HOUSEHOLD WATER TREATMENT AND SAFE STORAGE SOLUTIONS IN THE NORTHERN REGION OF GHANA

MASTER OF ENGINEERING PROJECT REPORT

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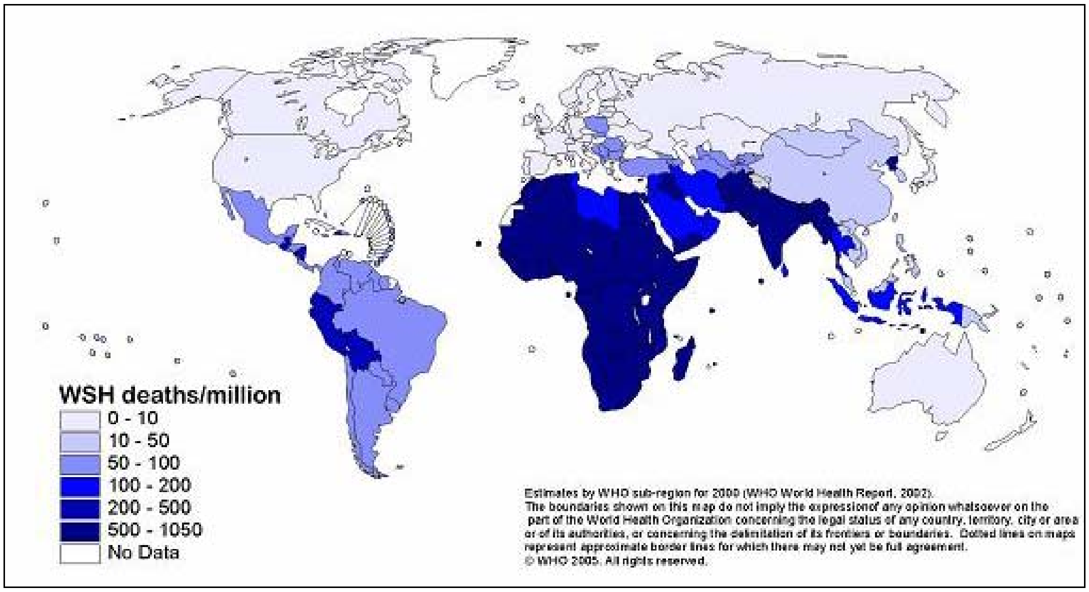
CHAPTER 1: INTRODUCTION

1.1 The Global Need for Improved Water and Sanitation

According to the World Health Organization (WHO), 1.1 billion people did not have access to an improved water supply in 2002, and 2.3 billion people suffered from diseases caused by contaminated water. Each year 1.8 million people die from diarrheal diseases, and 90% of these deaths are of children under 5. The figure below shows the per-capita deaths per million related to water and sanitation in each country in 2000 (*Figure 1.1*). Besides causing death, water-related diseases also prevent people from working and leading active lives (WHO/UNICEF, 2004).



Estimates by WHO sub-region for 2000 (WHO World Health Report, 2002).
The boundaries shown on this map do not imply the expressionof any opinion whatsoever on the part of the World Health Organization concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. Dotted lines on maps represent approximate border lines for which there may not yet be full agreement.
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Figure 1.1 - Deaths caused by unsafe water, sanitation, and hygiene for the year 2000, by country (WHO, 2002)

In 2000, 189 nations adopted the United Nations Millennium Declaration, and from that the Millennium Development Goals (MDGs) were derived. The MDGs include 8 main goals, 18 targets, and more than 40 indicators. Their purpose is to focus efforts, promote study, raise awareness, and encourage strong alliances. Goal 7 addresses environmental sustainability, and Target 10 is to "halve, by 2015, the proportion of people without sustainable access to safe drinking water and basic sanitation" (UN-NGLS, 2006). According to the United Nations report, 80% of the world's population used an improved drinking water source in 2004, up from 71% in 1990. Although improvement has been made, there will be challenges as populations increase. There are still a large number of people who will not even be covered by Target 10, and, significantly, an improved water supply is not necessarily a safe water supply.

1.2 Ghana Background

Ghana is located in West Africa (*Figure 1.2*) and has a total area of about 240,000km^2 and a population of approximately 22.5 million. The climate is tropical in the south near the coast, and semi-arid towards the north. Although the official language of Ghana is English, more than 70 (Ethnologue, 2007) other local languages are spoken. 63% of the population is Christian, 16% are Muslim (mostly in the Northern region) and 23% follow traditional indigenous beliefs (CIA, 2006).

Figure 1.2 - Map of Ghana (CIA, 2006)

The current environmental concerns in Ghana include soil erosion due to deforestation and overgrazing, recurring drought in the north which affects farming, and inadequate supplies of potable water (CIA, 2006).

The major diseases prevalent in Ghana are malaria, yellow fever, schistosomiasis (bilharzias), typhoid and diarrhea. Diarrhea is of particular concern since this has been identified as the second most common disease treated at clinics and one of the major contributors to infant mortality (Mattelet, 2006), which currently stands at about 55 deaths per 1,000 live births (CIA, 2006). Furthermore, the under-five childhood mortality rate is significantly higher in the Northern Region of Ghana, at 154 deaths per 1,000 live births (GSS, 2004). The major cause of diarrheal disease is lack of safe and sufficient drinking water, hygiene, and adequate sanitation. After Sudan, Ghana has the highest incidence of Dracunculiasis (guinea worm disease) in the world. 75% of these cases have been reported in Ghana's Northern Region (WHO, 2006).

1.3 Pure Home Water

Pure Home Water (PHW) is a non-profit organization established in 2005 to promote and disseminate household drinking water and safe storage (HWTS) products to low-income customers in the Northern Region of Ghana. It is the first social business of its kind in Ghana that aims at giving users options to affordable and locally manufactured HWTS products through rural promotion, hospital and school outreach.

Through funding from the Conrad N. Hilton Foundation, the PHW project was initiated in August 2005 in Tamale, one of the poorest cities in Ghana. The Conrad N. Hilton Foundation provided a start-up fund for two years from 2005 to 2007, amounting to a total budget of US$

150,000. Among the project's several goals are to reach low-income families with HWTS products and to be self sustaining by the sale of HWTS.

PHW is locally managed by two Ghanaian social entrepreneurs, namely Hamdiyah Alhassan, a civil and environmental engineer, and Wahabu Salifu, a development planner. The principle investigator for the project is Susan Murcott, a Senior Lecturer in the Department of Civil and Environmental Engineering at MIT. PHW is also working in close collaboration with World Vision and students from MIT, Harvard and Brandeis Universities. *Figure 1.3* shows the districts in the Northern Region represents PHW's target area.

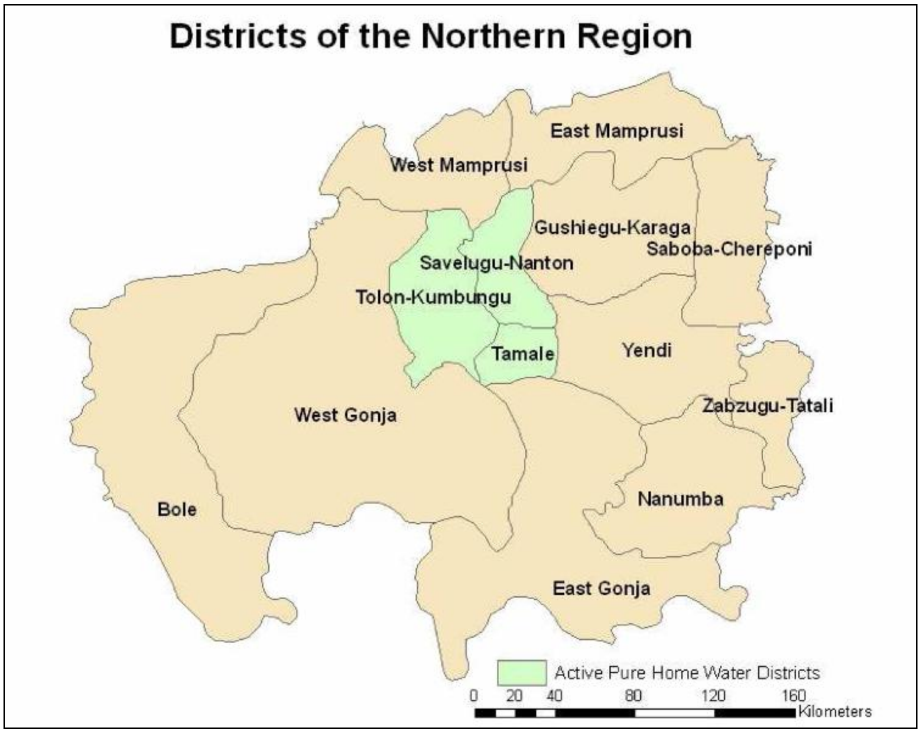

Figure 1.3 - Target regions of Pure Home Water in Northern Ghana (VanCalcar, 2006).

Although they began with a larger product line, PHW's major product is currently the *Kosim* filter, which is a Potters for Peace pot-type filter manufactured by Ceramica Tamakloe Ltd. in Accra.

1.4 Project Background and Goals

Last year three MIT Master of Engineering students and four MIT Sloan Business students of the Global Entrepreneurship Lab (G-Lab, 15.389) worked with Pure Home Water in Ghana during January. The engineering students' projects included GIS mapping, an epidemiological study of water and sanitation practices, and ceramic water filter evaluation using three different simple, low-cost tests (Mattelet, Peletz, Vancalcar, 2006)[1]. The business students spent their time with PHW's social entrepreneurs and focused on the "4Ps," product, price, place, and promotion.

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[1] URL: http://web.mit.edu/watsan/std_thesis_ghana.htm

This year's Master of Engineering team included Sophie Johnson, Teshamulwa Okioga and Iman Yazdani. These researchers worked at MIT in the fall and spring semesters, and during January they traveled to Ghana for three weeks of field research. Johnson surveyed ceramic filter use, Okioga researched sachet water vending, and Yazdani examined solar disinfection of drinking water (Johnson, Okioga, Yazdani, 2007)[2].

1.5 Pure Home Water's Business Approach

Last year, students in the Global Entrepreneurship Lab (G-Lab) used the first four P's, product, price, place, and promotion, to evaluate Pure Home Water's approach and to make recommendations for improved marketing and sales (Gordon, 2006). Starting with Product, the team found that PHW efforts to promote six different HWTS technologies complicated targeted promotion and supply-chain management. The team determined that PHW did not have the capacity to effectively market multiple products and that success would be better ensured if they targeted their single "best" product. The original set of products included modified safe storage clay pots, plastic safe storage containers, Ceramic Tamakloe *Filtrons,* Nnsupa candle filters, biosand filters, household chlorination, and SODIS (solar disinfection). Based on results from the engineering team, the group recommended that PHW focus on the Ceramica Tamakloe *Filtron* Filter and safe storage. For Price, the G-Lab team devised a new pricing scheme according to a breakeven analysis. Also, the team negotiated with the ceramic filter manufacturer to reduce the cost. They obtained a verbal agreement to a 37% price reduction. With Promotion, the students worked to develop marketing materials, organized market day sales events, improved the sales pitch, and made activity goals. These goals included four organization presentations per week, one market day per week, and one community visit per week. Lastly, to improve Place aspects, the students focused on improving communication with retailers of the products, and they also helped coordinate monthly training sessions with potential sales agents.

Unfortunately the Year 1 breakeven was not achieved because of the high filter prices of US$19-20 which limited sales to middle class customers. As a social business, PHW has a "double bottom line." Although self-sufficiency and independence from outside funding is important, the organization's primary goal is to reach low-income people without safe drinking water. Because the high ceramic filter prices excluded the people PHW wanted to reach the most, they turned to a segmented market approach in Year 2, as described in the following section.

1.5.1 Year 2 Strategy

In August 2006, Elizabeth Wood, a recent Harvard graduate, and Howard Shen, a recent graduate of MIT Sloan's Leader in Manufacturing program, conducted a one-month assessment of PHW's first year and recommended major revisions to its pricing, marketing, and promotion strategy. Towards the end of the year 2006, PHW implemented this Year 2 Strategy, which included new outreach initiatives that especially targeted the poor. Two prices were set for the filter: a "retail price" for urban areas and a "rural price" for rural areas. For the retail price, PHW sells to retailers for US$ 11.10 (GHC 100,000), who then sell the filters to customers for US$ 13.30 (GHC 120,000). PHW sells filters to distributors in rural communities for US$ 5.60,

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[2] URL: http://web.mit.edu/watsan/std_thesis_ghana.htm

and they are resold for US$ 6.70 (GHC 60,000). At these prices, PHW estimates that it could generate profit if the filters were manufactured locally for about US$ 6 (GHC 54,000).

