3 and 3.4 liters/hour. The author found 97% to 99.9% removal of coliforms and 99% removal of *E. coli*, measured using membrane filtration and Quanti-Tray™. However, the author's results are based on a sample size of only four total tests (using three filters). The filter system, including the filter, water storage container, and tap, costs GHS 18 (US$12).

1.4.1.3 Candle Filters

Two candle filters were commercially available in Northern Ghana prior to PHW's arrival. PHW planned on promoting the Nnsupa and Everest Aquaguard candle filters until testing by Mattelet found that neither performed satisfactorily.

1.4.1.3.1 Nnsupa Candle Filter

Research on production of the Nnsupa candle filter started in 2002 in Kumasi, Ghana with a US$15,000 grant, and full production began in 2004. These filters are made from kaolin clay and do not include a silver coating. The candle filter elements are 5 inches high and have a 3 inch diameter. The company advertises that the filters remove 100% of bacteria, cysts, and heavy metals. Testing by Mattelet, however, found that the filters removed only 0.4 logs (40%) of total coliforms, measured with membrane filtration. She measured the flow rates to be 0.34 liters per hour. PHW proposed selling the system for US$25. The replacement ceramic element costs US$1.50 to $2 to produce. Because of the low total coliforms removal, however, (CT filters removed 2.4 logs [99.6%]of total coliforms by Mattelet's measurements), PHW decided to stop distributing Nnsupa candle filters (Mattelet 2006).

1.4.1.3.2 Everest Aquaguard

The Everest Aquaguard is manufactured in India and sold in Ghana. It is also produced without silver and its dimensions are 7.7 inches high and 2.3 inches in diameter. Limited testing by Mattelet found that contamination was higher in the filtered water than the source water, likely due to contamination of the filter. The filtration rate was 0.55 liters/hour. The cost was US$14 to $18, depending on the size of the metal clean water storage container (between 20 to 27 liters) (Mattelet 2006).

1.4.1.4 Biosand Filters

In Tamale, three biosand filters were available for testing by PHW: 1) plastic biosand filters produced by MIT students with PHW staff for research purposes; 2) a concrete biosand filter from CAWST; and 3) a plastic biosand filter from HydraAid. Testing of 304 HydraAid filters found that they reduced turbidity by 85%, *E. coli* by 66%, and total coliforms by 82%, but HydraAid later closed down due to funding issues. Additionally, biosand filters have only been proven to work in water with low turbidity, and would need to be adapted to work with the highly turbid water (greater than 50 NTUs) typically found in surface sources in Ghana (Collin 2009).

1.4.1.5 SODIS

In the SODIS treatment method, water is stored in clear PET (plastic) 2 liter bottles, for example soda bottles, in an area where they will be exposed to direct sunlight for a minimum of six hours. In this timeframe, *E. coli* can be reduced by 5 log, viruses by 4 log, and parasites will be inactivated. While this system is effective in clear water, it is not well suited for the turbid waters in Ghana (Yazdani 2007). Since this technique is primarily a behavioral change, adoption rates are low. Studies in Nicaragua and India found that adoption rates during the study period were as low as 20% (Sobsey 2008). SODIS would be difficult to promote with PHW's goal of financial self-sufficiency because it is nearly impossible to commercialize. PHW would not be able to promote this technique without having another source of revenue to cover their training and supplies costs.

1.4.2 Focusing on Ceramic Filters

In 2006, a joint team of MIT Master of Engineering and Sloan MBA students traveled to Pure Home Water to evaluate the suite of products being promoted and devise a business plan. They determined that selling a variety of products was not very effective because it: 1) added complexity to the education and marketing campaign; 2) added overhead costs for PHW because PHW had to store all the additional merchandise; and 3) confused customers. The engineering students determined that not all solutions were equally appropriate for the area, particularly biosand filters and SODIS, due to the water turbidity. Other filters, such as the candle filters, did not perform as well as advertised when tested by MIT graduate students. The Sloan team recommended reducing the product line down to Safe Storage System and the CT filters (Gordon et. Al 2006). PHW decided not to promote biosand filters and safe water storage systems because biosand filters still needed modifications before they could be sold, and the safe water storage containers were not selling. Instead, Pure Home Water would focus their efforts, at least initially, on the CT Filters, the ceramic pot filters with safe storage containers produced by Ceramica Tamakloe.

PHW began selling the CT filters under the brand name "Kosim Filter," which means "safe water" in Dagbani, the most wide spread dialect in Northern Ghana. The complete Kosim filtering system consists of a 9-liter clay pot filter element suspended over a plastic water storage container and a lid to cover the system. A spigot at the bottom of the plastic container dispenses the water, and a sticker on the storage container explains how to use and clean the filter. This treatment method appeared to be the simplest and cheapest method to clean water in Northern Ghana. It is effective in removing *E. coli*, can be manufactured almost entirely out of local materials, and is culturally appropriate (Watters 2010). From 2005 to 2009, PHW purchased CT filters from Accra, Ghana (10 hours from Tamale by bus), and distributed them in Northern Ghana. However, full cost recovery proved elusive, because rural households were only willing to pay GHS 6 (US$4) for the system, when a sustainable price would be about GHS 18 (US$12). Even in urban areas, the filters were sold for GHS 12 (US$8). As a result, filter sales were primarily through NGOs, which were able and willing to pay full price for the filters. NGOs typically distributed them either for free or a highly subsidized price to poor households, which further eroding the willingness to pay for the system.

1.4.3 PHW Filter Factory

As PHW grew, purchasing filters from Ceramica Tamakloe in Accra became less efficient. CT filters were delivered behind schedule and with uneven quality. Additionally, half of the filters typically broke on the trip from Accra to Tamale, and while the CT factory would replace these broken pots, PHW had to pay for shipping (Murcott 2011).

In order to reduce these problems in the supply chain and better serve Northern Ghana, PHW began constructing its own factory in Tamale in late 2009. Construction of the building is still ongoing, but the factory owns two hydraulic mold presses, two kilns, and land to supply clay. In

Figure 10 Photos From the Pure Home Water Factory (January 2011)

(a) Factory building **(b) Hydraulic filter press** **(c) Filter drying wrack**

January of 2010, MIT students Reed Miller and Travis Watters established preliminary recommendations for clay recipes based on the filtration rates and filter strength with different proportions of combustible material and clay. However, their sample size was small (30 total filters, with two made of each of the 15 proposed formulas) (Miller 2010). When Claudia Espinoza, another MIT graduate student, traveled to the factory in the summer of 2010, pots she produced based on Miller's and Watters' directions were of an uneven quality and too brittle to be used (Espinoza 2010). Josh Hester, another MIT graduate student, traveled to Ghana in January of 2011 to test the effect of different clay properties on filter performance. He took samples at different depths and locations from within three different clay sites and made pots with each to compare their bacterial removal. During March 2011, Curt and Cathy Bradner traveled to the factory to further test filter production and work towards establishing a production procedure and quality controls.

The Bradners are founders and directors of the NGO Thirst-Aid, which operates multiple filter factories in Myanmar. They are experienced in developing the correct clay formulation to optimize filter strength and performance. Through these combined efforts, PHW is moving towards large scale production of filters.

Once the factory is in full production, it is expected to be able to produce 75 filters per day. It is overseen by an international board of directors, but the factory manager and all of its employees are Ghanaians drawn from the local communities. The factory currently has orders for 1,600 filters from World Vision and from 1,400 filters from Rotary Club (Murcott 2011).

1.4.4 Product Line Expansion

Pure Home Water currently produces one ceramic filter option, the Kosim Ceramic Pot Filter. Now that PHW has their own factory, they are interested in expanding the number of products that they produce at the factory in order to better target different customer segments. PHW wants to maintain their mission to bring water to the rural poor who are most in need, but financially, this market alone will not be a sustainable model. A model factory is one in Guatemala which is able to profitably sell ceramic water filters. Their business strategy has focused on creating a variety of products around the ceramic filter. For example, they offer hand-painted ceramic safe storage containers as an upscale alternative to the plastic receptacles. All filters provide the same level of bacterial removal, but the higher margin, more elegant storage containers bring in enough revenue to sell the downscale storage containers at a subsidized price to poorer households and still stay financially sound (Murcott 2011).

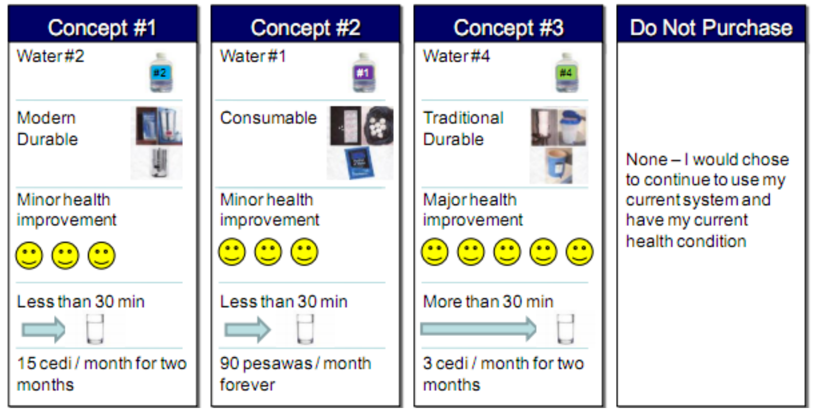
To this end, PHW is particularly interested in new products that can be made with their existing capacity, so that overhead costs stay low, and that can target a more up-scale consumer, so that profit margins can be higher to subsidize rural sales. Direct sales suffer when NGOs give away the same product to villagers for free. By having a variety of products, PHW can limit NGO sales to only one part of the product line in order to protect the selling price of the other products. This should allow PHW to meet its goal of financial sustainability while still bringing clean water to poor communities.

1.4.5 Consumer Preference Study

In order to determine what kind of product features local consumers would prefer, Vanessa Green, an MIT graduate student, performed a detailed consumer preference study for PHW in 2008 to indentify the relative importance of different product features. She interviewed 118 urban households and 119 rural households, spending about 45 minutes per interview, to perform a Choice-Based Conjoint assessment, which requires subjects to rank products with a variety of different features. Each subject was shown four concepts which varied by 1) the look and taste of the purified water, 2) product type (durable/consumable or modern/traditional for example), 3) health impact, 4) speed of treatment, and 5) price. The subject would then pick which option they would choose and this was repeated eight times, with four different concepts shown each time (Green 2008).

From this data, Green was able to determine which features were more important. She found that urban and rural households considered the degree of health improvements to be the most important factor when selecting a treatment technique. Both groups also preferred traditional durable treatments to consumables or modern designs, and they emphasized that they wanted products that would last a long time without needing continual financial inputs. Most households did not consider the treatment time, but a few households considered this to be the most important feature. Urban households generally placed a greater emphasis on quick treatment methods. Respondents did not emphasize water taste when selecting concepts and did not mind the taste of chlorine because this indicated to them that the water was treated. Rural users as well as urban users selected options without a major emphasis on cost, even though willingness to pay is usually lower in rural areas. Urban users sometimes preferred higher priced solutions because they associated the higher price with better quality (Green 2008).

Figure 11 Example of the Concept Choices in Choice-Based Conjoint Assessment
Source: Green 2008



2 KOSIM WATER KEG

The Kosim Water Keg (KWK) is a potential new product that Pure Home Water is considering as a future addition to their product line. The KWK, developed by Chris Schulz, a Senior Vice President at CDM, is designed to ameliorate the traditional drawbacks of ceramic filtration: slow filtration rates and the high recontamination risk. This is achieved by switching from a tube or pot shape to a sealed keg shaped filter, large enough to store the cleaned water inside of the filter (up to 18 liters). The candle and siphon filters have one major benefit over the pot filters in that they can be submerged in larger volumes of raw water. This allows for them to be used in a wider variety of containers and allows for additional hydraulic head to increase filtering rates. The KWK is similarly submerged in any raw water container and further increases its filtration rates above the candle and siphon filters by having a larger filter surface area. The other significant advantage of the KWK over candle and siphon filters is that by storing the filtered water inside of the completely sealed keg, the KWK filtered water cannot accidently be re-contaminated through improper handling of the storage container, which was observed in some field testing of the candle, siphon, and pot filters.

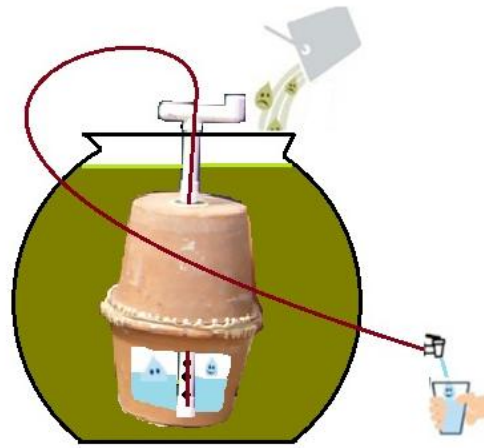
Figure 12 An Assembled KWK (without the siphon) in Front of the Ceramic Water Storage Vessel

In order to make the KWK easy to produce with the existing capacity of in-country ceramic filter factories, it has been designed as a composite of two ceramic pot filters. The openings of these two filters are sealed together to form the keg body. A hand pump or siphon is used to extract the clean water. For full construction instructions, see Appendix A-1.

Figure 13 Schematic Comparison between CPF and KWK

A) Standard Kosim Water Filter
Source: Jackson Murcott, 2010

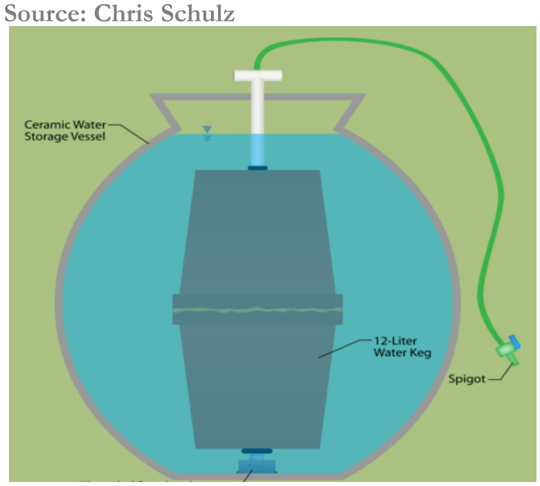
B) Kosim Water Keg
Source: Joanna Cummings, 2010



2.1 KWK OPERATION

To use the KWK, the owner places the KWK inside any large raw water vessel. The raw water filters from the exterior vessel into the keg interior. The maximum volume of clean water storage is limited by the size of the keg (about 18 liters). The raw water vessel can be any type of container that is already owned by the customer and does not need to be sealed or sterile. Larger vessels will increase filtration rates and decrease the frequency of water refills. With a large enough vessel, such as the 170 liter ceramic vessels typically owned by Northern Ghanaians, raw water can be poured into the storage container each morning and left to continually filter into the KWK throughout the day. To prevent bacterial growth inside the filter, the KWK interior should be disinfected periodically by the user with a diluted bleach or an Aquatab (the brand name for a popular chlorine tablet in Ghana) solution. When particulates clog the exterior pores, the ceramic needs to be manually scrubbed.

Figure 14 Schematic of Installed KWK with Siphon
Source: Chris Schulz



2.1.1 Filtration Mechanism

The Kosim Water Keg system uses the same method to remove bacteria and turbidity as the ceramic pot filters. As the water filters into the KWK through the tiny pores in the ceramic, bacteria and particulates are trapped in the tortuous pathways. The ceramic pots are still coated in silver when used for the KWK, and this silver coating prevents bacterial growth on the filter and kills some of the pathogens.

Water is pushed through the filter by gravity. Filtration rates are based on a combination of filter surface area and head (water depth above the filter). The KWK uses two CPFs, and so has twice the filter surface area. Since the KWK can be put in larger containers with more raw water, the pressure head above the KWKs is higher than with the CPF, further increasing filtration rates. To determine how much of the filtration rate increase is due to additional surface area and how much is due to the additional head pressure, the KWK's flow rate can be compared to the sum of the flow rates for the individual CPFs' used to make the keg body. For details, see Section VII subsection A which discusses the filtration rate test results.

2.1.2 Benefits of the KWK Compared to CPFs

The KWK is designed to be an easier to use version of traditional ceramic pot filters (CPF). There are three main problems with the CPFs. First, the filtration rate of the CPF is slow, with maximum rates between 1 to 3 liters per hour. The most that the system can filter without being refilled is the 9-liter capacity of the clay filter, and during some overnight trials, it was unable to completely filter even those 9 liters. The KWK has a larger filtering surface area and additional raw water storage, and so filtering rates are faster (6 to 11 liters per hour). The KWK is designed to be placed in the user's pre-existing water storage container, and the system is refilled on the same schedule that users previously had for collecting water. The user does not need to remember to separately refill the filter and monitor its water level.

The next concern with the ceramic pot filter is that it uses a relatively expensive plastic container as the water storage device; GHS 7.80 of the GHS 15.79 (US$5.15 of the total US$10.43) production price for the Kosim CPF filters comes from the 45-liter plastic container (Murcott 2011). With CPFs, Ghanaian users cannot use their traditional clay storage vessels, which keep water much cooler than plastic containers can. Both CPFs and KWKs use a separate container to store water, but with the KWK, it is the raw water that is stored separately. This means that the container does not need to be clean and can instead be an unsealed ceramic vessel. Because the CPF stores the filtered water in the other container, that container needs to be kept clean and sealed, which necessitates the use of a plastic container.

Finally, there is no residual disinfectant after ceramic filtration, and so the filtered water needs to be kept in clean conditions. If the CPF storage container is improperly used for contaminated water, or if the clay filter is cleaned improperly (for example by placing with the flat bottom on a normal table to dry), the drinking water can be re-contaminated before consumption. With the KWK, the filtered water is stored inside the sealed KWK, where accidently recontamination is less likely. The outside of the KWK filter does not need to be kept clean, and so the filter can be placed on a table or the floor without a contamination problem.

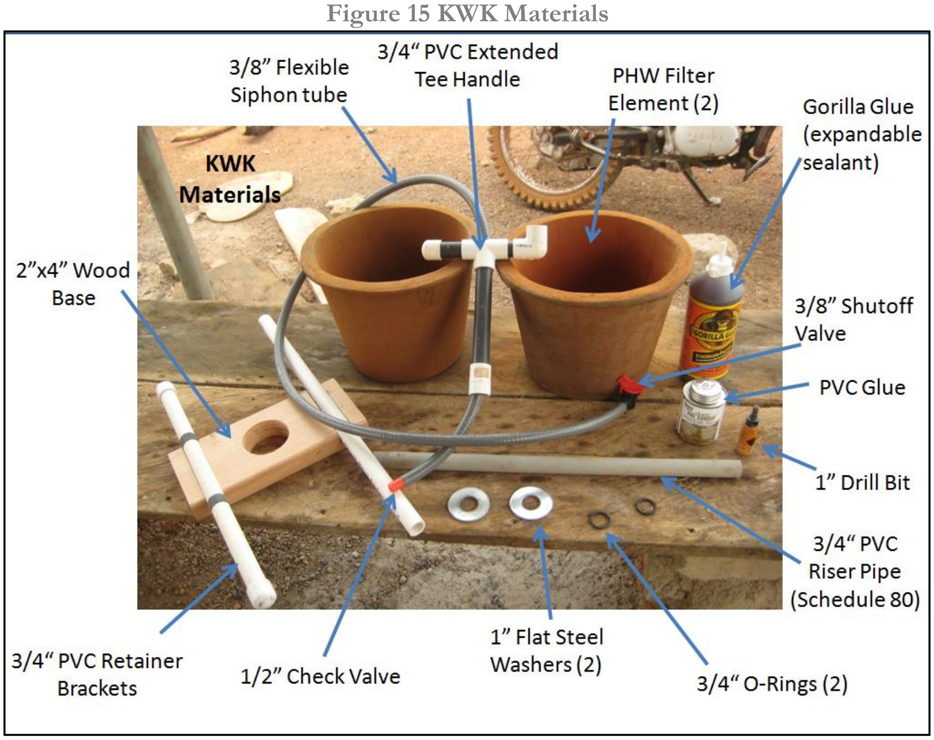
Table 3 Comparison of KWK to CPF

Characteristic	Kosim Water Keg	Ceramic Pot Filter
Flow Rate	9-11 liters/hour	1-3 liters/hour
Raw Water Storage	120 liters (depending on vessel)	7-9 liters
Clean Water Storage	18 liters	30-45 liters
Overnight Filtering Volume	15-17 liters	5-7 liters
Cleaning Procedure	Manually scrub and drop Aquatab into full KWK to disinfect insides	Scrub filter
Recontamination Pathways	Bacterial growth inside filter from imperfect filtration	• Bacterial growth on filter exterior from imperfect filtration, contact with people's hands/tables/ground, contact with raw water • Bacterial growth in clean storage container from improper cleaning, or using container for multiple purposes

2.2 KWK Components

The KWK is designed to be constructed with the tools already in place at Pure Home Water, and in ceramic pot filter factories in general. The image below shows the components that go into constructing a KWK. Full construction instructions are in Appendix A-1.

Figure 15 KWK Materials



2.2.1 Ceramic Pot Filters (two)

Two ceramic pot filters produced from a standard ceramic pot filter factory are used to form the body of the keg. Their top rims are sanded flat and they are sealed (glued) together.

Figure 16 (left) Two Ceramic Pot Filters (right) Two Ceramic Pot Filters Sealed Together Into Keg

2.2.2 PVC Riser Pipe and T-Joint

A three-quarter inch PVC pipe goes through the center of the KWK. A PVC end cap is glued to one end of the pipe, and the top of the PVC pipe is threaded. The pipe is then inserted through the bottom of the keg. The PVC T-joint is screwed onto the top of the pipe, and this provides a compressive force through the keg body to support it. The keg can be lifted out of the water storage vessel and carried by using the T-joint as a handle.

The siphon tubing enters the keg through the riser pipe. Holes at the bottom of the riser pipe allow water to flow into the tube. A hole at the top of the pipe (still inside the keg) allows air to flow out of the pipe as the water enters to ensure a smooth water flow.

Figure 17 (left) PVC Riser Pipe and Its Installation (right) Broken KWK Shows Location of PVC Pipe

2.2.3 Metal Washers (two) and O-Rings (two)

The metal washers and o-rings are both used to improve the connection between the PVC riser pipe and the keg. The **metal washers** are glued to the ceramic pot filters around the entry and exit hole for the riser pipe. This better distributes the weight to the ceramic pots and prevents cracks from forming around the holes.

Figure 19 Metal Washers and O-rings Used to Create Seal at Keg/PVC Pipe Interface

Figure 18 Metal Washer Sealed to the Ceramic Pot Filter Opening

O-rings are small rubber rings designed for making air-tight seals. In this design, one is added to the PVC riser pipe before it is inserted into the keg and then another is added to the riser pipe on top of the keg before the T-joint is screwed on. The T-joint is tightened until a slight compression is viewed in the o-rings, which indicates a good seal.

Figure 20 O-Ring Seal Between the PVC Pipe and Ceramic Keg

2.2.4 Siphon Tube

Electrical conduit is used to create a flexible tubing to siphon water out of the keg. It enters the keg through a hole at the top of the T-joint, and slides through the PVC riser pipe to the bottom of the keg. The tubing is cut long enough to allow the spigot to reach below the bottom of the vessel when the check valve is at the bottom of the KWK (to allow for most of the water to siphon out). A plastic check valve is super glued to the bottom end of the tubing and a plastic spigot is super glued to the other end. The check valve enables the

Figure 21 (left) Siphon Tube With Check Valve and Spigot Attached (right) Siphon Tube Installed in KWK

siphon to be started by shaking the tubing up and down. The spigot preserves the siphon force when the KWK is not in use. When the siphon is working properly, the user should only need to re-start the siphon when they siphoned out all of the filtered water the previous time they used it.

2.2.5 Wooden Restraint System

The KWK is quite buoyant when empty, and so it needs a device to hold it submerged underwater. The January field testing used a wooden restraint system. A 2x4" wooden board has a hole cut in the center, to slide down around the PVC T-joint, and three-quarter inch grooves cut into either end, to hold PVC arms in place. The wood is painted with a water proof veneer to make it durable in the water. The wood block is secured in place by catching the PVC arms against the concave walls of the water storage vessels. The grooves on the ends of the wood keep the PVC arms from rolling off of the wood. Friction tape is wrapped around the PVC arms to fix the wooden board in the center of the PVC arms.

Figure 22 Wooden Restraint System for KWK

2.3 Design Development

The KWK design was developed by Chris Schulz, a Senior Vice President with CDM. In collaboration with Espinoza and the author, he has taken the design through two major iterations over the past two years. The main areas of design alterations are 1) sealing the keg between the two ceramic pots and between the pots and PVC riser pipe; 2) extracting the clean water from the keg; and 3) securing the keg inside the raw water vessel.

2.3.1 First Design Iteration

The first design was tested by Claudia Espinoza in Tamale, Ghana from June to August 2010. She wrote a full report of her study entitled "Kosim Water Keg (KWK) Filter Study." During this time, she tested four KWKs for filtration rate and bacterial and turbidity removal.

Seal Design Iteration 1: Schulz tested many different sealing methods, such as clay, sponge rubber gaskets, epoxy glue and window waterproofing tape, in Denver, Colorado before settling on an expandable glue. He selected Gorilla Glue, an American glue which expands three to four times its original size to create a good seal. It dries in one to two hours, and works on both metal to ceramic and ceramic to ceramic surfaces.

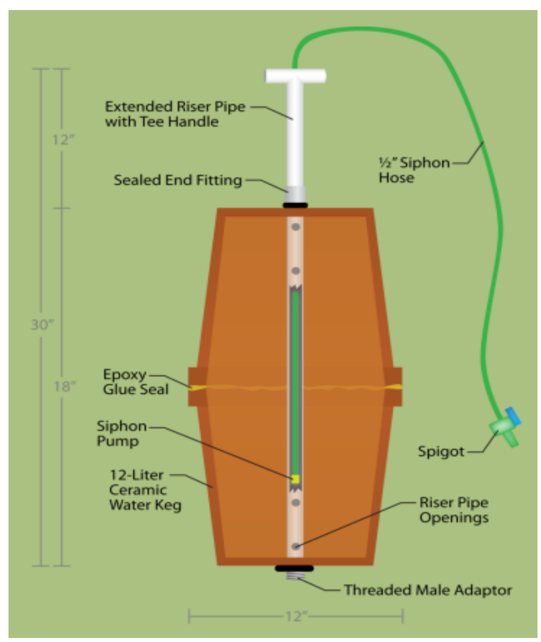
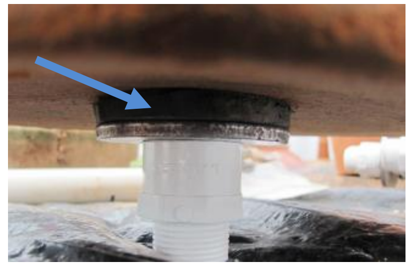


Figure 23 First Iteration KWK
Source: Chris Schulz

The connections between the interior riser pipe and the ceramic keg were sealed using two methods: first, the metal washer was glued on with epoxy. When this failed, a sponge rubber material was hand-cut to be the same size as the metal washer, and placed between the washer and the ceramic. When the T-joint was screwed onto the PVC riser pipe, the gasket compressed and created a seal.

Figure 24 Rubber Connection Between Metal Washer and Ceramic Keg Source: Espinoza 2010



Negatives in Design Iteration 1: The Gorilla Glue is relatively expensive, can only be purchased in the US, and while the MSDS report for the glue does not report any toxic properties (*Materials* 2010), it is not intended for use in drinking water applications. Additionally, the glue is difficult to control; its expansion is variable, especially at higher ambient temperatures, and it is thin and runny prior to drying.

For the seal between the PVC riser pipe and ceramic keg, the epoxy was not strong enough to keep the washer attached to the ceramic and simply broke off. The seal between the riser pipe and the keg leaked when the sponge rubber was used as a sealant. When the PVC riser pipe was screwed on tighter to prevent leaking, the kegs would frequently crack at the bottom.

Figure 25 Ceramic Filter Breaking When Metal Washer is Attached With Epoxy Source: Espinoza 2010

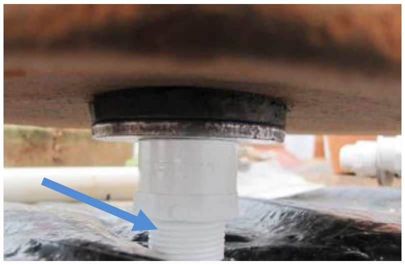
Water Extraction Iteration 1: Water extraction had two possible options based on the raw water vessel. First, the keg could be used inside of a plastic container with the spigot on the bottom. In this configuration, a hose connected an opening at the bottom of the keg to the spigot, and gravity pushed filtered water out through the spigot. If the keg was inside a ceramic water storage vessel with no spigot, water was siphoned out of the top of the keg using flexible plastic tubing, which avoided the need to drill a hole through the bottom of the ceramic vessel, which could break or crack the vessel. The siphon was started by sucking on the hose, and a copper sleeve was attached around the hose to kill the germs from people's mouth (copper is known to have biocide properties). A stopcock valve inserted at the end of the hose was effective in controlling flow and, when closed, for maintaining the siphon effect for subsequent uses without the need to suck on the hose each time to start the siphon.

Figure 26 Tubing Used to Extract Water From the Top of the KWK Source: Espinoza 2010

Negatives: Users in villages around Tamale did not like using a plastic container for water storage, which is why the storage vessel design is being investigated. The relatively high cost of the plastic containers was another drawback. The siphon for the ceramic vessel worked well when the KWK was full, but the starting method of sucking on the tubing needed to be changed for hygienic reasons. If germs accumulated on the spigot, the water could be re-contaminated as it passed through. Additionally, instructing people to put their mouth on the hose inculcates poor hygiene habits.

Submersion Restraint Method Iteration 1: A male threaded PVC fitting was screwed into the bottom of the PVC riser pipe had, and a female PVC fitting glued on the bottom of the clay water vessel. To secure the keg underwater, the bottom of the keg screwed into the PVC fitting at the bottom of the vessel.

Figure 27 Male Adaptor at the Bottom of the KWK to Attach It to the Bottom of the Water Vessel Source: Espinoza 2010



Negatives: This system broke the kegs. The buoyant force was too strong when the kegs were empty, and the bottoms of the kegs would break off. Additionally, the keg was not very stable with this configuration.

2.3.2 Second Design Iteration (January 2011)

This design was developed by Chris Schulz in response to the lessons learned by Claudia Espinoza's testing in the summer of 2010. It was tested by the author in Tamale, Ghana during January 2011. During this time period 11 prototype kegs were made using the 2nd design iteration, of which 8 survived for filtering rate and bacterial and turbidity removal testing.

Seal Iteration 2: Gorilla Glue continued to be the initial choice for glue but in-country alternatives were being considered. The Gorilla Glue worked well for attaching the metal washers to the ceramic, but when used for sealing the rims of the two filters together, it frequently did not expand as much as expected to seal gaps and had large bubbles which allowed for leakage.

Figure 28 (left) Gorilla Glue to Seal KWK (right) SBR Bond to Seal KWK

SBR Bond, a locally available glue, was also tried based on the recommendation of a local engineer. This is a sealant that is mixed with cement and designed for sealing pools. While it does not expand, it is much easier to control, particularly when painted on, and gave a good seal. Additionally, it was already locally available.

To improve the seal between the PVC riser pipe and the keg, rubber o-rings were added to the PVC pipe. This virtually eliminated leaking at the top and bottom of the keg.

Figure 29 Hole in Seal Due to Gorilla Glue Failing to Expand

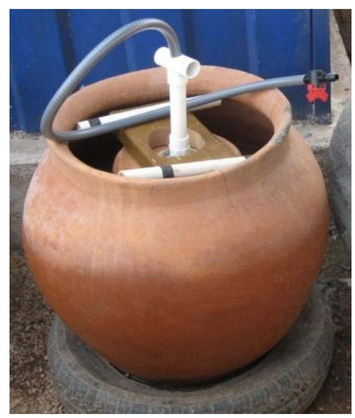
Negatives: The Gorilla Glue's performance was very uneven and unpredictable, especially when the glue was used in hot weather in Northern Ghana. Leaks were evident in all of the kegs after the first gluing; in four cases there were large, visible gaps in the glue. Repeated re-gluing had some effect, but several smaller leaks were left in place in most of the KWKs after three attempts to repair them led to no change.

SBR Bond's lack of expansion meant that it would only work well when the ceramic filters had very even surfaces, which they did when produced by PHW but not by CT. It dried very rapidly, and so any time it was mixed with cement, it needed to be used right away. Cracks in it were visible when completely dry, but none went all the way through the seal. Long-term cracking and potential leakage under varying ambient temperature conditions may be a problem for any cement based sealant.

While the o-rings did a good job sealing the joint between the keg and the PVC riser pipe, the height of the riser pipe still needed to be cut exactly to match the height of individual kegs. If riser pipes were slightly too long, leaking occurred, even if two o-rings were used. Additionally, if the riser pipe did not line up flush against the ceramic due to imperfections in the keg alignment or pipe threading, the o-ring would leak. Use of a longer segment of non-tapered threads at one end of the riser pipe should allow some variability in keg dimensions to affect a good seal using o-rings.

Water Extraction Iteration 2: A siphon continued to be used to withdraw the water, but the hose was replaced with 3/8 inch flexible PVC conduit tubing, which had sufficient rigidity to avoid kinking of the hose during use. A specially designed plastic check valve (called the Super Siphon) was glued to the end of the tubing submerged in the keg. The check valve is designed to start water siphoning by shaking the tubing up and down for 10 seconds or less. The check valve is designed to force water in one direction up the tube until the siphon is started. A spigot was still attached to the tubing to maintain the siphon when the water was shut off.

Figure 30 Siphon Mechanism to Extract Filtered Water from KWK



Negatives: A major challenge was that the ceramic water vessels were normally partially buried in the ground and were too big and heavy to be conveniently elevated. Their round bottom means that they can't simply be placed on top of a table. Since siphons needed to have the outflow below the inflow, this meant that the water containers needed to be filled at essentially ground level. The siphon only worked when the keg was nearly full of water, and even then, each keg had at least once occurrence where a siphon could not be maintained. Siphoning rates were also quite slow. While one keg once produced 6 liters at 2 liters per minute, 0.55 liters per minute was average. Mouth siphoning was still sometimes resorted to when the filters had lower water levels and pumping wouldn't start the siphon.

Water could always be removed through the siphon by continually pumping the tubing, but during household testing, this was frequently cited as the worst part of the KWK design. Additionally, the pumping the siphon caused the KWK to move around in the water vessel, knocking against the vessel wall and encouraging cracking of the vessel.

The plastic check valves also began leaking after a few days, and while tubing with leaking check valves were still able to siphon, this indicates a poor product quality that is unlikely to survive the lifespan of the keg.