1.5.1.1 Marketing Strategies

The Year 2 Strategy was categorized into three main areas based on the marketing approach and the target population, as follows:

1. Urban Outreach

In this outreach approach, business owners referred to as "retailers" are approached to sell filters at the "retail" price for a commission. The filters can be purchased by the retailers in installments, with the first installment being at least half the filter price and the remaining paid once the filters are sold. The retailers are trained on how to use and clean the filters, so that they can demonstrate to potential customers. They are also provided with promotional materials which include posters and pamphlets.

2. Hospital and School Outreach

The hospital outreach program is similar to the urban outreach in that filters are sold to individuals who resell them at the "retail" price and receive commission on sales made. In the hospital outreach program, the liaisons are primarily nurses who market the filters to patients that visit the hospital. In this program, free filters are also provided for each ward for the purpose of demonstration and use in the hospital. The nurses identified as retailers are responsible for cleaning and maintaining the free filters at the hospital on a voluntary basis.

In the school outreach approach, the PHW team works in collaboration with the Ghana Educational Services to reach out to schools. Identified teachers act as liaisons and give demonstrations to both school children and their fellow teachers on the use of the ceramic pot filter. The school children are asked to share information on the filter with their parents and members of their households. As in the Hospital Outreach Program, free filters are given out to each class for use and demonstrations, and they are maintained by the school liaisons.

3. Rural Outreach

This is a community level outreach approach, which involves identifying and training key opinion leaders such as chiefs, community elders, and other respected members of the rural society on use of the ceramic pot filter and providing them with free filters. The opinion leaders are expected to open their homes to their communities, show the filter in use, and allow visitors to taste and sample filtered water. Since the leaders are respected members of the society, it is expected that other members of the community will more readily consider what has already been accepted by the leader and become interested in purchasing a filter for their own family.

In the rural outreach, PHW also works with community liaisons who are generally responsible for reaching out to members of their communities by holding demonstration meetings on the use of the ceramic pot filter, distributing the filters to opinion leaders, and selling them at a subsidized price to other members of the rural communities. The liaisons earn a commission on filters sold at the subsidized price. The community liaisons also act as a link between the rural communities and PHW by obtaining user feedback information on the filter and answering questions posed by the communities.

1.5.1.2 Future Manufacturing Goals

Part of PHW's Year 2 Strategy is to manufacture its own ceramic filters in the Northern Region by December 2007 in order to reduce costs and enable the production and distribution of filters to be self-sustaining. The local manufacturing option is also expected to enhance quality control of the filter production. Other plans for the Year 2 Strategy include acquiring a vehicle to transport filters for distribution and sale.

1.6 MIT Consultants to Pure Home Water – Objectives, Scope of Work

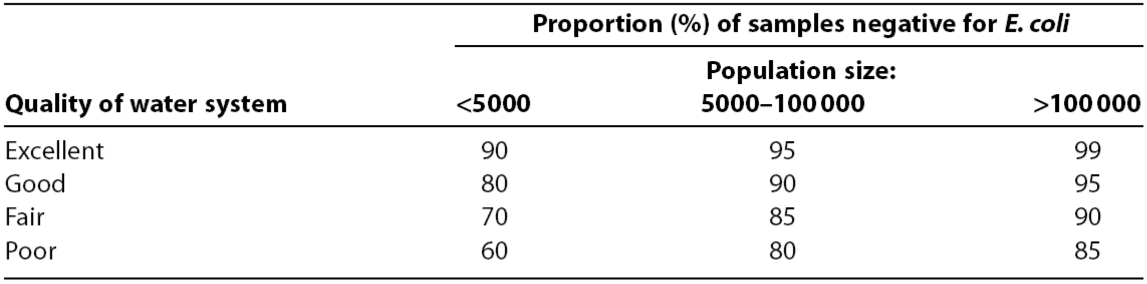
This year's MIT team has taken a diverse approach for helping PHW better reach its goal of providing safe drinking water to people in the Northern Region of Ghana. The projects have combined elements of both research and development (R&D) and monitoring and evaluation. The R&D projects have looked into new technologies and marketing strategies that PHW could utilize, and the monitoring and evaluation work has helped PHW know the effectiveness of their ceramic filter dissemination program. Such an approach ensures that PHW's current projects are successful while still looking to the future.

CHAPTER 2: WATER QUALITY TESTING

2.1 Guidelines for Drinking Water Quality

In recent years, the WHO has moved away from defining *set* values for microbiological water quality levels, to providing *recommendations* using a more realistic risk-based approach. *Table 2.1*[3] shows the levels of *E. coli*[4] in drinking water, and respective risk levels from the *WHO 3rd Edition Guidelines for Drinking Water Quality*:

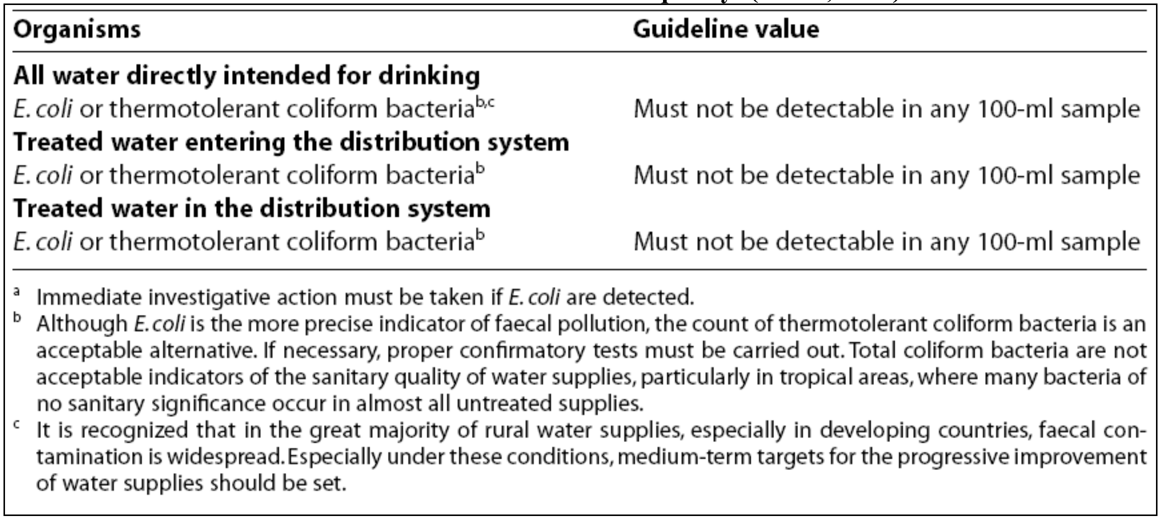
Table 2.1 – Categorization of drinking water systems based on compliance with performance and safety targets (WHO, 2004)



	Proportion (%) of samples negative for *E. coli*		
	Population size:		
Quality of water system	**<5000**	**5000–100 000**	**>100 000**
Excellent	90	95	99
Good	80	90	95
Fair	70	85	90
Poor	60	80	85

The *3rd Edition Guidelines*, *Table 2.2*[5], for the verification of microbial quality indicates that "*E. coli* or thermotolerant coliform bacteria must not be detectable in any 100mL sample" but goes on to say that "individual values should not be used directly from the *Guideline* tables." The guideline value should be used and interpreted with the information contained within the *Guidelines* (WHO, 2004). In many cases, particularly in the developing world, it is difficult to achieve zero *E. coli* per 100mL sample, making the risk-based framework depicted in *Table 2.1* particularly useful.

Table 2.2 – Guideline values for verification of microbial quality[a] (WHO, 2004)



Organisms	Guideline value
All water directly intended for drinking	
E. coli or thermotolerant coliform bacteria[b,c]	Must not be detectable in any 100-ml sample
Treated water entering the distribution system	
E. coli or thermotolerant coliform bacteria[b]	Must not be detectable in any 100-ml sample
Treated water in the distribution system	
E. coli or thermotolerant coliform bacteria[b]	Must not be detectable in any 100-ml sample

[a] Immediate investigative action must be taken if *E. coli* are detected.

[b] Although *E. coli* is the more precise indicator of faecal pollution, the count of thermotolerant coliform bacteria is an acceptable alternative. If necessary, proper confirmatory tests must be carried out. Total coliform bacteria are not acceptable indicators of the sanitary quality of water supplies, particularly in tropical areas, where many bacteria of no sanitary significance occur in almost all untreated supplies.

[c] It is recognized that in the great majority of rural water supplies, especially in developing countries, faecal contamination is widespread. Especially under these conditions, medium-term targets for the progressive improvement of water supplies should be set.

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[3] *WHO 3rd Edition Guidelines* (2004) p. 97, Table 5.2.

[4] *E. coli* is a microbial indicator of fecal contamination in water.

[5] *WHO 3rd Edition Guidelines* (2004) pp. 142-143, Table 7.7.

2.2 Microbial Testing

In order to ascertain the levels of microbial contamination in a sample of water, the MIT team conducted various water quality field tests. *E. coli* counts were performed since this is an indicator of fecal contamination in the water. In addition, total coliform (TC) counts were performed. A coliform is a gram-negative rod-shaped bacteria which ferments lactose with the production of acid and gas when incubated at 35^{o}C (Standard Methods, 1999). TC describes *all* coliform bacteria present in the water, including *E. coli*. The levels of *E. coli* are important in determining into which "risk-category" the water falls, as set out in the *WHO Guidelines for Drinking Water*. Total coliform is an important measure used to indicate HWTS system performance.

The three microbial tests used were the Membrane Filtration and 3M Petrifilm™ tests to detect coliform, and the Hydrogen Sulfide Presence/Absence test to detect hydrogen sulfide producing bacteria. The price of each test is given in T*able 2.3*:

Table 2.3 – Cost of microbial tests (Okioga, 2007)

Test Type	Approximate Cost per Single Test (US$)
Membrane Filtration	2.50
3M Petrifilm™	1.50
Hydrogen Sulfide (20mL sample size)	0.30

2.2.1 Membrane Filtration Test

Membrane Filtration (MF) is one technique that can be used to determine the number of *E. coli* and total coliform in a water sample (*see Appendix A.1 for complete test methodology*). It is a method that is recommended by the United States Environmental Protection Agency (EPA) (Millipore, 1992), providing results 24 hours after testing. The MF test works on the principle that coliform, given suitable conditions such as an appropriate temperature and availability of a nutrient medium, grow over the course of approximately 1 day. These colonies formed can then be counted.

Although MF is the costliest of the three types of microbial test performed, at ~US$2.50 per test (Okioga, 2007), it is also the most accurate. Within the context of this report, the MF test results will be used as the primary input for the analysis of two HWTS systems – the *Kosim* filter and SOLAIR, as well as for determining the water quality of source water and sachet vended water, whilst the 3M and H_2S Presence/Absence test results provide additional data to reinforce the conclusions made. *Figure 2.1* shows the results of a typical MF test, with blue spots representing total coliform and red spots representing *E. coli:*

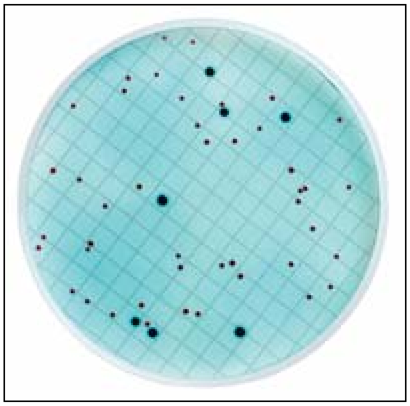

Figure 2.1 – A typical Membrane Filtration test (Millipore, 2007)

2.2.2 3M Petrifilm™ *E. coli*/Coliform Count Test

The 3M Petrifilm™ *E. coli*/Coliform Count test is a relatively cheap (~US$1.50) (Okioga, 2007), quick-and-easy method of coliform enumeration (*see Appendix A.2 for complete test methodology*). Each Petrifilm™ plate contains a Violet Red Bile nutrient medium and a colony enumeration indicator, set in a gelling agent. Approximately 95% of *E. coli* produces gas, since they are lactose fermenting coliforms. This gas becomes trapped in the Petrifilm™ plate, surrounding blue colonies (*E. coli*). Other coliform, which also produce gas, are visible as red colonies surrounded by gas (3M Microbiology, 2001).

A disadvantage of this test method is that only a 1mL sample can be tested, which is not always representative of the entire water body. This makes it reasonably accurate at high levels of coliform contamination but less sensitive, and hence, less accurate, at low levels of contamination (Mattelet, 2006).