Submersion Restraint System Iteration 2: The primary restraint system was a 2x4 inch wooden block collar held in place by a PVC rod on each side. The wooden block had a hole in the middle that the keg riser pipe went through to stay fixed in place. On each end of the wooden block, a square groove was cut across the top of the block to retain the PVC rods. Friction tape was attached to the two ends of the PVC pipe to prevent the pipe from sliding up and down on the wood. The whole system floats, and so the PVC pipes would wedge against the concave curve at the top of the raw water vessel and prevent the keg from floating up higher. A water-proof paint was applied to the wood to prevent it from warping. Nothing was glued together to make installation easier. The keg would be submerged in the vessel, then the wooden block would be placed on top of it, and finally the PVC rods would wedge it firmly in place.

Figure 31 Wooden Restraint System to Submerge and Secure KWK

Another alternative submersion restraint briefly tried was using 2 inch wire mesh to fix the keg. Wood is relatively expensive, and so removing it is a good target for reducing the KWK system cost. The mesh was cut into an octagonal shape to increase its contact with the round edges of the ceramic storage vessels. A larger hole was cut into the center of the mesh to allow passage of the T-joint top of the keg. To install, the wire mesh was rolled in half, pushed into the water vessel, and then allowed to expand back to its full size.

Figure 32 Wire Mesh Restraint System to Submerge and Secure KWK

Negatives: The wooden block system did a good job of keeping the keg centered when it was empty. As the keg filled up and the KWK sank lower, the PVC restraints were shorter than the wider diameter at the middle of the vessel, and so the keg knocked around more inside the vessel. This led to additional wearing of the keg edges and vessel interior, causing some KWKs and water vessels to crack during testing. The other major problem was that each raw water vessel has slightly different dimensions, and since PVC is rigid, each piece had to be cut individually for each vessel. Because exact measurements were hard to make due to the vessel curvature, pieces frequently had to be cut multiple times. In the long term, a faster installation process would be needed for mass production. Since no power tools are needed to cut the PVC, they could theoretically be cut individually at people's homes, but this would be time consuming. A

Figure 33 Wooden Restraint System Failing to Center KWK After KWK Fills With Water and Sinks

final problem was that this method makes it easy for the user to press down too hard on the keg while installing it, leading to the bottom of the keg cracking. This particularly occurs when the PVC pipe ends are cut slightly too long.

The wire mesh restraint system was extremely difficult to put in. Since it was all one piece and necessarily larger than the water vessel opening, it was difficult to get past the vessel opening. It took one person to hold the keg and one person to wrangle the mesh to install it, whereas the wooden restraint system can be installed by one person. Finally, while it was rigid enough to be difficult to install, it was flexible enough to allow the keg to bend it upwards. The mesh was partially deformed upwards from its installation, and the keg was able to further bend it enough to pop the mesh out of the vessel. A multi-part restraint system, such as the wooden block with PVC arms, proved to be preferable from an installation perspective.

2.3.3 Third Design Iteration

After the author returned from Ghana at the end of January 2011, she discussed her experiences in KWK construction with Chris Schulz. Based on this information, Schulz continued to improve the KWK design with Lauren Schmeisser, a graduate student at the University of Colorado. Details of their design improvements can be seen in Appendix A-3.

3 PROJECT OBJECTIVES AND TESTING METHODOLOGY

The field work took place from January 3rd to 28th in Tamale, Ghana using the second design iteration for the KWK. The goal was to determine how well the design improvements performed in Ghana and which design elements still needed further development. Claudia Espinoza's previous work using the first design served as a baseline for establishing testing protocols and identifying potential areas of concern. This study also began looking at consumer preferences and conducted a short-term trial where families used the KWKs in their homes and provided feedback on the design performance after they were more familiar with the product.

3.1 CONSTRUCTION TECHNIQUE

The KWK design had been modified as described in Section II since Espinoza's last field testing. There were five aspects of the construction process that were particularly emphasized due to past construction problems:

1) **Filter Element Durability**: The ceramic filter elements themselves must be strong enough to withstand the compressive forces of the KWK design. Espinoza found that the PHW filters she constructed at the factory were too brittle and easily cracked at the bottoms.
2) **Sealant**: The Gorilla Glue would continue to be used as the sealant, but a project goal was to investigate alternatives sealants that would be locally available.
3) **Seal Between PVC Riser Pipe and Ceramic Pots**: The addition of o-rings was expected to provide an improved seal between the PVC riser pipe and the ceramic keg. Schulz anticipated that this improvement would reduce over-tightening of the PVC riser pipe, which would hopefully reduce keg cracking during construction.

4) **Water Extraction Method**: The siphon was redesigned to be started using a check valve instead of mouth pipetting. New tubing was also being tested.
5) **Submersion Restraint System**: The restraint system was redesigned to put less concentrated stress on the KWK. This testing would determine how easily it could be installed and how stable it was both when the KWK was empty (buoyant) and full (sunken).

Espinoza's previous testing experience led to some changes in the construction procedure. First, she had a problem finding all the necessary parts in country, and ending up needing to custom make some parts. Because this field study period was shorter than hers, all KWK components, except the ceramic pot filters, were brought from the United States. All components of the new KWK design were selected for their probability of being local availability in Ghana, but the short time frame did not allow time for sourcing them in country.

Espinoza also had problems with the PHW filters being too brittle[3]. To make sure that an adequate supply of ceramic pot filters would be available for keg construction, CT pot filters were ordered. They would be used in place of PHW pot filters in the event that PHW filters could not be used. PHW filters were the first choice for the construction because the KWK is intended to be produced by the PHW factory. In the end, two of the eight KWKs tested on this trip were made from PHW filters.

A final component of the construction goals was to document the process of KWK production. The process was fully photographed in order to make an illustrated construction manual that would provide enough information for someone to make KWKs without any additional training.

Deliverables for the construction process research were:

1) An evaluation of which aspects of the design still need improvements
2) An illustrated construction manual

3.2 BACTERIAL REMOVAL

The key performance metric for the KWK design will be if it can maintain the same bacterial removal properties of the ceramic pot filters. This parameter is important because this factor will determine the potential health impact of the KWKs. Relative to CPFs, the KWK will have additional potential leaking points where raw water could contaminate the filtered water. Schulz has developed a leak test for the KWK, and this technique will be tested to see if it is an accurate predictor of bacterial removal.

[3] Ms. Espinoza participated in producing some of the very first filters manufactured at the PHW factory. This meant that the production process and resultant filters themselves were still in the prototype testing phase.

For bacterial testing, water samples were collected in 100 milliliter sterile WhirlPak® bags each morning from the water that had filtered into the KWKs overnight. The samples were stored in coolers with freezer packs until they could be refrigerated (usually 4 to 6 hours later). Samples were run usually within 8 hours but always within 12 hours of being collected. This delay is acceptable based on the research of Misty Pope who established that as long as samples were maintained at 10 degrees Celsius and not frozen, data analyzed between 8 and 48 hours after collection provided similar results to those analyzed within 8 hours of collection (Pope 2003). Two methods were used for quantifying bacterial removal: membrane filtration and Quanti-Tray™. All tests used undiluted 100 mL samples.

Figure 34 Water Samples Stored in Cooler With Ice Pack

Figure 35 Membrane Filtration Field Unit

The membrane filtration followed the field procedure outlined in the Millipore *Water Microbiology Laboratory and Field Procedures*. Testing was done using six Millipore Membrane Filtration Field Units. Sterile absorbent pads were placed in reusable stainless steel petri dishes. 2 mL ampoules of m-ColiBlue24 Broth from Hach were poured onto the absorbent pads and excess Broth was removed with a tissue. 100 mL of sample was suctioned through the Membrane Filtration Field Unit using the pumping syringe plunger. Two rinses with sterile water were suctioned through to ensure that all of the sample water went through the filter. Petri dishes and 100 mL measuring cups were sterilized by boiling them in water for at least 30 minutes. The Filtration Field Units were sterilized by soaking their wick rings in methanol and flaming them to produce formaldehyde. The Units were allowed to sit with the lid on for 15 minutes to complete the sterilization. After incubating the petri dishes for 24 hours, total coliforms were indicated by red dots and *E. coli* colonies were indicated by blue dots. Membrane filtration can measure up to 200 colonies per 100 mL sample without sample dilution.

Figure 36 Counting Quanti-Tray™ Results

The Quanti-Tray™ tests used IDEXX's 24-hour Colilert reagent and the Quanti-Tray/2000™, which includes a mixture of large and small sample wells to distinguish contamination levels at higher levels of contamination without sample dilution. Quanti-Tray™ produces a Most Probable Number (MPN) value per 100 mL sample. The number of small and large wells that turn a positive color were counted. These numbers were entered into IDEXX MPN Generator program which converts the well numbers into the MPN value and provides the MPN for the 95% confidence interval. Wells indicate the presence of total coliforms by turning yellow. Yellow wells that fluoresce under black light are positive for *E. coli*. Quanti-Tray™ can measure up to 2,419.6 MPN per 100 mL sample in undiluted samples.

For a comparison of results, bacterial testing was done on PHW and CT ceramic pot filters at the same time as the KWKs. The bacterial testing methodology selected varied by date of testing and not by filter type. Membrane filtration was used on the first two days of testing and Quanti-Tray™ was used the rest of the days.

The target for bacterial removal performance is to meet WHO *Guidelines for Drinking-Water Quality,* which recommends that there be no coliforms or *E. coli* in a 100 mL water sample (WHO *Guidelines* 2008). However, WHO guidelines also provide risk classifications for water based on *E. coli* concentrations (Table 4 below). A more realistic target is to ensure that the KWKs consistently provide "low risk" water after filtering.

Table 4 Water Risk Classification
Source: *Guidelines for Drinking Water Quality* (WHO 2008)

Count per 100 mL	Classification
0	Conforms with WHO Guidelines
0-10	Low Risk
10-100	Intermediate Risk
100-1,000	High Risk
> 1,000	Very High Risk

3.3 TURBIDITY REMOVAL

Turbidity results will be another metric to compare the KWK to the CPFs as a verification that the KWK design does not allow for contaminated water to leak into the filtered water. The marginal cost of a turbidity test is nearly free, whereas each bacterial testing can cost up to US$6. If turbidity removal does correlate to the integrity of a KWK, it will be a cheaper parameter to regularly measure.

Figure 37 Field Turbidity Measurement

To collect water samples for turbidity, each 15 mL sample was collected in a glass sampling bottle, and wiped dry with tissue paper. A drop of silicone oil was added to the glass and wiped off with the oiling cloth. Samples were taken in triplicate and averaged to ensure better quality. Samples were taken every morning at the same time as the water samples for bacterial testing.

Turbidity readings were measured in the field with the HACH 2100P IS Portable Turbidimeter, which has a range of 1 to 10,000 NTU.

To compare KWKs to CPFs, turbidity was measured for the raw and filtered water using ceramic filters produce by both PHW and CT.

The goal for the turbidity removal is to match the performance of the CPFs. The WHO does not have specific health guidelines with regards to turbidity removal. While 0.1 NTU is recommended to ensure the efficacy of chlorination, this is not required for filtration treatment. WHO says that 5 NTU is usually the level that people will aesthetically accept, although they specify that this can vary regionally (WHO *Guidelines* 1998). Based on conversations with locals in Taha, Ghana, people are tolerant of some turbidity in their drinking water because they are accustomed to highly turbid dugout water.

3.4 FILTRATION RATE TESTING

Filtration rates are an important factor for making the product convenient and appealing to users. Filtration rates are a function of filter area, which is relatively unchanging, and the available water head, which will change based on the height of raw water in the ceramic vessel and the height of the filtered water inside the keg. The four possible changing head scenarios are illustrated in the table to the right. Based on surveys of the households in Taha and Gbalahi, households usually refill their water vessels once a day, and so filtration rates were measured under falling head conditions, where the vessels were only refilled at the end of each day.

Table 5 Definition of Filtration Rate Scenarios

	Keg Level Rises	**Keg Level Stays Low Due to Draining**
Raw Water Level Constant Due to Refilling (Constant Head Test)	Head level decreases slowly	Head level stays constant
Raw Water Level Drops (Falling Head Test)	Head level decreases quickly	Head level decreases slowly

The method to measure the volume of filtered water varies by whether or not the filtered is being removed from the KWK. To measure the volume of filtered water while draining the KWK, filtered water was poured out into a 1 liter graduated cylinder, marked off at 50 mL intervals. To measure the volume without emptying the keg, a floating rod was calibrated to measure the height of the water in the keg. The rod was marked off with a height-volume correlation specific to each keg created by pouring 500 mL at a time into the keg and measuring the height at those known volume increments.

Figure 38 Measuring Volume Filtered by CPF

In the end, to filtration volumes were measured. First, the filtration rates per hour over four hours were measured as the volume in the vessel dropped and the KWKs were continually emptied. The other filtration scenario was the total water volume filtered overnight when the KWK was not emptied. The overnight filtration volume is important because it will represent the amount of water available for families each morning.

Standards for speed of water access could not be found in literature, but there are standards for minimal water volumes needed per person. WHO guidelines for basic access to clean water for water and sanitation purposes (including drinking, cooking, and hygiene) are 20 liters per person per day, which is still considered to be sustainable access but still a "high" health risk. "Optimal access" is considered to be 100 liters per person per day or higher (WHO *Guidelines* 2008). For just drinking water consumption, the WHO recommends 1 to 2.4 liters per person per day in normal conditions. Considering the heat in Ghana, households are most likely closer to the 2.8 to 3.4 liter range (Howard et. al, 2003).

Table 6 Daily Fluid Intake Reference Values in Liters Per Capita
Source: ***Domestic Water Quality, Service Level and Health*** (Howard 2003)

	Normal conditions	High average temp. 32°C	Moderate activity
Adults	1.0-2.4, average 1.9 (including milk); 1.4 (excluding milk)	2.8-3.4	3.7
Adult male	2	-	-
Adult female	1.4	-	-
Child (10 years)	1.0	-	-

To compare the KWK's performance to the CPFs, overnight filtering volumes were measured for PHW and CT CPFs. One hour flow rates were also measured. Hourly falling head filtration rates over a period of time were not measured for CPFs due to time constraints and instead, this data was pulled from previous research.

3.5 Siphon Rate Testing

The siphon rate determines how quickly filtered water can be accessed by the users. The expectation was that the siphoning would enable the users to extract water from the top of the KWK without needing to continually pump water[4]. The method for starting the siphon in the second design iteration had not been previously tested on the KWK in the field until the author's January 2011 work. This January testing would determine what volume of water needed to be inside of the KWK for the siphon to work and what percentage of the filtered water the siphon would be able to extract.

No global standards could be found for minimum flow rates. Users currently dip their cups or bowls into their water vessels to fill them up, but households that had working storage containers from PHW filters were using the spigots to access the water. This suggests that if siphoning rates out of the KWKs are comparable to that of the PHW spigots, people will accept it, but further research will be needed on this point.

Siphon rates were measured in 10 second increments using a 1 liter graduated cylinder marked off at 50 mL increments. To start the siphon, the hose was pumped for 10 seconds. Once a liter was reached, the spigot was turned off, the total time for that liter was written down, the graduated cylinder was emptied, and the spigot was turned back on without re-pumping. The measurements were taken until either 1) the siphon wouldn't start after three attempts to start it; 2) the siphon flow rate dropped below 0.20 per liter; or 3) the siphon flow stopped.

To compare the KWK design to CPFs, the flow rate out of the spigot of the PHW containers was measured in 10 second increments using the 1 liter graduated cylinder marked off at 50 mL

[4] Gravity fed systems extracting water from the bottom of the KWK would produce faster flow rates, but it was important to avoid drilling holes into the traditional vessels for fear of breaking the vessels or causing new leaks or cracks

increments. The containers each had about 3 liters of water in them for this test. The containers were tilted when they were nearly empty to release as much water as possible from the containers.

3.6 USER ACCEPTANCE

User feedback of the KWK design was used to determine which features people liked and did not like in the current design. This determined what design aspects deserve particular focus in future iterations and what to emphasize when marketing the KWK.

Figure 39 Surveying Households in Taha, Ghana

User feedback was gathered in two stages with the help of Chris Schulz, the CDM vice president and designer of the KWK, and Amuda Abdul-Rashid, a PHW employee and translator. First, ten families in Taha and six families in Gbalahi were interviewed to find out 1) the measurements of their water vessels; 2) their water source and collection habits; and 3) their experiences with Pure Home Water filters. These surveys were used to select five households to participate in the second method of user feedback: a 10 week in-home study of the Kosim Water Kegs. The KWKs were supplied to these families with a clay vessel storage vessel sized to accommodate the KWK diameter. Abdul-Rashid visited each household weekly to ask a series of questions regarding how the KWK performed in the past week. At the end of the survey, he asked families to make suggestions for KWK improvements. Families who had previously used the Kosim pot filter were asked to compare the performance of the KWK to the CPF.

4 FIELD CONSTRUCTION

The author worked with the Pure Home Water Factory to construct a total of 11 KWKs. The KWKs were made from both Pure Home Water (PHW) filters and Ceramica Tamakloe (CT) filters. Construction took place out-of-doors in conditions that closely simulated assembling KWKs at users' homes.

Figure 40 (left) Center Marked on CPFs (center) Hole Drilled Into Center of CPF (right) Metal Washer Sealed Around Hole



Figure 41 (left) Best Alignment Found to Match Up the CPFs (right) Gorilla Glue Applied to Rim

A complete guide to KWK construction is in Appendix A-1, but the basic steps are as follows. First, two traditional ceramic filters with flat rims are selected. A one inch hole is drilled into the center of each of their bases and a one inch steel washer is glued around each hole.

Next, the pot filters are stacked on top of each other and rotated to find their best alignment with the fewest gaps between the two rims. This position is marked with a pen. Glue is applied to one rim, and the two pots are glued together and allowed to dry with a PVC pipe placed through the pots to maintain a straight alignment.

The interior PVC riser pipe is made from drilling a series of holes in 3/4 inch schedule 80 PVC pipe. A hole in the top of the PVC pipe (inside the assembled keg) prevents a vacuum from forming inside the pipe during filtering. A PVC cap is glued onto the bottom end of the PVC pipe, and the other end of the pipe is threaded to be the appropriate height.

Figure 42 (top left) PVC Pipe With Holes Drilled In (bottom left) PVC Pipe Being Re-Threaded (bottom right) Screwing in PVC Riser Pipe with O-Ring Seals

An o-ring is added to the pipe, which is then put through the keg and topped with another o-ring and a T-joint. The T-joint is screwed on the top of the keg top to form a compression seal with the PVC cap at the keg bottom. A 3/8 inch flexible tube is inserted through a hole in the top of the T-joint and water is siphoned out.

Prior to use, the KWK is tested for leaks by screwing flexible tubing onto the top of the keg, submerging the keg underwater, and manually blowing into the tube. Places where air bubbles escape the filter are marked, the glue there is filed down, and new glue is applied. The KWKs were not used in this field study until they were able to exhibit acceptably small leakages in the leak test.

Figure 43 Leak Testing the Completed KWK

To construct KWKs that were initially clean, the interior of the kegs were scrubbed with clean water immediately before gluing. After gluing and prior to testing, the kegs were filled with chlorinated water that was shaken around the KWK interior. Prior to bacterial testing, this chlorine was removed by allowing the KWKs to filter their full volume at least twice.

4.1 CERAMIC FILTER PRODUCTION

Because of the project partnership with Pure Home Water, the author preferred constructing KWK filters from PHW pot filters. However, the factory is still establishing their filter production methodology and quality controls, and they were not yet in full-scale filter production. The author spent the first week of January producing filters for the KWK construction. Two clay/combustible formulas were selected based on the work of Travis Reed in January of 2009 at the PHW factory. The first mixture was the one recommended by Reed as being the best balance between filtration rate and strength. This used 11 parts clay, 1 part grog (formed by pounding up fired clay), and 4 parts combustible (for the PHW factory, this is sieved rice husks). Another mixture tested by Reed produced slightly slower flow rates but was stronger. This one used 11 parts clay, 1 part grog, and 3 parts combustible material (Reed 2009). Because previous testing of the KWK by Espinoza had indicated that filtration rates were acceptable but their strengths were inadequate, the author decided to test the stronger mixture to better meet the KWK's needs. One important challenge in using Reed's formulas during this trip was that Reed employed a hammer mill to grind the rice husk. His recipes called for a mixture of the crushed and uncrushed rice husk from the hammer mill. During this trip, however, the hammer mill was not operational. The rice husks were hand sieved, and only material that could pass through the sieves was used, but it is unknown how that particle size compares to the combustible material used by Reed.

Figure 44 Pressing the CPFs in the Flowerpot-Shaped Hydraulic Press

After the clay was mixed, the pots were pressed on the hydraulic press that produces flat-bottomed flowerpot-shaped filters. The KWK design requires a flat bottom to ensure a good seal with the metal water and the PVC riser pipe. The PHW factory owns two presses: an older flowerpot-shaped press and a newer egg-shaped press. The egg-shaped pots are completely rounded on the bottom; this makes them stronger and easier to press. To work with the KWK design, however, the bottoms would need to be flattened to have at least a 3 inch diameter flat circle on top. Attempts were made by Espinoza in the summer of 2010 to manually flatten the top of the egg-shaped pots, but the bottoms need to be completely flat and parallel to the ground for the assembled KWK to achieve a good seal. As a result, the egg-shaped mold, which is present in other ceramic pot filter factories in addition to the PHW factory, cannot be used without modifications to the mold itself.

The press design also affects the quality of the pressed pots for KWK construction. The egg press uses a male mold as the bottom part and presses the female mold on top. This allows for the pot to be lifted cleanly off the press and moved to the drying wrack without removing the pot from its drying board. The older press is the opposite, with the female mold on the bottom. As a result, after pressing, the user must flip the male mold upside down onto a wooden drying board. Because of the weight of the mold, the rim is frequently compressed on one side to a small but visible degree during this process. If the tilt is too pronounced, the pot cannot be used for the KWK, which requires the pot rims to be perfectly parallel to the ground to achieve a reliable seal.

After pressing, the pot filters require a full week to dry before they can be fired, and so the author's filters were not ready until the beginning of the third week of the trip. Due to the short trip length, the majority of the KWKs were made with CT filters to allow for a longer testing period. When the PHW filters were ready, two KWKs were made from them, but these filters were not silvered prior to use. All test results referencing PHW filters (KWKs and CPFs) are without silver.

4.2 Ceramic Filter Selection

KWKs are easier to construct well when their component ceramic pot filters are selected based on the following criteria.

4.2.1 Filtration Rate

To select filters for use in constructing KWKs, the one hour flow rate for each ceramic pot filter was measured. Standard quality control protocols for ceramic pots filters recommend having filtration rates between 1 and 3 liters per hour (Hagan 2009). Above that, and the filters are usually ineffective at removing bacteria, and below that, users lose interest in the filter. Pure Home Water had stopped using CT filters because of concerns with filtration rates that were too high. Of the 25 CT filters tested by the author, however, all but 4 of them were between 1 and 3 liters per hour. When pairing up CPF to form individual kegs, the author tried to select pairs of ceramic filters that would total to filtration rates of between 4 and 6 liters per hour.

4.2.2 Filter Strength

The KWK design is known from Espinoza's work to put more stress on the bottoms of the ceramic filters than their traditional use does. Therefore, the filters need to be particularly robust to perform well. The CT filters have distinctly thinner bottoms than their PHW counterparts. This caused the KWKs made from CT filters to be more prone to breaking if the PVC riser pipe was screwed on too tightly or if too much pressure was applied when submerging and securing the KWK in the raw water vessel. Of the ten kegs made, eight were good enough for testing, and four (half) broke at some point during the two weeks of testing. The breakages were consistently a collapsing of the bottoms and tops of filters along the perimeter where the thinner bases met the thicker filter walls.

PHW filters did not exhibit this problem during testing and also experienced less wearing around the edges compared to the CT filters.

4.2.3 Rim Shape

While the filters are sealed together with expanding glue, the seal is better when the rims of the two CPFs meet together smoothly. The CT filters have inconsistent rims th at make this more difficult to achieve. Some of their filters have rounded rims and others have flatter rims but neither surface is completely smooth. For this construction, the CT filter rims were filed down to achieve the desired smoothness. CPF pairs were matched up by how well they aligned together, and individual high spots were filed down. PHW filter molds produce much smoother and more even rims. However, when the pots are flipped onto the wooden drying board, the rims are sometimes smashed into a slight angle that needs to be filed down prior to KWK construction.

Figure 45 Filing Down the CT Filter's Rim

The rim width also affects the quality of the keg seal. CT filters have very narrow rims, and while filling them down does increase the flat surface, it was still only possible to put a small line of glue onto them. The sloping of the CT's rim, along with imperfections in filing, caused the glue to slide off of the CT filter's rim much more easily than with the PHW filters. The PHW filters have very wide, very flat rims, which allowed for thicker bands of glue.

4.3 Glue

The glue used as the sealant in the current design was Gorilla Glue[5], an American expanding water-proof glue. The glue's MSDS sheet lists it as non-toxic (Gorilla 2010), but there is no information as to whether it was tested in a situation of constant immersion.

4.3.1 Concerns with Gorilla Glue

The biggest concern with Gorilla Glue during this trip was its uneven expansion. There were never any problems with Gorilla Glue expansion when attaching the metal washers to the clay, but the glue was not expanding to its expected capacity in the ceramic to ceramic bonding between the two CPF. As the glue dried, some pots had much larger air bubbles in the glue, and these pots, when fully dry, had glue with virtually no expansion. This under-expansion was observed primarily in glue seals that were applied in the afternoon, and the author speculates that it could have been due to the direct heat and the dryness of the climate (the Gorilla Glue reaction requires some moisture to react properly). This work was all done out of doors and, for the first five KWKs, was done in the open sun. After the glue first failed to expand, subsequent

Figure 46 Gaps in the Seal Due to Lack of Gorilla Glue Expansion

[5] While Gorilla Glue is not normally available in Ghana, it can be special ordered through Hatoum Trading, a hardware store in Tamale.

gluings were done in the shade, but still in the warm climate, and the problem persisted. Prior to applying the glue, the surfaces are wetted down with clean water as directed, but Ghana is an unusually dry climate during this time of year. Ghana experiences Harmattan during January, the dry season where Sahara dust blows into Ghana. The glue may not work as well in these kinds of extreme environmental conditions. The lack of expansion could not be compensated for by applying more glue due to the limits of how much glue could fit on the pot filters' rim before running down the sides.

Another problem with Gorilla Glue was that it did not provide a complete seal on its first application. None of the KWKs made with Gorilla Glue passed the leak test after their initial gluing. Even with reapplying the glue two or three times to a leaking site, kegs would still have a leak in the same spot. Sanding down the glue first before glue reapplication helped some but was still not enough to consistently completely seal a leak.

4.3.2 Alternative Sealant

Figure 47 SBR Bond Used to Seal Two PHW CPFs

After consultation with Iyad Hatoum, the general manager of Hatoum Trading (a materials supply shop in Tamale, Ghana), SBR Bond was tried to seal the two pot filters together. SBR Bond is a rubberized cement that is traditionally used to seal pools. It is mixed with cement at a ratio of 1 part glue to 2 parts cement by weight to form a stiffer liquid. It is completely water-proof, but does not expand. The bottle does not list any ability to bond to metal, and so Gorilla Glue continued to be used to bond the steal washers to the filters. The SBR Bond was used only on PHW filters, which had smoother rims that could be sealed without expanding glue. Painting on the SBR Bond glue allowed for excellent control of the glue and created a more finished appearance to the KWKs. The glue could be laid on thickly enough to create a full seal, and of the two KWKs made with this glue, one keg passed the leak test after the first application of glue. The other keg had its leak sealed with Gorilla Glue once, and then could pass the leak test. SBR Bond did show some small cracks after it had dried, but they appeared to be shallow. No leaks were observed at those points. This could possibly be prevented by allowing the glue to dry more slowly by either keeping it moist, like is done normally for cement, or keeping it out of the direct sunlight.

4.4 INTERIOR PVC RISER PIPE

No significant problems were encountered with constructing the interior PVC riser pipe. The necessary tools (an electric drill, vice, pipe threader, and generator) for drilling the holes and threading the pipe were available at the PHW factory. A paper template was made to mark off the exact location of holes in the PVC pipe. At the pipe bottom, each pipe had five holes drilled into it set one inch apart in the vertical direction and every 90 degrees around pipe. The first hole was the only critical measurement; it was measured to rest just above the bottom of the KWK to ensure that the maximum amount of water could be extracted from the keg interior. A hole was also drilled into the top of the PVC riser pipe to allow the air displaced by the water to flow out of the pipe. This top hole was not at an exact measurement, but should be near the top of the KWK interior to prevent it from being submerged in water.

The one challenge in cutting the interior pipe came from the variable sizes of the CT filters. Each constructed KWK was a slightly different height, with up to a quarter inch in variation. This variation was enough so that the interior pipes were not interchangeable between KWKs, but instead had to be custom cut for each one. In order to make the construction process faster, all the pipes were cut longer than necessary and had their holes drilled and end caps glued on at the same time. After each keg finished drying, the exact height was marked for each KWK, and the tops of the PVC pipes were re-threaded to match individual KWKs. When two o-rings were tried in an attempt to compensate for a too-long PVC riser pipe, leaks were observed at the o-rings.

Figure 48 Measuring PVC Riser Pipe to Cut It for the KWK Height

4.5 COMPRESSION SEAL

The compression seal was applied carefully by hand. The assembler would lay the KWK on its side and hold the bottom cap still while twisting the top T-joint with their other hand. While this was quick to do, it was essential that the assembler carefully watch the o-rings and stop twisting as soon as the o-rings begin to deform. Applying too much pressure resulted in the bottom or top of the keg cracking, as happened with the first keg assembled by the author.

4.6 SIPHON

To remove water from the KWK, a siphon mechanism is used. A check valve was attached to the bottom of flexible tubing, and this tubing was inserted through the T-joint into the PVC riser pipe. Pumping the tubing up and down established the siphon; water is pushed into the tube every time the tube is moved down and is kept in the tube by the check valve when the tube is pulled up. Once the siphon begins, as long as the spigot is kept below the level of the water in the KWK, the siphon continues flowing.

Figure 49 Siphon Threaded Through T-Joint

This method to start the siphon was worked when there was a large amount of water (more than 8 liters) inside the keg. When water volumes in the tube were too low, an excessive amount of pumping was required to get any flow, and it would quickly stop. When the siphon worked, it performed well, but getting it to work took some practice. Typically pumping for 10 seconds was enough to get a steady flow, but after three attempts, a siphon was considered to not work. Where the siphon could not be established by pumping, sometimes the user could suck on the tubing to begin the siphon, and then have it flow normally. However, this method is not sanitary and would likely encourage users to normally treat the spigot like a straw, particularly since it visually looks like one.

The check valves were plastic and began to leak soon after using them. Originally, this leaking was thought to be the reason that the siphon was not working in the KWKs. However, after trading tubing between KWKs that were siphoning well and those that were not, it was determined that the observed minor leaks did not cause a problem in siphoning. However, the early sign of leaks is an indicator that the check valves may not have the durability to work throughout the lifespan of the KWK.

Overall, siphoning was not a very effective removal mechanism because the water storage vessels are normally kept at ground level. The clay vessels have rounded bottoms and are secured by either digging a hole into the ground or placing them into an old tire. In both scenarios, the height difference between the KWK water level and the user's cup is going to be small. For water to be siphoned out, the collection vessel must be shallow and placed flat on the ground to keep the spigot below the height of the filtered water inside the KWK. Building a stand for the water vessel to increase siphoning rates would be impractical due to the size of the water storage vessels. They hold between 80 and 120 liters of water which translates to 175 to 265 pounds of weight from the water alone (neglecting the clay vessel itself). Any stand would likely be prohibitively expensive.

4.7 Restraint System

The restraint system serves two functions: 1) it keeps the KWK submerged even when it's empty; and 2) it keeps the KWK centered to prevent it from knocking into the vessel walls and damaging itself or the vessel. The KWK is quite buoyant when empty and is naturally unstable in the water. The current restraint system places the PVC riser pipe through a hole in a wooden block. Grooves in the block hold short pieces of PVC pipe arms. The PVC pipe is cut to catch against the curves of the top of the ceramic water vessel.

Figure 50 KWK Submerged with Wooden Restraint System

4.7.1 Benefits of the Wooden Restraint System

The system works well in several respects. First, it can be put in place by one person using only one hand. It also allows the user to remove and re-install the keg repeatedly without needing any tools or disposable parts. It is extremely simple to make, and the supplies are durable[6] and readily available.

4.7.2 Problems with the Wooden Restraint System

One problem encountered with this restraint system was that if the PVC pipes were cut slightly too long, there was a tendency to press down too hard on the KWKs to make the PVC arms fit. This caused the bottoms of the KWKs to crack; two of the four failed KWKs broke this way. While this was due to user error (pressing down too hard on the KWK) the fact that the author made this error twice indicates that inexperienced home users are likely to make the same mistake. Sizing the PVC piping is an iterative process, and longer PVC pipes make the installed KWK more stable inside the vessel. The KWK sinks as it fills with water, and the vessel diameter widens towards the middle, and so the longer the PVC pips are, the more centered the KWK stays when full of filtered water.

[6] The wood block was coated in waterproof paint to extend its life underwater.

Figure 52 Bottom of KWK Cracked When Pressed Down Too Hard During Installation

Figure 51 KWK Loose in Vessel After It Filled and Sank

Another difficulty with the restraint design was that it put concentrated pressure on four points in the vessel wall. The author had problems with the ceramic water vessels cracking, and all six vessels needed to be repaired at least once during the two weeks. This could have been due to problems with the ceramic vessels provided to the author. These particular ceramic vessels did appear to be weaker than the vessels used by the villagers because the author saw cracks forming before anything was done the vessels. However, further testing should be done to determine what effect the restraint system does have on vessel lifespan, because the vessels are expected to last for years.

4.7.3 Wire Mesh Restraint System

Figure 53 Wire Mesh Restraint System

An attempt was made to switch the wooden restraint with a wire mesh grid restraint. The wood block is relatively expensive, and so using a one inch wire mesh would be cheaper. The mesh was cut into an octagon to provide more contact area with the vessel and a hole was cut in the middle for the PVC riser pipe. However, when the KWK was empty, the pressure against the mesh was too much, and the mesh quickly bent out of shape. Also, installing the wire mesh was much more cumbersome than installing the wooden restraint. Because the mesh was all one piece, compressing it through the constricted rim of the water vessel was tricky. With the wooden block restraint, the wooden block is smaller than the rim and the PVC pipe can be put into the vessel vertically to fit past the smaller diameter rim and rotated horizontally once they are in the wider middle of the vessel.

4.7.4 Restraint System Limitations

If the keg were to be implemented in another area, the restraint system would need to be adapted for local water containers. Currently, the restraint system only works on vessels that curve inwards and so would not work for water stored in converted oil drums or in any straight-sided plastic container.

4.8 Leak Test

The leak test was designed to be a way to determine which KWKs were not properly sealed. While some kegs had visible gaps after the first gluing, most leaks were too small to be visible without the leak test.

4.8.1 Leak Test Methodology

Figure 54 (left) Blowing into KWK for Leak Test and (right) Air Bubbles Escaping Through Leaks

To perform this test, first a threaded male adapter attached to a plastic hose was screwed onto the keg in place of the T-joint. Next, the keg was submerged in water just enough to inundate the bottom seal connecting the washer to the ceramic filter. Then, one person would blow into the plastic tubing, and another person would watch for any air bubbles emerging from the seal. After that, the keg would be submerged passed the central seal between the two pot filters, and again one person would blow while the other person slowly rotated the KWK around in the water and watched for air bubbles. Finally, the top seal between the metal washer and top filter was checked for leaks. Any leaks were marked onto the keg with a marker. To patch the leaks, the Gorilla Glue was filed down enough to have a groove for the new glue to be poured into, and Gorilla Glue was reapplied. The leak test was then repeated and holes re-sealed until either only small bubble streams were present during the leak test or bubbles were present at a spot that had had at least two previous attempts to re-seal them. When larger holes were found during a leak test, they would typically prevent smaller holes from being detected during the first test because most of the air escaped through the large hole, reducing interior air pressure. Only after the large leak was sealed could the smaller leaks be detected.

The backpressure, a subjective assessment of how hard it was to blow air into the KWK, was another indicator of the KWK seal during the leak test. While this amount of backpressure was not formally measured, it was noticeably different among the KWKs. When testing the PHW filters, no air was escaping through the seals, but air bubbles were coming out of the ceramic filters themselves. However, based on feeling less backpressure when blowing into the PHW kegs compared the CT kegs, the author suspects that the PHW filters were more porous and did not necessarily in fact have a better seal[7].

4.8.2 O-ring Seal

Leaks coming from between the o-ring and the PVC pieces were never observed when one o-ring was used with a properly sized interior pipe. When two o-rings were used to compensate for an overly long PVC riser pipe, occasional leaking was observed. The exception was CT-KWK-5, where leaking was observed at the o-ring/keg joint. This keg was not completely straight, and it was

[7] A different sealant (SBR Bond) was used on the PHW KWKs compared to the CT KWKs (Gorilla Glue), and so a direct comparison of the seals is further complicated.

difficult to get the bottom pipe end cap flush against the bottom of the keg. This is likely due to an imperfect filing job of the ceramic pot filter rims prior to assembling the keg, resulting in the top and bottom of the KWK not being perfectly parallel to each other.

4.8.3 Leak Test Results Over Time

The leak test was re-tried later in the testing period to see if it could detect micro-cracks forming in the KWK ceramic filters themselves due to wearing down of the ceramic. Specific KWKs began getting worse bacterial removal results, and all of the KWKs showed visible signs of wearing. No new leaks were observed in the seals and no specific cracks were observed in the filters. However, at the edges of the ceramic pots themselves, more bubbles were coming out during the leak test that previously. This is likely due to the ceramic being thinner in these areas than previously due to the corners being worn down by the kegs constantly being moved in and out of the water vessels.

5 BACTERIA RESULTS

Bacteria and turbidity tests were performed from January 18th through January 25th on the Kosim Water Kegs and the ceramic pot filters (manufactured by both CT and PHW). The goal was to compare the bacterial performance of the KWK[8]s to CPFs. While bacterial results would never be better than the ceramic pots that form the KWK, the design goal is to have the KWKs well enough sealed to be able to match the bacterial removal of CPFs.

Below is a summary of the percent removal using only bacterial measurements made using IDEXX Quanti-Tray™. Membrane filtration results were not included in this summary because these tests measured a lower percent removal, and the CPF-CTs were more frequently measured with membrane filtration than any other category of filter because they were tested early on. Comparing the membrane filtration percent removal to the Quanti-Tray™ percent removal is particularly inaccurate because in both cases, the raw water nearly always had more total coliforms colonies than could be counted, but in membrane filtration, samples can only measure up to 200 colonies whereas Quanti-Tray™ measures up to 2,419 MPN. This results in a lower minimum percent removal using membrane filtration than using Quanti-Tray™ [9].

[8] To name the filters, the type of filter (ceramic pot filter – CPF versus Kosim Water Keg – KWK) comes first followed by the source filter manufacturer (Ceramica-Tamakloe – CT versus Pure Home Water – PHW). When speaking of individual filters, last comes the filter's identifying number (for KWKs) or letter (for CPFs).

[9] This mathematically means that if the raw water has over 2,419 coliforms colonies per 100 mL, and the filtered water has only 1 coliforms colony, with membrane filtration, this would be at least 99.5% removal [(200-1)÷200] but with Quanti-Tray™ would be at least 99.96% removal [(2,419-1)÷2,419].

Table 7 Summary of Bacterial Removal for the KWKs and CPFs

	# Filters	N[10] (# of samples)	Coliforms Removal		*E. coli* Removal	
			%	Log	%	Log
CPF-CT Avg	3	4	98.5%	1.8	99.4%	2.2
KWK-CT Avg[11]	6 / 4	23 / 16	91.9% / 97.7%	1.1 / 1.6	96.0% / 97.7%	1.4 / 1.6
CPF-PHW Avg	4	8	65.9%	0.5	90.5%	1.0
KWK-PHW Avg	2	5	10.7%	0.0	70.4%	0.5

This data is preliminary due to the limited number of samples taken. However, the KWK was not able to achieve the same log removal of total coliforms or *E. coli* as the CPF. The KWK-CTs performed absolutely better than the KWK-PHWs and closer to the CPF-CT than the KWK-PHWs could to the CPF-PHW. When looking at the KWK-CTs, two of the KWKs performed worse than the other four. Of these two, one failed on the last day of testing, and so likely had smaller cracks forming earlier. The other had trouble forming a good seal with the o-rings. On the data table, the first number uses all six KWKs, and the second represents only the four better performing KWKS to show how well functioning KWKs perform.

The PHW filters performed poorly as both CPFs and KWKs. These filters were not lined with silver, and turned out to be under fired, which reduced their performance. The KWK-PHWs did particularly poorly with coliforms removal. During the leak test, no bubbles were visible at the seals, but bubbles were coming out of the ceramic pots themselves, even with very little air being blown into the kegs. The author suspects that the more porous PHW filters allowed the extra hydraulic pressure to push additional coliforms into the KWK.

5.1 Filter Cleaning Procedure Prior Collecting Bacterial Sample

For accurate bacterial analysis of filtered water samples, it was critical that there was no residual chlorine left on the ceramic or in the storage container to kill the bacteria, compromising the filter performance results. However, the only way to get clean water for washing the ceramic filters at the PHW factory was to chlorinate the water. To overcome this dilemma, each ceramic element was cleaned with chlorinated water, allowed to filter water, cleaned with its own filtered water, and only then were microbial sample taken of the filtered water.

To clean the CPF system, the filters and storage containers were scrubbed with chlorinated water (piped or trucked water with two Aquatabs soaked in the water for at least 20 minutes to ensure that the cleaning water had no contaminants). One bucket of chlorinated water was used to clean every

[10] Individual filters were measured multiple times (every filter was not measured the same number of times). To calculate average removal, multiple samples from the same filter were averaged together, and then the filters were averaged so that each filter's removal was given equal weight regardless of how many times it was measured. For example, if Filter A was measured three times and Filter B only once, Filter A's measurements would be averaged into one number, and then Filter A and Filter B would be averaged together, and this is the reported average for this filter group.

[11] Two CT KWKs performed worse than the other four. The first number is the bacterial removal using all six KWKs, and the second number only uses the four best KWKs.

four storage containers. For cleaning the ceramic filters, one bucket of chlorinated water was used as a pre-cleaning step and a higher concentration bucket of water was used as a cleaning step for up to twelve filters. To clean the KWKs, the two CP filters used to assemble the kegs were cleaned with chlorinated water several days prior to assembly. To keep them clean, they were kept inside their safe water storage containers. Immediately prior to assembly they were scrubbed with trucked water at the PHW factory. After assembly, water was allowed to filter into the KWKs and an Aquatab was dropped in. The chlorine water was then shaken around inside the KWK and then poured out.

After the cleaning, all traces of chlorine needed to be removed prior to collecting bacterial samples. To do this for the ceramic pot filters, the CPFs were filled with contaminated water and left to filter. The CPFs were completely filled at least twice prior to any samples taken from the spigot of the safe storage container. The filtered water from each filter was then used to scrub the outside of its own filter and its safe storage containers. Using their own filtered water as the final cleaning water for the filters helped scrub off any final chlorine residual with water that was only contaminated with the same bacterial loading that the filter itself normally let through. To remove trace chlorine from the KWKS, the kegs were left to filter overnight (typically filtering 15 to 17 liters), and then the filtered water was shaken around inside and poured out. The sample was then taken later in the day after several filtering cycles were shaken around and discarded.

5.2 SOURCE WATER

Figure 55 Man Fetching Water From Dugout

Raw water was collected from the Taha dugout located near the PHW factory. No rainfall occurred during this trip to dramatically change the water quality. This is the source of water for Taha when the community standpipes are not on. Water was collected by a local Taha woman using her own metal bucket.

For the CPFs, undiluted dugout water was collected that day and used in the filters.

For the KWKs, the filters were rotated daily between five different ceramic water storage vessels. Because there was not a convenient way to dispose of water or collect large amounts of new dugout water, it was not practical to empty and refill each of the water vessels[12] every day. Instead, the water storage vessels were topped off with undiluted dugout water each evening. The raw dugout water was further altered by mixing it with the KWK filtered water. During the daily filtration rate testing, once the filtered water was removed from the KWKs, pouring the water onto the ground made the area too muddy. Instead, the majority of the filtered water was poured back into the water storage vessels, remixing it with the raw water it had been extracted from. After testing started, the vessels were never cleaned nor otherwise had any particulates removed from the vessels. The vessels were also

[12] Each vessel held around 150 liters of water, and it took multiple hours for the woman to gather enough water to fill all five vessels.

never stirred or otherwise specifically agitated to re-suspend any solids that may have settled over the two week time period, but when turbidity measurements were taken of one vessel from the top, middle, and bottom of the vessel on one of the last testing days, the turbidity levels were all the same. Each of the five water vessels, however, had slightly different bacterial and turbidity loads. KWKs were rotated daily between the five vessels to ensure that differences in KWK removal performances were not due to differences in the source water or individual vessel dimensions.

As a result of the variation in source water, comparing the bacterial removal between filters should be viewed with caution. Direct comparison between the KWK and CPF bacterial removal are not completely fair because the two filters received different source water. CPFs always received newly collected dugout water whereas KWK's dugout water was older, had time to settle, and was filtered more than once. Unfortunately, there was not time to duplicate results with each KWK and CPF using different raw water sources. Due to the large volume of water needed for KWK testing, future testing could be done more efficiently by testing the KWKs in a location adjacent to the contaminated source water.

5.3 BACTERIAL SAMPLE COLLECTION PROCEDURE

Samples were collected each morning at the PHW factory site from the water that had filtered overnight. Samples were collected using 100 mL sterile sampling Whirl-Pak® bags, which were stored in a cooler with ice packs for four to six hours until they could be refrigerated at the PHW lab. Samples were always tested within eight to twelve hours of collection. Because the source water varied daily and between storage vessels, the raw water and the filtered water were both sampled at each collection.

5.4 TESTING METHODOLOGY

Bacteriological testing method is a trade-off between the time it takes to run, the accuracy, the necessary skill level, and the cost of the test. Two different testing methods were used during the January trip. Membrane filtration (MF) is a comparatively low cost way to measure quantitative results. Field membrane filtration kits reuse their supplies (i.e. with metal petri dishes and metal measuring cups), but the process is slow, and requires sterilizing all the materials between each test. Additionally, at least 200 mL pure (and chlorine free) water is needed to perform the MF test, and this can be difficult to get in the field. Quanti-Tray™ (QT) is rapid, and all its components are disposable, which reduces the risk of cross-contamination. Additionally, QT can detect a much wider range of colony concentrations without using dilution. However, Quanti-Tray™ costs more than membrane filtration (around US$6 per QT test compared to US$3 per MF test). The original intention was to use membrane filtration, but after two days of using membrane filtration, it quickly became apparent that all the field work could not be completed if the afternoons were spent performing membrane filtration. Additionally, as more KWKs were completed, the number of bacterial tests performed each day became unwieldy for membrane filtration. The decision was then made to switch to the much faster, but more expensive, Quanti-Tray™ test.

5.4.1 Membrane Filtration procedure

Membrane filtration was used to test 16 samples during the first two days of lab testing. Six membrane filtration devices were used to run samples simultaneously. All testing was performed in the lab at the PHW office. Prior to beginning testing, the table surfaces were wiped down with isopropanol. The membrane filtration used re-usable stainless steel Petri dishes which were cleaned all in one batch by first soaking in a highly concentrated chlorine solution for half an hour. They were then boiled for half an hour and allowed to cool. They were stored in a zip-lock baggie in the refrigerator. The membrane filtration devices themselves were sterilized according to their recommended procedure of soaking the wick ring in methanol, lighting it with a match, capping the filter, and letting it stand that way for 15 minutes. This procedure forms formaldehyde, which sterilize all the interior parts of the metal filtration unit. Tweezers were also sterilized by soaking in ethanol and flaming. The 100 mL stainless steel measuring cup was sterilized between tests by swirling boiling water in the cup and then allowing it to cool before a new water sample was measured.

Each water test used 100 mL of undiluted sample water. Because of limited access to clean, chlorine free water, after the sample was filtered, only 30 mL of water, added in three 10mL rinses, instead of the recommended 100 mL, was used to rinse the sample cup. The water used was distilled water in plastic ampoules (normally used for electrical purposes) that could be squirted onto the sides of the cup to ensure that sample water was not left on the sides of the funnel. The use of six membrane filtration devices simultaneously improved the speed of processing a dozen water samples. Only three could be actually filtering simultaneously due to limits in the number of vacuum pumps, but all six could be sterilized at the same time. While three were filtering, the other three were cleaned and assembled with the next samples so that new samples could immediately begin filtering as soon as any of the original samples finished. In order to reduce the risk of cross-contamination, filtered water was always tested before the source water for each sample.

All samples were read immediately after the 24 hour incubation period. One difficulty with the MF results is that only undiluted samples were run of the raw and filtered water. The ideal colony count range from MF is between 20 and 80 colonies, and any colony count above 200 is "too numerous to count" (TNTC). Raw water samples were always above this number for coliforms counts, and results were often outside of the ideal range.

5.4.2 Quanti-Tray™ Procedure

Each Quanti-Tray™ water test used 100 mL of undiluted sample water. The 100 mL was measured using the sterile, disposable 100 mL sample bottles with sodium thiosulfate (used to deactivate any chlorine in the water sample). All samples used IDEXX's 24-hour Colilert reagent and the Quanti-Tray/2000™, which includes 49 large and 48 small sample wells to distinguish contamination levels at up to 2,419 Most Probable Number (MPN) per 100 mL without needing to do separate dilutions of the water sample. The IDEXX sealer and incubator were borrowed from Innovations for Poverty Action, the local branch of an international NGO. Samples were read immediately after the 24 hour incubation period. The number of positive water wells was converted to MPN colony counts and 95% confidence intervals using the free program IDEXX MPN Generator downloaded off of the IDEXX website (http://www.idexx.com/view/xhtml/en_us/water/mpn-generator.jsf).

5.4.3 Incubation Method

Samples were put in the incubator at 35 degrees Celsius for 24 hours. During all the membrane filtration samples, the power supply was uninterrupted. However, during the Quanti-Tray™ tests later in the week, rolling black outs in Tamale resulted in interrupted power supplies to the incubator. When the power was out, the incubator door was never opened. During the day, the incubator was moved outdoors into the full sun in order to help it maintain its internal temperature.

5.5 BACTERIA RESULTS

Bacterial tests were done from January 18th to 25th, 2011 in Tamale, Ghana. Table 8 below provides the complete number and type of test performed on each filter along with the average log removal of total coliforms and *E. coli* colonies. Log removal measured with MF and QT were averaged together, which introduces some error into the comparison. For each of the filter tests, the source water used was also tested, except in cases where the same recently collected dugout water was used in multiple filters, in which case only one sample of the dugout water was tested.

Table 8 Type and Quantity of Bacterial Tests Run on Each Filter and Average Log Bacterial Removal

ID	Filter Type	Manu-facturer	# of Membrane Filtration Tests	# of Quanti-Tray™ Tests	Total Number of Bacterial Tests	Average Coliforms Log Removal	Average *E. coli* Log Removal
PF-CT-A	CPF	CT	1	0	**1**	1.5	2.5
PF-CT-B	CPF	CT	1	1	**2**	0.9	2.2
PF-CT-C	CPF	CT	0	2	**2**	2.0	2.1
KWK-CT-1	KWK	CT	1	3	**4**	0.9	1.2
KWK-CT-2	KWK	CT	0	3	**3**	1.8	1.7
KWK-CT-3	KWK	CT	1	4	**5**	1.9	1.9
KWK-CT-4	KWK	CT	broke when first being installed in vessel				
KWK-CT-5	KWK	CT	2	3	**5**	0.3[13] (0.6)	1.3 (1.1)
KWK-CT-6	KWK	CT	0	3	**3**	1.7	1.7
KWK-CT-7	KWK	CT	1	5	**6**	0.7	1.5
KWK-CT-8	KWK	CT	had significant gaps in glue seal so not tested				
KWK-CT-9	KWK	CT	had significant gaps in glue seal so not tested				
PF-PHW-D	CPF	PHW	0	1	**1**	0.7	1.5
PF-PHW-E	CPF	PHW	0	3	**3**	0.2	0.6
PF-PHW-F	CPF	PHW	0	1	**1**	1.2	1.4
PF-PHW-G	CPF	PHW	0	3	**3**	0.4	1.6
KWK-PHW-10	KWK	PHW	0	3	**3**	0.1	0.6
KWK-PHW-11	KWK	PHW	0	2	**2**	0.0	0.5
	Total number of Tests		**7**	**37**	**44**		

[13] The membrane filtration tests of the KWK-CT-5 measured many fewer coliforms colonies in the source water in two cases (one of these had too many colonies to count [> 200 colonies]), which lowered the overall percentage removal of coliforms. The top number represents the average percent removal using all five tests, and the lower number in parenthesis represents only the Quanti-Tray™ percent removal results.

5.5.1 Problems Encountered with Membrane Filtration Results

The membrane filtration process was not as reliable as Quanti-Tray™. First, only undiluted samples were run for both processes because there was no previous knowledge of estimated colony counts for the source or filtered water. However, while Quanti-Tray™ can provide a colony count for up to 2,419 colonies, membrane filtration can only accurately provide results up to 200 colonies without sample dilution. This makes it difficult to determine accurately the percentage removal by the filters tested with MF for comparison with QT. For example, CPF-CT-B had 68 coliforms colonies in its filtered water during one membrane filtration test, and the source water had too many colonies to count (more than 200 colonies). If this value of 200 colonies per 100 mL is used, the percent removal is at least 66% (0.5 log removal). However, if the dugout water had more than 2,419 colonies per 100 mL, as it consistently did when tested with Quanti-Tray™, the percent removal would be over 97% (1.5 log removal).

All the bacterial results are shown in Appendix B. Results that were not used in the averages displayed at the end are shown with a strike line through the data. These removed results, all from membrane filtration, were removed because they were dissimilar to the trend of filter performance and suspected of being outliers (although there were not enough data points to make a definitive calculation for indentifying outliers). Overall, due to limitations in the testing environment and the skill of the author, the membrane filtration results were not viewed to be as reliable as the Quanti-Tray™ results.

5.5.2 Changes in Bacterial Removal Over Time

The original intent of testing the same KWK over a period of time was to see if continual use of the KWK would lead to reduced bacterial removal performance. However, the testing period was reduced from three weeks down to eight days due to delays in KWKs' construction. KWK filters constructed from CT filters were tested over eight days, and in this time period, no trends were observed in bacterial removal, but this data is too small of a sample size over too short of a time period to be conclusive. Additionally, when KWKs were not being tested for bacterial removal on a specific day, they were drained and put on a stand to dry. This could have inhibited bacterial growth in the filter. This is an area that definitely needs further research over a series of months to determine how much of a concern bacterial growth on the filter is and examine methods to inhibit that growth.

The KWK-CT results measured over these eight days are below in Table 9.

Table 9 Bacterial Removal Over Time By KWK

Filter	Date	Raw Water	Filtered Water	Coliforms % Removal	Raw Water	Filtered Water	*E. coli* % Removal
		Coliforms			*E. coli*		
KWK-CT-1	18-Jan	269	4	98.51%	122	0	100.00%
	19-Jan	>300	35.9	88.03%	94	6.3	93.30%
	20-Jan	> 2419.6	261.3	89.20%	184.2	25.3	86.26%
	21-Jan 22-Jan						
	25-Jan (pm)	> 2419.6	727	69.95%	517.2	26.9	94.80%

KWK-CT-2	18-Jan						
	19-Jan						
	20-Jan						
	21-Jan	866.4	6.3	99.27%	24.1	0.5	97.93%
	22-Jan	1046.2	13.5	98.71%	39.3	0.5	98.73%
	25-Jan						
	25-Jan (pm)	> 2419.6	67	97.23%	517.2	17.3	96.66%
KWK-CT-3	18-Jan	113	2	98.23%	0	0	-
	19-Jan						
	20-Jan	1203.3	0.5	99.96%	410.6	0.5	99.88%
	21-Jan	> 2419.6	96	96.03%	101.4	4.1	95.96%
	22-Jan						
	25-Jan	980.4	2	99.80%	68.3	0.5	99.27%
	25-Jan (pm)	> 2419.6	14.8	99.39%	517.2	0.5	99.90%
KWK-CT-5	18-Jan	173	142	17.92%	155	0	100.00%
	19-Jan	>300	286	4.67%	>300	3	99.00%
	20-Jan	> 2419.6	435.2	82.01%	547.5	6.3	98.85%
	21-Jan	> 2419.6	410.6	83.03%	74.8	9.6	87.17%
	22-Jan						
	25-Jan						
	25-Jan (pm)	> 2419.6	1046.2	56.75%	517.2	57.6	88.86%
KWK-CT-6	18-Jan						
	19-Jan						
	20-Jan	> 2419.6	5.2	99.79%	77.6	0.5	99.36%
	21-Jan						
	22-Jan	816.4	37.4	95.42%	13.4	0.5	96.27%
	25-Jan						
	25-Jan (pm)	> 2419.6	44.8	98.15%	517.2	7.5	98.55%
KWK-CT-7	18-Jan						
	19-Jan	228	204	10.53%	1	0	100.00%
	20-Jan	> 2419.6	111.2	95.40%	547.5	2	99.63%
	21-Jan	> 2419.6	18.5	99.24%	117.8	2	98.30%
	22-Jan	> 2419.6	130.9	94.59%	83.6	0.5	99.40%
	25-Jan	> 2419.6	64.4	97.34%	22.3	0.5	97.76%
	25-Jan (pm)	> 2419.6	152.3	93.70%	22.3	3	86.55%

KWK filters made from PHW filters were not tested over a series of days because the PHW filters were not available for KWK construction until late in the testing period.

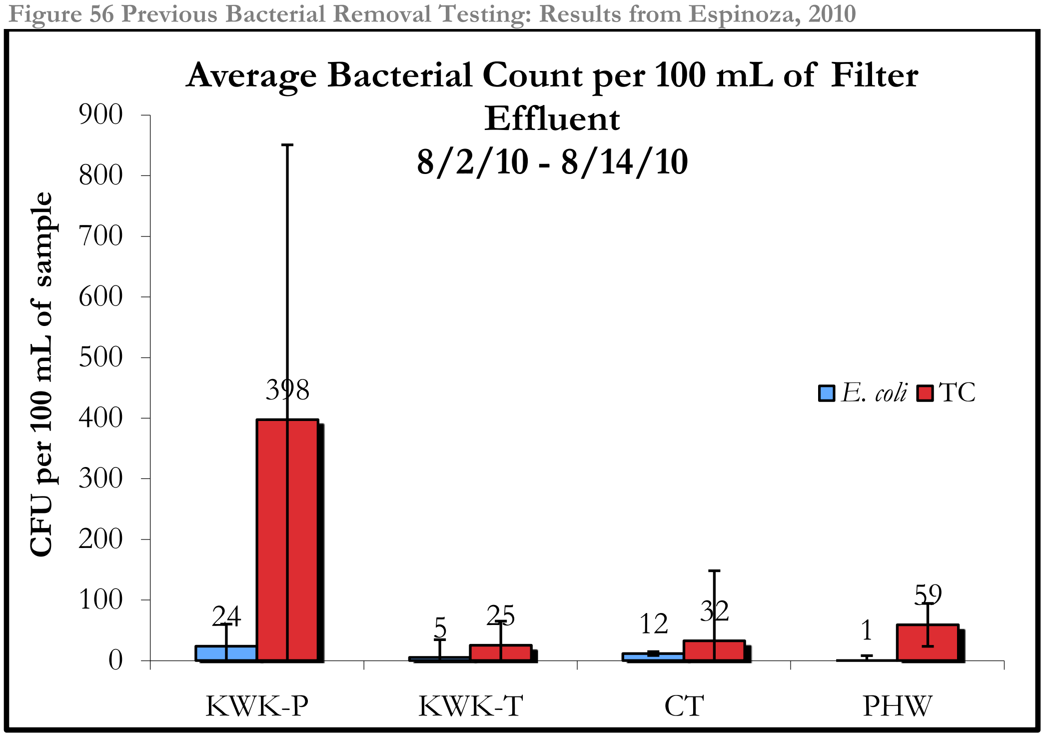
KWK-CT-5 saw a precipitous decline on the 21st, but on the 25th, the next time the KWK was tested, the keg bottom broke off, and so the author suspects that unobserved hairline cracks were present during the previous day. CT-KWK-7 developed small but visible cracks on January 25th, and its testing also declines on the last day of testing, but not as significantly as CT-KWK-5. CT-KWK-1 performed poorly on the last day of testing as well, and this keg had trouble obtaining a good seal at the top o-ring. It was also the first KWK to be constructed, and it is certainly possible that its quality was lower than for the subsequent KWKs due to a learning curve in construction practices.

More testing is needed to determine if bacteria grows on the interior of the KWK filters over time. It is expected that the kegs will need to be periodically chlorinated, but a schedule cannot be recommended at this time because long-term testing has yet to be performed.

5.5.3 Comparison to Previous KWK Testing

Claudia Espinoza, an MIT Master of Engineering student, performed the only previous field bacterial testing of the KWK in Tamale, Ghana in the summer of 2010. She conducted her testing using membrane filtration over 12 days, from August 2 to 14, 2011. She tested two KWKs submerged in 40 liter plastic containers (KWK-P), two KWKs submerged in 80 liter traditional vessels (KWK-L), two PHW CPFs (PHW), and two CT CPFs (CT).

Figure 56 Previous Bacterial Removal Testing: Results from Espinoza, 2010



Her source water was dugout water alternatively from Taha and Gbalahi. Both sources had an average *E. coli* concentration of 100 CFU and the total coliforms concentration varied from 500 to over 6,000 (measured using diluted samples).

Espinoza's bacterial results are consistent with the 2011 bacterial results measured by the author. Espinoza saw a wide variation in KWK performance, and one lesson from her work was the need to develop a more consistent approach to constructing and evaluating the fitness of the KWKs.

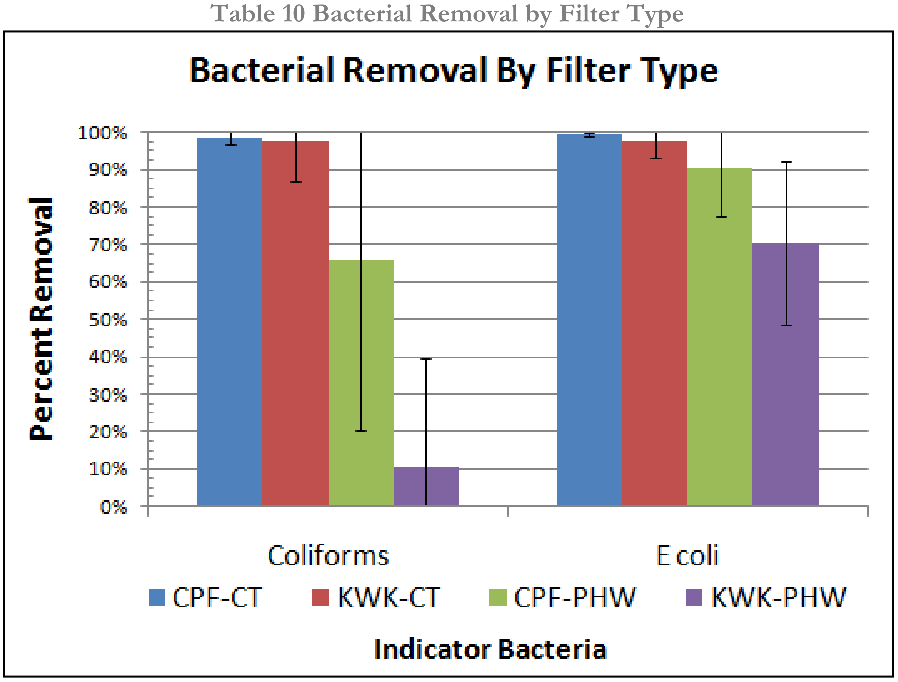
The CT ceramic pot filters tested by Espinoza (coded as "CT" on the graph) performed worse than those tested by the author. This is likely an illustration of the quality problems experienced by Pure Home Water when they were purchasing filters from the CT factory in Accra. The author selected CT filters to test in her work by flow rate testing a larger group of CT filters and only using filters whose flow rates were between 1 and 3 liters for testing. It is possible that had the author not down selected the CT filters with this criterion, the CT filters would not have performed as well on average.

Espinoza's PHW filters tested as CPFs (coded as "PHW") performed much better than those tested by the author. Both the author and Espinoza built their own pots with the Gbalahi women potters at the PHW factory, and so the processes would have been slightly different, although an effort was made to use the same clay/rice husk ratio. The author's PHW pots are thought to have performed poorly because they had been under-fired, but Ms Espinoza also had trouble with firing her PHW. Both batches of PHW pots were of inconsistent quality due to the continued efforts to establish quality control procedures at the PHW factory, and their bacterial results do not reflect how the KWK design itself performs.

5.6 Comparison Between KWK and CPF

The intention of the KWK design is that it will achieve the same bacterial results as the source ceramic pot filters. Table 10 below compares the average quality for the filtered water by type of filter. The estimated number of colonies from MF and QT are averaged together in the chart below. The chart takes out data (those data points with strikethroughs in Appendix B), primarily derived from membrane filtration, that does not fit with that filter's typical performance in order to show an average without suspected outliers (there is not enough data to calculate the actual cutoff for an outlier).

Table 10 Bacterial Removal by Filter Type



WHO water quality guidelines are based on the number of *E. coli* colony forming units per 100 mL in the filtered water, not percent removal. However, an average number of colonies in the filtered water is not an accurate picture of the relative performance of different KWKs and CP filters because the source water had different microbial loading for each test. Pure dugout water was not used for each test, but instead, water vessels with the KWK had a mixture of already filtered water and old dugout water and were only topped off with fresh dugout water each evening, as was discussed in Section 5.2. CPF filtered recently collected dugout water for each of their tests. Looking only at tests taken when the source water total coliforms colonies were greater than 2,419 colonies/100mL, a better approximation[14] of a comparison can be made of the total coliforms concentrations of the filtered water.

Table 11 Total Coliforms Removal by Filter When Source Water Had >2,419 MPN of Total Coliforms

Filter	**Coliforms Filtered Water**			**Coliforms % / log Removal**	Filter Average		Filter Type Average		
	Lower 95%	**MPN**	**Upper 95%**		MPN	%	MPN	%	Log
PF-CT-B	0	< 1.0	3.7	99.98% / 3.7	1	99.98%	1.5	99.95%	3.3
PF-CT- C	0.3	2	5.9	99.92% / 3.1	2	99.92%			
KWK-CT-1	170.9	261.3	398.5	89.20% / 1.0	494	79.57%	227.9	90.58%	1.0
	475.7	727	1048.9	69.95% / 0.5					
KWK-CT-2	46.5	67	92	97.23% / 1.6	67	97.23%			
KWK-CT-3	68.5	96	132.1	96.03% / 1.4	55	97.71%			
	8.5	14.8	25.1	99.39% / 2.2					
KWK-CT-5	276.2	435.2	650	82.01% / 0.7	631	73.93%			
	260.6	410.6	618.9	83.03% / 0.8					
	705	1046.2	1509	56.75% / 0.4					
KWK-CT-6	2.3	5.2	11.9	99.79% / 2.7	25	98.97%			
	30.2	44.8	63.4	98.15% / 1.7					
KWK-CT-7	79.3	111.2	151.7	95.40% / 1.5	95	96.05%			
	11	18.5	29.2	99.24% / 2.1					
	88.2	130.9	187.2	94.59% / 1.3					
	44.6	64.4	88.6	97.34% / 1.6					
	102.6	152.3	228.4	93.70% / 1.2					

The ceramic pot filters are reducing total coliforms by over 2 log more than the KWK filters, and so improvements still need to be made to the KWK design. The KWK is able to provide a 1 to 2 log reduction in coliforms, however, which is still an appreciable improvement in the water quality.

[14] This comparison is still not completely accurate because it is unknown how much above 2,419 MPN limit the coliforms concentration is for each sample, and it could vary between samples. It seems likely that the values do vary since KWKs perform differently when tested repeatedly, such as is particularly seen with KWK-CT-1 and KWK-CT-7.

When looking at *E. coli* reductions for these same samples, the source water did not have uniform *E. coli* concentrations. While this is not a perfect comparison, it is the closest proxy available from the limited data collected to compare absolute bacterial counts in the filtered watery. The cutoff for "low risk" water according to the WHO is 10 *E. coli* colonies per 100 mL (WHO *Guidelines* 2008), and so while the pot filters were able to consistently meet this target, only half of the six KWK filters did.