2.2.3 Hydrogen Sulfide Presence/Absence Test

Fecal contamination in water can be determined by testing for the presence of suitable indicator organisms, such as hydrogen sulfide producing bacteria (*see Appendix A.3 for complete test methodology*). This category of bacteria includes the Salmonella, Citrobacter, Proteus and Edwardsiella species (HACH, 2003). The Hydrogen Sulfide (H_2S) Presence/Absence (P/A) test is a simple alternative to testing for *E. coli*.

A positive result is obtained if H_2S producing bacteria are present in the sample, leading to the formation of a black iron sulfide precipitate. The P/A test is not recommended as the *only* method in testing for fecal contamination due to the tendency for false positive and false negative results to occur. These false results can be caused by a source of H_2S in the sample, other than from the aforementioned bacteria (Peletz, 2006). Manja et al. (1982) conclude that H_2S producing bacteria are consistently associated with the presence of coliform in water. This is backed up by tests done by Grant et al. (1996) which show that there is a 85-95% agreement between fecal coliform detection using the Membrane Filtration method, and the P/A test. They also showed that, for total coliform, the agreement between the two tests ranged from 93-99%.

This relatively inexpensive (~US$0.30) (Okioga, 2007), convenient and simple test method provides a reasonably reliable indication of fecal contamination in the water.

2.3 Turbidity

Turbidity readings were obtained using a portable HACH 2100P turbidimeter (*Figure 2.1*):

Figure 2.1 – Turbidimeter

The water sample is placed in a 30mL glass vial, placed in the turbidimeter and a reading was taken.

2.4 Temperature and pH

The temperature of the water was measured using an alcohol-filled thermometer whilst pH was measured using pH indicator strips, the readings of which could be interpolated to the nearest 0.25.

CHAPTER 3: HEALTH AND WATER QUALITY MONITORING OF PURE HOME WATER'S CERAMIC FILTER DISSEMINATION IN THE NORTHERN REGION OF GHANA

BY
SOPHIE JOHNSON

3.1 Objective

Through household surveys and water quality testing, this portion of the group study:

- Obtained baseline data on hygiene practices, sanitation access, and water use.
- Compared *Kosim* filter users and non-users in traditional communities.
- Ensured that PHW is reaching communities most in need of the technology.
- Determined the quality of source water.
- Assessed the performance of the ceramic water filters in the field.
- Determined filter acceptability for the users and highlighted problems from the users' perspective.

The results are intended to enable PHW to spread the *Kosim* filter more effectively.

3.2 Epidemiological Survey Methods

3.2.1 Survey Design

MIT Master of Engineering student Rachel Peletz (2006) conducted a cross-sectional study of 50 households during January 2006 in the Northern Region of Ghana to obtain baseline data on drinking water and sanitation practices. The aim was for these results to help Pure Home Water (PHW) in its efforts to spread household drinking water treatment and safe storage (HWTS) technologies.

Peletz chose questions that would be of value to PHW, and she received feedback from project advisor Susan Murcott, epidemiology professor Julie Buring, the social entrepreneurs Hamdiyah Alhassan and Wahabu Salifu, and William Duke, M.D., from the Centre for Affordable Water System Technology. Peletz's survey instrument was submitted to and approved by MIT's Institutional Review Board, called the Committee on the Use of Humans as Experimental Subjects. Because the study involved minimal risk to participants, it qualified for "exempt status." All of Peletz's survey participants gave their informed consent.

3.2.2 Survey Implementation

3.2.2.1 Community selection

The original goal of this portion of the overall MIT Ghana team study was to visit 30 new households from traditional communities and to revisit several of the eight filter users from modern communities that Peletz surveyed in January 2006. Time allowed for 35 households from six traditional communities and six households from two modern communities to be surveyed. The traditional communities were chosen from those recently reached by PHW's rural outreach strategy. By January 2007, PHW had done community presentations and had sold filters in 8 traditional villages. Five of these villages, including Gbanyamni, Chenshegu, Taha, Gbalahi, and Shenshegu, were chosen for surveying based upon convenience of access and quantity of filters sold. One traditional village, Kalariga, was chosen because Alioune Dia, a Masters student at Brandeis University, was conducting a study there.

Peletz interviewed 50 households, including eight pot-shaped ceramic filter users from three different modern communities, Kamina Barracks, Vitin Estates, and Jisonayili. At the time of Peletz's study, PHW had not sold any filters in traditional communities, so her study could only include filter users from modern communities. Kamina Barracks and Vitin Estates were both revisited, surveyed, and sampled by the author. Because Peletz surveyed just one filter user in Jisonayili, this community was not revisited.

3.2.2.2 Household and Participant Selection

PHW's rural marketing strategy involves recruiting a community liaison who serves as a link between PHW and the village. In return for a commission on each filter sale, the liaison conducts information sessions on the filters and markets them throughout the community. The community liaison from five of the villages helped the author select households for the surveys. If the liaisons had cellphones, they were called in advance to setup a visit. Upon arrival, the liaison was found, and a visit was made to the village chief to get permission to conduct the surveys. Then the liaison was asked to choose several homes with filters and several without filters. Although the liaison was asked to choose the households randomly, there could have been selection bias. Even though most households visited had children under five, it was necessary in some cases to visit homes without young children because of the limited number of households with filters. In Kalariga, because there is not a PHW community liaison, households were selected by the interim chief. If a woman of the household was not at home, another home was chosen.

Most men in the traditional homes have several wives, and household members chose one woman to respond to the survey. Oftentimes the senior wife was the respondent. Women were interviewed because they are usually responsible for water provision and are assumed to know the most about diarrhea occurrence in children. The participation rate of women asked was 100%.

In the modern communities, only filter users who were visited by Peletz were chosen. She interviewed 4 filter users in Kamina Barracks, and because one woman had moved, only 3 were revisited. She interviewed 3 filter users in Vitin Estates, and since two of the users were not home, their relatives were interviewed instead. A son and a niece were interviewed in place of the original respondents.

3.2.3 Logistical Details

Although English is Ghana's official language, all of the interviews in the traditional communities were conducted in local dialects. Wahabu Salifu and Shakool (Shak) Ibrahim served as translators, and Alioune Dia often helped record answers. Because water quality tests had to be done within six hours of collection, sometimes Salifu and Dia went to homes without filters, while Ibrahim and the author went to homes with filters in order to save time. Oftentimes the community liaison and many family members were present as well. Having so many people present, especially foreigners, could have influenced the responses. In the modern communities, fewer family members were present, and several of the surveys were conducted in English.

Surveys took 15 to 45 minutes. In traditional communities, four to eight households were surveyed in a day. In the modern communities, only filters users surveyed by Peletz were visited, so just three households were surveyed each day.

Responses were recorded on copies of the survey and were subsequently entered into the statistics program SPSS (originally Statistical Package for the Social Sciences) within a week. Although SPSS could have been used for calculations, the entries were copied from SPSS into Excel for all analyses.

3.3 Water Quality Testing Methods

3.3.1 Sampling Methods

Two samples of water were taken from each surveyed household. Respondents without ceramic filters were asked for a drinking water sample, and those with filters were asked for both an unfiltered and filtered water sample. *Figure 3.1* shows how respondents typically provided unfiltered samples. In homes with ceramic filters, the unfiltered water came from inside the ceramic element when water was there, representing the water that had not yet passed through the filter. If no water was inside the ceramic element, unfiltered water was collected from a point of storage in the household. The water was collected in Whirlpack bags at the end of each interview and then stored in a cooler with ice packs during transport. Once back at the field laboratory, the samples were refrigerated until the water quality tests were performed. The testing occurred within six hours of sample collection.

Figure 3.1 - Woman providing an unfiltered water sample by dipping a cup into a ceramic vessel behind her

3.3.2 Testing Methods

In the field laboratory, two different procedures, membrane filtration and 3M™Petrifilm™, tested for levels of total coliform and *E. coli*, and one procedure tested for the presence or absence of hydrogen sulfide-producing bacteria. In addition to the three bacteria analyses, samples were tested for turbidity. Any contamination in the filtered water showed a weakness in the filter's ability and/or indicated contamination in the storage receptacle.

3.4 Business Analysis Methods

During the household surveys described earlier, additional questions were asked to evaluate PHW's rural marketing strategy and find ways to improve it. The results were assessed in terms of the 4P's framework: product, price, place, and promotion.

Households without filters were asked questions about their interest in treating their water and how much they would be willing to spend on treatment. They were asked who in the family typically decides what to buy. Because of PHW's rural outreach program, respondents were asked if they were aware of ceramic filters in their village, if they had drunk water from a filter, and if so, what they thought of the filter's performance. They were also asked if they had attended the PHW village presentation.

Households with the filters were asked many questions about its purchase, its acceptability, and its operation and maintenance. Respondents were asked if they had attended a PHW village presentation, where they found out about the filter, and who decided to purchase it. They were asked how often they use the filter and whether they treat all the water the family uses for drinking. Data was also gathered on perceived health improvements. For acceptability, respondents were asked if they were happy with the technology, if it is easy to use, if they would recommend it to others, and if they have had any problems with it. For operation and maintenance, they were asked how often they clean it, whether they would buy a new one if it broke, how much they would pay for a new one, and whether their neighbors would buy one for that price.

3.5 Epidemiological Survey Results

3.5.1 General Results

The results from all 41 households are summarized below and shown in *Table 3.1*. Charts include arithmetic averages and standard deviations (STDV).

3.5.1.1 Household Information

Surveys were conducted in six traditional villages and in two modern communities. Sometimes respondents gave estimates for the number of household members since they were unsure of the exact number. The average size of all households was 12 people. Usually other wives, neighbors, and children were present during the interviews in traditional households.

Most respondents were asked to give their age, and an estimate was given when the exact age was unknown. The respondents averaged 39 years old. In general the respondents were mothers of children under five, but there were some instances when this was not possible. In the modern communities, households surveyed by Peletz (2006) were intentionally revisited. In two cases, the original respondent was not home, and another family member (niece and son) were surveyed instead. It is assumed that these respondents provided information similar to that of the original respondents. The overall average years of education of the survey respondents was 1.7 years.

An estimate of each household's average expenses was also recorded. Many figures given were rough ballpark estimates, and some women declined answering since they were not sure. The average for all households per person per month was US $8.60 (GHC 78,000).

Respondents were also asked about their sources of information, and many listed the radio, friends, and family members.

Most families used firewood and charcoal (88% and 73%, respectively). Only 22% had electricity and only 9.8% had gas.

3.5.1.2 Diarrheal Knowledge and Incidence

Respondents were asked about diarrheal prevalence for family members within one week of the survey. These responses were used to determine diarrheal prevalence for households, people, and children under five, respectively. To calculate the diarrheal prevalence for all households, the number of households with at least one person with diarrhea was divided by the total number of households. The diarrheal prevalence for all people was found by dividing household members with diarrhea by the total number of members. Likewise, the prevalence for children under five was found by dividing the number of children with diarrhea by the total number of children under five. Diarrheal prevalence for people was 4.4%, for households was 37%, and for children under five was 16%. The 2003 *Ghana Demographic and Health Survey* (GDHS) for the Northern Region found that 15.3% of children under 5 had had diarrhea in the past two weeks at the time of the survey (GSS, 2004). The numbers are comparable even though the GDHS used two weeks as opposed to the one week used for this work.

When respondents were asked what causes diarrhea, most answers were dirty food, water, or environment. Other responses included sweets, children teething, and dirt. After the general question, respondents were prompted if certain things caused diarrhea, and almost all said yes to each prompt. To be considered knowledgeable about diarrhea, respondents had to answer affirmatively that unclean water, food, and hygiene could cause diarrhea. Although the unprompted question usually indicated a certain level of diarrheal knowledge, the respondents could have been aiming to please the interviewer during the prompted questions. Ninety-five percent of respondents were found to be knowledgeable about diarrheal causes. Respondents typically treat diarrhea with medicines, and some go to hospitals or clinics for severe cases. Only 9.8% (4/41) of respondents cited oral rehydration salts (ORS) as a treatment method.

3.5.1.3 Hygiene Knowledge

Respondents were asked to give the times that they wash their hands, whether they use soap, and whether they had soap at the time of the interview. Respondents were considered to practice appropriate hand-washing if they said that they wash with soap, have soap, and wash their hands after using the toilet, before eating, and before cooking. Because no prompts were given for hand-washing, many respondents did not list all three critical hand-washing times. Many said that they wash their hands before praying or whenever they are not clean. Only 34% of the respondents were considered to practice appropriate hand-washing, compared to 86% of Peletz's respondents. This is likely due to the difference in how the question was asked and also partially due to the fact that this survey pool was comprised largely of traditional households, whereas Peletz's survey pool was comprised of equal numbers of modern and traditional households.