Table 12 *E. coli* Removal by Filter When Raw Water Had >2,419 MPN of Total Coliforms

Filter	**Raw Water**	***E. coli* Filtered Water**			*E. coli* % Removal	Filter Average			Filter Type Average	
	E. coli	**Lower 95%**	**MPN**	**Upper 95%**		MPN	WHO rating	% Removed	MPN	% Removed
PF-CT-B	**77.6**	0	< 1.0	3.7	99.36%	1	Low Risk	99.36%	1.0	99.03%
PF-CT- C	**77.6**	0.1	1	5.5	98.71%	1	Low Risk	98.71%		
KWK-CT-1	**184.2**	16.1	25.3	37.7	86.26%	26	Intermediate Risk	90.53%	12.6	95.07%
	517.2	17.1	26.9	39.8	94.80%					
KWK-CT-2	**517.2**	10.3	17.3	28.2	96.66%	17	Intermediate Risk	96.66%		
KWK-CT-3	**101.4**	1.7	4.1	9.5	95.96%	2	Low Risk	97.93%		
	517.2	0	0.5	3.7	99.90%					
KWK-CT-5	**547.5**	2.9	6.3	13.7	98.85%	25	Intermediate Risk	91.63%		
	74.8	4.4	9.6	16.9	87.17%					
	517.2	39.9	57.6	80	88.86%					
KWK-CT-6	**77.6**	0	0.5	3.7	99.36%	4	Low Risk	98.95%		
	517.2	3.6	7.5	14.9	98.55%					
KWK-CT-7	**547.5**	0.3	2	7.1	99.63%	2	Low Risk	96.33%		
	117.8	0.3	2	7.1	98.30%					
	83.6	0	0.5	3.7	99.40%					
	22.3	0	0.5	3.7	97.76%					
	22.3	0.7	3	7.4	86.55%					

The KWK is again able to deliver a significant reduction in *E. coli* colonies, but while the average performance of all six KWKs was close, it did not meet the WHO "low risk" cutoff. The important aspect to note is that the higher average is not caused by all of the kegs performing poorly, but rather half of the kegs consistently performed well and half performed poorly. KWK-CT -3, -6, and -7 all performed comparably to the pot filters. Once it can be determined what factors cause some KWK to be more successful than others in *E. coli* removal, KWKs will be able to be manufactured to a more consistent quality.

6 Turbidity Results

Turbidity is the easiest water quality parameter to monitor because the test can be done quickly in the field. While the portable turbidimeter is quite expensive, the marginal cost of each test is virtually nothing. Turbidity is also a visibly apparent water quality parameter, which makes it easier to show the effect of a filter on water quality to the general public.

Table 13 Summary of Turbidity Removal for KWKs and CPFs

Filter Type Averages	n	Turbidity Source NTU	Filtered NTU	% Removal %
KWK-CT	46	93.9	41.5	55%
CPF-CT	6	85.1	18.9	78%
KWK-PHW	7	107.0	53.0	50%
CPF-PHW	8	106.0	32.3	69%

WHO guidelines for turbidity in water have no maximum limit for health reasons. Based on general water appearance and consumer acceptability, WHO recommends that water should be below 5 NTU but cautions that individual locations can have different turbidity tolerances. When chlorination is being used as the disinfection method, they recommend having less than 0.1 NTU in the water (WHO *Guidelines* 2008). During this field testing, the average raw water turbidity was 95.9 NTU and the average filtered water turbidity was 42.0 NTU, a reduction of 56%. While this water is still well above the recommended WHO guidelines, the reduction was visibly noticeable.

6.1 Methodology

The turbidity testing was done at the PHW factory site using a HACH 2100P Portable Turbidimeter. Samples of the source water and filtered water were taken each morning after the filters had been left to filter overnight. Each sample vial was rinsed out with the sampled water and then filled with the sample. The outside was wiped dry with tissues and then dust was removed with the velvet cloth included with the turbidimeter.

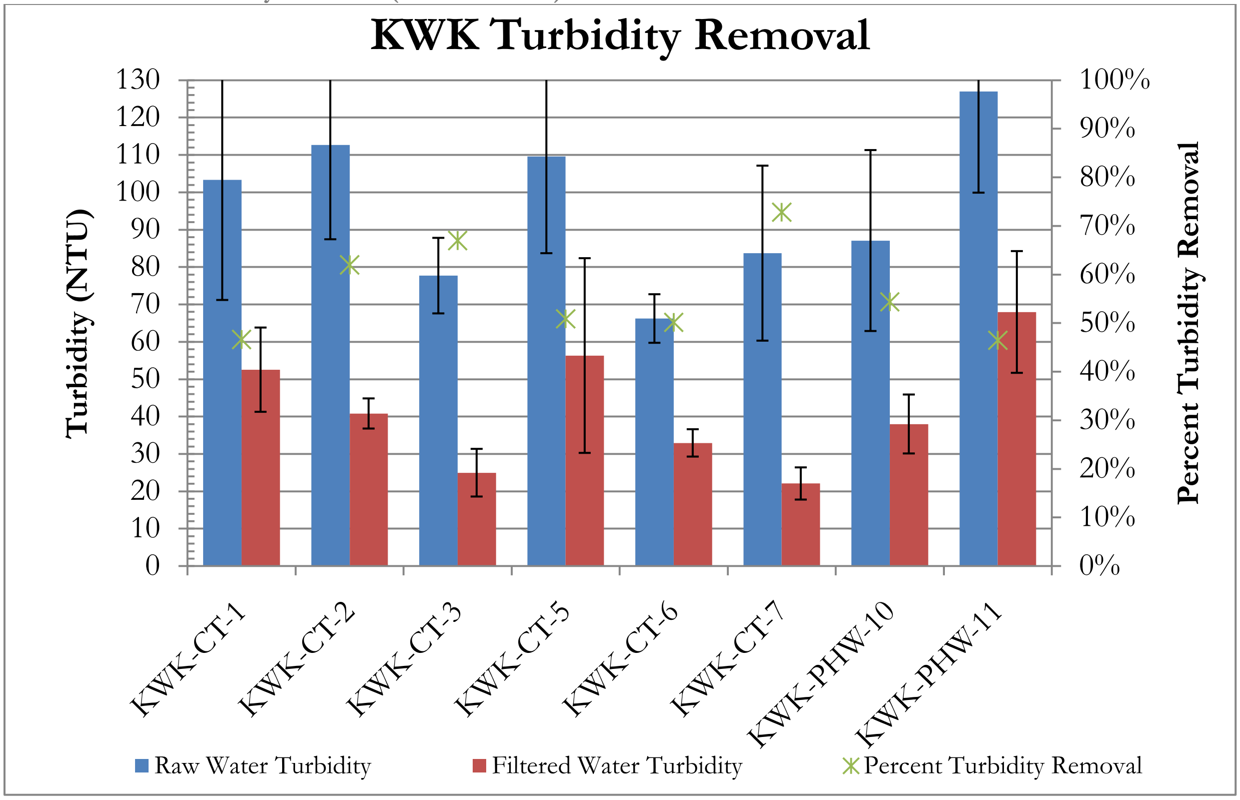
6.2 Results

On average, the KWK filters were able to remove about half of the turbidity in water. Table 14 below shows average turbidity for the source water and the filtered water for each keg. All of the source water was dugout water, but not always newly collected dugout water. The variability in the average source water turbidity is because when the filtered water was taken out of the KWK during filtration rate testing, it was poured back into the ceramic water storage vessels. Each evening, additional raw water was poured into the ceramic water vessels until they were full to replace water lost to evaporation. The raw water in the vessels was not regularly mixed, and over the two week period, some particles likely settled out.

Table 14 Average Turbidity Removal For Each KWK

Filter	n	Turbidity Source NTU	Filtered NTU	% Removal %
KWK-CT-1	8	103.4	52.5	47%
KWK-CT-2	8	112.7	40.8	62%
KWK-CT-3	9	77.7	25.0	67%
KWK-CT-5	9	109.6	56.3	51%
KWK-CT-6	7	66.2	32.9	50%
KWK-CT-7	5	83.7	22.1	73%
KWK-PHW-10	5	87.1	38.0	54%
KWK-PHW-11	2	127.0	68.0	46%

Table 15 KWK Turbidity Removal (CT and PHW)



The Ceramica Tamakloe filters performed better on average than the Pure Home Water filters, but there is not a statistically significant difference between the percent removals of CT versus PHW KWKs. While the source water had different turbidities for different KWK tests, the performance of the CT filters can be compared to that of the PHW filters because the difference in turbidity for the source water for the CT versus PHW KWKs was not statistically significant. The filtered water turbidity has a correlation of 0.73 to the source water turbidity for both CT and PHW kegs. The similar performance of the two ceramic filter sources in turbidity removal, especially compared to the significant difference in the performance of CT versus PHW KWKs in bacterial removal, probably indicates that turbidity is more dependent on filtration rates (which were similar for both PHW and CT KWKs) than bacterial removal is.

When looking at the individual KWK-CT performances, there was not a significant difference between KWK-CT-1, -CT-5, and -CT-6 in percent turbidity removal. KWK-CT-2 and -3 also did not have a significant difference from each other in their percent turbidity removal. To see a complete list of measured turbidity removal for individual filters, see Appendix B.

6.3 Comparison to Ceramic Pot Filters

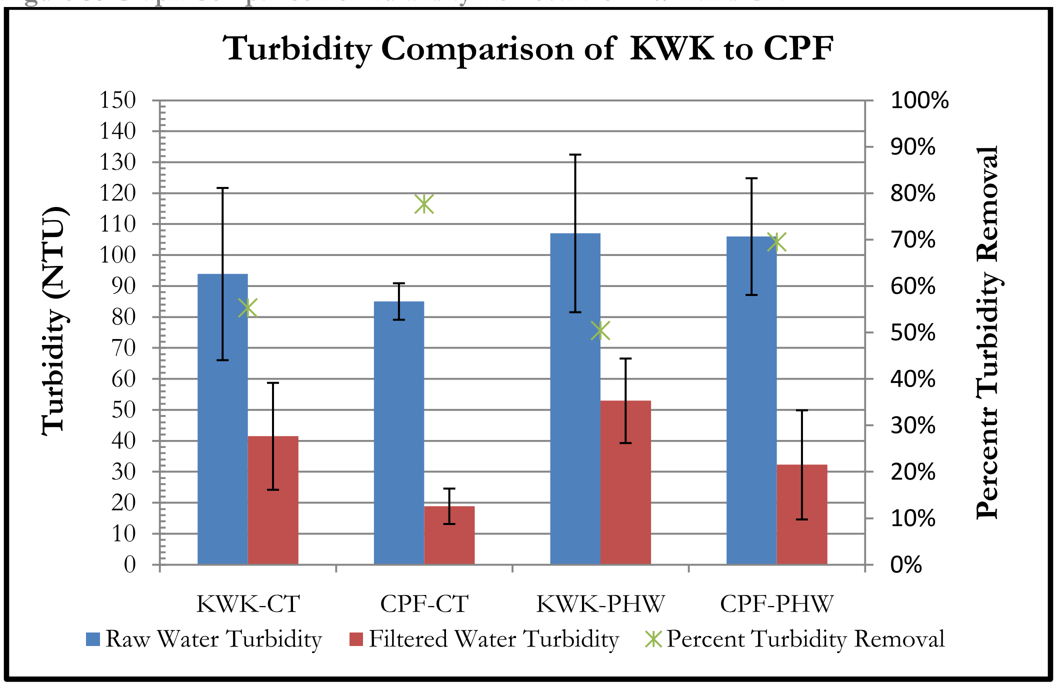
Table 16 Turbidity Removal of CPF

Filter	n	Turbidity Source NTU	Filtered NTU	% Removal %
CPF-CT-A	3	84.8	21.5	75%
CPF-CT-B	3	84.8	18.3	78%
CPF-CT-C	3	85.5	17.0	80%
CPF-PHW-D	3	102.6	23.7	77%
CPF-PHW-E	1	92.0	17.8	81%
CPF-PHW-F	3	102.6	55.1	46%
CPF-PHW-G	1	127.0	32.6	74%

Table 17 Comparison of Turbidity Removal for KWKs and CPFs

Filter Type Averages	n	Turbidity Source NTU	Filtered NTU	% Removal %
KWK-CT	46	93.9	41.5	55%
CPF-CT	6	85.1	18.9	78%
KWK-PHW	7	107.0	53.0	50%
CPF-PHW	8	106.0	32.3	69%

Figure 57 Graph Comparison of Turbidity Removal For KWK and CPF



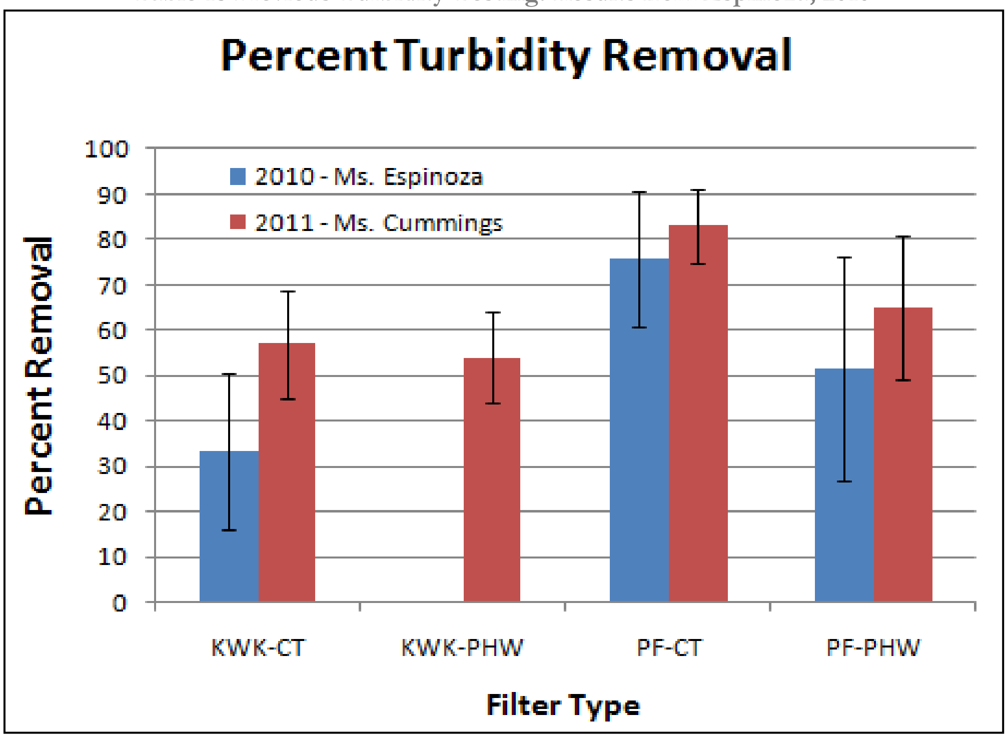
A direct comparison between the CPFs and KWKs cannot be made with certainty from this data because the two filter types had different raw water sources: the CPFs were filled each night with newly collected dugout water whereas the KWKs were in the larger water vessel where the raw water was not completely replaced each day. The ceramic pot filters still consistently got better turbidity removal than the Kosim Water Kegs, and this held true for both CT and PHW filters. Considering that the CPF-CTs had more turbid source water than the KWK-CTs during this trial and that the CPFs were still able to deliver filtered water with less absolute turbidity than the KWK, the CPFs are likely much better than the KWKs at removing turbidity.

From this data, the question still remains regarding what is causing this difference. Additional particles may be able to get into the KWKs around the seals, or the increased turbidity could be due to the increased water pressure pushing more turbidity through the ceramic. An important future test is to look at whether or not reducing the filtration rates into the KWK, by reducing the hydraulic pressure of the raw water, improves the turbidity removal to levels comparable to CPFs.

6.4 Comparison to Past Testing

Espinoza also measured turbidity removal during her testing in Tamale, Ghana in the summer of 2010. She found lower turbidity removal than the testing in 2011 for both KWKs and CPFs. The improved turbidity removal of the KWKs in 2011 is most likely due to improvements in sealing the kegs. With the wide variation in results and closeness of the averages, the difference in the ceramic pot filters (PF in this chart) turbidity removal between 2011 and 2010 is not significant.

Table 18 Previous Turbidity Testing: Results from Espinoza, 2010



7 Flow Rate Results

The rate at which users can access clean water is a function of both how quickly the KWKs can filter water and how quickly the siphon can remove that filtered water. While siphoning is quicker than the filtering process (0.55 liters per minute for siphoning compared to 0.18 liters per minute for filtration), the low siphoning rate is expected to be more inconvenient for users. This is because the KWK can be passively filtering throughout the day and night, but when people are extracting water, they will need to wait for it to siphon out. With an average the siphon rate of 0.55 liters per minute, someone would have to wait at least two full minutes to fill up a one liter water bottle.

7.1 Filtering into the KWK

Filtration rates into the KWK are dependent on the raw water height in the outer vessel and filter water height inside the KWK. To approximate how users will be interacting with the KWK, two different filtration rates were measured. First, the author measured the volume that the KWKs can filter when left alone overnight without refilling the raw water or extracting water out of the keg. This will be the volume of water available to users each morning, and this volume is important to determine if the full storage capacity of the KWK is utilized or if falling raw water heights in the water vessel cause filtration to stop prior to filling the KWK. The second filtration rate of interest is how much the keg can filter hourly as the raw water level drops in the outer storage vessel but the filtered water is removed from the KWK. This will approximate a user filling their vessel only once each day and using the filtered water throughout the day, which is consistent with the water collection habits reported by local households.

7.1.1 Method of Measuring Filtered Volume

The filtered volume was directly measured by removing the water from the keg. At the end of each hour, the KWKs were removed from the water storage vessel, and the filtered water was poured into a bucket. The volume was then measured using either a 1 liter graduated cylinder, with 10 mL increments market off or a 1 liter plastic beaker, with 50 mL increments market off. This method was time consuming and did not allow for monitoring the filtration rate change as the KWK filled, since the filtered water had to be removed to be measured.

An attempt was made to create a volume-depth relationship for the KWKs so that the filtered water volume could be measured without removing the water from the keg. This relationship would need to be established for each keg individually due to variations in the KWK dimensions constructed from CT pot filters. While this was tried, it was not achievable in the limited time available for this research[15]. However, for a long-term study, establishing this relationship would be worth the time, because it would allow for much more rapid measurements of filtration volumes and would allow for taking measurements at more frequent intervals.

7.1.2 Hourly Filtering Rates

Filtering rates are a function of filter area and the depth of the water above the filter. Each of the five water vessels had different heights (+/- 1 inch) and diameters, and each of the KWKs had slightly different heights (+/- 0.125 inches). Height of the water in the vessel decreased through a combination of filtering into the keg and evaporating through the vessel walls. Falling head filtration tests, where the KWK filtered water volume was emptied every hour but the source water was not replenished, were run for four hours using different combinations of the KWKs in the five different water vessels over four days. Individual filtering rates for specific KWKs can be found in Appendix C.

While records were kept of which KWKs were in which vessels during each filtration rate testing, the sample size (10 trials) is too small to make any conclusions regarding the effect of vessel dimensions versus individual keg characteristics on filtration rates.

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[15] Known volumes of water were poured into the KWK and the height for each volume was measured with floating rod and marked off. However, to prevent the water from filtering out of the keg, the KWK needs to be submerged in water, with a plastic bag wrapped around it to prevent water from filtering in. While this was being done, results were not duplicable and would change depending on how long the author waited between pouring in the water volume and taking the reading. With more time, however, this affect could be documented and controlled for.

Table 19 Falling Head Filtration Rate Sorted by Water Storage Vessel

	Vessel A	Vessel B	Vessel C	Vessel D	Vessel E	Average
depth:	20.5"	22.25"	22.5"	21.5"	21"	
Time	n=3	n=3	n=2	n=1	n=1	**n=10**
(hours)	L/hr	L/hr	L/hr	L/hr	L/hr	**L/hr**
1	9.3	11.5	11.2	9.2	11.0	**10.4**
2	7.1	7.0	8.9	7.0	9.8	**8.0**
3	7.0	7.4	7.8	5.1	5.7	**6.6**
4	3.7	3.8	4.0	5.9	5.2	**4.5**

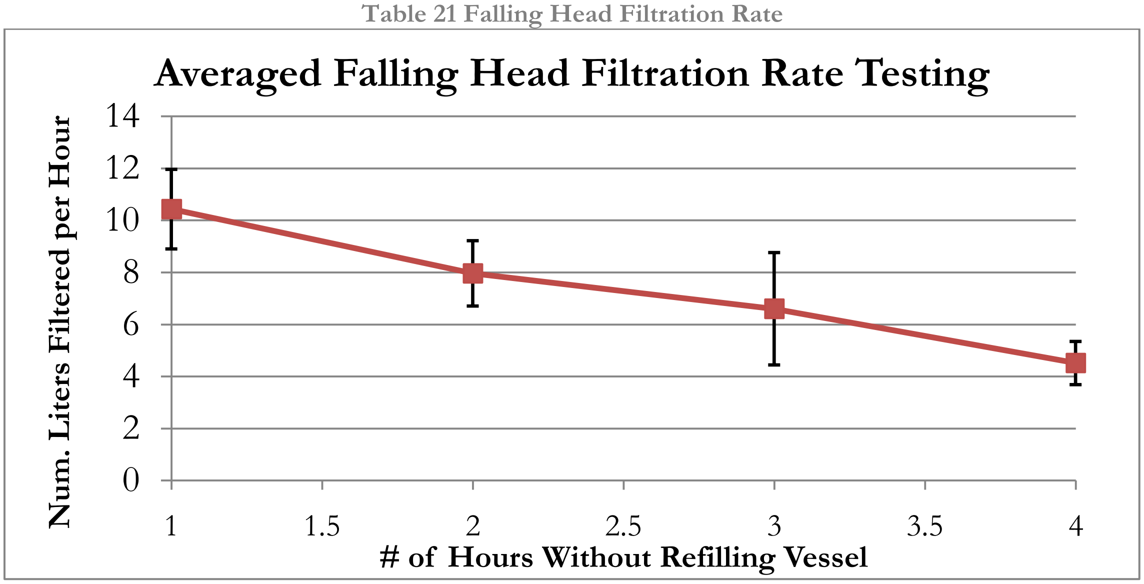
Table 20 Falling Head Filtration Rate Sorted by KWK Filter

	KWK-CT-1	KWK-CT-3	KWK-CT-5	KWK-CT-6	KWK-CT-7	Average
height:	18.125"	18.25"	18.0"	18.25"	18.25"	
Time	n=2	n=2	n=2	n=1	n=3	**n=10**
(hours)	L/hr	L/hr	L/hr	L/hr	L/hr	**L/hr**
1	11.8	11.2	10.4	11.0	9.1	**10.7**
2	8.8	6.4	6.9	9.8	6.5	**7.7**
3	8.1	5.3	7.4	5.7	6.6	**6.6**
4	4.0	3.8	5.9	5.2	3.5	**4.5**

The expectation is that the vessel depth will make a difference in filtering rates because that will determine how much raw water is stored above the filter. In this trial, vessel depths were all within two inches of each other. However, in households the depth of the filters varies more from vessel to vessel (from 24 to 30 inches), and they nearly all are deeper than the test vessels.

When the 10 filtration measurements are averaged together, the correlation between time elapsed and filtration rate is nearly perfectly linear (correlation = -0.994). Total filtration over the four hours is nearly 30 liters.

Table 21 Falling Head Filtration Rate



7.1.3 Overnight Filtration Rates

The overnight filtration volumes give the slowest possible filtration rate. As the KWK fills up, only the area not holding clean water can be used for further filtration, reducing the active filtering area. Once the full storage volume has been reached, filtration stops.

Table 22 Volumes Filtered Overnight By Each KWK

	KWK-CT-1	KWK-CT-2	KWK-CT-3	KWK-CT-5	KWK-CT-6	KWK-CT-7	KWK-PHW-10
18-Jan	13.95 L		14.55 L	14.28 L			
19-Jan	15.60 L			14.32 L		15.10 L	
20-Jan	15.65 L		15.00 L	15.45 L	15.50 L	17.10 L	
21-Jan		14.00 L	17.35 L	18.00 L		15.00 L	12.55 L

As expected, the Table 22 overnight filtration volumes are significantly lower than the sum of the hourly filtration rates. However, even without refilling of the raw water, the KWK is able to filter water to nearly its full capacity. This means that the keg size is not too large for the water vessels. If the kegs were too large, and so displaced too much space within the vessel, the falling water level of the raw water would equalize with the water height within the keg and filtering would stop before the keg was full.

To see how soon filtering would have stopped due to falling raw water height, the heights of the water in the KWKs and in the storage vessels were measured (Table 22 below). Because of the curved base in the outer vessel, its water depth could not be directly measured when the KWK is installed. Instead the distance from the rim to the water height was measured. At the end of the testing period, the depth of each vessel was measured and the difference in the two measurements was the water depth. To measure the water height inside the keg, a fishing float was attached to a line of straws. The straws were pushed to the bottom of the keg, and this height was marked. Then the float was allowed to float on the water level and this height was marked. The difference in the two marks was the depth of the water in the keg.

Table 23 Comparison of Water Height in the Outer Storage Vessel and KWK Interior After KWKs Filtered Overnight

	KWK-CT-1		KWK-CT-2		KWK-CT-3		KWK-CT-5		KWK-CT-6		KWK-CT-7		KWK-PHW-10	
	vessel	keg	vessel	keg	vessel	keg	vessel	keg	vessel	keg	vessel	keg	vessel	keg
18-Jan	13.5"	13.5"			15.5"	12.6"	15.3"	14.0"						
19-Jan	15.75"	15"					13.3"	14.3"'			15.0"	14.5"		
20-Jan	16.3"	14.8"			16.8"	15.3"	16.0"	17.3"	14.3"	14.6"	14.5"	14.5"		
21-Jan			17.0"	17.0"	17.8"	17.8"	16.0"	17.3"			14.0"	15.0"	16.5"	14.9"

Over all, the heights of water in the KWKs are very close to the heights of the water in the outer raw water vessels, meaning that making the KWK larger would not result in any additional water filtering into the keg. If the KWK storage capacity hadn't been reached, filtration would stop due to insufficient raw water pressure. When water levels inside the keg was measured to be higher than that in the outer vessel (which happens twice with KWK-CT-5), the guess is that the height difference is actually close to zero and inaccuracies in measuring the depth of the water in the outer vessel caused this discrepancy. The vessel rims were not even all the way around and so depth measurements changed based on where on the vessel they were measured.

7.1.4 KWKs Filtration Rate Comparison to CPFs

Prior to making the KWKs from the CPFs, the one hour flow rate for each pot filter was measured. The KWK one hour flow rates are higher than the sum of the hourly flow rates of each of its two component pots. Table 24 shows the number of liters filtered in the first hour for the ceramic pot filters and the KWKs that used those specific pot filters. The increase in filtration rates above the sum of the two component filters is the extra filtration that comes from the increasing the volume of raw water storage, which increases the water pressure pushing the water through the filter.

Table 24 Comparison of 1 Hour Filtration Rate of KWK to the 1 Hour Filtration Rate of Its Component CPFs

	Pot One 1 hr Filtration Rate	Pot Two 1 hr Filtration	Sum of Pot Filters' Filtration Rate	KWK 1 hr Filtration Rate
	L/Hr	L/Hr	L/Hr	L/Hr
KWK-CT-1	2.20	2.85	5.05	11.80
KWK-CT-3	3.30	2.65	5.95	11.23
KWK-CT-5	2.85	3.30	6.15	10.40
KWK-CT-6	1.77	3.00	4.77	11.04

During the January research period, no falling head filtration rate tests were performed on the CPFs beyond a single hour. However, data for overnight filtration volumes was collected and is organized in the Table 25 below.

Table 25 Overnight Filtration Volumes of CPFs

	PF-CT-A	PF-CT-B	PF-CT-C	PF-PHW-D	PF-PHW-E	PF-PHW-F
18-Jan						
19-Jan	6.32	7.00	8.00			
20-Jan	5.80	6.90	6.35			
21-Jan				5.80	5.36	5.36
22-Jan						

Table 26 One Hour Filtration Rates for CPFs

1 Hr Filtration Rate (L)	PF-CT-A	PF-CT-B	PF-CT-C	PF-PHW-D	PF-PHW-E	PF-PHW-F	PF-PHW-G
	2.36	1.66	2.28	3.95	3.45	3.5	4.3

One hour filtration rate tests on the CPFs used for the bacterial testing in Section 5 were also measured (Table 26 above). The CPFs were completely filled, and allowed to filter for one hour without any further refilling.

7.1.4.1 Previous Filtration Rate Comparison between CPF and KWK

During her summer 2010 research, Claudia Espinoza measured the hourly filtration rate of both PHW and CT pot filters and KWKs. Her results are shown in the graph below. The KWK flow rates measured by Espinoza are much lower than the ones measured by the author because Espinoza submerged the KWKs in plastic containers, with less raw water storage, and so less pressure, instead of the larger traditional ceramic vessels.

Figure 58 Previous Filtration Rate Testing: Results from Espinoza, 2010

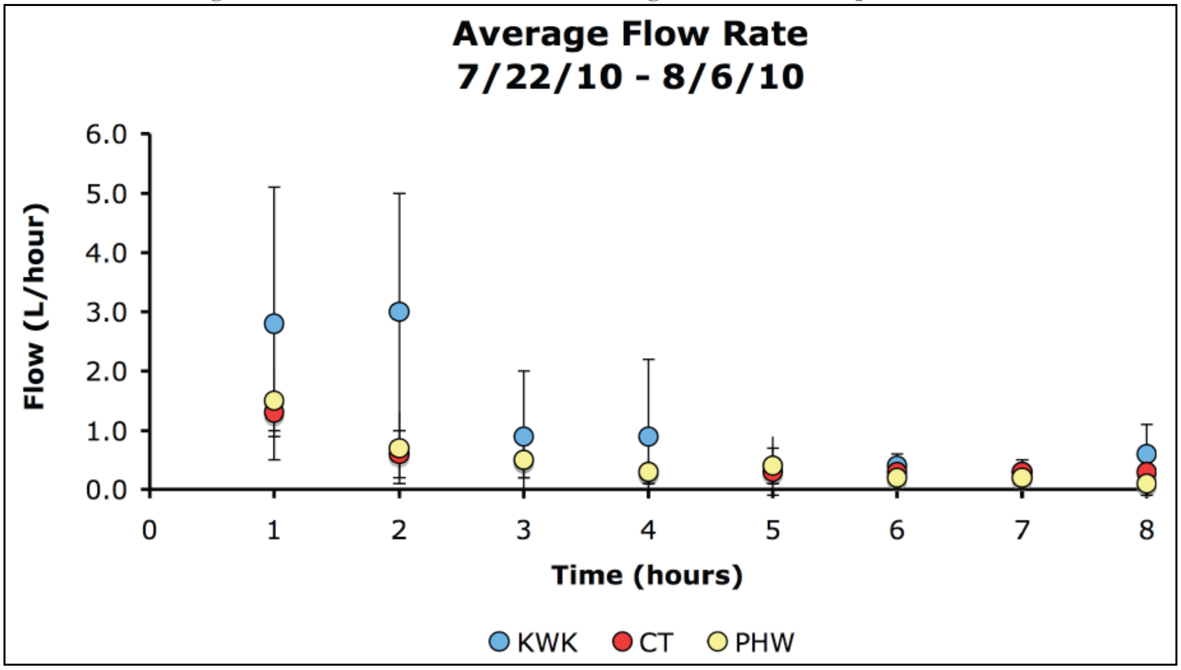


Table 27 Falling Head Filtration Rate Comparison Between KWKs and CPFs

	Hour							
	1	2	3	4	5	6	7	8
	L/hr	L/hr	L/hr	L/hr	L/hr	L/hr	L/hr	L/hr
KWK-CT (2011)	**10.4**	**8**	**6.6**	**4.5**				
KWK-CT (2010)	2.8	3.0	0.9	0.9	0.4	0.4	0.3	0.6
PF-CT	1.3	0.6	0.5	0.3	0.3	0.3	0.3	0.3
PF-PHW	1.5	0.7	0.5	0.3	0.4	0.2	0.2	0.1

Espinoza did perform falling head filtration testing on CPFs over a full day (Table 27 above), and her data shows a precipitous decline in hourly filtration rates for CPFs from CT and PHW. Her measurement showed the KWKs performing better than the CPFs during the first two hours, but after that, filtration rates dropped to being comparable to that of the CPFs. This drop-off in filtration rate is due to using the KWKs in smaller raw water storage vessels (which had only a third of the raw water storage as those used in the January 2011 testing done by the author).

7.2 SIPHONING OUT OF THE KWK

A siphon was used to remove the filtered water from the KWK interior. The siphon consists of electrical conduit hose with a check valve on one end and a spigot on the other. The check valve is submerged in the filtered water. The siphon is started by shaking the hose up and down; on the down movement, water is pushed into the hose, and when the hose is pulled up, the check valve keeps the water inside the hose. Eventually this brings the water over the high point of the hose, and the siphon force keeps the water flowing after the hand pumping stops. Closing the spigot while the siphon is flowing preserves the siphon for the next usage, meaning re-pumping should not be necessary. A siphon was selected because it doesn't require electricity or continual pumping to extract the water. The original intention was that the water storage vessel with the filter could be elevated, as it is when using the traditional siphon filter. However, because the water storage vessels traditionally used in Ghana are extremely large, elevating the vessels is not a viable option, and so the siphon mechanism performed worse than planned.

To measure the volume accessible by siphon, the tubing was be pumped for 10 seconds, a length of time selected because trial and observation indicated this was enough time to get a steady flow coming out of the keg. The siphoned water was collected in the 1 liter plastic beaker because the wider mouth allowed for the spigot to be placed closer to the ground, which improved flow rates. If the siphon lasted for less than 1 liter, pumping was tried twice more for 10 seconds each. If the siphon still failed to deliver 1 liter of water, it was considered non-working.

Of the 21 attempts to siphon water out of full kegs, the siphon worked 10 times and in 2 additional cases, it removed for two liters or less. In the other 9 attempts, the siphon couldn't be maintained, which again was defined as failing to flow after at least three repeated attempts to start the siphon by either pumping it for 10 seconds or mouth suctioning it. The siphon always failed to remove all of the filtered water in the KWK; the most the siphon was able to drain was 13 of the 17 liters of filtered water. Table 28 (below) shows the volume that was siphoned out of the KWKs after they had filtered overnight (siphoning volumes obtained from only partially full kegs are not included). While the total volume of filtered water was not always measured, based on past performance, the total volumes would be between 15 and 17 liters.

Table 28 Frequency of Siphon Working and the Volume that Could Be Siphoned Compared to the Volume of Water in the KWKs

Date	CT-1	CT-2	CT-3	CT-5	CT-6	CT-7	PHW-10	PHW-11
19-Jan	No			No		No		
20-Jan	No		No	No		7L / 17.1L		
21-Jan		2L / 14L	13L / 17.3L	No		1L / 15L	6L/12.5L	
22-Jan		13L / ?			No	4.4L / ?	No	9.7L / ?
24-Jan	8L / ?		9L / ?	7L / ?	No	13L / ?		

key:
volume siphoned / volume filtered

7.2.1 Siphoning Flow Rates

The flow rate out of the siphon varied widely during each run, even with the same KWK holding around the same volume of filtered water. The following chart shows the liters per minute flowing out of the siphon for each liter (i.e. If the first liter filtered in 2 minutes, it had a flow rate of 0.5 L/min and if the second one filtered in 2 minutes 30 seconds, it had a flow rate of 0.4 L/min). Table 29 shows the decline in siphoning rates as the keg drains lower. All of these siphoning rates start with a keg that has filtered overnight, and so they should each have about the same amount of filtered water (15 to 17 liters) in the kegs.

Table 29 Speed of Siphon (liters/min) for Each Liter Siphoned from KWKs

Liter #	Average	CT-1	CT-2	CT-3		CT-5		CT-7		PHW-10	PHW-11
1	0.69	0.58	0.34	2.00	0.50	0.47	0.57	0.52	0.62	0.74	0.52
2	0.59	0.41	0.50	1.82	0.36	0.40	0.36	0.67	0.57	0.38	0.44
3	0.53	0.38	0.44	1.67	0.44	0.39	0.35	0.44	0.44	0.33	0.41
4	0.55	0.37	0.43	1.71	0.50	0.37	0.34	0.68	0.36	0.32	0.40
5	0.51	0.34	0.40	1.50	0.50	0.33	0.38	0.73	0.34	0.24	0.37
6	0.47	0.32	0.37	1.46	0.49	0.30	0.22	0.70	0.22	0.26	0.33

Quick siphoning times during one test did not predict equally good results the next time that water was siphoned out of that KWK. The best siphoning rate was 2 liters per minute, which occurred once with KWK-CT-3, but the next time siphoning was successful with this keg, the siphoning rate was slightly below average.

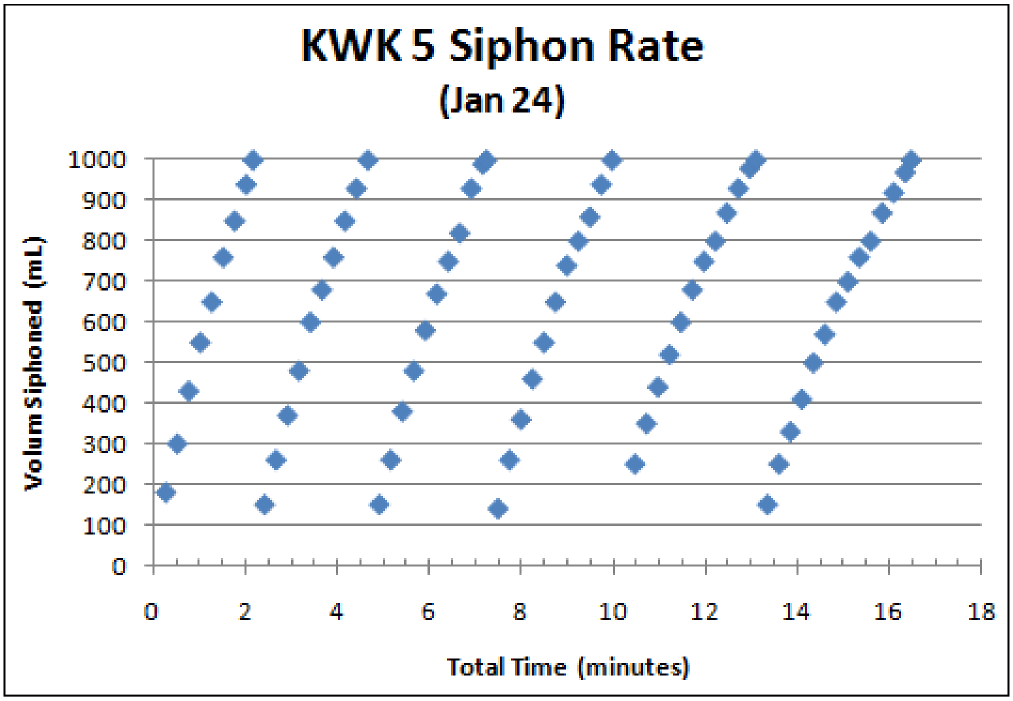
Additionally, quick siphoning times for the initial few liters did not guarantee that more liters would be siphoned from the keg. Table 30 below gives the time it took to siphon out each liter from each keg. Measurements only stopped when the siphon stopped flowing. This chart also shows how kegs did not consistently yield the same number of liters each time. For example KWK-CT-2 only was able to siphon 3 liters one time, and relatively quickly, and the next time it was able to siphon 13 liters, but at the slowest rate. The reason for this rate difference is still unknown.

Table 30 Siphoning Speed (Minutes/Liter) Per KWK

CT-3	CT-2	PHW-10	CT-5	CT-7	CT-1	CT-5	PHW-11	CT-7	CT-3	CT-5	CT-2
0:30	1:05	1:21	1:30	1:37	1:43	1:45	1:55	1:56	2:00	2:09	2:58
0:33	1:34	2:37	1:40	1:45	2:28	2:45	2:16	1:30	2:45	2:30	2:00
0:36	1:36	3:00	1:48	2:15	2:36	2:53	2:25	2:15	2:15	2:35	2:15
0:35		3:08	1:58	2:45	2:43	2:58	2:31	1:28	2:00	2:44	2:21
0:40		4:07	2:25	2:58	2:54	2:37	2:42	1:22	2:00	3:08	2:31
0:41		3:51		4:30	3:05	4:38	3:00	1:26	2:02	3:23	2:42
0:46				4:45	3:26		3:11	1:25	2:00	4:00	2:55
0:58					4:17		3:08	1:30	2:00		3:09
0:41							3:20	1:45	3:00		3:23
0:46								3:00			3:30
0:55								2:30			3:35
1:05								2:00			3:54
1:16								2:24			3:52

The siphoning rates also visibly changed based on how high the spigot was held, even when the height varied only by the depth of the graduated cylinder (around eight inches). The siphoned volume was measured in 15 second increments, and every time the water filled up the one liter beaker, it was emptied, and the time restarted. The siphoning rate in the last 15 seconds filling the beaker was up to 0.2 liters per minute slower than the first 15 seconds in the newly emptied beaker. This was due only to the height difference in the spigot, since the water level in the KWK would be

Figure 59 Siphoning Rates Decrease as the Graduated Cylinder Fills Up and Increase Again After Graduated Cylinder Emptied (every 1,000 mL)



slightly lower as time passed. Figure 59 (above) shows the volume measured coming out of the siphon. Each point is at 15 second increments, and so the larger vertical distance between dots, the faster the flow rates. As the volumes approach the top of the beaker (at one liter), the flow rates slow down (and the hashes get closer together). Flow rates improve after the beaker is emptied and the spigot is again moved to the bottom of the beaker (hashes at the bottom of the "Volume Siphoned" axis are spaced further apart). This shows how highly dependent the siphon rate is on the height of the collection bucket, which means users will need to use shallow dishes and keep them very close to the ground to optimize siphon flows.

7.2.2 Siphon Rates During Normal Usage

The previous siphoning rates occurred when the KWKs were nearly completely full of water from filtering overnight. Filtration rates from Section 7.1 were calculated from pouring out the filtered water from the keg directly, not from siphoning out the water. To determine how quickly people could access clean water with the siphon throughout a normal day, after they've used up the night's water, KWKs were installed in full vessels and monitored roughly every hour (Table 31 below). The siphoning speed per liter was recorded (in minutes), when siphoning was possible. Partial siphoning means that after pumping for 10 seconds, the siphon would work for a few seconds before needing more pumping. At the end of the day, the remaining volume in the KWKs was measured to determine both what percentage of the clean water people can access through the siphon and the total volume of filtered water that the KWKs produced.

Table 31 Filtered Water Volume Available by Siphon Throughout a Day (no water in KWK at time 0)

Hours	KWK-CT-1		KWK-CT-2		KWK-CT-3		KWK-CT-5		KWK-CT-6	
	Siphon Vol. (Min/L)	Turbidity NTU	Siphon Vol. (Min/L)	Turbidity NTU	Siphon Vol. (Min/L)	Turbidity NTU	Siphon Vol. (Min/L)	Turbidity NTU	Siphon Vol. (Min/L)	Turbidity NTU
0.5	0.6 L	57.6	no siphon	59.9	no siphon	29.2	0.45 L (partial siphon)	52.3	1 L (2:46)	37.1
1					0. 52 L (partial siphon)	24.4	2 L (1:57 / 3:29)	79.9	4 L (1:44 / 1:59 / 2:03 / 2:30)	35.0
1.5	1 L (partial siphon)	56.7	0.45 L (partial siphon)	48			0.5 L	83.1	can't hold siphon	34.9
2			1 L (2:56)	43.9	6 L (1:39 / 1:30 / 1:36 / 2:15 /	22.7				
2.5	1.8 L (3:43 / 3:38)	59.5								
3			3 L (2:39 / 3:22 / 4:33)	40.2			3 L (1:27 / 2:00 / 2:40)	79.5	2 L (2:30 / 2:29)	34.7
3.5	1 L (3:00)	62.7			no siphon	20.7				
4			0.6 L (partial siphon)	41.6			2 L (1:53 / 2:30)	75.1	1 L (partial siphon)	22.4
5.5	2.4 L (1:19 / 3:08 / 1:42)	63.5	no siphon	41.1	3 L (1:45 / 3:48 / 2:13)	20.7	3 L (1:33 / 2:15 / 2:17)	68.9		
6									3 L (2:03 / 2:43 / 2:48)	31.8
6.5					0.85 L (partial siphon)	20.7	2 L (2:05 / 2:29)	61.9		
Vol. in Keg	**10 L**		**11 L**		**5 L**		**9 L**		**9 L**	
Vol. Siphoned	**6.8 L**		**5 L**		**10.4 L**		**13 L**		**11 L**	
Total Filtered Vol.	**16.8 L**		**16 L**		**15.4 L**		**22 L**		**20 L**	

Overall, the siphoning mechanism is not an effective way of accessing the filtered water. Using only the siphon, all but one of the kegs were half full at the end of the day because the siphons were unable to remove the other half of the filtered water. This means that half of the filter capacity is not being used because it was continually filled with inaccessible water. When the KWK is fully drained every hour, the kegs can filter over 25 liters in four hours, or over 200% faster than the filtration rates measured here. When the KWK is not fully emptied, as happened during this testing due to incomplete siphon removal, the KWK could only filter 16 liters in six hours. Additionally, even though the kegs would have filtered 10 liters in the first hour, users of the siphon would still need to wait one to two hours to siphon any of that filtered water out. This delay of water access after the KWK is completely emptied will be particularly inconvenient for users who use the KWK infrequently, such as only on days when they are using dugout water.

7.2.3 Comparison to Traditional Filters

Flow rates out of the water storage container's spigot used for the ceramic pot filters (CPF) was also measured for two CPFs that had been filtering for an hour (total volume inside the containers was just over three liters). In Table 32 (below) the flow rates out of the KWK siphons are compared to the flow rates out the CPF spigots[16].

Table 32 Comparison of Siphon Removal Rates for Individual KWK Filters to Spigot Removal Rates from Individual CPFs (liters/minute)

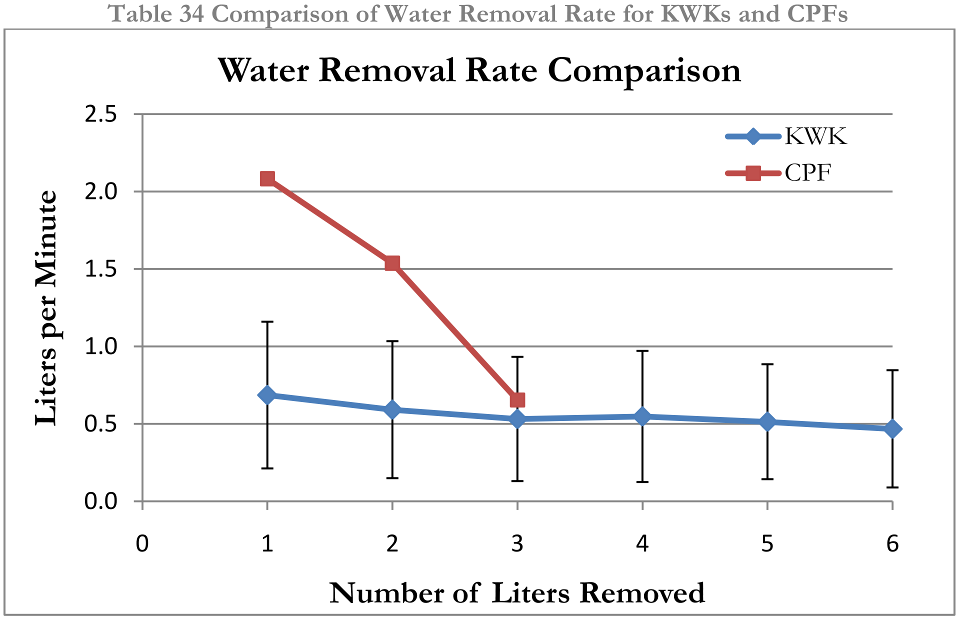
KWK-CT-1	KWK-CT-2		KWK-CT-3		KWK-CT-5			KWK-CT-7			KWK-PHW-10	KWK-PHW-11	PF-CT-A	PF-CT-B
0.58	0.92	0.34	2.00	0.50	0.47	0.57	0.67	0.62	0.34	0.52	0.74	0.52	2.40	1.76
0.41	0.64	0.50	1.82	0.36	0.40	0.36	0.60	0.57	0.29	0.67	0.38	0.44	1.88	1.20
0.38	0.63	0.44	1.67	0.44	0.39	0.35	0.56	0.44	0.27	0.44	0.33	0.41	0.51	0.80

The CPF spigots are significantly faster than the KWK siphon for the first liter, although the speeds drop off rapidly for the second and third liter. However, the CPF spigots should have even faster flow rates when the containers are fuller, such as when they have the six to seven liters that the CPFs are normally able to filter over night. Additionally, all of the filtered water is able to be extracted through the spigot, with some tilting of the container, whereas the siphon is consistently unable to siphon more than 13 liters out of the KWKs.

Table 33 Average Siphon Removal Rate from KWKs Compared to Average Spigot Removal Rate from CPFs

KWK Average	PF Average
0.68	2.08
0.57	1.54
0.52	0.65

Table 34 Comparison of Water Removal Rate for KWKs and CPFs



[16] Note, for the pot filters, technically only CT filters were measured. However, the manufacturer of the ceramic filter is irrelevant because when measuring the flow rate out of the storage container, the only thing that matters is the water depth inside the storage container and the spigot design. Both CT and PHW pot filters use the same storage container and spigot, and so these results can be generalized for both. If the filters had been allowed to filter overnight instead of just for one hour, flow rates would have been faster due to the higher water head originally in the storage container.

7.2.4 Siphon Evaluation

Overall, the siphon does not perform well enough to be the permanent water extraction solution, at least in cases where the source water can't be elevated above the ground. While the siphon mechanism is cheap and easy to make, the siphon performance is too uneven. The first problem is how unreliable the siphon is to start. Even when the KWK filters were full, over 40% of the time, the siphon couldn't last long enough to siphon a full liter out of the keg. When the KWKs aren't full, such as when users are attempting to empty the kegs throughout the day, the siphon is even less reliable.

The second problem is that the siphon flow rates aren't as fast as the ceramic pot filters' gravity powered spigots. Quick flow rates are important because currently users dip their pots into their water vessels to access their water, and so they are not expected to be willing to wait very long for their purified water. While in one instance KWK-CT-3 sustained faster rates than the CPF spigots, the overall average siphoning rate was 0.55 liters per minute. This means that filling up a 10 liter pot would take over 20 minutes, which people are unlikely do to when they could just dip the pot into the raw water and fill it up in seconds.

The final problem with the siphon is that it cannot remove all of the filtered water. At its best, the siphon left behind around four liters clean water, and the majority of the time it was leaving ten liters in the keg. This dramatically reduces the functional volume of the KWK and decreases filtering rates. If people are exclusively using the siphon, they will only have access to 6 to 13 liters of the 15 to 17 liters of filtered water.

Overall, the siphoning mechanism needs to be improved or replaced with a new device. Cheap hand pumps exist that could be purchased and modified to work with the KWK, and research should focus in this area for new alternatives.

8 CONSUMER STUDY

Two different consumer studies were done to learn about current water habits and perceptions of the KWK design. First, a general survey of 16 households established a baseline for water collection and purification habits. This was followed by five families using the KWKs for ten weeks to gather data on how well the KWK met the water needs of households throughout their normal routine. Amuda Abdul-Rashid, a PHW employee, worked as a collaborator and translator on all of this survey work.

8.1 VILLAGE SURVEY

A basic survey of water collection and treatment habits was conducted on 10 houses in Taha and 6 households in Gbalahi, with each survey lasting about 15 minutes. The households interviewed were not random but instead were selected by Abdul-Rashid, who was familiar with the area, and specifically targeted village leaders. Questions were focused on soliciting feedback on the KWK design (based on pictures and a verbal description of the filter) and selecting households to participate in the 10 week study. For each household, the author recorded:

1) The number and dimension of water storage vessels
2) The source of water, and how often the family gathered it

3) How often they cleaned their vessels
4) If the family had a Kosim (CPF) filter, if they used it, and who had acquired it
5) Reaction to the KWK design

A complete listing of survey responses by households can be found in Appendix D-1.

8.1.1 Water Storage Vessels

Figure 60 Traditional Ceramic Water Vessels Used to Store Water in Rural Ghana

Four of the sixteen households had 1 water storage vessel, six had 2 water vessels, and six had 3 or more. Each vessel is handmade, and sizes varied from vessel to vessel. The vessel opening diameters range from 9 to 13 inches, and usually are not perfectly circular. Vessel depths range from 24 to 30 inches, with only two vessels shallower. All households reported gathering water in comparable blue metal bucket, which measured 14 inches deep with a 13.5 inch diameter (holding 32.8 liters). When asked how many buckets of water each water storage vessel could hold, people estimated between 4 buckets (130 liters) and 7 buckets (230 liters), with an average of 5.3 buckets (175 liters).

Water vessels traditionally have conical bottoms, and so they are secured by either being partially buried or set into a tire. Leaks are patched with either a mixture of egg and clay or by a coating of concrete. No one could give a specific expected lifetime for the vessels, but one family stated they had had theirs for over ten years, and another family estimated that the vessels last at least five years. The vessels were generally expected to be quite durable.

8.1.2 Water Source

Figure 61 Dugout Water, a Common Drinking Water Source in Rural Northern Ghana

Every household preferred to use tap water, gathered from community standpipes, and used the dugout water only when piped water was unavailable. Households in Taha reported that the taps worked more frequently in their community than the taps in Gbalahi, but in both communities, members stated that the taps operated irregularly and without a set schedule. All but two households gathered their water daily, usually in the morning but the time varied based on when the taps were flowing. When the taps were off, people would line up their buckets in front of the spigots to establish an order for when the water started flowing.

8.1.3 Cleaning Practices

Eleven families were asked about their cleaning practices, and six said that they cleaned out their clay storage vessels daily before refilling them with water. The other five said they cleaned their vessels 3 to 4 times per week or whenever the vessels looked dirty. When asked about their cleaning routine, however, most families were simply scrubbing the vessels out with sand or rinsing the vessels. Cleaning was mostly based on visual clues of dirt; the dugout water partially settles in the vessels and leaves silt at the bottom. No one talked about using chlorine to decontaminate the vessels.

Figure 62 View Inside a Water Vessel Reserved for Clean Tap Water

Six households specifically mentioned reserving one vessel for tap water, and using the other vessel(s) for washing or dugout water. People were very consistent about covering their vessel reserved for drinking water. When the piped water is unavailable for a full day or series of days, however, it seemed that the "clean" vessel was used for dug out water, since people reported going through all of their water storage each day. It was unclear that people would do more than rinse out these vessels before transitioning them back to the cleaner piped water.

8.1.4 Kosim Water Filter Use

Ten of the sixteen households surveyed had at one point owned a Kosim ceramic pot filter. Of those ten, one household could show the author their filter in use. Two households reported using the filter but lacked access to the filter during the day. Three other households had intact ceramic filters, but used only the plastic container and kept the ceramic filter element in storage. At the remaining four households, the ceramic filters had broken, and three also had had their storage containers leak. The ceramic elements had lasted 3 to 4 years before breaking. None of those four households had tried to replace their filters, frequently citing cost as a concern. It was also not clear that they would know where to go to purchase a new filter element. No one reported having recently purchased a Kosim filter. One household interviewed had recently moved into Taha, and she had not heard of the Kosim filters.

Figure 63 (top) Household Using the Plastic Bucket from Kosim Filter But They Removed the Ceramic Filter Element
(bottom) Kosim Filter Owned by Household But Used Infrequently

People who had intact filters said that they only used the filters when drinking dugout water. Piped water was considered clean enough to drink without filtering. Based on the unclean condition of the filters and the presence of dugout water but not tap water, the author believes that only one household uses their filter regularly, even though six reported using their filter for at least dugout water. The author thinks that the users over-reported how often they used the filter because they knew the survey was being conducted on behalf of Pure Home Water, who had provided the villagers with discounted filters. Dugout water was clearly being used for consumptive purposes during the interviews, and so households would have been using their filter at the time of the interview if these households did indeed regularly use their filters as claimed.

People had either gotten their Kosim filters for GHS 6 (US$3.95) or free. Four people were specifically asked who had acquired the filter, and twice it was the landlord (the owner of the compound of houses who rented out individual units).

8.1.5 KWK Reactions

At each household, people were shown a photo of the Kosim Water Keg, and Abdul-Rashid would explain how the filter worked and its potential benefits. Users were asked what they thought of it in general and compared to the Kosim Filter. People overwhelmingly liked that it was a bigger filter and so could provide faster filtration rates. Five people liked how it would keep water cool and work inside the traditional clay vessel. Price was a major concern; while a few people said they would be willing to purchase it, people expressed that money was not readily available.

8.1.6 Prices

People stated the price for their clay water storage vessel as being between GHS 14 and 20 (US$9.25 to $13.20). The metal buckets used for gathering water cost from GHS 6 to 10 (US$3.95 to $6.60) (all of these buckets looked identical), and their expected lifespan was long, but not precisely known. Gathering water from the standpipe in both communities cost GHS 0.20 (US$0.13) per three buckets (each bucket held about 30 liters). One family stated that this money is collected by a person monitoring the standpipe, but when the author observed women collecting water, there was not a clear person collecting fees. Users do not need to collect all three buckets at once, but rather the person monitoring the standpipe remembers how many buckets each user has collected. In the household trial of the KWK, when asked what households did not like about standpipe water, two of the five households cited the high cost of the piped water, although they were still willing to pay that amount. Collecting water from the dugout is free.

Based on this information, the KWK, at GHS 20 (US$13.20), is likely to be seen as expensive but within households' ability to purchase, with price the similar to the high end of water storage vessels. See Appendix A-3 for the cost break down, at current small-scale construction estimates, for producing the KWK.

8.2 HOUSEHOLD TRIALS

After the author determined that the KWK could remove an acceptable percentage of bacteria from the water in the short term (over two weeks), the next step was to try the KWKs in normal household use to determine if the filtering and siphoning rates could meet the users' needs. The author was also interested in feedback from users who were familiar with operating the product.

The author worked with Chris Schulz and Amuda Abdul-Rashid to develop a weekly survey for the users regarding recent performance experiences (i.e., how the filter had performed in the previous day) and a beginning and ending survey regarding general practices and attitudes towards water purification and opinions on KWK performance. Abdul-Rashid was tasked with delivering the filters to the selected families, spending a half day training each family on proper use of the filter, and then following up with each family once a week for ten weeks.

Originally, the author had planned on selecting eight households to leave kegs with for a 10 week long study. However, the ceramic vessels made for PHW were not as durable as the ones in people's homes. By the end of the author's four weeks in Ghana, only five vessels remained of the eight that had been fabricated. Four of the CT kegs and 1 PHW keg were selected for home trials based on their previous performance.

Abdul-Rashid installed the KWK filters in five households on February 3rd and 4th and explained to the households how to use the filter. He visited each household weekly to ask the families questions regarding their water source that week and the KWK performance. During that time period, all KWK filters survived intact; however the trial was still hampered by the poor performance of the ceramic water vessels. One vessel broke on February 25th and another on March 4th. A third family stopped participating in the survey after a death in the family. As a result, only two families used the KWK for the full study period.

8.2.1 Water Habits of Study Participants

The water source varies seasonally for the households. All five families report using dugout water in the summers and using the tap during the winters. Two families also use wells during the winters. During this specific survey period, everyone used dugout water at least part of the time. Only one family ever reported using only tap water for a week, while among all five families there were in total 9 weeks of only dugout use (out of a total of 24 data points). Families varied from week to week between the evening and morning for when they had last collected water but families were usually refilling their vessels three times a day. Women, and occasionally children, were collecting water. The households were collecting about 12 buckets of water per day, which took 5 to 15 minutes to collect from the dugout (except one household for whom it took an hour), and 2 to 5 minutes to collect from the standpipe.

Across all five families, people liked the tap water because it is clean and safe, and they didn't like that is was available infrequently. Two families also cited the cost of the water as being a problem. The best features of the dugout water were that it is free, but two households specifically said they were using it only because they had no other choice since sometimes it is the only available water. People did not like that the dugout water is dirty, with one family citing an unpleasant smell to the dugout water. People did not have much to say about general filtered water; they liked that it is clean but no family gave a negative.

Assessing whether or not water is safe to drink was based entirely on the appearances of the water. Only dugout water is treated, and in the initially survey, only one household reported treating dugout water with the Kosim filter, and this household also treated their tap water with a cloth Guinea worm filter. The other four households reported using a cloth Guinea worm filter for their dugout water and doing nothing to treat tap water. All five households reported storing tap water and dugout water in different vessels. All five families also had had a Kosim filter at one point; three had gotten them for free and the other two families had each paid GHS 7 (US$4.62) for them. Three families reported using their filter (and had water in the filter at the time of the survey) at the beginning of this study. These filters were cleaned twice a week using a brush and Aquatabs (a brand-name chlorine tablet sold in Ghana). Cleaning was done whenever the flow rate started decreasing. Filtered water was reserved for drinking purposes only.

8.2.2 KWK Performance

Households reported that they noticed an improvement in the look, taste, and temperature of the filtered water compared to the raw water. Abdul-Rashid observed that households were using the KWK (or at least still had them installed in water vessels that contained water) and that the kegs worked (water filtered in and could be drawn out). However, four of the five kegs had cracks beginning to form in the seal within three weeks of installation. Also, two of the five households discontinued use after the water storage vessel broke.

The households reported that the KWK usually provided enough drinking water to meet their needs. Each week, they reported wanting water but not being able to get any only one to three times per week (household sizes varied from 5 to 13 members). The top four characteristics that households like about the KWK are that 1) it purifies the water; 2) the treated water is cooler; 3) the KWK looks nice. In the beginning, they liked the pumping mechanism, but after the novelty wore off, by the end households were citing this as a problem due to it being too slow. While people were using the siphon tubing, no one reported actually siphoning out water. Instead they would continually pump the tubing up and down. However, when Abdul-Rashid checked if the KWKs could siphon, he consistently found that they could, although siphoning one liter of water took between two and three minutes. In comparison to the traditional pot filter, all households thought the KWK filtered faster. Opinion was divided on whether the KWK was easier or the same difficulty to use as CPFs, and three of the five families thought the KWK was harder to clean. They thought that the clarity of the water out of the KWK or the pot filter was about the same. Three of the five households thought KWK water tasted better than the traditional filter's water, and the other two households thought it was the same.

People had no serious critiques of the KWK itself in the middle of the study, but by the end, households did not like having to pump the siphon to extract water, and they found that process to be too slow. All households wanted to be able to cover the raw water, and this would require a lid to be designed to accommodate the KWK stem that sticks up above the vessel. The ceramic water vessels produced for KWK testing were of a very poor quality as previously mentioned. Users primarily commented on the quality of the ceramic water storage vessel, which is not actually part of the KWK.

People were cleaning the KWK based on the appearance of the filter and the flow rate. They all reported using a brush and Aquatabs to clean it, but the use of Aquatabs could be artificially high because a supply of Aquatabs was included with the KWK installation. During the interview process, Abdul-Rashid would observe a cleaning event, he reported that they included using an Aquatab inside the keg, scraping the keg exterior, and cleaning the water storage vessel. The perceived difficulty of cleaning the KWK could be that households were not regularly cleaning their CPFs and that the cleaning schedule used for the KWK in this study was more frequent than necessary.

The five households each paid between GHS 9 and 12 (US$5.95 to $7.95) for their water storage vessels. By the study end, all households said that they would pay this much or more for the KWK, but it is strongly suspected that the households believed that the KWK was a system which included the ceramic water vessel, instead of being strictly the filter. This is supported by the household who originally would not pay that amount for the KWK stating that their reason was that the ceramic vessel was too small.

9 Discussion of Results and Avenues for Continued Research

Based on the technical performance of the KWK (bacterial and turbidity removal, and filtration and siphoning rate), the KWK is a technology that warrants continued research. The KWK design still needs some improvements. The sealant method and water extraction method need to be improved to match CPF performance. The size and shape of the keg needs to be better adapted to local water vessel dimensions. All the KWK parts should be standardized so that all the parts can work in any KWK and water vessel without needing to be re-sized.

Bacterial testing is expensive, and with current knowledge, it is not possible to estimate a KWK's bacterial removal performance without actually running bacterial testing. More research is needed to find ways to determine a KWK's integrity and real-time performance that is more accurate than the leak test.

Finally, a plan for moving forward with longer-term, larger-scale testing needs to be developed to verify the preliminary findings collected during this January research period.

9.1 Improvements to the KWK Construction

When constructing and using the KWK, four areas stood out as needing particular attention in further design iterations: the sealant material; the water removal system; the keg size and shape; and finally standardizing all the KWK components.

9.1.1 Sealant Material

The glue sealants used in this trial do not allow the KWK to remove the same amount of bacteria as the CPFs. Additionally, the Gorilla Glue performance was unreliable and could not provide a complete seal. A composite system may be best, where an expandable glue connects the ceramic pots together, and then a non-expandable but waterproof seal is applied on top of the glue to seal out leaks.

It would be better if in later designs the KWKs did not require glue in their construction. First, the expanding and sealing glues identified so far are relatively expensive. Second, when the KWKs are glued, if one pot breaks, the whole keg must be thrown out. If there was a method of only bolting or screwing the pots together, if one pot became worn or broken, it could be changed out for a new one. Without glue, KWKs would be easier to assemble on-site, which would make shipping more efficient. The assembled KWK is bulky and fragile to ship, whereas the ceramic pots could be shipped nested, which would be easier to secure from breaking and a smaller volume to ship. Additionally, if individual pots broke during shipping, it would not ruin the entire KWK. Unbroken pots would simply be matched up to form the kegs after arriving, which will reduce the costs of shipping damage.

9.1.2 Water Removal System

The siphon system only worked about half the time and was unable to extract all of the water in the kegs. Even when working, removal rates were slow (0.5 liters/minute), and so a new water extraction system needs to be developed. Pumping the siphon tubing using the check valve was a surprisingly effective way to access the water, but a more efficient system should be possible. Further research into existing cheap hand pump designs should yield a more effective method. The device needs to be cheap, durable, and reliable. Considering the short height that the water is being lifted (around 18 inches), hand powered products should exist that can be used for the KWK either directly or after minor modifications.

9.1.3 Keg Size and Shape

The current KWK size is based on the filter size produced by Pure Home Water. A typical ceramic filter holds 7.5 to 9 liters, is about 8 inches deep and has an 11 inch diameter (sized for the 40 liter plastic storage containers). For the KWK, however, a narrower diameter is preferable based on the diameter of the opening of the traditional clay vessels in most households. There is no standard opening size for the traditional vessels, but most vessel diameters are between 9 and 12 inches. Since they were not perfect circles, rarely could a perfectly circular 11 inch diameter pot fit through the opening. For this testing, new vessels were specially made that had wider mouths. In the future, however, it would be preferable if a new press mold could be made to create smaller filters for the KWK. The smaller surface area would reduce filtering rates some, but more source water would fit into the vessel surrounding the keg, and so there would be a slight increase in pressure forcing the water through the filter. Most importantly, more households would be able to use the KWK without needing to purchase a new water vessel.

9.1.4 Standardize Components

In the current design, the PVC interior riser pipe and the wooden restraint system both need to be individually measured and cut to match specific KWKs (in the case of the riser pipe) and specific water storage vessels (in the case of the wooden restraint system). This significantly slows down the construction process because the tolerance for error on both these parts were low, and they both frequently needed to be re-measured and re-cut more than once. To scale-up production, parts should be interchangeable between different KWKs and vessels.

9.2 PROXY MEASUREMENTS FOR BACTERIAL REMOVAL

Bacterial testing is relatively expensive and cumbersome to perform. To evaluate ceramic pot filters, instead of doing bacterial testing, typically their one hour flow rate is measured, and each factory has a standard for what flow rates are acceptable (usually between 1 and 3 liters). If a reliable indicator could be found for the KWK design that would predict how well it would remove bacteria, this would be an easier way to monitor quality. Two proposals were considered here as proxies to monitor bacterial testing: 1) the leak test, where air is blown into the submerged keg, and air bubbles are checked for; or 2) turbidity removal, which particularly in the highly turbid Ghanaian dugout water does vary measurably between KWKs. The individual KWKs performed at very different levels, and so it will be important to have a method for reliably detecting KWKs with defects.

9.2.1 Leak Testing Results Compared to Bacterial Removal

The leak testing over all had very little relationship to how well the KWKs did at removing bacterial. CT-KWK-2's entire rim was full of small leaks, so much so that re-gluing was not even attempted. The author assumed that this KWK would perform too poorly to be worth fixing, and bacterial testing was only performed as a worst case scenario for KWK performance. Surprisingly, CT-KWK-2 had some of the best bacterial removal rates. More testing needs to be done to determine if there is an air bubble size that indicates a leak that is too small to affect bacterial removal.

Table 35 (below) lists the notes from the leak tests of the kegs listed by the *E. coli* percent removal.