3.5.1.4 Sanitation Access

None of the traditional households and all of the modern households had access to improved sanitation facilities. The traditional households primarily used nearby outdoor areas, and one community had public ventilated and improved pit (VIP) latrines. According to the UNICEF/WHO Joint Monitoring Programme (2006), public latrines are not considered improved. All modern households surveyed used private or shared flush toilets, which are considered improved. An estimate of the time to the facility was recorded, and facilities inside homes were assigned times of zero. The average time to facility for all households was 3.8 minutes.

3.5.1.5 Water Access and Practices

Primary Water Sources

Primary water sources included household taps, standpipes, rainwater collection, dams, unprotected wells, and tanker trucks. Of these sources, household taps and standpipes are considered improved, and 12% of households surveyed always used an improved source. Primary sources varied significantly during the dry and wet seasons; the use of unprotected wells and rainwater collection increased and the use of dam water decreased during the wet season. None of the traditional households always used an improved water source throughout the year. Five out of six modern households always use nearby or in-home standpipes or household taps, which are considered improved. Several of the household taps only provide water 1-2 days per week, so those families must store water in large drums.

Water Collection

Respondents were asked how many trips were taken each day to collect water during the dry and wet season, and estimates of how long each trip took were recorded. Collection times averaged 70 minutes during the dry season but only 14 minutes in the wet season when sources are closer. Because times could be as great as several hours in the dry season, the number of daily trips was lower at 3.7, compared to 4.2 during the wet season. Usually women and children are responsible for water collection, but when closer sources become dry, sometimes young men travel on bikes to collect water.

Water Sources When away from Home

When away from home, many respondents drink any water that is available to them, and some specify that they drink anything as long as it is cloth filtered. Factory-produced sachet water and hand-tied water, shown below in *Figure 3.2*, are popular.

Figure 3.2 - Factory-produced sachet water (left) and hand-tied sachet water (right) are commonly drunk by people when they are away from home (Photo courtesy of Teshamulwa Okioga)

Storage Containers

Many containers were used to store drinking water in households. In households that used the ceramic water filter, it ranked the highest as a storage container. More than half of the households stored water in ceramic vessels, pictured in *Figure 3.3*. Jerry cans, metal drums, plastic bottles, and cooking pots were also used. Households were considered to practice proper storage if the containers were always covered and if they accessed the water by pouring it, using a spigot, or using a cup with a handle. Cups without handles, such as metal cans, allow users' hands to touch the water, which could introduce contamination. One such cup is pictured in *Figure 3.3* resting on the ceramic storage vessels. Forty-four percent of households were found to practice proper storage. However, even if the containers are covered and used correctly, they could still be contaminated if they are not cleaned properly.

Figure 3.3 - Ceramic vessels commonly used to store water in traditional households. A cup without a handle rests on the vessels, and the vessel in the front has a cloth filter over it.

3.5.1.6 Household Water Treatment

Only 2 out of 41 households believed their water was safe to drink without treatment, and all households reported using some type of treatment. Eighty percent (33/41) of households surveyed treated their water with cloth filters, and 61% (25/41) of households used ceramic filters. The Guinea Worm Eradication Campaign has widely promoted the use of cloth filters to remove the copepods that carry the guinea worm vector. All but two of the 19 traditional households with ceramic filters reported using cloth filters as a preliminary step before using the ceramic filter.

Table 3.1 - Survey results from all households

Communities surveyed	Traditional	35/41 = 85%	
	Shenshegu	4/41 = 9.8%	
	Taha	6/41 = 15%	
	Gbalahi	6/41 = 15%	
	Chenshegu	6/41 = 15%	
	Gbanyamni	8/41 = 20%	
	Kalariga	5/41 = 12%	
	Modern	6/41 = 15%	
	Vitin Estates	3/41 = 7.3%	
	Kamina Barracks	3/41 = 7.3%	
Household Information	Average number of people in household	12 people (STDV = 6.7)	
	Average number of children under 5	2 children (STDV=1.8)	
	Average age of respondent	39 years old (STDV=13)	
	Average number of years of education of respondent	1.7 years (STDV=4.4)	
	Average expenses per person per month	78,000 cedis (US $8.60) (STDV=53,000 (US $5.90))	
	Types of Energy Used		
	Electricity	9/41 = 22%	
	Gas	4/41 = 9.8%	
	Charcoal	30/41 = 73%	
	Firewood	36/41 = 88%	
Diarrheal Prevalence and Knowledge	Diarrheal Prevalence (people)	21/474 = 4.4%	
	Diarrheal Prevalence (households)	15/41 = 37%	
	Diarrheal Prevalence for children under 5	13/80 = 16%	
	Knowledgeable about diarrheal causes	39/41 = 95%	
Hygiene and Sanitation	Appropriate Hand-washing	14/41 = 34%	
	Adequate sanitation facility	6/41 = 15%	
	Average time to sanitation facility	3.8 minutes (STDV=3.0)	
Water Access	Primary Water source	Dry Season	Wet Season
	Household Tap	6/41 = 15%	5/41 = 12%
	Standpipe	2/41 = 4.9%	1/41 = 2.4%
	Rainwater Collection	0/41 = 0%	3/41 = 7.3%
	Dam	31/41 = 76%	20/41 = 49%
	Unprotected Well	1/41 = 2.4%	11/41 = 27%
	Tanker Truck	1/41 = 2.4%	1/41 = 2.4%
	Always using Improved Water Source	5/41 = 12%	
	Average time to Collect Water		
	Dry season	70 minutes (STDV = 66)	
	Wet season	14 minutes (STDV = 12)	
	Number of Trips to Collect Water		
	Dry Season	3.7 trips (STDV=2.3)	
	Wet Season	4.2 trips (STDV=2.7)	
	Primary water sources while traveling	Any Available, Sachet, Tied	
Water Storage	Storage containers		
	Ceramic vessels	21/41 = 51%	
	CT Filter Receptacle	22/41 = 54%	
	Jerry can	3/41 = 7.3%	
	Metal tank/drum	2/41 = 4.9%	
	Plastic bottles	2/41 = 4.9%	
	Cooking Pots	1/41 = 2.4%	
	Proper Storage	18/41 = 44%	
Water Quality Perception and Household Water Treatment	Believe water is safe without treatment	2/41 = 4.9%	
	Treatment method: some type	41/41 = 100%	
	Tamakloe	25/41 = 61%	
	Cloth	33/41 = 80%	

3.6 Analysis of Epidemiology Survey Results

3.6.1 Analysis Methodology

Peletz (2006) conducted a relative risk analysis using her epidemiological survey data and her water quality data in order to understand connections between certain exposures and outcomes. Diarrheal illness was used for the outcome, and exposure factors included use of PHW products, type of community, sanitation access, and drinking water quality. For each analysis, she calculated an odds ratio and used the chi-square test to determine statistical significance. This same procedure was conducted by the author so that Peletz's results could be combined and compared with those in this report. Peletz organized the observed data in tables, as shown in *Table 3.2*, in order to calculate the odds ratio and the chi-square value.

Table 3.2 - Observed data tabulated for the analysis

	Disease	No Disease
Exposure	a	b
No Exposure	c	d

3.6.1.1 Odds Ratio

An odds ratio (OR) compares the odds of an event occurring in one group to the odds of occurrence in a second group. If the odds ratio equals 1, then the outcome is just as likely in both groups. The event is more likely in the first group if the odds ratio is greater than 1 and is less likely in the first group if the odds ratio is less than one. The odds ratio was used to determine the relationship between diarrheal illness and various exposure factors. It is defined as:

$$OR = \frac{(a \times d)}{(c \times b)}$$

3.6.1.2 Chi-Square Test

The chi-square test was used to determine if the two factors analyzed had significantly different outcomes or not. The chi-square value was determined using the following equation:

$$X^2 = \sum \frac{(O-E)^2}{E}$$

where O is the observed outcome and E is the expected outcome. The expected outcome was found by multiplying a cell's row total by the cell's column total and then dividing by the total of all observations, as shown in *Table 3.3* below. For the chi-square test to be valid, the expected outcome in a 2x2 table should not be less than 5. Because of this restriction, it was not possible to look at modern households alone using just the author's data from 2007. Chi-square values from each outcome and exposure pair were then summed.

Table 3.3 - Expected outcome calculation method

	Disease	No Disease
Exposure	(a+b)(a+c)/(a+b+c+d)	(a+b)(b+d)/(a+b+c+d)
No Exposure	(c+d)(a+c)/(a+b+c+d)	(c+d)(b+d)/(a+b+c+d)

Once the chi-square value was obtained, the p-value was found to see if the results were significant enough to allow for the rejection of the null hypothesis. To do this, the degrees of freedom were determined. A table's degrees of freedom (df) equals:

$$df = (r-1)(c-1)$$

where r is the number of rows and c is the number of columns in the table. All tables in this section are 2x2, so df = (2-1)(2-1) = 1. Then a chart was used to pinpoint a p-value based on the chi-square test and the degree of freedom. Significance is more likely if the relationship is strong and if the data set is large. Results were considered statistically significant if the p-value was greater than 0.05, which corresponds to a chi-square value of 3.84.

3.6.2 Relationship between Exposure Factors and Diarrheal Illness

Two analyses resulted in statistically significant results, and these are shown below. The first uses data from Peletz and the author to compare household diarrhea incidence in households with and without a filter. The data from Peletz includes both modern and traditional households, and some households used ceramic filters other than the ceramic pot-shaped filter. The second analysis uses the author's data to compare diarrhea incidence for people living in households with and without ceramic filters.

Household Diarrhea Incidence for Filter Users and Non Users

With the data combined, there is a stronger connection between filter use and household diarrheal prevalence. Households with filters are 76% less likely to have a member with diarrhea than households without a filter. The p-value is 0.008 which indicates that the relationship *is statistically significant*. This increased difference in diarrheal prevalence may be caused in part by the fact that all of Peletz's filter users were from modern households, which typically have fewer exposure factors than traditional households. The larger data set also helps make the results more statistically significant.

Table 3.4 - Filters and household diarrhea incidence (Combined Data)

	Diarrhea	No Diarrhea
Filter	5	25
No Filter	25	30

OR = 24%

$X^2 = 7.04$

p-value = 0.008

Filters and Diarrheal Illness for All People in Traditional Households

The second analysis uses the author's data from traditional households to find the relationship between filters and diarrheal illness for all people in the traditional households. The odds ratio (OR) was 31%, which indicates that people living in households without the filters are about three times as likely to have diarrhea as those living in households with the filters. With a chi-squared value of 4.46, the p-value is 0.035. Therefore, the results *are statistically significant* at the 0.05 level.

Table 3.5 - Filters and diarrhea incidence for all people

	Diarrhea	No Diarrhea
Filter	4	219
No Filter	12	203

OR = 31%

$X^2 = 4.46$

p-value = 0.035

3.7 Water Quality Results and Analysis

3.7.1 Summary of Results

Water quality tests were conducted to assess the effectiveness of the ceramic pot filters in the field. Source water samples and filtered samples were collected and tested for total coliforms, *E. coli*, and hydrogen sulfide-producing bacteria, and turbidity. The results for three bacterial tests and for turbidity are summarized in *Table 3.6* for traditional and modern communities.

Table 3.6 - Summary of water quality test results

Traditional Communities		Source Water	Filtered Water	Percent Removal for Paired Samples
Membrane Filtration	Average *E. coli* CFU/100mL	690	2.5	99.7%
	Average Total Coliform CFU/100mL	23,000	170	99.4%
3M Petrifilm (25 samples)	Average *E. coli* CFU/100mL	330	0	100%
	Average Total Coliform CFU/100mL	5700	180 or 810*	94%
Hydrogen Sulfide Bacteria Presence/Absence	Positive for H2S Bacteria	97% (30/31)	13% (2/16)	85% (13/15)
	Negative for H2S Bacteria	3.2% (1/31)	88% (14/16)	
Turbidity	Average NTUs	190 (33 samples)	11 (19 samples)	92%

Modern Communities		Source Water	Filtered Water	Percent Removal for Paired Samples
Membrane Filtration	Average *E. coli* CFU/100mL	1.4	0.21	85%
	Average Total Coliform CFU/100mL	1500	150	90%
3M Petrifilm (7 samples)	Average *E. coli* CFU/100mL	0	0	100%
	Average Total Coliform CFU/100mL	440	57	78%
Hydrogen Sulfide Bacteria Presence/Absence	Positive for H2S Bacteria	29% (2/7)	0% (0/7)	100% (1/1)
	Negative for H2S Bacteria	71% (5/7)	100% (7/7)	
Turbidity	Average NTUs	4.5 (7 samples)	1.4 (7 samples)	68%

3.8 Business Survey Results and Assessment

3.8.1 Summary

Table 3.7 and *Table 3.8* summarize the survey results of consumer perceptions, attitudes, knowledge, and practices related to water treatment using ceramic water filters. The subsequent sections analyze these results within the 4P's framework.