Table 35 Leak Test Results for Each KWK, Sorted by *E. Coli* Percent Removal

Sample ID	Leak Test Description	Average Filtered Water			Average % Removal			Fate
		Turbidity	Coliforms	E. coli	Turbidity	Coliforms	E. coli	
CT-KWK-6	Re-glued 2 times and left with two tiny leaks.	27.7	21.3	0.0	54.4%	97.6%	100.0%	Used in household trial
CT-KWK-7	Entire rim glued twice and then re-glued leaks 2 more times. Left with one leak.	22.5	86.9	1.3	75.5%	96.4%	99.3%	Hairline cracks on last day of testing
CT-KWK-2	Small air bubbles everywhere, and so considered unrepairable	43.4	28.9	5.8	50.2%	98.4%	98.9%	Used in household trial
CT-KWK-3	Re-glued 2 times, and left with only two tiny leaks and good back pressure (meaning well-sealed)	24.0	32.7	1.4	71.2%	98.6%	98.7%	Used in household trial
CT-KWK-5	Re-glued 3 times and left with two small leaks.	35.8	630.7	24.5	65.3%	73.9%	91.6%	Broke on last day of testing
CT-KWK-1	Entire rim glued twice and then re-glued leaks 4 times. Three leaks remained in the same spots.	43.9	341.4	19.5	40.0%	85.9%	91.5%	Used in household trial

CT-KWK-6 performed the best, but it happened to have less contaminated water both times it was tested (additionally, the other KWKs were each tested an extra time). CT-KWK-5 and CT-KWK-1 both had problems with the seal around the bottom o-ring not being fully sealed, but this did not show up in the leak test. However, it could be determine by trying to wiggle the PVC riser pipe when it was fully assembled. CT-KWK-3 had the best performance during the leak test, but this did not show up in the bacterial removal results.

When the results are re-listed by turbidity removal instead of *E. coli* removal, they do correspond well with the leak test (i.e., the order of performance in the leak test is the same order of performance in turbidity removal), with the one exception of CT-KWK-3 performing slightly worse on turbidity removal than CT-KWK-7, even though CT-KWK-3 performed slightly better on the leak test.

Table 36 (below) sorts the data based on turbidity removal. To compare the order, the grey shaded column provides the order of KWK performance (best to worst) listed by *E. coli* removal.

Table 36 Leak Test Results, Sorted by Turbidity Percent Removal

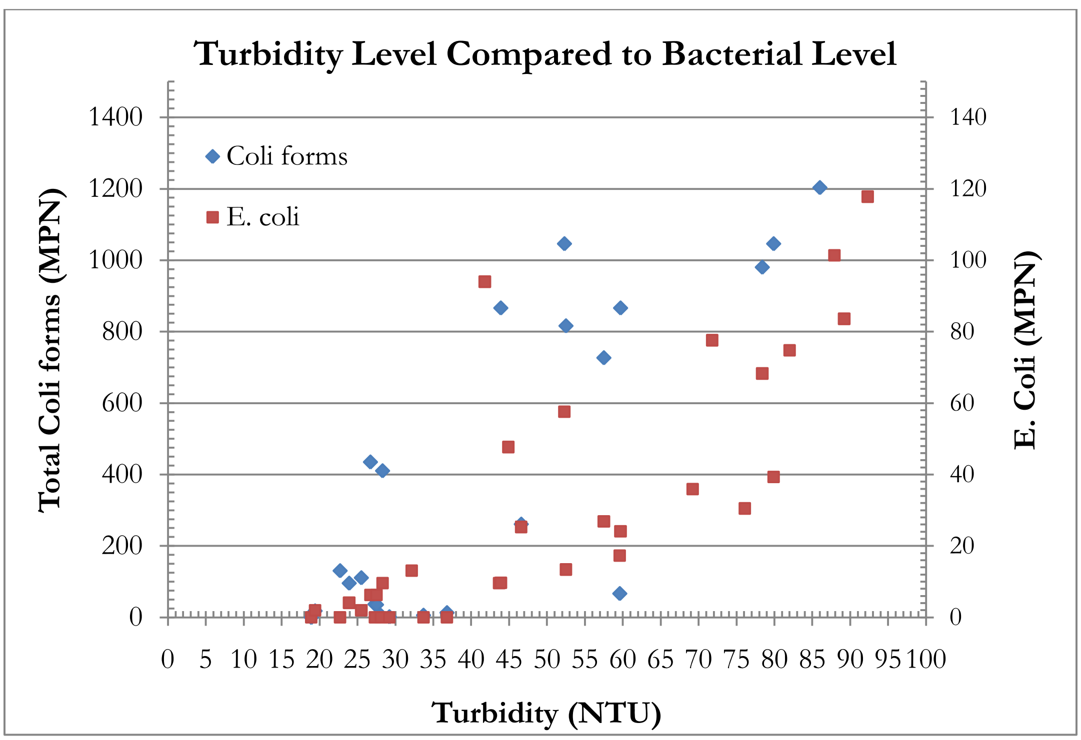
KWK Performance Order by E. Coli Removal	KWK Performance Order by Turbidity Removal	Leak Test Description	Turbidity	E. coli	Coliforms
CT-KWK-6	CT-KWK-7	Entire rim glued twice and then re-glued leaks 2 more times. Left with one small leak.	75.5%	99.3%	96.4%
CT-KWK-7	CT-KWK-3	Re-glued 2 times, and left with only two tiny leaks and good back pressure (meaning well-sealed)	71.2%	98.7%	98.6%
CT-KWK-2	CT-KWK-5	Re-glued 3 times and left with two small leaks.	65.3%	91.6%	73.9%
CT-KWK-3	CT-KWK-6	Re-glued 2 times and left with two small leaks.	54.4%	100.0%	97.6%
CT-KWK-5	CT-KWK-2	Small leaks everywhere, and so considered unrepairable	50.2%	98.9%	98.4%
CT-KWK-1	CT-KWK-1	Entire rim glued twice and then re-glued leaks 4 times. Three leaks remained in the same spots.	40.0%	91.5%	85.9%

With this limited data set, it seems that the leak test is not a good way to predict bacterial removal but does do well in predicting turbidity removal. More information is needed about what size leak is acceptable. (The size of the bubbles observed varied widely based on the size of the leak and the pressure of air blown into the tube.)

9.2.2 Turbidity Level Compared to Bacterial Level

While the percent removal of turbidity does not correlate well with the percent removal of *E. coli*, the raw numbers do correlate fairly well (see Figure 64 below). Over the range of turbidity levels measured in both filtered and raw water, turbidity has a 0.725 correlation with *E. coli* colonies per 100 mL (n=40) and a 0.715 correlation with total coliforms (n=40).

Figure 64 Turbidity Level Correlated to Bacterial Level



This correlation may only exist because the water in Ghana is so turbid. Completely clear water can have high bacterial loads, and so this correlation is not expected to be widely applicable. However, when dealing with dugout water, monitoring the decrease in turbidity is a rough approximation for the decrease in bacterial levels. However, a presence/absence bacterial test would still be necessary to determine if the total coliforms and *E. coli* have been removed from the water.

9.3 Filtration Rate Correlation to Bacterial and Turbidity Removal

During this testing period, data was not collected in a way to allow for a comparison between filtration rate and bacterial removal or filtration rate and turbidity removal. Future testing should run tests where different water heads are used on the KWKs to see if the resulting changes in filtration rates for the same KWKs alter the bacterial and turbidity removals. Similarly, the CPFs could have their raw water storage expanded to see if this causes a decrease in their performance. Knowing if there is a correlation between filtration rate and bacterial and turbidity removal would establish if filtration rates truly can be increased without any harm to the purification process.

9.4 Future Steps for KWK Development

As it is currently designed, the Kosim Water Keg is a promising technology. It has been designed to be easy and convenient to use. The author expects this technology to be popular with users, but more large-scale testing is necessary before this product can move into mass production. First, long-term testing needs to be done to determine product durability and performance, particularly in regard to long-term bacterial removal. The construction procedure needs to be refined as discussed in Section 9.1. Next, long-term, large-scale testing in households should be done to gather more detailed user feedback for further design iterations and develop educational and marketing materials for the KWK based on what users like and what they find difficult.

9.4.1 Non-Consumption Field Testing

The next step towards developing a working design for mass production is to do a three to six month study to establish the KWK performance over a longer time period. While the short-term performance of the KWK is positive, there are three KWK characteristics of particular concern that could come out only during long term testing:

1) Long-term bacterial removal
2) Long-term flow rates
3) Long-term durability of KWK components

While the flow rate and part breakage can be partially investigated during pilot testing, confidence in the long-term bacterial results is ethically necessary prior to prolonged testing of the KWKs in people's homes.

During this period, three aspects of the KWK design need further improvement: 1) a new restraint systems to accommodate a wider variety of water vessels; 2) alternative sealants to seal the two ceramic pot filters together; and 3) a more efficient water removal system. While re-designing cannot go on indefinitely, these are the three components of the design that seem to have the most variety in available options and a significant impact on the KWK performance.

9.4.1.1 Bacterial Removal

There are two concerns with regards to long-term bacterial removal: the development of micro-cracks and bacterial growth on the filter interior. The first concern is that wear and tear on the Kegs during normal usage could cause tiny cracks to form that are too small to be observed. During the testing in Ghana in January 2011, the kegs normally failed catastrophically (for example with the entire bottom part of the keg breaking off) and so were this to happen, a poorly trained user would still understand that this was a signal to discontinue use. However, the bacterial results for KWK-CT-5 began declining prior to its visible failure. KWK-CT-7 exhibited hairline cracks at which point it was no longer used in testing, but a casual user, particularly one who rarely removed the KWK from its vessel, could miss these more subtle signs of failure and continue using the keg even though these cracks would be allowing an increasing amount of bacteria through. A reliable, and obvious, way to detect these difficult to see failures needs to be developed and tested.

The second significant concern is bacterial growth inside of the keg. Bacterial growth has been noticed on the inside of candle and siphon filters after long-term field trials, and the KWK interior could similarly provide a hospitable environment for bacteria. KWK ceramic filters will be impregnated with silver, which candle and siphon filters sometimes lack, and this silver will provide a degree of anti-bacterial protection, but currently the author does not have evidence showing that this will be enough to protect the water quality over the three years that the filter is targeted to last.

The author and Schulz expect that a degree of cleaning the KWK interior with chlorine tablets will be needed to maintain the cleanliness of the keg interior. During these three months, KWKs will have Aquatab chlorine tablets dropped into the keg and shaken around at different schedules to determine how long the KWKs can go without chlorination. Some kegs will never be chlorinated as worst case scenarios.

9.4.1.2 Filtration Rate

The highly turbid water in Ghana is expected to clog the pores in the ceramic filters over time. Testing needs to measure the filtration rate over several months to record the amount of decline in filtering rates and determine how effective scrubbing is at restoring filtration rates. KWK scrubbing should be less frequent than for CPFs because while particulates collect in the bottom of the CPFs, the particulates will settle into the storage vessel instead of onto the KWK. Scrubbing information from testing will be used to advise households in the pilot study on how often they should scrub their filter. A previous MIT study of siphon filters found that users scrubbed the filters far more often than necessary, which caused the filters to wear out prematurely (Ziff 2009). Knowing ahead of time how often to expect to need to scrub the filter, if at all, should help in explaining proper maintenance.

The effect of alum pre-treatment of highly turbid water has not yet been explored in relation to the KWK performance. Decreasing turbidity through coagulation, for example by adding alum to the raw water, will reduce bacterial loading and the amount of maintenance required. Quantifying this improvement will better illuminate the tradeoffs involved for users in adding the extra alum step to their water treatment habits.

9.4.1.3 Product Durability

The goal of the KWK design is that it will be able to last the three years that CPFs typically last. In the three to six month tests, the target is to see if any parts are beginning to show wear. The ceramic filter itself and rubber o-rings are points where wearing is of particular concern. The KWKs will overall be carefully observed during this test period to see which parts are the most likely to cause trouble or break.

In order to be able to begin marketing the product without performing three or four years of pure testing, one strategy could be that for the first few years of sales, three year warranties could be offered to replace any broken parts for free. This could only be done when sales are local, where the seller is naturally in regular contact with their customers in order for customers realistically to be able to bring back their filters for fixing. The goal of the guarantee is to both ensure that the customer is getting a good value while the KWK design is still being finalized and to ensure that feedback reaches the KWK producers when there are problems with the design.

9.4.2 Pilot Testing in Select Communities

Once there is confidence in the filters' durability and long-term bacterial removal, a more detailed household study is needed to investigate how well the KWK meets users' needs. This soft start will provide practice for scaling-up production and installation of the KWKs in communities. It would focus on soliciting detailed user feedback and building on the preliminary information found from the small five person study in Taha and Gbalahi in February through April 2011.

Information collected from this exercise would be used towards two purposes. First, it would help finalize the KWK design. Chris Schulz is interested in designing a new mold specifically for KWKs, and this testing would refine what this mold should look like. Additionally, this study would provide objective data on KWK performance that can be shown to established NGOs working in the Household Water Treatment Systems (HWTS) space to interest them in testing or adopting the KWK design.

9.4.2.1 Larger Scale Production

Producing a few hundred KWKs will overall be a way to practice mass production and identify any construction inefficiencies that require design modification. For the keg to become commercially viable, other aspects of the design become much more important that do not relate specifically to bacteria and turbidity removal. For example, shipping costs are going to be a significant portion of KWK expenses, particularly in more rural areas. Designing the KWK so that it can be shipped disassembled could nearly double the number of units that can fit on one truck.

Producing KWKs on the scale of a few hundred kegs would clearly identify any aspects of the design that are too difficult or time consuming to build or assemble. An example is the restraint system, which currently is a block of wood with PVC arms that are sized to wedge against the vessel wall. This works great on a small scale, but every vessel has different dimensions. Individually cutting PVC arms for hundreds of vessels would be impractical. This production run will be a chance to try out more uniform solutions, for example possibly fixing screws to the end of the PVC arms that are adjustable to a range of vessel sizes. Similarly, the interior PVC riser pipe for the test KWK built with CT filters had to be a different height for every keg. If this continues to be a problem with the better quality controlled PHW filters, a procedure will need to be developed to better streamline the cutting of these pipes.

9.4.2.2 User Feedback

At this stage, the technical performance of the KWK should be well understood, but the design may still need improvement based on user experiences. Factors such as the kegs storage capacity and the sufficiency of the water removal mechanism depend on how much water users need and when they need it. Other factors, such as the clearance under the spigot for buckets, are similarly solely a matter of user preferences. The only way to determine if the current dimensions are preferable is through user feedback and testing.

During this pilot study, a better profile of the kinds of customers who find the KWK the most useful should be developed. More data is needed on where customers get their information on best water practices, where they normally shop for their kitchen appliances, and how they save money for large purchases. Getting this feedback to finalize the design will make the KWK more appealing to local Ghanaians. This will also help determine which features to particularly advertise as important when trying to sell KWKs and what avenues will best reach the people most likely to be interested in the KWK.

9.4.2.3 User Understanding

Another significant element that needs more research is how intuitive proper use and maintenance of the KWK is. Should the KWK go into large-scale production, sellers will no longer be able to spend as much time demonstrating proper keg usage to individual customers or follow up with users to ensure that they remember cleaning procedures. Instead, the KWK will need to come with clear instructions that people of any literacy level can understand and follow that explain how to install, maintain, and use the KWK. Additionally, people will need to have a basic understanding of how the KWK works, and so that if something breaks, they will be able to tell if it is something that is easily fixed or if the KWK needs to be replaced.

During this phase, pictorial instructions should be developed that provide all the information users would need to properly use the KWK. Pictorial instructions are preferable to written directions because of the high rates of illiteracy in Ghana and the multitude of regional languages. In order to test the effectiveness of the images, and evaluate if certain explanations are clearer than others, villagers could be challenged to install or clean KWKs using only the directions as guidance. After customers have used the KWK for several weeks, it would be interesting to present users with malfunctioning KWKs to see if they can figure out what is wrong. This information could be used to develop a trouble shooting manual. The more that users do not need individual explanations to adopt the KWK, the faster the KWK would be able to spread in the long run, and the more rural areas it would be able to reach.

9.4.3 Scaling-Up Dissemination

The KWK is designed to be able to be produced by existing ceramic pot filter factories without requiring them to invest in new machinery. Once the KWK design is more fully developed and tested, the KWK could be disseminated most widely by introducing CPF factories to the design, and offering training on how to produce the KWK.

The KWK is expected to be well-suited to areas where people store large volumes of water in their home. Areas where users either don't store water or store water only in smaller containers would either need to purchase a water storage container, which makes the KWK more expensive as a system, or would not experience as high of filtration rates into the KWK (since there would be lower water pressure from the raw water storage). The KWK should work well for rural areas where access to piped water tends to be less reliable or non-existent and where keeping the CPF clean would be particularly challenging.

The KWK design itself should be able to be used in different global regions without major adaptation, since the ceramic filter technology itself is already familiar to many areas. The restraint system to keep the KWK submerged in raw water would need to be designed to work with the local water storage containers. Additionally, the marketing and education campaigns and materials would need to be re-evaluated for each new location. By having existing ceramic filter factories produce the KWK, however, they can use their existing expertise to decide where and how best to promote the KWK.

10 CONCLUSIONS

The Kosim Water Keg has the potential to be a valuable addition to the suite of technologies known as Household Water Treatment Systems, and it is worth continued research investment. In this small-scale testing, the KWK (using CT filters) could consistently achieve a 1 log reduction in total coliforms and over 1 log reduction in *E. coli*. The best performing KWKs could remove 98% of total coliforms and *E. coli*, and all of the KWKs made from CT filters had at least one filtration test where the filtered water had fewer than 10 colonies per 100 mL, the WHO guideline for "low risk" water (WHO *Guidelines* 2008). However, the bacterial tests done so far have only looked at the KWK performance in the short term. Other candle filters and CPFs have had problems with bacterial growth on the filters over time under certain conditions, and the KWK has the potential to experience the same problem. Longer-term testing needs to be conducted on the KWK to determine what cleaning regime and schedule will preserve the optimal performance of the KWK.

In turbidity removal, the KWKs did not perform as well as their CPF counterparts (KWK removed 55% of turbidity and CPFs removed 78%), but more research needs to be done on the correlation between filtration rates and turbidity removal. It may be that there is a tradeoff between how quickly the water filters and the final turbidity level. The WHO does not have a health standard for turbidity, and if this is borne out by future testing, user studies will be needed to determine what the optimal filtration rate is from the customer's perspective.

Regarding filtration speed, the KWK far outperforms the CPFs. The KWKs consistently filtered over 10 liters per hour when the raw water vessels were completely full. The KWK could fill its entire volume (up to 17 liters) without needing the user to refill the raw water vessel. This compares quite favorably to the 2 to 3 liters per hour that the CPF could filter. Overnight, CPFs could only filter 5 to 7 liters in total due to their smaller raw water storage volume. Over time, the KWK is expected to reduce its filtration rate due to filter clogging with trapped particulates. Longer term testing is needed to measure how frequently the keg exterior will need to be scrubbed to remove these particulates and restore filtration rates at different raw water turbidity levels. As for accessing the filtered water, the KWK does not do as well as CPFs. The siphoning rate out of the keg was slow (at 0.55 liters per minute), which compares poorly to the CPFs, which could release over 2 liters per minute out of its gravity fed tap. The siphon could be pumped up and down to remove water, but the households who tried this method found it inconvenient and time consuming. The next design iteration should consider new ways to remove the filtered water from the keg.

The KWK does not require any special machinery, and, once the design is fully developed, it should be able to be produced by existing CPF factories after a few days of training. The three areas where the KWK design still needs work is in the sealant between the ceramic pots, the mechanism to remove filtered water from the keg, and the restraint system that keeps the KWK submerged in raw water. The seal between the two pots forming the KWK still needs further development to use materials that will be readily locally available and materials that are more reliable and controllable than Gorilla Glue proved to be. As mentioned before, the siphon removal system from the KWK, while it does work, works very slowly, and other mechanisms, such as hand pumps, that can remove water from the keg cheaply and without electricity should be researched. Finally, the restraint system used to keep the KWK submerged in the raw water also needs improvement to: 1) reduce the stress that it puts on the raw water vessel; 2) improve the stability of the KWK when the keg has filled with water and is sunken lower in the raw water vessel; and 3) be more standardized across different size and shaped water vessels so that each restraint does not need to be custom cut for an individual vessel.

A more formal system needs to be developed for evaluating if a KWK is constructed well enough to perform well. The leak test tried out during this trip did a good job of identifying leaks, but more practice is needed to determine which size of bubble flows are acceptable and what size needs to be re-sealed. Additionally, a better way to detect early cracking in the ceramic pots should be developed so that there can be an easy way for users to determine when they should stop using their KWK in advance of catastrophic failure (where the bottom of the keg breaks off).

The design of the KWK itself appears to be popular with the target consumers. The households in the survey were positive about the KWK, but more surveys will be needed to determine how much users would actually be willing to pay for the KWK. Based on what households are spending on other goods, such as their water vessels, most should have the ability to pay GHS 20 ($12.30), a price which covers KWK production costs. However, it is not clear that their willingness to pay for a water filter is this high. Several families qualified their interested in the KWK to hedge on price, and families around the PHW factory are likely expecting any water product to be heavily subsidized based on their past experience with NGOs. In order to command a price relative to the cost of producing the KWK, it may be best to emphasize the KWK performance in regard to its ability to cool water down, since this is a property in high demand based on customer surveys. This property is also clearly a luxury good that consumers will not expect to receive for free as a human right.

In order to promote better adoption and compliance rates with household water treatment systems, it is imperative that researchers continually try to redesign these systems based on customer feedback to make them integrate seamlessly with local water practices. The KWK is a good effort in that direction, and by continually working closely with the intended future customers in addition to lab testing, hopefully a product will emerge that target customers are eager to purchase and use.

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12 APPENDICES

12.1 KOSIM WATER KEG CONSTRUCTION

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12.1 KOSIM WATER KEG CONSTRUCTION

A-1 Construction Manual

A-2 Recent Design Improvements

A-3 Materials Pricing

A-1 Construction Manual

KWK Design
January 2011

Note:

The design for the KWK described here is still being tested and redesigned, and so the digital copy of this thesis does not include the full instructions. These on-line instructions are to illustrate the principles of the design and are not intended to be used alone for KWK construction.

For detailed construction instructions or for the most updated design e-mail the author at: jkc@alum.mit.edu

Prepare the PHW Filter Elements

1. If filter rims are rounded, they should be filed down until they are flat and smooth.
2. The two filters should be lined up and slowly rotated to find the position where there are the fewest gaps between the two filter rims. This alignment should be marked off.

Filing the filter rims flat

Rotating the two filters around to find the best alignment to minimize gaps between the two rims

Drill Hole in the Center of the Filter

1. Use a permanent marker to mark the center of the filter bottom.
2. Use the circular drill bit to drill a hole in the exact center of the ceramic pots (the PVC pipe will only be able to thread through the final keg if the holes align).
3. Make sure that the drill is straight side/side and front/back.

Marking off the center of the ceramic filter

Drilling the hole with a wooden guide

Glue on the Flat Metal Washers Around the Hole in the PHW Filter Elements

1. Sand down the inside of the holes.
2. Pour glue onto the metal washers.
3. Place the filter on a completely flat surface.
4. Put a PVC pipe through the ceramic hole and slide the washer down it onto the ceramic pot bottom. (The PVC pipe prevents the washer from covering the hole.) Place the washer down gently and turn it a quarter turn and back.


Sanding the hole smooth


Applying glue to the washers


Gluing the steel water to the ceramic filter, held in alignment by the PVC pipe

Finish the Attaching the Metal Washer and PHW Filter

1. Let the glue dry undisturbed.
2. Remove the PVC pipe by twisting it until the PVC pipe spins freely and then pulling it out.
3. Remove the excess glue from the metal washer but leave the excess glue on the ceramic. Sand the hole to ensure that a PVC pipe can still slide through it.


Dried glue


Removing the PVC pipe by first twisting it free and then pulling it out



Removing the excess glue on top of the metal washer but leaving alone the glue on the ceramic

Glue the Two PHW Filter Elements into a Keg

1. Wash out the inside of both of the PHW filter elements.
2. Level an area (checked with a level) to ensure that the glue spreads evenly.
3. Apply the glue generously around the rim of one filter.
4. Put a PVC pipe through the hole in the filter with glue and slide the other filter around the PVC pipe and line it up to the marks showing the best alignment.
5. Let the keg sit without moving it until glue is completely dry. Then remove PVC pipe.

Leveling the surface under the pot that glue is being applied to

Applying glue around one pot rim

Sliding the second pot onto the first over the PVC pipe and align to the mark

Leaving the PVC pipe in keg to keep alignment as keg dries

PVC Riser Pipe Construction: Drill Holes in PVC Pipe

1. Glue one end cap to on side of the PVC pipe.
2. Mark off a series holes evenly around the bottom of the pipe and one hole at the top of the pipe.
3. Drill holes through the PVC pipe.

Marked off PVC pipe

Drilling holes through the PVC pipe. Drill goes straight through the PVC pipe so in the end, there are holes every 90 degrees around the pipe (easier done with a vice)

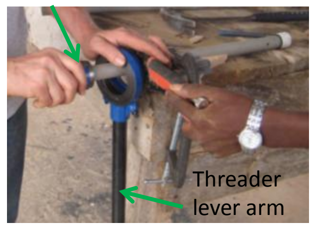
PVC Riser Pipe Construction: Cut and Thread Pipe

1. Put the PVC pipe in the keg and mark off the correct height.
2. Cut the PVC pipe at the mark with a saw or PVC cutters.
3. Thread the PVC pipe so that the T-Joint can twist on snuggly when the PVC pipe is inside the KWK.

Measuring out exact height for PVC riser pipe

Cutting PVC pipe to the right size (Pipe held in place with a wrench)

threader



Threading the pipe – first by hand (left), and then using lever arm (right)

Assemble the KWK

1. Place O-ring on the PVC pipe, push the PVC pipe through the ceramic keg, and put another O-ring on PVC pipe.
2. Take a T-Joint and drill a hole through the top. Take a short piece of PVC pipe and at one end, glue it to the center part of the T-Joint and at the other end to a threaded to non-threaded PVC adaptor.
3. Turn the keg onto its side and hold the bottom PVC endcap in one hand. Carefully screw the T-Joint handle to the top of the PVC riser pipe. Watch both O-rings, and stop tightening as soon as the O-rings begin to deform.

With an O-ring at the bottom, pushing the PVC pipe through keg

Pushing another O-ring onto the top of the PVC riser pipe

Screwing the T-joint handle to the top with the keg on its side

Leak Test the KWK

1. Replace the T-Joint with the rubber tubing for the leak test.
2. Submerge the keg underwater, starting first with the bottom seal, then the center seal, and last the top seal. At each stage, manually blow into the rubber tubing.
3. Look for streams of bubbles and mark any bubble streams.
4. File down the glue around all the leak marks, reapply Gorilla Glue and let dry.
5. Re-do the leak testing, marking any new or old bubble streams and repeat until no more bubble streams are visible.

Replacing T-joint with rubber tubing

Blowing air into keg and marking any bubble streams

Re-applying glue to leaking spots

Assemble the Siphon

1. Cut a length of tubing at least twice as long as the KWK height (including the T-joint). Tubing must be long enough to have the shutoff valve below the tubing entrance at the bottom of the KWK.
2. Superglue the check valve to one end of the tubing and the shut off valve to the other end.

Applying superglue to check valve

Applying superglue to shutoff valve

Pressing shutoff valve into tubing

Assemble Wooden Restraint System

1. Cut a hole in the middle of the wood block.
2. Cut a groove large enough to fit the PVC pipes
3. Coat the wood in waterproof paint.
4. Lay short pieces of PVC in the grooves and mark on the PVC where the wooden block falls on both sides. Wrap friction tape around the PVC pipe at these two points to prevent the PVC pipe from sliding.
5. Put the restraint system inside the water vessel to cut the PVC arms to the correct size (may take several cuts).

Marking where the wood hits the PVC pipe to indicate where to add friction tape

Top PVC pipe can slide left and right, but the bottom, with friction tape on, is held still

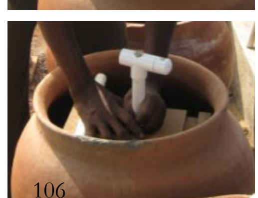
Install the KWK

1. Use one hand to hold the KWK underwater. Be careful not to press too hard down or the keg bottom will break.
2. Loop the hole in the wooden restraint over the T-joint (wooden grooves face upwards).
3. Put in one, then the other, PVC pipe arm in the wooden grooves.
4. Release the KWK and let the buoyancy of the KWK push the PVC arms into the curving top of the water vessel.

Picking up the KWK by the T-joint and putting it into water vessel

Placing central hole around the T-joint

Inserting one than the other PVC arm into wooden grooves



A-2 Recent Design Improvements

Appendix A-2
Design Improvements Made After the January 2011 Ghana Field Testing

These design changes were made in response to the field testing experiences in Ghana in January 2011 and have not yet been tested outside of Colorado. However, Mr. Schulz in collaboration with Ms. Lauren Schmeisser, a graduate student at the University of Colorado, has lab tested this design at the University of Colorado.

Seal Iteration 3: The Gorilla Glue was replaced with a polyurethane sealant, manufactured by Sika, which is designed for waterproofing concrete and masonry leaks. This is a caulk that comes in a caulking gun and so can be applied with greater control. This product was effective in providing a watertight seal and in bonding the ceramic-to-ceramic surfaces together. The Sika product was also used to seal the stainless steel washers to each end of the keg.

Figure 1 KWK sealed with Sika sealant
Source: Chris Schulz

> *Negatives:* The caulk takes up to 7 days to dry (3-5 days at temperatures above 80 deg F), which means that during mass production, the kegs would need to ship fully assembled. This is because when a user purchases a KWK, the installer needs to cut the restraint to fit that specific assembled KWK and water storage vessel. If the glue takes 7 days to dry, the installer would either need to visit the home twice or bring the KWK fully assembled.

Water Extraction Iteration 3: The siphon system was replaced with a hand pump manufactured in China. The hand pump is available in bulk for $1.25, which is cheaper than the siphon tubing. The pump is designed to extract water from 5 gallon water carboys (such as those used in water cooler dispenser systems), which are of similar depths to the keg. Users press a button on top of the keg to pump water, and it can pump water at 2 to 3 liters per minute. The pump is on top of the keg and it can easily pump water into a taller water storage container. The pump pressurizes the air inside of the keg, which forces water up through a riser pipe and out the spigot. At the same time, pressurized air is also expelled from the porous keg walls, providing a means of removing entrapped particles from the outer surface of the keg to maintain high filtration rates.

Figure 2 Water being removed from KWK with plastic hand pump
Source: Chris Schulz

> *Negatives:* No disadvantages have been seen so far based on lab testing by Mr. Schulz at the University of Colorado, but it hasn't been tested yet in Ghana. A new restraint system was developed for use in conjunction with the hand pump, as discussed below. There is also some concern that the plastic pump could degrade in the sun or not be durable enough to

last the full 3 year lifespan intended for the KWK. A white sock fitted over the hand pump may be beneficial in prolonging the service life of the plastic pump.

Submersion Restraint System Iteration 3: The new restraint is completely made of wood; a long piece lies on top of the vessel, and a shorter piece underneath wedges against the rim of the vessel. This system means that the wood is supported from below and so when the hand pump is used, the downward pressure is put on the strong water vessel instead of the more fragile keg. Under the old system, the wooden restraint was supported by the vessel from above, and so any downward pressure went straight to the keg. The keg riser pipe is secured by a hole in the center of the wood with fittings on both sides of the opening to keep the keg in a fixed position. This allows the keg to be located at a predetermined depth below the water surface to maximize filtration rates.

Figure 3 New design for wooden restraint to keep the KWK submerged Source: Chris Schulz

Negatives: This design uses more wood, which adds to the cost. The system still needs to be individually cut to each water vessel, and this design requires tools (a power jigsaw) to cut, which would be difficult to do at individuals' homes.

Newest Restraint System Update: A new variation of this design was recently developed by Mr. Schulz which uses three pieces of wood nailed together to increase the width of the bracket for improved stability. Each end of the bracket is secured by a clothesline and hanging weights (e.g., bricks or bags of sand), or alternatively stakes nailed into the ground on each side of the storage vessel, to counteract the buoyant force of the keg when it is empty. This low cost design is attractive because it can be used with different sized top openings of the storage vessel, but it remains to be field tested.