Table 3.7 - Survey Results for Filter Users

	Filter Users	
Filter Awareness and Decision to Purchase	Attended PHW Presentation*	13/15 = 87%
	Source for Learning about the Filter*	
	PHW Presentation	1/16 = 6.3%
	Family Member	3/16 = 19%
	Community Liaison	3/16 = 19%
	Neighbors	1/16 = 6.3%
	Member of PHW Marketing Program**	5/16 = 31%
	Member of Alioune Dia's Research Study	3/16 = 19%
	Family Member Who Decided to Purchase Filter	
	Father	9/25 = 36%
	Mother	4/25 = 16%
	Father and Mother	4/25 = 16%
	n/a since given for free	8/25 = 32%
Filter Use and Acceptability	Average Days/Week Filter is Used	7 days
	Treat all Water Family Drinks	22/25 = 88%
	Noticeable Improvements in Family Health	25/25 = 100%
	Happy with Technology	25/25 = 100%
	Technology is Easy to Use	25/25 = 100%
	Problems with Filter	
	Spigot Problems	3/25 = 12%
	Flow is too Slow	4/25 = 16%
	Need Brush to Clean It	2/25 = 8%
	Cracked Receptacle	1/25 = 4%
	Incorrect Use	1/25 = 4%
	Would Recommend Filter to a Friend	25/25 = 100%
Willingness to Pay	Willingness to Pay for Filter	
	Traditional Households	US $6.40 (GHC 57,000)
	Modern Households	US $11.40 (GHC 103,000)
	Neighbors Would Pay this Price	
	Yes	21/25 = 84%
	No	1/25 = 4%
	Maybe	3/25 = 12%

*Not all households were asked

**Member of community liaison or chief's household

Table 3.8 - Survey results for non filter users

Non Filter Users	
Want to Treat Water	16/16 = 100%
Family Decision Maker	
Father	9/16 = 56%
Mother	1/16 = 6.3%
Father and Mother	3/16 = 19%
Oldest Family Members	2/16 = 13%
Young Males	1/16 = 6.3%
Aware of Ceramic Filter in Village	15/16 = 94%
Has Drunk Water from a Filter	5/16 = 31%
Attended PHW Presentation*	3/9 = 33%
Willingness to Pay for Filter	US $4.40 (GHC 39,000)

*Not all households were asked

3.8.2 4 P's Analysis

Product

PHW's primary product, the *Kosim* filter, was evaluated through the household surveys and water quality tests described in earlier sections. Overall, filter owners seemed to be very satisfied with the product. All households (25/25) said that the filter is used seven days a week. Also, 88% (22/25) claimed that they treat all the water that the family uses for drinking. Three out of 25 families do not treat all water because sometimes untreated water is more convenient, and sometimes the filter does not provide enough water for all family members. It is probable that more people drink unfiltered water than was reported since family members at several households were observed drinking from vessels containing unfiltered water.

Several questions were asked about how acceptable the ceramic filter is to the users. One hundred percent of users (25/25) said that they are happy with the technology, that it is easy to use, and that they would recommend it to others. One respondent had recommended the filter to several people who then bought the product for their households. All respondents (25/25) said they would replace their filter if it broke. Some problems were cited, including a few broken spigots in the filters in use for over one year, slow flow rates, and one broken receptacle. It is recommended that PHW give families an option to pay more for a metal spigot instead of the plastic spigot that is provided. Although the metal spigots do not turn off automatically and are more expensive, they are much more durable. Also, a couple of households needed the brush that is supposed to come as part of a filter purchase. Respondents with turbid water reported cleaning their filter several times each week, while others said they clean it a couple of times each month, as necessary. Because households are typically large in this region, PHW could suggest that families buy multiple units if possible. One family interviewed had two filters, and it is likely that many of the larger families could better meet their needs with a second filter.

Price

As described previously, PHW has changed its pricing scheme. Since PHW changed the price charged to traditional households in Year 2 to US$ 6.70 (GHC 60,000), the demand has increased, indicating that the price is within reach of most people in traditional communities. Filter users were asked what they would pay to replace their filter if it broke, and most said that they would pay the price at which they purchased it. The average response in traditional households was US $6.40 (GHC 57,000), and modern households averaged higher at US $11.40 (GHC 103,000). Filter users were asked if their neighbors would buy one at the price they gave in the previous answer, and 84% (21/25) said "yes." Non-users from traditional households were also asked what they would pay for a ceramic filter unit, and their average response was a little lower at US$ 4.40 (GHC 39,000). *Figure 3.4* shows the willingness to pay for *Kosim* filters for both non-users and users from all households.

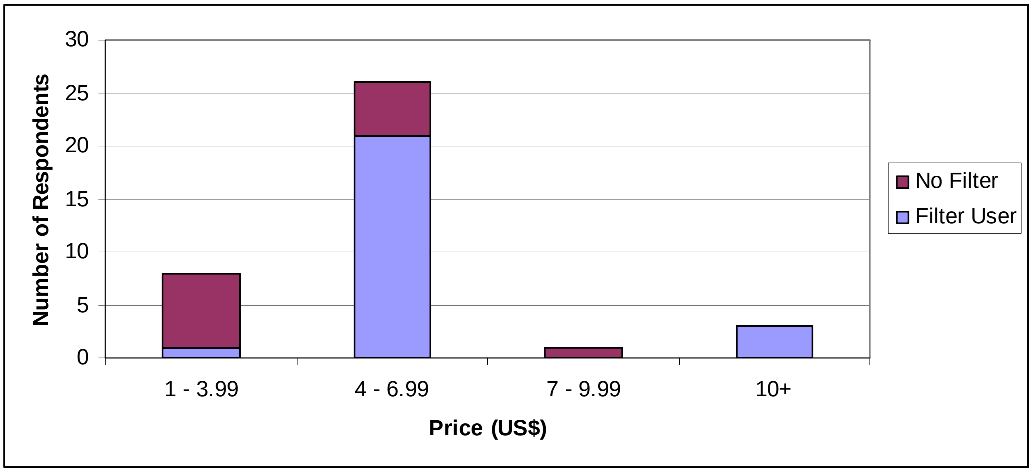

Figure 3.4 - Willingness to pay for a ceramic water filter for households with and without a filter unit.

Place

Place is analyzed in two respects, both the target communities PHW is reaching and the marketing channels by which they are doing so.

The household surveys determined that PHW is reaching people in greatest need for the ceramic filters. Whereas PHW's Year 1 strategy mostly reached people from modern communities in the urban areas and outskirts of Tamale that have access to improved water and sanitation, Year 2's strategy has made it possible to reach poorer people in rural communities. Zero percent (19/19) of the filter users from the rural communities have year-round access to an improved water supply or improved sanitation, and only one of the rural filter users had attended school.

PHW's marketing channels also seem effective. Community liaisons in each village are accessible for people who want to buy filters or who have questions about them. Although these marketing channels have reached low-income rural people and generated demand, there have been delivery delays from the factory in Accra. Hopefully PHW's assuming a new role in local ceramic manufacturing in the not-so-distant future will prevent these delays from occurring.

Promotion

The rural promotion efforts seem to be reaching many people in each village. Ninety-four percent (15/16) of non-users were aware of the ceramic filters in their village, and one third of the non-users (5/16) had had water from a filter. Many noted that the filtered water tasted very good and was clear. All sixteen non-users expressed an interest in treating their water. Most filter users first found out about the filters from a family member or from the community liaison. Respondents were also asked if they had attended the Pure Home Water village presentation, and the results are shown in *Figure 3.5*. The numbers indicate that presentation attendance might encourage people to buy the filters.

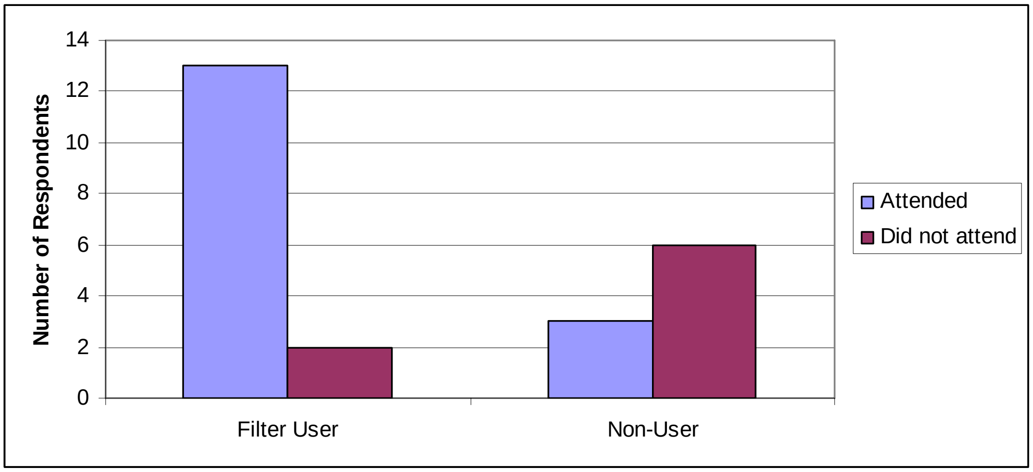

Figure 3.5 - Attendance at Pure Home Water's village presentation for respondents with and without ceramic filters.

3.9 Conclusions

3.9.1 Key Findings

PHW is reaching communities that need the filter the most, and the filters are performing well and are acceptable to users. The following key findings support these conclusions:

- Whereas 83% of modern households surveyed always have access to an improved water source, and 100% of modern households surveyed have access to improved sanitation, 0% of traditional households surveyed always have access to improved water or sanitation. PHW is reaching these traditional communities.
- In membrane filtration testing, the filters reduced *E. coli* by 99.7% in traditional households and by 85% in modern households.
- The filters reduced total coliform by 99.4% in traditional households and by 90% in modern households according to membrane filtration testing.
- Turbidity was reduced by 92% in traditional households and by 68% in modern households.
- People living in traditional households with filters were 69% less likely to have diarrhea than people living in households without the filters.

- The filters are acceptable to users, and non-users are interested in treating their water with the filters.
- The pricing scheme works well for most traditional households.

3.9.2 Discussion of Findings

Baseline data for filter users and non users was collected in the household surveys conducted by the author in January 2007. For the first time, it was possible to gather data from filter users in traditional households because before all filter users were from modern communities. From the data on filter users in traditional communities, it is clear that Pure Home Water is reaching those with the greatest need for the ceramic water filter. Some points from the surveys are highlighted below:

- 29% of respondents from traditional households and 67% of respondents from modern households practice appropriate hand-washing.
- Traditional households spend an average of 82 minutes per trip to collect water during the dry season.
- Surprisingly, traditional households without the filters reported a higher income per person per month (US$ 7.60) than households with the filters (US $5.50). Even people who live on much less than $1 per day seem to be able to afford to buy the filter at PHW's price.

Although the filters are providing significantly cleaner water to users, the water provided by the filter may still not be safe. Traditional households averaged 170 total coliform CFUs/100mL in the filtered water, which is still not very good, even though it is a vast improvement upon the source water, which averaged 23,000 CFU/100mL. The problems could arise because the filter is unable to remove all bacterial contamination, or the problems could be due to improper filter use or manufacturing flaws.

According to the risk assessment analysis, households with filters were 76% less likely to have a member with diarrhea than non-filter households. Also, when comparing all people from traditional households, people in a household with a filter were 69% less likely to have diarrhea than people in a household without a filter. The diarrheal rates for children under five showed less contrast between filter and non-filter households. Children under five may be more likely to be exposed through additional contamination pathways.

The results from the business survey found that the filters are acceptable to users and that non-users were interested in treating their water with the filters. Users thought the filters performed well and were easy to use. The pricing scheme works well for most traditional households, and the community liaisons are providing an effective link between the communities and Pure Home Water. Many households that had been using the filter for over one year cited problems with the spigot, and Pure Home Water should offer households the opportunity to purchase a more durable metal spigot.

3.9.3 Recommendations to Improve PHW's Practices

PHW should take additional steps to ensure all filters provide safe water to users. To address possible improper filter use, PHW should ask its community liaisons to periodically check to ensure users understand how to use and maintain the filter. Until PHW begins its own manufacturing, additional quality control methods should be implemented to address possible manufacturing flaws. PHW already inspects each shipment from the manufacturer and rejects many of the filters, and an inspection checklist could be made that included current criteria and some additional tests. An inspection checklist could include:

- A check to ensure the filter fits correctly in the receptacle so water does not leak around the sides.
- A knocking audio test and visual inspection to check for cracks.
- A flow rate retest to ensure a flow of approximately $2m^3/s$.
- Bacterial tests to ensure over 99% of bacteria are being removed.

Because the flow rate test and bacterial tests would require significant time commitments, PHW could test a percentage of filters from each shipment from the manufacturer. The bacterial tests could include membrane filtration if time allowed, but 3M™ Petrifilm™ and hydrogen sulfide tests may be better screening options since they are less expensive and much quicker to perform. The source water samples should include a range of turbidities and bacterial concentrations.

Future studies could continue to monitor filter use through epidemiological studies and water quality testing. Spigot problems were cited for households using the filter for over one year, and additional problems may arise with further use. Long-term studies of several years could help identify these problems. A more comprehensive epidemiological study with a survey size of several hundred households could determine better relationships between diarrheal rates for people drinking filtered water compared to those not drinking filtered water. Although results from a larger scale health impact study would be interesting for the field of HWTS technologies, they would not be critical to PHW's operation.

PHW will need to monitor its rural outreach strategy to ensure that the most effective opinion leaders in each community are being chosen to promote the filters. A study could be done to assess the effects of opinion leaders in each community. For instance, households could be surveyed on their thoughts about the opinion leaders and whether or not their actions are actually influential. Chiefs of communities may in fact not be the best opinion leaders. Also, future studies could assess the school and hospital outreach programs through both surveys and water quality testing.

When PHW begins its own filter manufacturing facility in the Northern Region, flow rate tests, bacterial tests, and turbidity tests will be necessary to ensure that the filters are performing well. If chemical contamination in drinking water sources becomes an identified concern, PHW will need to test the filters' removal ability for the contaminants. After several months of operation, only flow rate tests will be required for every filter, while turbidity and bacterial tests should be done for a percentage of filters produced each week. Students could try to change clay/sawdust mix ratios to optimize flow rates without sacrificing performance. Another project could focus on strengthening the lip of the filter.

CHAPTER 4: WATER QUALITY AND BUSINESS ASPECTS OF SACHET-VENDED WATER IN GHANA

BY
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4.1. Introduction

Based on the success of the sachet-water industry in Ghana, which is a dynamic and profitable new "bottom of the pyramid" industry, this aspect of the MIT Ghana team project aims to identify key marketing strategies successfully used by sachet-water vendors, especially those that can be applied by PHW, a start-up enterprise that likewise seeks to be dynamic and profitable. The study also aims to analyze the microbial quality of sachet-vended water and assess the feasibility of promoting PHW products to sachet-water vendors. The general and specific objectives are summarized below.

4.1.1 General Objective

The overall objective of this portion of the group's efforts is to investigate the quality of sachet-vended water and suggest strategies for improving its water quality.

4.1.2 Specific Objectives

The specific objectives are to:

1. Test the quality of sachet-water samples;
2. Identify the source water and prior treatment process of sachet-vended water ;
3. Interview sachet-water vendors and understand the packaging, handling and distribution practices, as well as the business aspects of sachet-water vending including the 4P's : product, price, place (distribution) and promotion as they relate to sachet water;
4. Analyze the feasibility of marketing PHW's ceramic filter to hand-tied sachet-water vendors.

4.2 Water Vending – Definition

The WHO Guidelines for Drinking Water Quality (WHO, 2002 and 2006) do not include bottled or packaged water in its category or definition of vended water, but instead restricts it only to vendors selling unpackaged water to households or at "collection points".

For the purpose of this section of the group report, the water vending or the water vendors enterprise is an individually-run or small to medium-scale, independent and private enterprise, that is managed, owned or served by retailers, resellers or distributors of water, whose goal is to generate profits as a main source of income and whose core business activities involve selling packaged or unpackaged water, that may or may not be further treated for enhanced quality, and that is sourced from utility supplies or other secondary sources.

4.3 Sachet Water in Ghana

Ghana has small and large scale industries that pack and machine-seal sachet water. This water is referred to as "pure water" by many of the locals. Sachet water is also sold in hand-filled, hand-tied plastic bags. This is locally referred to as "ice-water". In this report machine-sealed sachet water that is produced in industries is referred to as "factory-produced", while that produced by manually filling plastic bags with water and knotting the water-filled bags is referred to as "hand-tied" sachet water.

Figure 4.1 shows sachet-water production in factories, while *Figure 4.2* shows hand-tied sachet water being produced. The production process is discussed in *section 4.8.*

Figure 4.1- Factory-produced sachet with sealing machine in the background

Figure 4.2 - Hand-tied sachet water being manually filled

4.4 The Food and Drugs Board of Ghana and the Ghana Standards Board

The Ghana Standards Board (GSB) and the Food and Drugs Board of Ghana (FDB), established in 1965 and in 1992 respectively, are both responsible for ensuring that products being marketed in Ghana are of required quality. While the GSB generally develops and regulates standards for varying products that range from foods, drinks, and drugs to electrical and other engineered products, the FDB regulates and certifies only food, drinks, drugs, cosmetics, and other products which have health implications for the consuming public (GSB, 2004).

Both the FDB and the GSB regulate and certify sachet-water production and therefore there is some duplication of functions by the two authorities. However, while it is optional to have factory-produced sachet water registered with the GSB, it is mandatory to have the products approved and registered with the FDB. The main advantage of being registered by the GSB is to build product reputation.

4.5 Water Quality Testing Methodology for Sachet Water

The GSB (GSB, 1998) specify that the appropriate number of samples considered for water quality analysis, obtained for a lot that contains up to 1000 units of packaged water should at least be 15 units per lot. However, the number of samples tested by the author of this study was limited to the 3 weeks time available and the main aim was to sample as many brands of packaged water as possible. In total 15 individual samples of hand-tied sachet water and another 15 factory-produced sachet-water samples were analyzed using the MF test, 3M™ Petrifilm™ test, and the P/A H_2S test. Turbidity and pH test were also conducted.

4.6 Survey Methodology

Semi structured interviews were conducted with sachet-water producers including 5 sachet-water factories, namely: Divine Love, Voltic, First Class, Jaf Lover, and Aqua-ba and 5 producers of hand-tied sachet water. The surveys also involved interviewing 30 customers/buyers of sachet water and 10 road-side sachet-water vendors. These interviews and surveys followed a more structured approach.

The road-side vendors interviewed in Tamale included:

- Retailers of factory-produced sachet water;
- Vendors of hand-tied sachet water;
- Venders that sold both factory-produced and hand-tied sachet water.

The vendors were asked to respond to questions regarding the cost of sachet water, the brands and types they sold, the places the vendors sold the water and reasons for choosing those respective areas. This information was considered useful in better understanding the sachet-water business and also valuable to PHW in determining where to potentially set up an intended HWTS future retail shop for general sale and promotion of the ceramic filters and related products that they intend to market.

Information regarding the main customers targeted by the vendors, the average amount sold per day and the income generated was also obtained. Vendors that sold hand-tied water were asked whether or not they treated their water and how much they were willing to invest in implementing or improving water treatment systems for their products. This information was used to determine if the sachet-water vendors would feasibly be included as part of PHWs outreach programs for ceramic filters and to determine other affordable alternatives to improve their services.

Through the customer surveys, information that included the type of sachet water bought (hand-tied or factory-produced) and the amount bought per day was obtained. Other information included the customers' perceptions on price, quality of sachet water and quality of service offered by sachet-water vendors. Their responses were used to determine the characteristics of service the customers appreciated most, and the water quality characteristics they considered important for drinking water. A comparison of how much water people drank in their homes and away from home was also obtained from the survey results. This was done to assess the impact of promoting HWTS in areas away from home and, in particular, through sachet-water vendors by them using HWTS products to treat their water. Customers both in Tamale and the adjacent district-town of Savelugu were interviewed.

4.7 Source and Treatment of Tap Water Used by Sachet-Water Vendors in Tamale

The main source of water for both hand-tied and factory-produced sachet water is tap water. The source of Tamale's tap water is the White Volta River. A field visit to the Tamale water supply intake point at Nawuni and the Dalun Water Treatment Plant was therefore conducted to better understand the centralized water treatment processes taking place prior to the decentralized treatment that is applied by individual sachet-water producers and in sachet-water factories. The treatment processes observed at the Dalun Water Treatment Plant included coagulation, flocculation, settling and sludge disposal, filtration, disinfection, post liming and finally distribution.

4.8 Sachet-Water Producers in Tamale, Ghana

Semi-structured interviews were conducted with employees and owners of the 5 sachet-water factories and 5 producers of hand-tied sachet water, for the purpose of understanding the industry and process of sachet-water production qualitatively, rather than for the purpose of collecting statistical data. The semi-structured interviews with the sachet-water producers therefore followed a fairly open framework which allowed for two-way interaction with the individuals interviewed. The producers were interviewed at the production premises where they also demonstrated how they packaged sachet water.

4.9 Factory-Produced Sachet Water

4.9.1 Water Treatment

At the sachet-water factories, water is treated by a point-of-entry (POE) system that makes use of filtration, and in some cases ultra violet (UV) disinfection.

A typical sachet-water factory setting consists of a storage system (tanks), a conveyance system (piping), a decentralized water treatment system (filters, UV disinfection units), and a packaging system. The packaging is done by making use of automatic liquid filling and packaging machines, also commercially know as "automatic liquid packaging machines", "form, fill and seal machines", "form, fill, seal, vertical (flow) sachet machines" or simply "sachet machines". In this report, "sachet machines" is used. A typical set-up of a sachet-water factory is shown in *Figure 4.3*, which shows two sachet machines, with the treatment system comprised of filtration and UV disinfection units attached to the wall in between the 2 sachet machines. The storage tanks (not in the photo) consist of a tank or a series of multiple tanks placed outside, within the factory compound or inside the factory building.

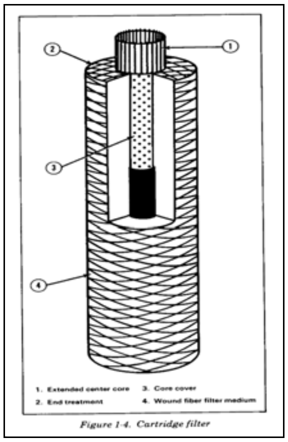
Figure 4.3 - Typical sachet-water factory set-up

4.9.1.1 Filter Types

The filters used for the factories that were surveyed included yarn (strung wound) filters, granular carbon filters, and fiber matrix carbon filters. The filters cartridges and housings came in two sizes, 20'' and 10'' sizes, which corresponded to the filter lengths.

Yarn Filter Cartridge

This is a sediment removal strung-wound filter cartridge made of yarn continuously wound around a plastic center core that has perforations. The yarn material used includes polypropylene, rayon, acrylic, polyester, nylon, fiberglass, or Teflon (GlobalSecurity, 2007). The filter is capable of removing dust, rust, silt, scale, sediments, and micro-organisms. It is considered as a "rough filter" for removing large sized particles. *Figure 4.4* shows the key elements of a yarn filter: a center core, the wound fiber and core covers and end treatments which reduce chances of media migration. Flow occurs from the outer surface of the wound filter medium to the center core.



1- Center Core
2- End Treatment
3- Core cover
4- Wound fiber filter medium

Figure 4.4 - Yarn filter cartridge (GlobalSecurity, 2007)

Wound filters can also contain a layer of activated granular carbon as shown in *Figure 4.5*. The outer-most layer is wound yarn, followed by the activated carbon layer and finally an inner winding which is a polishing step.

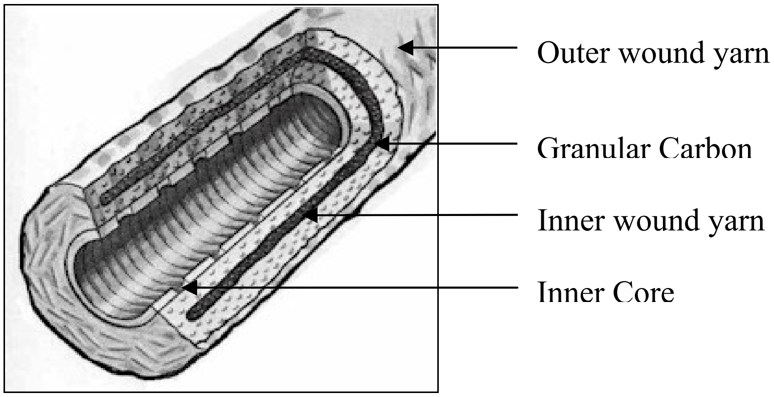


Figure 4.5 - Yarn filter cartridge with granular carbon layer (KTH Sales, Inc., 2007)

Fiber Filter Cartridge

Unlike the strung-wound filter cartridge, the fiber filter cartridge is a non-woven filter cartridge, made of microfibres. Like the strung-wound filter, it is also used for sediment removal but has a much lower porosity. The channels in the windings of yarn filter may sometimes allow particles to penetrate directly into the filtrate, and the fiber filter cartridge thus offers more superior treatment in comparison to the simply strung-wound filters.