Figure 4 Another wooden restraint option for keeping the KWK submerged in the water vessel
Source: Chris Schulz

A-3 Materials Pricing

Kosim Water Keg - Bill of Materials (March 2011)

				KWK (Iteration 2)		KWK (Iteration 3)	
Item	**Description**	**Units**	**Unit Cost (US$)**	**Quantity**	**Total Cost (US$)**	**Quantity**	**Total Cost (US$)**
1	Ceramic Pot Filter Element	Each	$3.00	2	$6.00	2	$6.00
5	3/8" Flexible PVC Nonmetallic Conduit	Ft	$0.30	6	$1.80		
6	3/8" Plastic Irrigation Shutoff Valve	Each	$0.50	1	$0.50		
4	Plastic Hand Pump	Each	$1.20			1	$1.20
8	2" x 3/4" Bushing Sch 40 Slip x Slip	Each	$0.55			1	$0.55
14	3/4" Sch 40 Elbow	Each	$0.25	2	$0.50		
7	3/4" Sch 80 PVC Pipe	Ft	$0.20	2	$0.40	2	$0.40
9	3/4" Adaptor Sch 40 Slip by FPT	Each	$0.25	1	$0.25	1	$0.25
11	3/4" Sch 40 End Cap	Each	$0.35	1	$0.35	1	$0.35
12	3/4" Sch 40 Slip by Slip Tee	Each	$0.35	1	$0.35	1	$0.35
16	1.04" ID O-Ring	Each	$0.02	2	$0.04	2	$0.04
17	1.04" ID x 2.5" OD Steel Flat Washer	Each	$0.19	2	$0.38	2	$0.38
18	Polyurethane Sealer	LS	$0.50	1	$0.50	1	$0.50
19	2" x 6" Pine Lumber (for support bracket)	Ft	$0.30	1	$0.30	1	$0.30
20	2" x 4" Pine Lumber (for support bracket	Ft	$0.20	1.5	$0.30	1.5	$0.30
21	Rubber Strip (for support bracket)	Each	$0.50	2	$1.00	2	$1.00
22	3/8" Polyethylene Tubing	Ft	$0.20		$0.00	1.5	$0.30
			Total Cost:		$12.67		$11.92

12.2 WATER QUALITY RESULTS

B-1 Bacterial Results

B-2 Turbidity Results

B-1 Bacterial Results

Bacterial Removal for CT Filters (CPFs and KWKs)

Filter ID	Date	Coliforms Raw Water			Coliforms Filtered Water			Coliforms	*E. Coli* Raw Water			*E. Coli* Filtered Water			*E. Coli*	Average % Coliform	Average %
		Lower	Coliforms	Upper	Lower	Coliforms	Upper	% Removal	Lower	*E. coli*	Upper	Lower	*E. coli*	Upper	% Removal	Removal	*E. Coli* Removal
	18-Jan																
CPF-CT-A	19-Jan	n/a	>300	n/a	n/a	10	n/a	96.67%	n/a	>300	n/a	n/a	1	n/a	99.67%	96.67%	99.67%
	20-Jan																
	18-Jan																
CPF-CT-B	19-Jan	n/a	~~>300~~	~~n/a~~	~~n/a~~	~~68~~	~~n/a~~	~~77.33%~~	~~n/a~~	~~>300~~	~~n/a~~	~~n/a~~	~~2~~	~~n/a~~	~~99.33%~~	99.98%	99.36%
	20-Jan	1439.5	> 2419.6	infini.e	0	< 1.0	3.7	99.98%	55.3	77.6	104.5	0	< 1.0	3.7	99.36%		
	18-Jan																
CPF-CT-C	19-Jan	n/a	>300	n/a	n/a	6	n/a	98.00%	n/a	>300	n/a	n/a	1	n/a	99.67%	98.96%	99.19%
	20-Jan	1439.5	> 2419.6	infini.e	0.3	2	5.9	99.92%	55.3	77.6	104.5	0.1	1	5.5	98.71%		
	18-Jan	n/a	269	n/a	n/a	4	n/a	98.51%	n/a	122	n/a	n/a	0	n/a	100.00%		
	19-Jan	n/a	>300	n/a	24.2	35.9	51.9	88.03%	n/a	94	n/a	2.9	6.3	13.7	93.30%		
	20-Jan	1439.5	> 2419.6	infini.e	170.9	261.3	398.5	89.20%	134.9	184.2	251.4	16.1	25.3	37.7	86.26%		
KWK-CT-1	21-Jan															86.42%	93.59%
	22-Jan																
	25-Jan																
	25-Jan (pm)	1439.5	> 2419.6	infini.e	475.7	727	1048.9	69.95%	338.4	517.2	763.6	17.1	26.9	39.8	94.80%		
	18-Jan																
	19-Jan																
	20-Jan																
KWK-CT-2	21-Jan	583.8	866.4	1245.4	2.9	6.3	13.7	99.27%	14.8	24.1	36.5	0	0.5	3.7	97.93%	98.40%	97.77%
	22-Jan	705	1046.2	1509	7.8	13.5	23.4	98.71%	26.5	39.3	55.9	0	0.5	3.7	98.73%		
	25-Jan																
	25-Jan (pm)	1439.5	> 2419.6	infini.e	46.5	67	92	97.23%	338.4	517.2	763.6	10.3	17.3	28.2	96.66%		
	18-Jan	n/a	113	n/a	n/a	2	n/a	98.23%	n/a	0	n/a	n/a	0	n/a	-		
	19-Jan																
	20-Jan	810.8	1203.3	1750.7	0	0.5	3.7	99.96%	260.6	410.6	618.9	0	0.5	3.7	99.88%		
KWK-CT-3	21-Jan	1439.5	> 2419.6	infini.e	68.5	96	132.1	96.03%	74.3	101.4	136.1	1.7	4.1	9.5	95.96%	98.68%	98.75%
	22-Jan																
	25-Jan	660.6	980.4	1410.2	0.3	2	7.1	99.80%	48.7	68.3	93	0	0.5	3.7	99.27%		
	25-Jan (pm)	1439.5	> 2419.6	infini.e	8.5	14.8	25.1	99.39%	338.4	517.2	763.6	0	0.5	3.7	99.90%		
	18-Jan	n/a	~~173~~	~~n/a~~	~~n/a~~	~~142~~	~~n/a~~	~~17.92%~~	~~n/a~~	~~155~~	~~n/a~~	~~n/a~~	~~0~~	~~n/a~~	~~100.00%~~		
	19-Jan	n/a	~~>300~~	~~n/a~~	~~n/a~~	~~286~~	~~n/a~~	~~4.67%~~	~~n/a~~	~~>300~~	~~n/a~~	~~n/a~~	~~3~~	~~n/a~~	~~99.00%~~		
	20-Jan	1439.5	> 2419.6	infini.e	276.2	435.2	650	82.01%	358.2	547.5	804.5	2.9	6.3	13.7	98.85%		
KWK-CT-5	21-Jan	1439.5	> 2419.6	infini.e	260.6	410.6	618.9	83.03%	54.8	74.8	98.5	4.4	9.6	16.9	87.17%	73.93%	91.63%
	22-Jan																
	25-Jan																
	25-Jan (pm)	1439.5	> 2419.6	infini.e	705	1046.2	1509	56.75%	338.4	517.2	763.6	39.9	57.6	80	88.86%		
	18-Jan																
	19-Jan																
	20-Jan	1439.5	> 2419.6	infini.e	2.3	5.2	11.9	99.79%	55.3	77.6	104.5	0	0.5	3.7	99.36%		
KWK-CT-6	21-Jan															97.78%	98.06%
	22-Jan	550.1	816.4	1174.6	24.5	37.4	54.5	95.42%	7.4	13.4	22.3	0	0.5	3.7	96.27%		
	25-Jan																
	25-Jan (pm)	1439.5	> 2419.6	infini.e	30.2	44.8	63.4	98.15%	338.4	517.2	763.6	3.6	7.5	14.9	98.55%		
	18-Jan																
	19-Jan	n/a	~~228~~	~~n/a~~	~~n/a~~	~~204~~	~~n/a~~	~~10.53%~~	~~n/a~~	~~1~~	~~n/a~~	~~n/a~~	~~0~~	~~n/a~~	~~100.00%~~		
	20-Jan	1439.5	> 2419.6	infini.e	79.3	111.2	151.7	95.40%	358.2	547.5	804.5	0.3	2	7.1	99.63%		
KWK-CT-7	21-Jan	1439.5	> 2419.6	infini.e	11	18.5	29.2	99.24%	86.3	117.8	158.2	0.3	2	7.1	98.30%	96.05%	96.33%
	22-Jan	1439.5	> 2419.6	infini.e	88.2	130.9	187.2	94.59%	59.6	83.6	113.8	0	0.5	3.7	99.40%		
	25-Jan	1439.5	> 2419.6	infini.e	44.6	64.4	88.6	97.34%	13.7	22.3	34.1	0	0.5	3.7	97.76%		
	25-Jan (pm)	1439.5	> 2419.6	infini.e	102.6	152.3	228.4	93.70%	13.7	22.3	34.1	0.7	3	7.4	86.55%		

CPF Average	98.53%	99.40%
KWK Average	91.88%	96.02%

Note: Strike through means values were dropped (all measured with Membrane Filtration) from the average because the values were unrepresentative

KWK = Kosim Water Keg
CPF = Ceramic Pot Filter

CT = Ceramica Tamakloe (manufactured filter)
PHW = Pure Home Water (manufactured filter)

Bacterial Removal for PHW Filters (CPFs and KWKs)

Filter ID	Date	Coliforms Raw Water			Coliforms Filtered Water			Coliforms % Removal	*E. Coli* Raw Water			*E. Coli* Filtered Water			*E. Coli* % Removal	Average % Coliform Removal	Average % *E. Coli* Removal
		Lower	Coliforms	Upper	Lower	Coliforms	Upper		Lower	*E. coli*	Upper	Lower	*E. coli*	Upper			
CPF-PHW-D	21-Jan															82.01%	96.91%
	22-Jan																
	25-Jan	1439.5	> 2419.6	infini.e	276.2	435.2	650	82.01%	338.4	517.2	763.6	9.2	16	26.4	96.91%		
CPF-PHW-E	21-Jan	1439.5	> 2419.6	infini.e	140.2	214.3	320.9	91.14%	86.3	117.8	158.2	21.7	33.2	47.9	71.82%	30.38%	72.22%
	22-Jan	1439.5	> 2419.6	infini.e	1439.5	> 2419.6	infini.e	0.00%	218.9	344.8	520.7	70.2	95.9	127.6	72.19%		
	25-Jan	1439.5	> 2419.6	infini.e	1439.5	> 2419.6	infini.e	0.00%	338.4	517.2	763.6	103.5	141.4	187.8	72.66%		
CPF-PHW-F	21-Jan	1439.5	> 2419.6	infini.e	102.6	152.3	228.4	93.70%	86.3	117.8	158.2	2.3	5.2	11.9	95.59%	93.70%	95.59%
	22-Jan																
	25-Jan																
CPF-PHW-G	21-Jan	1439.5	> 2419.6	infini.e	195.3	307.6	471.2	87.28%	86.3	117.8	158.2	0.1	1	5.5	99.15%	57.68%	97.29%
	22-Jan	1439.5	> 2419.6	infini.e	218.9	344.8	520.7	85.75%	218.9	344.8	520.7	5.6	10.9	19.5	96.84%		
	25-Jan	1439.5	> 2419.6	infini.e	1439.5	> 2419.6	infini.e	0.00%	338.4	517.2	763.6	12.7	21.3	32.6	95.88%		
KWK-PHW-10	21-Jan	1439.5	> 2419.6	infini.e	1439.5	> 2419.6	infini.e	0.00%	19.4	30.5	44.8	6.8	13.1	21.8	57.05%	21.39%	76.14%
	22-Jan	1439.5	> 2419.6	infini.e	1439.5	> 2419.6	infini.e	0.00%	24.2	35.9	51.9	4.4	9.6	16.9	73.26%		
	25-Jan	1439.5	> 2419.6	infini.e	583.8	866.4	1245.4	64.18%	338.4	517.2	763.6	4.5	9.7	17.2	98.12%		
KWK-PHW-11	21-Jan															0.00%	64.73%
	22-Jan	1439.5	> 2419.6	infini.e	1439.5	> 2419.6	infini.e	0.00%	218.9	344.8	520.7	34.9	47.7	63.6	86.17%		
	25-Jan	1439.5	> 2419.6	infini.e	1439.5	> 2419.6	infini.e	0.00%	338.4	517.2	763.6	232	293.3	365.5	43.29%		

CPF Average	65.94%	90.50%
KWK Average	10.70%	70.44%

KWK = Kosim Water Keg

CPF = Ceramic Pot Filter

CT = Ceramica Tamakloe (manufactured the filter)

PHW = Pure Home Water (manufactured the filter)

Turbidity and Bacterial Removal Measured At the Same Time

Filter ID	Sample Date	Raw Water			Filtered Water			% Removal			Average Raw Water			Average Filtered Water			Average % Removal		
		Turbidity	Coliforms	*E. coli*	Turbidity	Coliforms	*E. coli*	Turbidity	Coliforms	*E. coli*	Turbidity	Coliforms	*E. coli*	Turbidity	Coliforms	*E. coli*	Turbidity	Coliforms	*E. coli*
		NTU	MPN	MPN	NTU	MPN	MPN	%	%	%	NTU	MPN	MPN	NTU	MPN	MPN	%	%	%
KWK-CT-1	1/19/2011	41.8	2419.6	94	27.5	35.9	6.3	34%	99%	93%	78.8	2419.6	265.1	43.9	341.4	19.5	40%	86%	91%
	1/20/2011	67.6	2419.6	184.2	46.6	261.3	25.3	31%	89%	86%									
	1/25/2011	127	2419.6	517.2	57.5	727	26.9	55%	70%	95%									
KWK-CT-2	1/21/2011	59.7	866.4	24.1	33.7	6.3	0	44%	99%	100%	88.9	1444.1	193.5	43.4	28.9	5.8	50%	98%	99%
	1/22/2011	79.9	1046.2	39.3	36.8	13.5	0	54%	99%	100%									
	1/25/2011	127	2419.6	517.2	59.6	67	17.3	53%	97%	97%									
KWK-CT-3	1/20/2011	86	1203.3	410.6	18.9	0	0	78%	100%	100%	84.1	1534.4	193.4	24.0	32.7	1.4	71%	99%	99%
	1/21/2011	87.9	2419.6	101.4	23.9	96	4.1	73%	96%	96%									
	1/25/2011	78.4	980.4	68.3	29.2	2	0	63%	100%	100%									
KWK-CT-5	1/20/2011	94	2419.6	547.5	26.7	435.2	6.3	72%	82%	99%	101.0	2419.6	379.8	35.8	630.7	24.5	65%	74%	92%
	1/21/2011	82	2419.6	74.8	28.3	410.6	9.6	65%	83%	87%									
	1/25/2011	127	2419.6	517.2	52.3	1046.2	57.6	59%	57%	89%									
KWK-CT-6	1/20/2011	71.8	2419.6	77.6	28.1	5.2	0	61%	100%	100%	62.2	1618.0	45.5	27.7	21.3	0.0	54%	98%	100%
	1/22/2011	52.5	816.4	13.4	27.3	37.4	0	48%	95%	100%									
KWK-CT-7	1/20/2011	94.6	2419.6	547.5	25.5	111.2	2	73%	95%	100%	92.0	2419.6	249.6	22.5	86.9	1.3	76%	96%	99%
	1/21/2011	92.3	2419.6	117.8	19.4	18.5	2	79%	99%	98%									
	1/22/2011	89.2	2419.6	83.6	22.7	130.9	0	75%	95%	100%									
KWK-PHW-10	1/21/2011	76.1	2419.6	30.5	32.2	2419.6	13.1	58%	0%	57%	90.8	2419.6	194.5	39.9	1901.9	10.8	53%	21%	76%
	1/22/2011	69.2	2419.6	35.9	43.7	2419.6	9.6	37%	0%	73%									
	1/25/2011	127	2419.6	517.2	43.9	866.4	9.7	65%	64%	98%									
KWK-PHW-11	1/22/2011	88.7	2419.6	344.8	44.9	2419.6	47.7	49%	0%	86%	107.9	2419.6	431.0	56.5	2419.6	170.5	48%	0%	65%
	1/25/2011	127	2419.6	517.2	68.0	2419.6	293.3	46%	0%	43%									
CT KWK Average											84.5	1975.9	221.2	32.9	190.3	8.7	59%	92%	97%
PHW KWK Average											99.3	2419.6	312.8	48.2	2160.7	90.7	51%	11%	70%
Total Samples Average											88.2	2086.8	244.1	36.7	682.9	29.2	57%	72%	90%

KWK = Kosim Water Keg

CT = Ceramica Tamakloe (manufactured the filter)

PHW = Pure Home Water (manufactured the filter)

B-2 Turbidity Results

Turbdity Removal for Filters Made At Ceramica Tamakloe

KWK-CT-1			KWK-CT-2			KWK-CT-3			KWK-CT-5			KWK-CT-6			KWK-CT-7		
Source NTU	Filtered NTU	% Removal %	Source NTU	Filtered NTU	% Removal %	Source NTU	Filtered NTU	% Removal %	Source NTU	Filtered NTU	% Removal %	Source NTU	Filtered NTU	% Removal %	Source NTU	Filtered NTU	% Removal %
41.8	27.5	34.3%	59.7	33.6	43.7%	52.5	26.0	50.4%	66.0	25.5	61.3%	52.5	27.3	48.0%	42.7	13.9	67.4%
67.6	46.8	30.9%	79.9	37.0	53.7%	78.2	38.8	50.4%	76.9	29.5	61.7%	69.0	37.1	46.2%	58.7	20.8	64.6%
82.6	46.1	44.2%	112.7	40.8	62.0%	78.4	29.2	62.8%	82.0	28.3	65.5%	69.0	35.0	49.3%	89.2	22.7	74.6%
103.4	52.5	46.6%	127.0	48.1	62.2%	78.4	24.4	68.8%	94.0	26.7	71.6%	69.0	34.7	49.6%	92.3	19.4	79.0%
127.0	63.5	50.0%	127.0	43.9	65.5%	78.4	22.7	71.0%	127.0	52.3	58.8%	69.0	31.8	53.9%	94.6	25.5	73.1%
127.0	62.7	50.7%	127.0	41.6	67.2%	78.4	20.7	73.6%	127.0	79.9	37.1%	69.0	31.7	54.0%			
127.0	59.5	53.1%	127.0	41.1	67.7%	81.5	33.6	58.7%	127.0	83.1	34.5%	71.8	28.1	60.9%			
127.0	57.6	54.6%	127.0	41.1	67.7%	86.0	18.9	78.0%	127.0	79.5	37.4%						
127.0	56.7	55.4%	127.0	40.2	68.3%	87.6	24.1	72.5%	127.0	75.1	40.8%						

note: cells highlighted in grey were measured throughout a single day

CPF-CT-A			CPF-CT-B			CPF-CT-C		
Source NTU	Filtered NTU	% Removal %	Source NTU	Filtered NTU	% Removal %	Source NTU	Filtered NTU	% Removal %
83.4	25.2	69.8%	83.4	24.5	70.6%	83.4	16.8	79.9%
94.1	19.2	79.6%	94.1	23.4	75.2%	94.1	14.4	84.7%
77.0	20.1	73.9%	77.0	6.9	91.0%	79.1	19.8	74.9%

KWK = Kosim Water Keg
CPF = Ceramic Pot Filter

CT = Ceramica Tamakloe (manufactured filter)
PHW = Pure Home Water (manufactured filter)

Turbdity Removal for Filters Made At Pure Home Water

KWK-PHW-10			KWK-PHW-11		
Source NTU	Filtered NTU	% Removal %	Source NTU	Filtered NTU	% Removal %
69.2	43.7	36.8%	88.7	44.9	49.3%
71.8	27.4	61.9%	127.0	68.0	46.5%
76.1	35.7	53.1%			
76.1	28.7	62.2%			
127.0	43.9	65.5%			

CPF-PHW-D			CPF-PHW-E			CPF-PHW-F			PF-PHW-G		
Source NTU	Filtered NTU	% Removal %	Source NTU	Filtered NTU	% Removal %	Source NTU	Filtered NTU	% Removal %	Source NTU	Filtered NTU	% Removal %
92.0	19.5	78.8%	92.0	17.8	80.7%	127.0	32.6	74.3%	92.0	56.1	39.0%
88.7	21.0	76.4%							88.7	44.4	49.9%
127.0	30.5	76.0%							127.0	64.8	49.0%

12.3 Flow Rate Results

C-1 Filtration Rates

C-2 Siphon Rates

C-1 Filtration Rates

KWK Falling Head Filtration Rates

Hour	KWK-CT-1			KWK-CT-3			KWK-CT-6
	Test 1	Test 2	**Average**	Test 1	Test 2	**Average**	Test 1
	L/hr	L/hr	**L/hr**	L/hr	L/hr	**L/hr**	L/hr
1	11.8	11.8	**11.8**	11.2		**11.2**	11.0
2	8.4	9.1	**8.8**	6.9	5.9	**6.4**	9.8
3	9.6	6.7	**8.1**	5.3		**5.3**	5.7
4		4.0	**4.0**	3.7	3.9	**3.8**	5.2

Hour	KWK-CT-5				KWK-CT-7			
	Test 1	Test 2	Test 3	**Average**	Test 1	Test 2	Test 3	**Average**
	L/hr	L/hr	L/hr	**L/hr**	L/hr	L/hr	L/hr	**L/hr**
1	11.7	9.2		**10.4**	10.5	7.7		**9.1**
2	7.9	7.0	5.8	**6.9**	8.6	6.7	4.2	**6.5**
3	9.6	5.1		**7.4**	9.0	4.3		**6.6**
4		5.9		**5.9**		3.7	3.4	**3.5**

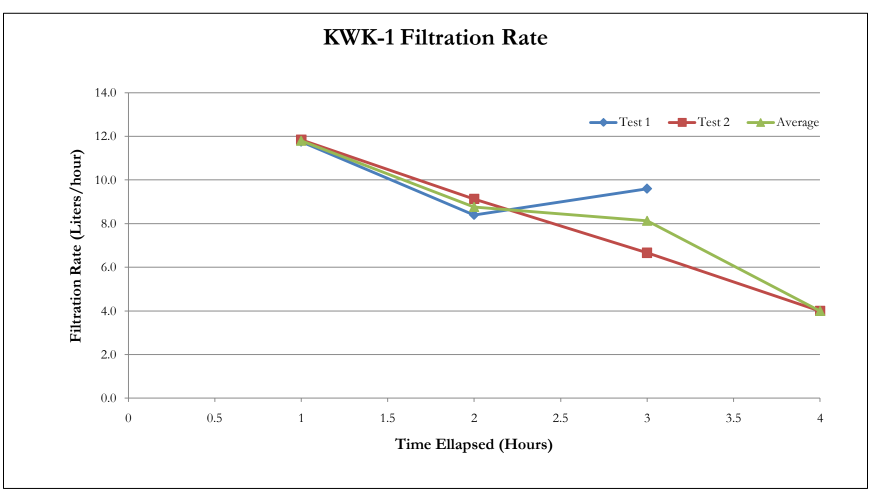
Note: No falling head filtration rate tests were done on the CPFs. The data presented in the thesis comes from the work of Claudia Espinoza in Tamale, Ghana Summer 2010

Graphs of Falling Head Filtration Rates

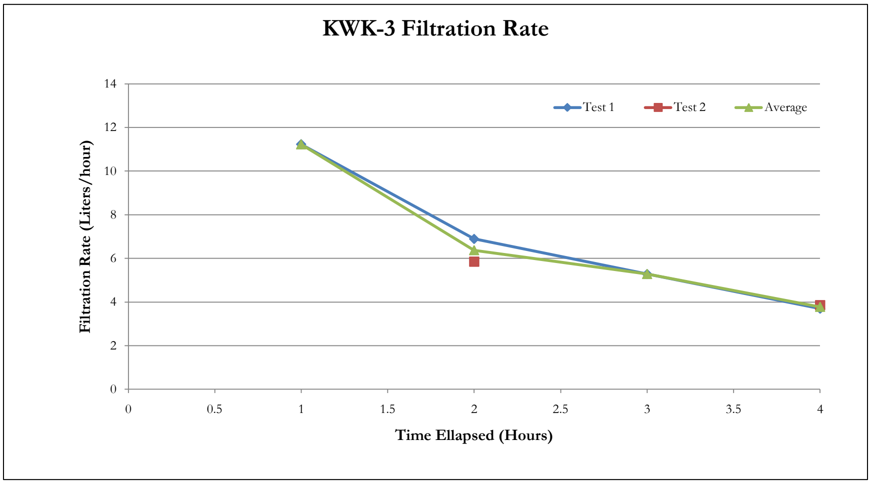
KWK-CT

#1, 3, 5, 6, 7

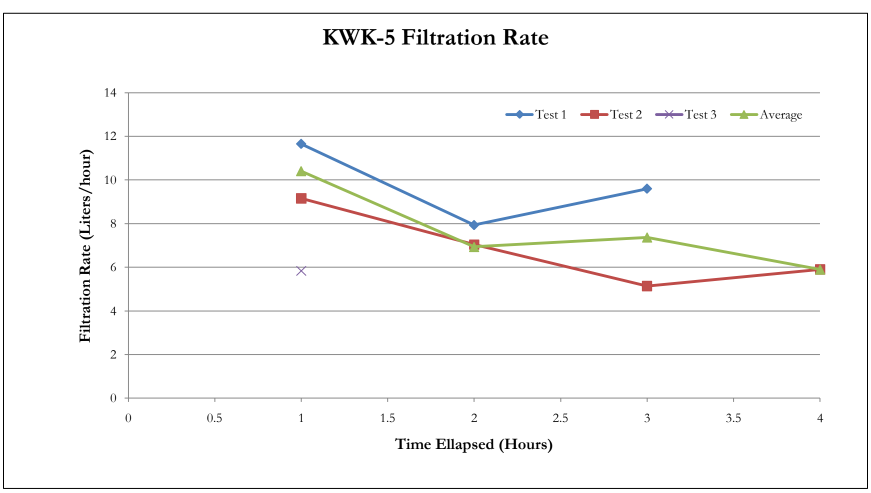
KWK-1 Falling Head Filtration Rate



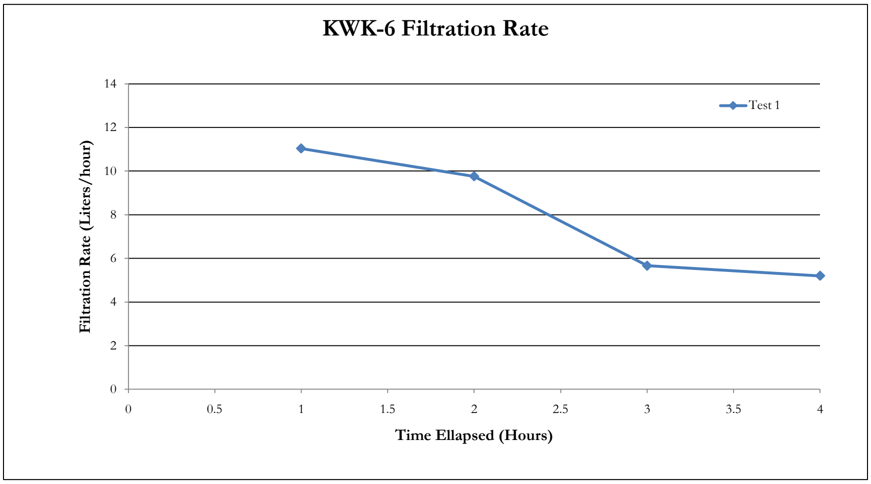
KWK-3 Falling Head Filtration Rate



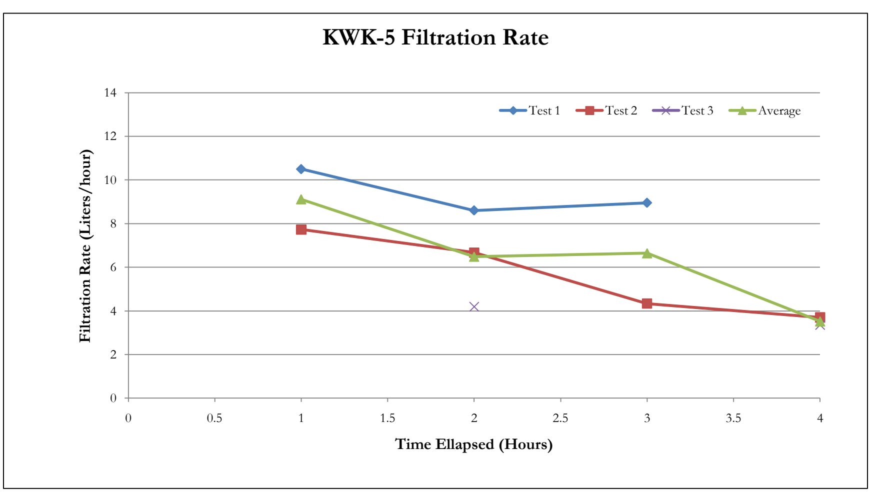
KWK-5 Falling Head Filtration Rate



KWK-6 Falling Head Filtration Rate



KWK-7 Falling Head Filtration Rate



C-2 Siphon Rates

Siphoning Rate Out of KWKs

Liter #	KWK Average	KWK-CT-1			KWK-CT-2		KWK-CT-3			KWK-CT-5						KWK-CT-6	
	L/min	L/min	L/min	L/min	L/min	L/min	L/min	L/min	L/min	L/min	L/min	L/min	L/min	L/min	L/min	L/min	L/min
1	**0.67**	---	---	0.58	0.92	0.34	---	2.00	0.50	---	---	---	0.47	0.57	0.67	---	---
2	**0.60**			0.41	0.64	0.50		1.82	0.36				0.40	0.36	0.60		
3	**0.55**			0.38	0.63	0.44		1.67	0.44				0.39	0.35	0.56		
4	**0.55**			0.37		0.43		1.71	0.50				0.37	0.34	0.51		
5	**0.55**			0.34		0.40		1.50	0.50				0.33	0.38	0.41		
6	**0.51**			0.32		0.37		1.46	0.49				0.30	0.22			
7	**0.51**			0.29		0.34		1.30	0.50				0.25				
8	**0.55**			0.23		0.32		1.03	0.50								
9	**0.67**					0.30		1.46	0.33								
10	**0.64**					0.29		1.30									
11	**0.59**					0.28		1.09									
12	**0.56**					0.26		0.92									
13	**0.49**					0.26		0.79									

"---" indicates siphon wouldn't start

Flow Rate out of Spigot of CPFs

Liter #	CPF Average	CPF-PHW-A	CPF-PHW-B
	L/min	L/min	L/min
1	**2.08**	2.40	1.76
2	**1.54**	1.88	1.20
3	**0.65**	0.51	0.80

Siphoning Rate Out of KWKs

Liter #	KWK Average	KWK-CT-7						KWK-PHW-2		KWK-PHW-4
	L/min	L/min	L/min	L/min	L/min	L/min	L/min	L/min	L/min	L/min
1	**0.67**	---	---	0.62	0.49	0.34	0.52	0.74	---	0.52
2	**0.60**			0.57		0.29	0.67	0.38		0.44
3	**0.55**			0.44		0.27	0.44	0.33		0.41
4	**0.55**			0.36		0.26	0.68	0.32		0.40
5	**0.55**			0.34			0.73	0.24		0.37
6	**0.51**			0.22			0.70	0.26		0.33
7	**0.51**			0.21			0.71			0.31
8	**0.55**						0.67			0.32
9	**0.67**						0.57			0.30
10	**0.64**						0.33			
11	**0.59**						0.40			
12	**0.56**						0.50			
13	**0.49**						0.42			

"---" indicates siphon wouldn't start

Flow Rate out of Spigot of CPFs

Liter #	CPF Average	CPF-PHW-A	CPF-PHW-B
	L/min	L/min	L/min
1	**2.08**	2.40	1.76
2	**1.54**	1.88	1.20
3	**0.65**	0.51	0.80

12.4 SURVEY QUESTIONNAIRES

D-1 Household Water Practice Survey

D-2 KWK User Survey

D-1 Household Water Practice Survey

	Taha									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
# structures in compound	6 structures/2 stove structures	7 structures/3 stoves	5 structures/1 cooking	2 structures/1 stove	8 structures/1 outdoor cooking structure	3 structures/1 stove			4 structures	2 big houses/building a 3rd
Vessel 1										
diameter	13x12"	12x11.5"	11x11"	11.5x11"	10x10"	10.75x12"	10.5x10.25"	12x12"	9.5x9.75"	10.75x10.25"
depth	29.5"	28.25"	26" (no rim)	30"	25.75"	29.25"	27.75"	30.5"	24"	26.5"
# buckets to fill	5	4		6.5		6		7		4.5
Vessel 2										
diameter	12x12"	10.5x10.5"	11x10"	9.75x9.75"	11x11.5"	10.5x11.5"	10.5x11.75"			
depth	28.25"	26.75"	28"	28.25"	30"	30"	29.5"			
# buckets to fill	5	4				6				
Vessel 3										
diameter	13x12"				11x10.75"					
depth	28.5"				24.75"					
# buckets to fill	5									
Vessel 4										
diameter					10.75x11"					
depth					28.25"					
# buckets to fill										
Vessel 5										
diameter					9.75x8.75"					
depth					25.25"					
# buckets to fill										
Water Fetcher	Blue metal bucket	Blue metal bucket		Blue metal bucket	Blue metal bucket	Blue metal bucket		Blue metal bucket	Jerry can	Blue metal bucket
Water Source	Standpipe / Dugout	Standpipe / Dugout	Standpipe / Dugout	Standpipe / Dugout	Standpipe / Dugout	Standpipe / Dugout	Standpipe	Standpipe / Dugout	Standpipe / Dugout	Standpipe
How Often Get Water	Daily	Daily	Every 3 days					Every 3 days		Daily
Cleaning Schedule	4 times per week	daily before refill				whenever vessel looks dirty prior to filling	daily before refilling vessels	when getting more water	whenever vessel looks dirty prior to filling	each morning
Cleaning Process	Scrub vessels with brooms and a little water						Scrub the vessels			Scrub the vessels
Have PHW filter?	Yes / Not used	No	Yes / Not used	Yes / Filter broke		Yes / In sewing shop	Yes / In use inside	Yes / Filter and tap broken	No	Yes / Only lid left
Purchaser? Price?	Landlord		Wife	Wife / GHS 6						
Comments on Its Use	Reported using filter, but filter was locked inside landlord's house, and family had no access to it.		During interview, household had stored baggies of beans in filter; Report only filtering dugout water	Bought filter 3 years ago, but it broke recently and have not tried to replace it.		Use filter only for dugout water.		The filter broke after 4 years; Use the plastic bucket for water storage now.	New in community and hadn't heard of the PHW filters.	
Comments on KWK Design	Like that the KWK is easy to use.	Like that the KWK works with the traditional vessel.		Like the KWK but worried about its price.		Like that the KWK is a bigger filter and keeps the water cool.	Like the KWK the same amount as the standard PHW filter.	Like the shape of the KWK; that it doesn't break as easily; and that it uses the traditional vessels	Like the concept of the KWK.	Curious about how the KWK worked.
General Comments	Tapwater costs 20 peswas to fill 3 buckets (about 90 L total); Caretaker at pump collects money.	Blue bucket is 14" deep x 13.5" diam (32.8 liters); Use one of their water vessels for drinking (tap water) and one for washing (dugout water).	Use one vessel for drinking and one for washing.	Pay other people to fetch water for them from the dam.	Use vessel #5 (covered) for drinking, #3 for washing, and #4 for rice soaking; Have a 50 gal. drum for rainwater catchment; Blue Metal bucket costs 10 cedi and the water vessels GHS 15-20 (Lasts over 5 years).	Blue bucket is GHS 7; Use alum to treat water when they have it - They uses 2 balls of alum per vessel and buy alum in other town (not sold inlocal shops).	When Vessel 2 started leaking, they fixed it by coating it in concrete.	Bought blue bucket for GHS 6, and their clay vessel for GHS 14.	Store their drinking water indoors in a small bucket - Use it (not blue bucket) to get water from standpipe; Pay 20 peswas for 3 buckets of standpipe water.	

	Gbalahi					
	11	**12**	**13**	**14**	**15**	**16**
# structures in compound	7 structures/1 chicken house	7 structures/2 animal sheds	Too many structure to count/3 animal sheds	8 structures		
Vessel 1						
diameter	7x11.5"	10.5x10.25"	11x11.5"	11.75x12"	10.75x11"	11x11"
depth	25.75"	27"	27.5"	27"	30"	27.75"
# buckets to fill	5	4		6.5	7	5
Vessel 2						
diameter	11.5x11.5"	10.5x10.25"	11x9.5"	10x10.5"	10.75x10.75"	
depth	27"	30"	25"	27.5"	26.25"	
# buckets to fill	5	6		5.5	5	
Vessel 3						
diameter		9x9.25"	11x12"	12.5x13"		
depth		21.75"	29.5"	23.5"		
# buckets to fill		5.5		4		
Vessel 4						
diameter						
depth						
# buckets to fill						
Vessel 5						
diameter						
depth						
# buckets to fill						
Water Fetcher	Blue metal bucket	Blue metal bucket				
Water Source	Dugout / Standpipe off	Dugout / Standpipe off for week	Dugout / Standpipe rarely flows	Dugout / Sometimes standpipe	Dugout / Sometimes standpipe	Dugout because standpipe not flowing
How Often Get Water	Daily	Use one vessel each day	Daily	Twice a day	Daily	
Cleaning Schedule		daily		daily or when empty	3 times per week	Every few days with standpipe water; daily with dugout water
Cleaning Process		Clean out the mud from vessels			Wash out vessel	Washes vessels
Have PHW filter?	Yes / Not really used	Yes / Filter broke and bucket leaks	No / Didn't buy when available	No	Yes / Removed filter	No
Purchaser? Price?	Free because distributed filters	Husband			Landlord	
Comments on Its Use	Use the filter for dugout water only - Plan to clean filter out soon and start using again.	Filter broke about 2 months ago and can't afford to buy new one. Had filter since 2006.			Nothing they don't like, but they don't use the filter (It's in good shape) because they're using tap water now.	She's seen others use the filters.
Comments on KWK Design	Like that the KWK holds more water; is kept outside so passerbys can drink from it; and keeps water cool in the clay.	Likes that the KWK is bigger and keeps water cooler.	Interested in KWK but only if it's free; Like the KWK for the health benefits of clean water.	Prefer the KWK to the PHS filter but have no specific reason why; Would be willing to buy KWK if affordable	Like that it's bigger and has a faster flow rate; Would use just for drinking; Would buy one.	Like that KWK is bigger and sealed so that things can't fall into it.
General Comments			Pay 20 peswas for 3 buckets of standpipe water but taps rarely flow; Reserve Vessel 1 for tap water (Although during interview, Vessel 1 had twigs in it)	All their water vessels are over 10 years old.	When standpipe water is available, reserve one of their Vessels for standpipe water.	Use an old tire to hold up their water vessel but are not sure where the tire came from; House has a rainwater catchment set up with 50 gal. drum.

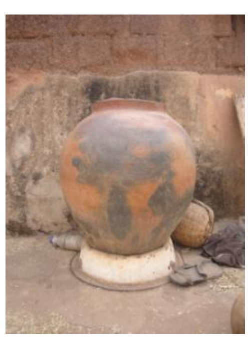
Household 1, Taha

Example Water Vessel

Household Compound

Household 2, Taha

Example Water Vessel



Household Compound

Household 3, Taha

Water Vessels

Household Compound

Household 4, Taha

House with Water Vessels

Stove Structure with Water Vessels

Household 5, Taha

Water Vessels

Household Compound

Household 6, Taha

Water Vessel with Other Compound Structures

One Compound Structure

Household 7, Taha

CPF in Use In-Doors

House on Compound

Household 8, Taha

CP Filter Bucket in Use; Ceramic Filter Element Removed

View of Compound

Household 9, Taha

Collected Dugout Water

Structure on Compound

Household 10, Taha

Covered Water Vessel

Houses in Compound (Forefront Structure is House in Construction)

Household 11, Gbalahi

View of Compound; CPF in Forefront, Not in Use at Interview Time

Another View of Compound

Household 12, Gbalahi

Water Vessels with Water Gathering Buckets

Houses on Compound

Household 13, Gbalahi

Tap Water in "Clean" Water Vessel

View of Compound

Household 14, Gbalahi

Vessel With Cloth Filter (for Guinea Worm)

View of Compound

Household 15, Gbalahi

CP Filter Bucket in Use Without Ceramic Filter Element; Filter (right) Not Cleaned at Time of Interview

View of Compound

Household 16, Gbalahi

Water Vessel next to Blue Barrel for Rainwater Catchment

View of Compound

D-2 KWK User Survey

KOSIM WATER KEG HOUSEHOLD SURVEY

A. Opening/Closing Questions

COMMUNITY______________________________

1. NAME OF HOUSEHOLD____

2. HOW MANY PEOPLE ARE IN THE HOUSEHOLD? ______________________

3. SOURCE OF WATER

 Winter ___________________ Summer ______________________

4. WHO USUALLY FETCHES THE WATER AND HOW MANY OF THEM PER HOUSEHOLD (LIST NUMBER OF PEOPLE FOR EACH TYPE)?:

 Woman:____ Child:____ Man:_____

5. WHEN IS WATER COLLECTED?

 Morning afternoon evening whenever tap is on

6. HOW MUCH WATER IS COLLECTED EACH DAY?

 _____No. of Buckets ____ No. of Storage Vessels Filled

7. HOW LONG DOES IT TAKE TO COLLECT WATER FROM:

 The dugout __________________

 The tap______________________

8. HOW DO YOU KNOW IF WATER IS SAFE TO DRINK?

____

9. DO YOU STORE TAP AND DUGOUT WATER IN SEPARATE STORAGE VESSELS? Yes_____ No____

10. DO YOU TREAT:

 Dugout water? Yes No Method_________________________

 Tap water? Yes No Method_________________________

11. WHAT DO YOU LIKE ABOUT:

 TAP WATER ____

 DUG OUT WATER ____

 FILTERED WATER____

12. WHAT DO YOU NOT LIKE ABOUT:

 TAP WATER ____

 DUG OUT WATER____

 FILTERED WATER____

13. ARE YOU CURRENTLY USING A FILTER?

 Yes no

 a. HOW DID YOU GET THE FILTER?

 Free Purchased – Price______ - husband wife landlord other_________

 b. NUMBER FILTERS IN HOUSEHOLD

 1 2 3 4 5

 c. HOW OFTEN IS THE FILTER REFILLED EACH DAY?

 one two three more_______ only when using dug out water

 d. WHEN IS IT FILLED

 morning afternoon evening

 e. WHERE IS THE FILTER LOCATED?

 Outside kitchen family room storage other ____________

 f. DO YOU CLEAN FILTER?

 yes No

 g. HOW DO YOU KNOW WHEN TO CLEAN FILTER? _________________________________

 h. HOW OFTEN IS IT CLEANED EACH WEEK?

 1 2 3 other__________

i. WHAT DO YOU USE TO CLEAN It?
Brush Aquatab Other____________________________

j. WHAT IS FILTERED WATER USED FOR?
drinking bathing cooking other_________

k. ANY PROBLEMS IN USE, MAINTENANCE OF FILTETR?
leakage breakage water temperature water taste Other__________

l. LEVEL OF WATER IN PLASTIC CONTAINER
¼ ½ ¾ FULL

m. REPLACEMENT PARTS NEEDED
Ceramic filter tap plastic bucket washer

Kosim Water Keg Number _______________
DATE:_________/_____________/___________

B. Middle and End Additional Questions

1. HOW DOES THE KOSIM WATER KEG COMPARE TO THE FILTER IN FILTERING SPEED?
FASTER SLOWER NO DIFFERENCE
2. HOW DOES THE KOSIM WATER KEG COMPARE TO THE FILTER IN TERMS OF WATER TASTE?
BETTER WORSE THE SAME
3. HOW DOES THE KOSIM WATER KEG COMPARE TO THE FITLTER IN TERMS OF WATER CLARITY?
BETTER WORSE THE SAME
4. HOW DOES THE KOSIM WATER KEG COMPARE TO THE FILTER IN TERMS OF WATER TEMPERATURE?
COOLER WARMER THE SAME
5. HOW HARD IS THE WATER KEG TO USE COMPARED TO THE FILTER?
EASIER HARDER THE SAME
6. HOW HARD IS THE WATER KEG TO CLEAN COMPARED TO THE FILTER?
EASIER HARDER THE SAME
7. WHICH DO YOU LIKE BEST FOR YOUR WATER?
TAP WATER AQUATAB FILTER WATER KEG
8. WHAT DESIGN CHANGES WOULD YOU SUGGEST TO MAKE THE KEG BETTER?
____
9. WHAT DO YOU LIKE MOST ABOUT THE KEG?
____
10. WHAT DO YOU LIKE LEAST ABOUT THE KEG?
____
11. HOW MUCH DID YOU PAY FOR YOUR CERAMIC STORAGE VESSEL? ______________________
12. WOULD YOU BE WILLING TO PAY THE SAME OR MORE FOR THE KEG? ______________________

C. PHW End-User Observations

1. OBSERVATIONS ON KEG USAGE BY HOUSEHOLD MEMBERS:

____
____
____
____

2. OBSERVATIONS ON KEG CLEANING PROCEDURES:

3. FIELD NOTES ON KEG WATER QUALITY SAMPLE COLLECTION AND H2S TESTING:

Community	Taha		Taha		Taha	Gbalahi		Gbalahi	
Keg Number	KWK-6		PHW-2		KWK-2	KWK-1		KWK-3	
Date	2-Mar-11	22-Apr-11	2-Mar-11	22-Apr-11	2-Apr-11	2-Apr-11	23-Apr-11	2-Apr-11	23-Apr-11
Number in household	11	9	5	5	13	9	9	7	9
Source of Water:									
Winter	Standpipe	Standpipe	Standpipe	Standpipe	Standpipe	Well and Standpipe	Well and Standpipe	Well and Standpipe	Well and Standpipe
Summer	Dugout	Dugout	Dugout	Dugout	Dugout	Dugout	Dugout	Dugout	Dugout
Who collects the water?	woman	woman	woman	woman	woman	woman	woman / man	children	woman / men / children
When is Water Collected?	morning/ evening/ whenever tap is on	morning/ evening/ whenever tap is on	morning/ evening/ whenever tap is on	morning/ evening/ whenever tap is on	morning/ evening/ whenever tap is on	morning/ evening/ whenever tap is on	morning/ evening/ whenever tap is on	morning/ evening/ whenever tap is on	morning/ evening/ whenever tap is on
How much water is collected each day?									
No. Buckets	12	9	10	10	14	12	12	6	9
No. Vessels		2		2			3		4
How long does it take to collect:									
Dugout water	10 min	10 min	10 min	10 min	15 min	1 hour	40 min	5 min	30 min
Tap water	2 min	2 min	3 min	3 min	4 min	5 min	5 min	2 min	2 min
How do you know if water is safe to drink?	By its appearance	By its appearance	By its appearance	By its appearance	By its appearance	By its appearance	By its appearance	By its appearance	By its appearance
Do you store tap and dugout water in separate storage vessels?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Do you treat:									
Dugout water	yes - Kosim filter and cloth filter	Yes - KWK and Kosim filter	Yes - Cloth filter	Yes - KWK and cloth filter	Yes - Cloth filter	Yes - Cloth filter	Yes - KWK and cloth filter	Yes - Cloth filter	Yes - KWK and cloth filter
Tap water	Yes - cloth filter	No	No	No	No	No	No	No	No
What do you like about:									
Tap water	Is clean	Is clean	Is clean	Is clean	Is clean	It is safe	Is clean and healthy	Is near and safe	Is clean and healthy
Dugout water	Is free	Tastes good	Is free	Is free	Is free	No choice - always available	Not expensive and always available	Is the last resort	Free and always available
Filtered water	Is clean	Is healthy and clean	Is clean	Is clean	Is clean	Is clean	Purifies water and prevents diseases	It filters the water	Purifies water and prevents diseases
What do you not like about:									
Tap water	Frequently closed	Frequently closed	Frequently closed	Frequently closed	Frequently closed	The taste	The cost	The cost	Frequently closed
Dugout water	Is dirty	None	Is dirty	Is dirty	Is dirty	Is not safe and has an odor	Is dirty	Is dirty	Is dirty
Filtered water	None	None	None	The taste	None	None	Pumping out the water	None	None
Are you currently using a filter?	Yes	Yes	Yes	No	No	No	No	Yes	No
How did you get the filter?	Free		Paid GHS 7		Free	Paid GHS 7		Free	
Number of filters in household	1	1	1	1	1	1	1	1	1
How often is the filter refilled each day?	2	1	2		2			Only for dug out water	
When is it filled?	Morning/ Evening		Morning/ Evening					Morning	
Where is the filter located?	Family room	Family room	Family room		Family room	Family room		Family room	
Do you clean the filter?	Yes	Yes	Yes					Yes	
How do you know when to clean the filter?	Low flow rate	By its appearance	Low flow rate					When it isn't filtering well	
How often is it cleaned each week?	2	1	2					2	
What do you use to clean it?	Brush / Aquatab	Brush / Aquatab	Brush / Aquatab					Brush / Aquatab	
What is filtered water used for?	Drinking	Drinking	Drinking		Drinking	Drinking	Drinking	Drinking	
Any problems in use or maintenance of the fitler?	No	No	No	Breakage		Breakage		Breakage / Bucket cracking	Breakage
Level of water in the plastic container	Half full	Quarter full	Quarter full					Half full	

Community	Taha		Taha		Taha	Gbalahi		Gbalahi	
Keg Number	KWK-6		PHW-2		KWK-2	KWK-1		KWK-3	
Date	2-Mar-11	22-Apr-11	2-Mar-11	22-Apr-11	2-Apr-11	2-Apr-11	23-Apr-11	2-Apr-11	23-Apr-11
replacement parts needed?	No		No			Ceramic filter	Ceramic filter	Plastic bucket	Ceramic filter / plastic bucket
How does the KWK compare to the filter in terms of:									
Filtering Speed	Faster	Faster	Faster	Faster	Faster	Faster	Faster	Faster	Faster
Water Taste	Better	Better	Same	Same	Better	Better	Better	Same	Better
Water Clarity	Same	Same	Same	Same	Same	Same	Same	Same	Same
Water Temperature	Cooler	Cooler	Cooler	Cooler	Cooler	Cooler	Cooler	Cooler	Cooler
Difficulty of Use	Easier	Harder	Easier	Easier	Easier	Same	Same	Easier	Same
Difficulty to Clean	Harder	Harder	Harder	Harder	Harder	Easier	Easier	Easier	Easier
What do you like best for your water?	KWK	KWK	Tap water	KWK	Tap water	KWK	KWK	KWK	KWK
What design changes would make the KWK better?	The vessel should be improved		It should have a lid		The vessel should be improved	It should have a lid	It should have a lid to stop children from playing with it		The vessel should be improved
What do like most about the KWK?	The process of pumping or siphoning	It cools and cleans the water	It cools and cleans the water	It cools the water and is healthy	Is traditional and beautiful	It cools and cleans the water	It cleans the water	It cools the water	It cools and cleans the water
What do you like least about the KWK?		The pumping is slow		Nothing		Pumping the siphon	Pumping is too slow, especially when water level low	The vessel cracks	
How much did you pay for your ceramic storage vessel?	GHS 10	GHS 15	GHS 10	GHS 10	GHS 9	GHS 9	GHS 9	GHS 12	GHS 12
Would you pay the same or more for the KWK?	Yes	Yes	Yes	Yes	Yes	no because the vessel is small	Yes	Yes	Yes

KOSIM WATER KEG HOUSEHOLD SURVEY: Weekly Questions

COMMUNITY______________________________
1. NAME OF HOUSEHOLD____

2. WHERE DID YOU GET YOUR WATER YESTERDAY?
   Dug out tap did not collect water yesterday
3. WHEN DID YOU LAST FILL UP THE VESSEL WITH THE KEG?
   Yesterday morning yesterday evening this morning other______________
4. HOW MANY TIMES YESTERDAY DID YOU FILL UP THE VESSEL WITH THE KEG?
   0 1 2 3 4 ______________
5. WHAT IS FILTERED WATER USED FOR YESTERDAY?
   drinking bathing cooking other_________________
6. WHAT WATER DID YOU TREAT IN THE KEG THIS WEEK?
   Dug out water tap water both neither
7. DID YOU CLEAN THE FILTER THIS WEEK? Yes no
8. HOW MANY TIMES THIS WEEK DID YOU CLEAN IT? 1 2 3 4
9. HOW DO YOU KNOW WHEN TO CLEAN KEG? _________________________________
10. WHAT DO YOU USE TO CLEAN IT?
   Brush Aquatabs Other______________________________
11. HOW OFTEN HAVE YOU REMOVED THE KEG FROM THE VESSEL IN THE PAST WEEK?
   0 1-3 4-7 multiple times a day
12. HOW DOES THE FILTERED WATER TASTE COMPARED TO SOURCE WATER?
   The same worse better
13. HOW DOES THE FILTERED WATER LOOK (is it clear) COMPARED TO SOURCE WATER?
   The same worse better
14. WHAT IS THE TEMPERATURE OF THE FILTERED WATER COMPARED TO THE SOURCE WATER?
   The same warmer cooler
15. IN THE PAST WEEK, HAVE YOU EVER NOT BEEN ABLE TO GET ENOUGH WATER FROM THE KEG? HOW MANY TIMES?
   0 1-3 4-6 every day multiple times each day not in use
16. HOW DO YOU GET WATER OUT OF THE KEG?
   pump the water syphon the water pour the water don't use
17. HOW MANY TIMES HAVE YOU HAD TO PUMP TO MAKE THE SIPHON START?
   0 1-3 4-7 multiple times each day never worked
18. HAVE YOU HAD ANY PROBLEMS WITH THE KEG?
   WATER QUALITY PROBLEMS____
   FLOW RATE PROBLEMS____
   KEG BREAKAGE PROBLEMS____
19. WHAT WOULD MAKE THE KEG BETTER?
____
20. WHAT WOULD MAKE THE KEG EASIER TO USE?
____
21. WHAT DO YOU LIKE ABOUT THE KEG?
____
22. WHAT DO YOUR NEIGHBORS THINK OF THE KEG? DO THEY DRINK WATER FROM IT?
____

WEEKLY OBSERVATIONS:
1. LOCATION OF KEG out of vessel in vessel [*with water* (yes / no) *with hose* (yes / no)
2. LOCATION OF WATER VESSEL
   Inside outside; elevated ground level
3. KEG IN USE yes no

4. KEG IN WORKING CONDITION yes no______________________________
5. PHYSICAL INSPECTION OF:
   a. SEAL CRACKS cracks no cracks
   b. CERAMIC cracks serious wear no cracks
   c. SIPHON TUBE in holder out of holder clean dirty
   d. SIPHON TUBE VALVE open closed

6. CLEANLINESS OF CONTAINERS USED FOR DRINKING clean not clean
7. OBSERVE CLEANING EVENT. Well done not well done
   INCLUDES:
   SCRAPING KEG yes no
   AQUATAB DISINFECTION yes no
   STORAGE VESSEL CLEANING yes no
8. CHECK THAT WATER IS SIPHONING
   Siphons siphons after pumping can't syphon doesn't have hose
   time to remove 1 Liter ____________
9. TAKE WATER SAMPLE FOR H2S TEST contamination no contamination

NAME OF OFFICER:_____________________________
DATE:_________/_____________/___________
Keg number ___________________________________

	Community	**Taha**										
	KWK Number	**KWK-6**										
	Date	3-Feb	7-Feb	11-Feb	18-Feb	25-Feb	4-Mar	11-Mar	18-Mar	25-Mar	1-Apr	8-Apr
2	**Where did you get your water yesterday?**	dugout / standpipe	dugout / standpipe	dugout / standpipe	dugout	dugout / standpipe	dugout / standpipe	dugout	dugout	dugout	dugout	dugout
3	**When did you last fill up your water vessel?**	yesterday evening	this morning	this morning	yesterday evening	yesterday evening	yesterday evening	this morning	this morning	yesterday evening	this morning	this morning
4	**How many times yesterday did you fill up your vessel?**	4	1	3	3	3	3	3	3	3	3	3
5	**What was filtered water used for yesterday?**	drinking	drinking	drinking	drinking	drinking	drinking	drinking	drinking	drinking	drinking	drinking
6	**What water did you use in the keg this week?**	dugout	dugout	dugout	dugout	dugout	dugout	dugout	dugout	dugout	dugout	dugout
7	**Did you clean the filter this week?**	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
8	**How many times this week did you clean it?**	1	2	1	1	1	1	1	1	1	1	1
9	**How do you know when to clean the keg?**	low flow rate	appearance	low flow rate	flow rate and appearance	flow rate and appearance	appearance	flow rate	appearance	flow rate and appearance	appearance	flow rate
10	**What do you use to clean it?**	brush /aquatab	brush /aquatab	brush /aquatab	brush /aquatab	brush /aquatab	brush /aquatab	brush /aquatab	brush /aquatab	brush /aquatab	brush /aquatab	brush /aquatab
11	**How often have you removed the keg from the vessel in the past week?**	1 to 3	1 to 3	1 to 3	1 to 3	1 to 3	1 to 3	1 to 3	1 to 3	1 to 3	1 to 3	1 to 3
12	**How does the filtered water taste compared to the source water?**	better	better	better	better	better	better	better	better	better	better	better
13	**How does the filtered water look compared to the source water?**	better	better	better	better	better	better	better	better	better	better	better
14	**What is the temperature of the filtered water compared to the source water?**	cooler	cooler	cooler	cooler	cooler	cooler	cooler	cooler	cooler	cooler	cooler
15	**In the past week, have you ever not been able to get enough water from the keg? How many times?**	0	multiple times each day	0	1 to 3	1 to 3	0	0	1 to 3	1 to 3	1 to 3	1 to 3
16	**How do you get water out of the keg?**	pumping the siphon	pumping the siphon	pumping the siphon	pumping the siphon	pumping the siphon	pumping the siphon	pumping the siphon	pumping the siphon	pumping the siphon	pumping the siphon	pumping the siphon
17	**How many times have you had to pump to make the siphon start?**	1 to 3	1 to 3	1 to 3	1 to 3	0	1 to 3	1 to 3	1 to 3	1 to 3	1 to 3	1 to 3
18	**Have you had any problems with the keg?**											
	Water Quality	no	no	no	no	no	no	no	no	no	no	no
	Flow Rate	no	no	no	no	no	no	no	no	no	no	no
	Keg Breakage	no	no	no			no	no	no	no	no	no

	Community	Taha										
	KWK Number	KWK-6										
	Date	3-Feb	7-Feb	11-Feb	18-Feb	25-Feb	4-Mar	11-Mar	18-Mar	25-Mar	1-Apr	8-Apr
19	**What would make the keg better?**	a big vessel with lid		cover for the vessel				better vessel with lid	lid for the vessel	lid for the vessel	lid for the vessel	better water vessel
20	**What would make the keg easier to use?**	is fine as is		is ok as is	is fine as is	is fine as is	is fine as is	is fine as is	is fine as is		no more pumping to get water	
21	**What do you like about the keg?**	the way it cools water	cool and clean water	it gives cool water	it purifies the dirty water	it purifies the dirty water	it is traditional and purifies the water	it treats the water	it is beautiful and cleans the water	it purifies the dirty water	it purifies the dirty water	it purifies the dirty water
22	**What do your neighbors think of the keg? Do they drink water from it?**	yes - they wish they had their own	yes - they want their own	yes - they like drinking from it	yes - they wish they had their own	yes - they wish they had their own	yes - they wish they had their own	yes - they wish they had their own	yes - they wish they had their own	yes - they like to always drink it	yes	yes
	Observations											
1	**Location of the keg**	in vessel with water and hose	in vessel with water and hose	in vessel with water and hose	in vessel with water and hose	in vessel with water and hose	in vessel with water and hose	in vessel with water and hose	in vessel with water and hose	in vessel with water and hose	in vessel with water and hose	in vessel with water and hose
2	**Location fo the water vessel**	outside and elevated	outside and elevated	outside and elevated	outside and elevated	outside and elevated	outside and elevated	outside and elevated	outside and elevated	outside and elevated	outside and elevated	outside and elevated
3	**Keg in use?**	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
4	**Keg in working condition?**	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
5	**Physical Inspection:**											
a	**seal cracks**	yes		no	no	no	no	no	no	no	no	no
b	**ceramic cracks**		no		no	no	no	no	no	no	no	no
6	**Cleanliness of containers for drinking**	clean	clean	clean	clean	clean	clean	clean	clean	clean	clean	clean
7	**Obversation of cleaning event**											
	Quality	well done	well done	well done	well done	well done	well done	well done	well done	well done	well done	well done
	Includes Scrapping?	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
	Incluides aquatab?	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
	Includes storage vessel cleaning?	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
8	**Check that water is siphoning**	siphons after pumping	siphons after pumping	siphons after pumping	siphons after pumping	siphons after pumping	siphons after pumping	siphons after pumping	siphons after pumping	siphons after pumping	siphons after pumping	siphons after pumping
	Time to siphon 1 liter (min:sec)				2:36 min	2:05	2:00	2:00	3:00	3:00	5:00	

	Community	**Taha**								
	KWK Number	**PHW-2**								
	Date	7-Feb	11-Feb	18-Feb	4-Mar	11-Mar	18-Mar	25-Mar	1-Apr	8-Apr
2	**Where did you get your water yesterday?**	dugout / standpipe	dugout / standpipe	dugout	dugout / standpipe	dugout	dugout	dugout	dugout	dugout
3	**When did you last fill up your water vessel?**	yesterday evening	this morning	this morning	this morning	this morning	yesterday evening	this morning	yesterday evening	yesterday evening
4	**How many times yesterday did you fill up your vessel?**	2	3	3	3	3	3	3	3	3
5	**What was filtered water used for yesterday?**	drinking	drinking	drinking	drinking	drinking	drinking	drinking	drinking	drinking
6	**What water did you use in the keg this week?**	dugout	dugout	dugout	dugout	dugout	dugout	dugout	dugout	dugout
7	**Did you clean the filter this week?**	yes	yes	yes	yes	yes	yes	yes	yes	yes
8	**How many times this week did you clean it?**	2	1	1	1	1	1	1	1	1
9	**How do you know when to clean the keg?**	low flow rates	low flow rates	low flow rate	appearance	low flow rate	appearance	low flow rate	appearance	low flow rate
10	**What do you use to clean it?**	brush /aquatab	brush /aquatab	brush /aquatab	brush /aquatab	brush /aquatab	brush /aquatab	brush /aquatab	brush /aquatab	brush /aquatab
11	**How often have you removed the keg from the vessel in the past week?**	1 to 3	1 to 3	1 to 3	1 to 3	1 to 3	1 to 3	1 to 3	1 to 3	1 to 3
12	**How does the filtered water taste compared to the source water?**	better	better	better	better	better	better	better	better	better
13	**How does the filtered water look compared to the source water?**	better	better	better	better	better	better	better	better	better
14	**What is the temperature of the filtered water compared to the source water?**	cooler	cooler	cooler	cooler	cooler	cooler	cooler	cooler	cooler
15	**In the past week, have you ever not been able to get enough water from the keg? How many times?**	1 to 3	1 to 3	0	1 to 3	1 to 3	0	1 to 3	1 to 3	1 to 3
16	**How do you get water out of the keg?**	pumping the siphon	pumping the siphon	pumping the siphon	pumping the siphon	pumping the siphon	pumping the siphon	pumping the siphon	pumping the siphon	pumping the siphon
17	**How many times have you had to pump to make the siphon start?**	1 to 3	1 to 3	1 to 3	1 to 3	1 to 3	1 to 3	1 to 3	1 to 3	1 to 3
18	**Have you had any problems with the keg?**									
	Water Quality	no	no	no	no	no	no	no	no	no
	Flow Rate		no	no	no	no	no	no	no	no
	Keg Breakage	no	no	no	no	no	no	no	no	no

	Community	Taha								
	KWK Number	PHW-2								
	Date	7-Feb	11-Feb	18-Feb	4-Mar	11-Mar	18-Mar	25-Mar	1-Apr	8-Apr
19	What would make the keg better?	improve the vessel	improve the vessel	lid for the vessel	lid for the vessel		better vessel			impove the vessel
20	What would make the keg easier to use?									is ok now
21	What do you like about the keg?	is beautiful and clean water	it gives clean and cool water	the way it cools the filtered water	it treats and cools the water	it cools the water	it treats the water	it treats and cools the water	cleans the water	purifies the water
22	What do your neighbors think of the keg? Do they drink water from it?	yes - is amazing to them	yes - they all like it	yes - they all like it	yes - they all like it	yes - they all like it	yes	yes	yes	yes - they come for the water
	Observations									
1	Location of the keg	in vessel with water and hose	in vessel with water and hose	in vessel with water and hose	in vessel with water and hose	in vessel with water and hose	in vessel with water and hose	in vessel with water and hose	in vessel with water and hose	in vessel with water and hose
2	Location fo the water vessel	outside and elevated	outside and elevated	outside and elevated	outside and elevated	outside and elevated	outside and elevated	outside and elevated	outside and elevated	outside and elevated
3	Keg in use?	yes	yes	yes	yes	yes	yes	yes	yes	yes
4	Keg in working condition?	yes	yes	yes	yes	yes	yes	yes	yes	yes
5	Physical Inspection:									
a	seal cracks		no	yes	yes	no	no	yes	no	no
b	ceramic cracks	no		no	no	no	no	no	no	no
6	Cleanliness of containers for drinking	clean	clean	clean	clean	clean	clean	clean	clean	clean
7	Obversation of cleaning event									
	Quality	well done	well done	well done	well done	well done	well done	well done	well done	well done
	Includes Scrapping?	yes	yes	yes	yes	yes	yes	yes	yes	yes
	Incluides aquatab?	yes	yes	yes	yes	yes	yes	yes	yes	yes
	Includes storage vessel cleaning?	yes	yes	yes	yes	yes	yes	yes	yes	yes
8	Check that water is siphoning	siphons after pumping	siphons after pumping	siphons after pumping	siphons after pumping	siphons after pumping	siphons after pumping	siphons after pumping	siphons after pumping	siphons after pumping
	Time to siphon 1 liter (min:sec)				0.125	3:24	3:00	3:40	3:00	4:30

	Community	Taha			Gbalahi					Gbalahi			
	KWK Number	KWK-2			KWK-1					KWK-3			
	Date	3-Feb	7-Feb	11-Feb	7-Feb	11-Feb	18-Feb	25-Feb	4-Mar	7-Feb	11-Feb	18-Feb	25-Feb
2	**Where did you get your water yesterday?**		standpipe	dugout / standpipe	dugout	dugout / standpipe	dugout	dugout / standpipe	**Water vessel broke**	dugout	dugout / standpipe	dugout / standpipe	**Water vessel broke**
3	**When did you last fill up your water vessel?**		yesterday morning	yesterday evening	this morning	this morning	this morning	this morning		yesterday morning	yesterday evening	this morning	
4	**How many times yesterday did you fill up your vessel?**		2	4	3	3	3	3		3	4	3	
5	**What was filtered water used for yesterday?**		drinking	drinking	drinking	drinking	drinking	drinking		drinking	drinking	drinking	
6	**What water did you use in the keg this week?**	dugout	dugout	dugout	dugout	dugout/tap	dugout	dugout		dugout	dugout	dugout	
7	**Did you clean the filter this week?**	yes	yes	yes	yes	yes	yes	yes		yes	yes	yes	
8	**How many times this week did you clean it?**	1	1	1	1	1	1	1		2	1	2	
9	**How do you know when to clean the keg?**	poor flow rate	when the vessel looked dirty	appearance and flow rate	slow flow rate	low flow rate	appearance	appearance		low flow rate	low flow rate	appearance and flow rate	
10	**What do you use to clean it?**	brush /aquatab	brush /aquatab	brush /aquatab	brush /aquatab	brush /aquatab	brush /aquatab	brush /aquatab		brush /aquatab	brush /aquatab	brush /aquatab	
11	**How often have you removed the keg from the vessel in the past week?**	1 to 3	1 to 3	1 to 3	0-Jan	1 to 3	1 to 3	1 to 3		4 to 7	1 to 3		
12	**How does the filtered water taste compared to the source water?**	better	better	better	better	better	better	better		better	better	better	
13	**How does the filtered water look compared to the source water?**	better	better	better	better	better	better	better		better	better	better	
14	**What is the temperature of the filtered water compared to the source water?**	cooler	cooler	cooler	cooler	cooler	cooler	cooler		cooler	cooler	cooler	
15	**In the past week, have you ever not been able to get enough water from the keg? How many times?**	1 to 3	1 to 3	1 to 3	1 to 3	0	1 to 3	1 to 3		1 to 3	0	0	
16	**How do you get water out of the keg?**	pumping the siphon	pumping the siphon	pumping the siphon	pumping the siphon	pumping the siphon	pumping the siphon	pumping the siphon		pumping the siphon	pumping the siphon	pumping the siphon	
17	**How many times have you had to pump to make the siphon start?**	1 to 3	4 to 7	1 to 3	1 to 3	1 to 3	1 to 3	1 to 3		4 to 7	1 to 3	1 to 3	
18	**Have you had any problems with the keg?**												
	Water Quality	no	no	no	no	no	no	no		no	no	no	
	Flow Rate	no	no	no	no	no	no	no		no	no	no	
	Keg Breakage	no	vessel leaking	no	no	no	no	no		vessel leaking	no	no	

	Community	Taha			Gbalahi					Gbalahi			
	KWK Number	**KWK-2**			**KWK-1**					**KWK-3**			
	Date	3-Feb	7-Feb	11-Feb	7-Feb	11-Feb	18-Feb	25-Feb	4-Mar	7-Feb	11-Feb	18-Feb	25-Feb
19	**What would make the keg better?**	improve the vessel	improve the vessel	a better vessel	should be bigger	a better vessel	lid for the vessel	lid for the vessel			a big vessel with lid	improve the vessel	
20	**What would make the keg easier to use?**		is ok as is							already easy to use	is ok as is		
21	**What do you like about the keg?**	it gives clean and cool water	it filters dirty water	the pumping and its clean water	it gives clean and cool water	it gives clean water	it treats the water	it treats and cools the water		pumping the siphon	the way it cools the water	the pumping and its clean water	
22	**What do your neighbors think of the keg? Do they drink water from it?**	yes - they all like it	yes - many people drink from it	yes - the school children drink from the keg	yes - they wish they had their own	yes - no all neighbors drink water from her house	yes - Now she has more visitors in her house because of the keg	yes - they all like it		yes- they love it	yes - they wish to have one too	yes - they drink from it	
	Observations												
1	**Location of the keg**	in vessel with water and hose	in vessel with water and hose	in vessel with water and hose	in vessel with water and hose	in vessel with water and hose	in vessel with water and hose	in vessel with water and hose		in vessel with water and hose	in vessel with water and hose	in vessel with water and hose	
2	**Location fo the water vessel**	outside and elevated	outside and elevated	outside and elevated	outside and elevated	outside and elevated	outside and elevated	outside and elevated		outside and elevated	outside and elevated	outside and elevated	
3	**Keg in use?**	yes	yes	yes	yes	yes	yes	yes		yes	yes	yes	
4	**Keg in working condition?**	yes	yes	yes	yes	yes	yes	yes		yes	yes	yes	
5	**Physical Inspection:**												
a	**seal cracks**	no	yes	yes	no	no	yes	yes		no	yes	yes	
b	**ceramic cracks**	no			no		no	no		no		no	
6	**Cleanliness of containers for drinking**		clean	clean	clean	clean	clean	clean		clean	clean	clean	
7	**Obversation of cleaning event**												
	Quality	well done	well done	well done	well done	well done	well done	well done		well done	well done	well done	
	Includes Scrapping?	yes	yes	yes	yes	yes	yes	yes		yes	yes	yes	
	Incluides aquatab?	yes	yes	yes	yes	yes	yes	yes		yes	yes	yes	
	Includes storage vessel cleaning?	yes	yes	yes	yes	yes	yes	yes		yes	yes	yes	
8	**Check that water is siphoning**	siphons after pumping	siphons after pumping	siphons after pumping	siphons after pumping	siphons after pumping	siphons after pumping	siphons after pumping		siphons after pumping	siphons after pumping	siphons after pumping	
	Time to siphon 1 liter (min:sec)					2 min	3:00	2:34					