Granular carbon filter

This is a non-membrane type filter that makes use of granular activated carbon. This is capable of adsorbing and thus reducing odor, color, chlorine and other undesired tastes, salt and organic matter. This is the jar type filter media as is found, for example, in a Brita Filter.

Matrix Carbon Filters

This consists of activated carbon granules covered by a synthetic netting, and inner carbon powder (*Figure 4.6*). The filter core is encased in a fine microfibre that ensures no carbon is filtered through. Like the granular carbon filter, this filter is also used for reducing odor, color, chlorine and other undesired tastes, salt and organic matter.

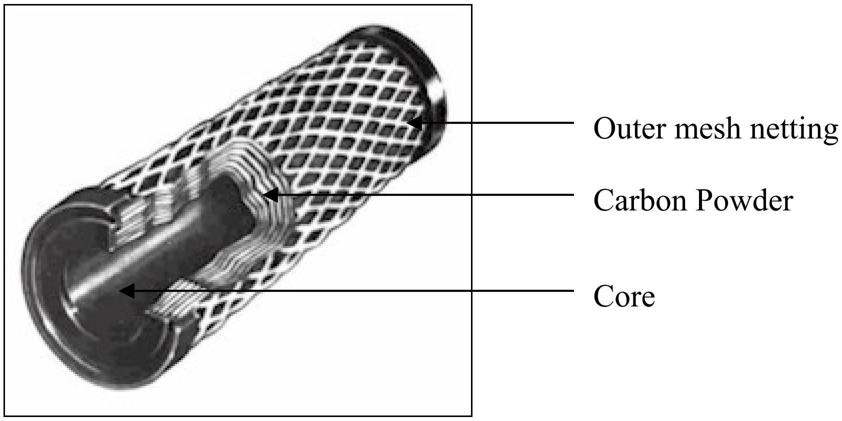


Figure 4.6 - Matrix carbon filter (KTH Sales, Inc., 2007)

Divine Love, Voltic and Aqua-ba used filtration and UV disinfection to treat water, while First-class and Jaf-Lover only used filtration.

4.9.2 Sachet-Water Quantities Produced

The number of sachets produced per factory varied from approximately 15,000 sachets per day (7,500 l/day) during the rainy and cold seasons to approximately twice as much (30,000 sachets or 15,000 l/day) during the dry and hot seasons. The quantities produced from the five factories visited are shown in *Table 4.1*.

Table 4.1 - Quantity sachet water produced per day by sachet-water factories

	Divine Love	Voltic	First Class	Jaf Lover	Aqua-ba	
Production per day (Individual Sachets)	18,000 to 24,000	28000	15000	18000	21,000 to 24,000	
No. of Individual sachets per bag	30	20	25	30	30	
Production per day (bags)	600 to 800	1400	600	600	700 to 800	
Volume (liters produced/day)	10,500	14,000	7,500	9,000	11,250	Average ≈7,500

Packaging

The sachet water was packaged using sachet machines. Each sachet contained 500ml of water. The factories had one to four machines each.

The Sachet Machine

The sachet machine can be used to package different types of liquid products other than water, including sauces, soft drinks such as juice, milk as well as some chemical products. The plastic films used in the machine are bought as single-sheet rolls.

The main parts of the machine include:

- The bag-forming devices that fold the polythene bags used for sachet water before the bags are heat-sealed;
- The sealing devices, which seal the bags first vertically and then horizontally after filling with water;
- The filling and metering devices that fill the bags with water and monitor flow;
- A UV disinfection bulb that disinfects the inner plastic film used to package sachet water, and;
- An automatic counter that registers the number of bags produced.

Preparation of the Sachet Machine

The machine preparation procedure, which involved loading the polythene rolls used for packaging, was demonstrated at the Divine Love sachet-water factory. The machine preparation was done after backwashing the filtering units. The filter units are backwashed everyday and the cartridges changed after 1 to 3 months.

To operate the sachet machine, pre-printed films in the form of high-density polyethylene (HDPE) rolls were loaded to central shaft of the machine and secured in the film roller shown in *Figure 4.7*. The pre-printed rolls generally had the name of the sachet-water product, product logo, the FDB (or both FDB and GSB) registration numbers and authorization marks and other features to fit the labeling requirements given by the GSB. The rolls were then locked in place, and a small length pulled from the back to the front of the machine.

The extended length was folded onto the base board of the bag-former, shown in *Figure 4.8*. An additional length of roll, of about 0.5m, was heat-sealed longitudinally as shown in *Figure 4.9*, and the lower end sealed transversely using the vertical sealing and horizontal sealing devices respectively. The length below the transverse seal was then adjusted by trimming the ends manually with a pair of scissors as shown in *Figure 4.10*. The machine was then ready for use.

At the Aqua-ba sachet-water factory, other features of the sachet filling and packaging machine were pointed out. These included the UV-bulb that was fitted inside the machine. The UV light was used to disinfect the polythene roll before sealing and filling with water. This is shown in *Figure 4.11*. Another feature was an automatic counter that kept track of the number of sachets produced. The sachet filling and packaging machines automatically printed, on the sachets, the batch number of bags produced thus making it easy to keep track of the production (*Figure 4.12*).

Figure 4.7 - Loading of polythene rolls in sachet machine

Figure 4.8 - Polythene rolls adjusted by folding on base board of bag former

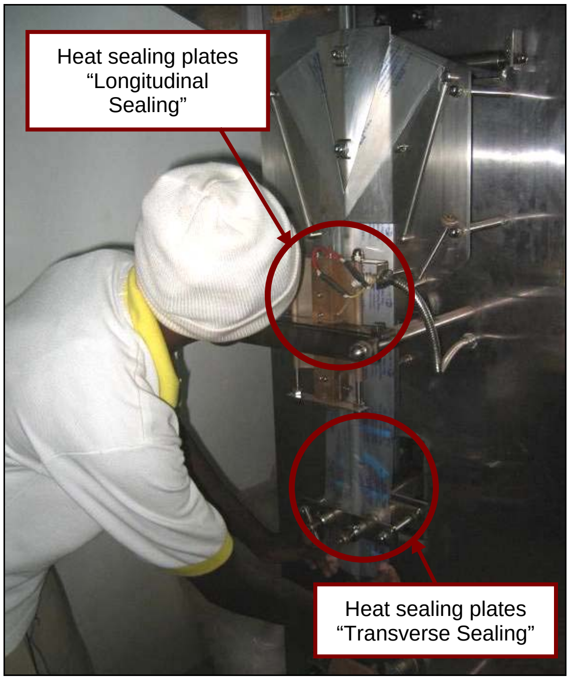


Figure 4.9 - 0.5m of sachet rolls sealed longitudinally and at one end

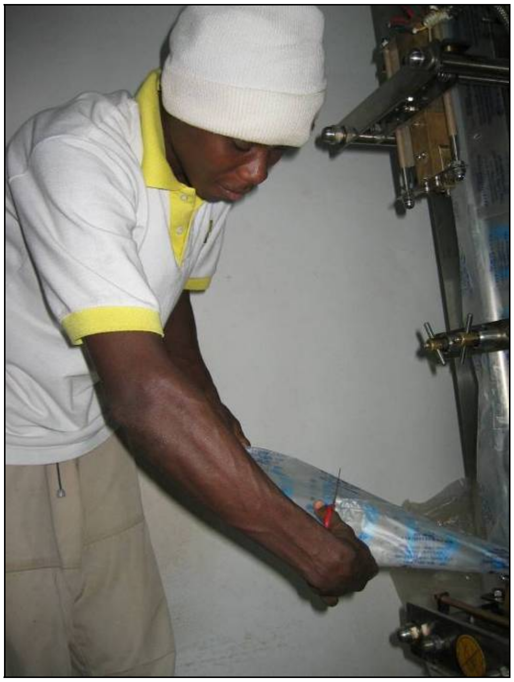


Figure 4.10 - Final adjustment of roll and trimming below seal

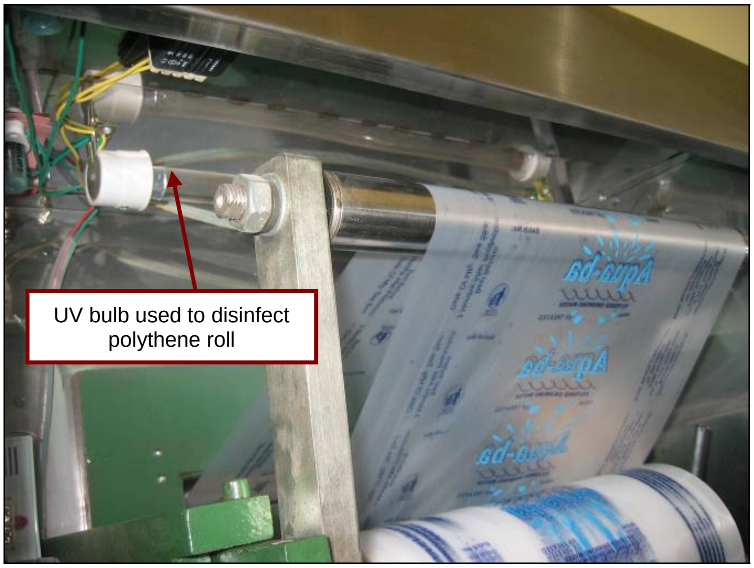


Figure 4.11 - UV-bulb in sachet machine used to disinfect polythene roll

Figure 4.12 - Automatic Counter (Shown blown up)

4.9.3 Business Structure and Strategy

The number of people working in the sachet-water factory varied from 3 to 16. The factory employees were either employed on a part-time or full-time basis by the different factories. *Table 4.2* shows the number of employees and their gender as well as the duration of time since the factories were open. The oldest (1999) is First Class and the most recent (2006) is Aqua-ba.

Table 4.2 - Characteristics of factory-produced sachet-water factories

	Type of Business	Operation in Tamale Since	Employees			
			Male	Female	Total	Comments
Divine Love	Family owned	2005	1	2	3	All part-time
Voltic	Franchise	2000	8	8	16	All full-time
First Class	Family owned	1999	10	0	10	All full-time
Jaf Lover	Family owned	Not know by two employees interviewed	4	1	5	All part-time
Aqua-ba	Family owned	2006	9	0	9	All full-time

All the sachet-water factories visited sold sachet-water only in bulk to distributors, resellers, retailers as well as the consumers. Here, the distributors refer to those who bought sachet water in bulk from the factories and sold them to other entrepreneurs rather than the consumers or ultimate buyers. Resellers refer to those who also sold the sachet water in bulk but to the end consumers, while retailers to those who sold individual sachets to the end consumers. For the bulk sales, individual sachets of water were packed in larger bags that contained 20, 25 or 30 sachets. The main buyers were retailers and distributors and included gas stations, shops, mini-markets, and distribution trucks.

The retailer cost per bulk bag of 20 to 30 sachets ranged from between US$ 0.50 to US$ 0.56 (GHC 4500 to 5000). The individual sachets were sold by the retailers for US$ 0.04 to US$ 0.06 (GHC 400 to 500), indicating that retailers would ideally make more than 100% profit on their sales.

Table 4.3 - Cost of sachet water purchased in bulk and as individual sachets – for factory-produced sachet water (each individual sachet is 500ml)

Factory-produced cost	**Cost (US$)**	**Cost (GHC)**
Cost per bulk bag of 20-30 sachets	**0.50-0.56**	**4500-5000**
Equivalent average cost of individual sachets bulk purchase	**0.02**	**190**
Retail price	**0.04-0.06**	**400-500**

All the factories kept detailed records of sales including the number of sachets produced and sold, debtors, creditors and salaries paid. The records were updated daily. Since the sachet-water sealing machines automatically printed the batch number of bags produced on the sachets, it was easy for the producers to keep track of the production quantities. All information was entered manually in record books.

The marketing strategy used by the sachet-water factories includes giving out free sachet-water samples as promotions, networking, radio advertisements, using promotional material such as T-shirts, and producing and distributing stands, with the sachet-water brand name and logo, to retailers.

4.9.3.1 Investment, Operation and Maintenance Costs Required for Factory-Produced Sachet Water

The main investment required for factory-produced sachet water is that required for the sachet machine. From information provided by the sachet-water producers, the machine cost approximately US$ 3,333 (GHC 30,000,000) in Ghana. Two makes of the machine that were used were KOYO and TOYO (China).

In order to obtain a rough estimate of the capital investment and operations cost of the sachet-water business, the author, in addition to getting information from the local producers also visited a retail shop in Tamale town, Water Health Care. Water Health Care supplies filter housings, filter cartridges, UV disinfection units and other POE water treatment components. Retail costs of the replacement units necessary to run a sachet-water factory were thus obtained.

4.9.3.2 Total Cost of Printed Polythene Bags (Packaging Material)

The total costs of printed polythene bags used for packaging sachet water was calculated from information given by Divine Love and Voltic sachet-water producers. The total cost per month for packaging material was US$ 3,330 (GHC 30,060,000) for the production of 15,000 individual sachets per day (the average number of sachets produced per day) or 450,000 sachets per month.

4.9.3.3 Cost of Storage Tanks

The costs of storage tanks were obtained from the owners of Aqua-ba sachet-water factory, who also owned a retail shop in Tamale, which sold polyethylene tanks, among other items. The average cost of storage per liter is US$ 0.18/liter (GHC 1600/liter).

Considering the daily average water requirement for sachet-water production (7500 liters for 15,000 sachets produced per day), and assuming that at least 2 tanks would be required as a factor of safety (total volume of 15,000 liters), the storage costs required was calculated as US$ 2700 (GHC 24,000,000).

4.9.3.4 Salaries

There were 3 distinct levels of salaries that were obtained from interviews with the sachet-factory owners and employees. These corresponded to salaries paid to the technical operators, many times referred to as "engineers", salaries paid to drivers and salaries paid to casual workers involved in the production and packaging of sachets (*Table 4.4*).

Table 4.4 - Average monthly salaries paid to employees of factory-produced sachet water

Employee Category	**Salary/month (GHC)**	**Salary/month (US$)**
Technical Operators	**550,000**	**61**
Drivers	**575,000**	**64**
Casual Workers	**223,750**	**25**

The average salary of each category given in *Table 4.4* was compared to the wages compiled from 1988 to 1998 by Teal (2000). Teal drew nominal wages from the Ghana Standard of Living Survey (GSLS) for the periods 1987/88, 1988/89 and 1991/92 and surveys conducted between 1992-1998 by two firms: The Regional Program on

Enterprise Development (RPED) organized by World Bank, and the Ghana Manufacturing Enterprise Survey (GMES) organized by the Ghana Statistical Office (GSO) and the Center for the Study of African Economies (CSAE) at Oxford University.

Teal converted the nominal wages to fixed prices by deflating the wages based on the 1997 consumer price index of 100. The fixed wages calculated are used for comparison in this report. These are summarized in *Table 4.5* and *Table 4.6* for the years 1987 to 1992 and 1992 to 1998 respectively.

In *Table 4.5*, workers are classified into public employees and private employees. A third category of workers are those exclusively employed in the manufacturing industry. Individuals that earn less than US$ 2 per month and more than US$ 500 per month are not included in the samples.

Table 4.5 - Monthly Earnings for workers aged over 18 in Ghana (1987-1992)

Description	**Monthly Earnings in US$**			
	1987/88	**1988/89**	**1991/92**	**Average**
Public Employees	**55**	**55**	**71**	**60**
Private Employees	**68**	**67**	**67**	**67**
Manufacturing Sector	**51**	**57**	**57**	**55**

Salary data obtained from Teal (2000)

We see that while the wages earned by technical operators and drivers in the sachet-water industry are comparable to the average wages in Ghana, the casual workers earn less than average in all categories listed.

Table 4.6 classifies workers into skilled and unskilled workers, in the manufacturing sector, and gives the average wages computed for the two categories from 1992-1998. Here, we see that all categories of sachet-water workers receive less than 45% the average wage of skilled workers. However, the average wage of the technical operators and drivers in the sachet-water industry is comparable only to the unskilled workers average but close to double the casual workers earnings. Since Teal was covering the whole of Ghana, this discrepancy may be due to the fact that manufacturing is concentrated in the cities of the South.

Table 4.6 - Monthly earnings for skilled and unskilled workers in the manufacturing sector aged over 18 in Ghana (1992-1998)

Description	Monthly Earnings in US$							
	1992	1993	1994	1995	1996	1997	1998	Average
Skilled workers	103	97	93	119	122	128	143	115
Unskilled workers	61	47	43	54	49	52	56	52

Data obtained from Teal (2000)

4.9.3.5 Cost of Raw Water

All the five factories visited were strategically located around Jisonaayili town (shown in *Figure 4.13*), where pipe water supply was relatively reliable in terms of water pressure and continuous supply. The sachet-water factories paid a commercial rate, set by GWCL, of US$ 0.8 (GHC 6,911) per m^3 of water. To this charge 1% was added for "fire-fighting" costs and 2% for rural water development.

Other water rates set by GWCL include those that apply to domestic water use, water use in public institutions, water obtained from boreholes and that obtained from premises with no connections.

For each 1000 liters produced the average total cost of water is approximately US$ 1.

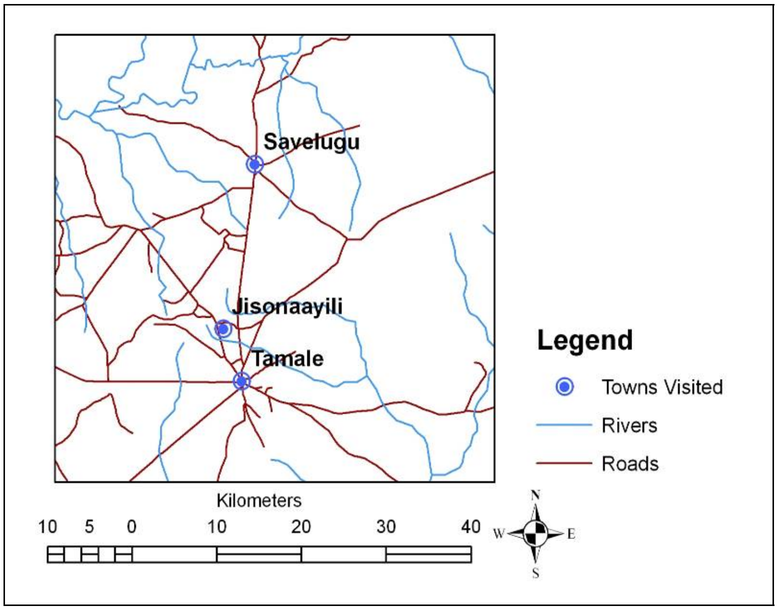


Figure 4.13 - Jisonaayili, Tamale and Savelugu towns, Northern Region of Ghana

4.9.3.6 Electricity, Monthly Rent, Tank Maintenance

Information about the electricity, monthly rent and tank maintenance costs were provided by the Divine Love sachet-water producers. The rent they paid for the sachet-water factory premise was US$17 (GHC 150,000) per month for a floor area of approximately 5m by 5 m (area assumed from observation).

The electricity consumed was prepaid and the cost was approximated at US$ 8 (GHC 72,000) per month.

Chlorine tablets were used to clean the water storage tanks. Aquatabs, manufactured by Medentech Ltd, Ireland , are an example of chlorine tablets that were sold locally. One pack had a total weight of 8.68 g (60 tablets) and according to information given by Divine Love, the chlorine tablets cost US$ 28 (GHC 250,000) per pack.

For tank cleaning purposes, six 8.68g Aquatabs are first dissolved in 20 liters of water. This is equivalent to a 2.6g per liter solution. For tank disinfection purposed, 10 liters of the chlorine solution is required for every cubic meter of tank volume (Delahunty, 2007). Therefore for a total tank capacity of 15,000 liters ($15m^3$), 45 Aquatabs would be required or ¾ of the pack sold. Assuming that tanks are disinfected annually, the disinfection cost is equivalent to US$ 21 (GHC 187,500) per year or US$ 1.75 (GHC 15,625) per month.

4.9.3.7 Licensing Costs

Based on information that was provided by the FDB, the registration fee for food products, a category which includes sachet water, is US$ 111 (GHC 1,000,000) per brand of product. The registration is valid for three years after which it should be renewed at the same cost. The equivalent monthly expenditure on licenses is therefore US$ 3 (GHC 27,778) per month. Since registration with the GSB is not mandatory, the associated costs were not included.

4.9.3.8 Sachet Stands

Sachet stands were distributed for free to retailers that bought sachet water in bulk and for re-sale. These stands were also used to advertise the sachet-water brand as they displayed the name and logo of the brands. The stand cost approximately US$ 67 to US$ 78 (GHC 600,000 to GHC 700,000) for a stands that stored 50 bags (bulk) and US$ 111 (GHC 1,000,000) for those which stored 100 bags.

4.9.3.9 Pump Costs

One of the most common types of pumps used in sachet-water production, according to the Water Health Care, Accra, is an AquaSystem pump (Italy), which costs approximately US$ 255 (GHC 2,300,000).

4.9.3.10 Other Costs

Other costs that were incurred but not considered in this study included taxes, costs associated with purchasing, maintaining and fueling distribution trucks and costs associated with promotional material. Also capital costs obtained did not include piping costs for the conveyance system.

4.9.3.11 Total Costs

The total investment cost was computed as approximately US$ 7300, while total monthly expenses as approximately US$ 4200**.**

4.9.3.12 Monthly Income

Taking the cost of 30 sachets as US$0.56 (GHC 5000) and an average production of 15,000 individual sachets per day (or 500 bags per day), the net income per day was calculated as US$ 280 (GHC 2,500,000). This translated to US$ 8400 per month, which is two times the total monthly costs calculated above (100% profits) and 1.2 times the capital costs. This gives a rough indication of how profitable the sachet-water business is.

4.10 Hand-tied Sachet Water

As was done with the factory-produced sachet-water producers, so too five producers of hand-tied sachet water in Tamale were visited and interviewed. In this case the interviews were also semi-structured and open-ended.

4.10.1 Storage Treatment and Packaging

Hand-tied sachet water was mainly treated by filtering with a cloth or sponge, or simply not treated at all. Hundreds of thousands of cloth filters have been distributed for free by the Guinea Worm Eradication Campaign in the Northern Region of Ghana and as a result they are widely prevalent. Only one of the vendors visited used the ceramic pot filter to treat her water, but it was noted that her filter pot had a crack running through it, having been inadvertently dropped.

The hand-tied water was sourced mainly from the GWCL tap water supplies and occasionally, from vended water. The water was mainly stored in relatively small capacity storage tanks, (approximately 1000 liters), 200 liters plastic and metal drums, and smaller capacity vessels including large traditional ceramic storage vessels, jerry cans and buckets. Other than the vendor who used the ceramic pot filter, no other vendor used safe storage containers, defined as containers with a narrow mouth, lid, and a spigot to prevent recontamination (CDC, 2006). *Figure 4.14* shows the typical procedure of bagging hand-tied sachet water.

The amount bagged by the producers varied from 30 to 200 sachets per day, depending on the capacity of the producers, and sold at US$ 0.02 (GHC 200) per sachet. Each hand-tied sachet-water bag contained approximately 700 ml of water.

4.10.2 Business Structure

None of the hand-tied sachet-water producers visited kept any records of the business. The main customers of these vendors included passer-bys and business-owners around the areas they sold. The marketing strategies used by these vendors were mainly built on customer relations. Since, for the case of hand-tied sachet-water production, not much was invested in treatment of water, the costs associated with starting the business were mainly from storage requirements.

Filter used for raw water **Storage (background)** **Filling sachets** **Knotting the sachets**

Figure 4.14 - Hand-tied sachet-water production

The only cost required for running the hand-tied sachet-water business included the cost of water and the cost of the plastic packaging bags. Sachet packaging bags for hand-tied sachet water costs US$ 0.3 (GHC 3000) per pack of 100 bags. The amount paid for water varied depending on the source.

The average cost of tanker and other vendor distributed water (US$ 0.005 per liter) costs 5 times that of supplies from the GWCL (US$ 0.001). The approximate running cost of hand-tied sachet water, which includes the cost of packaging bag and average cost of pipe water, is approximately US$ 0.004 (GHC 33) per 700ml sachet pack. Given that one sachet costs US$ 0.02, the vendors therefore make nearly 400% profits from their sales, assuming all the water used is from the GWCL tap water supplies.

4.11 Water Quality Results for Sachet-water Samples Tested

This section discusses the results of tests that were conducted on sachet-water samples. The test results are summarized in the form of graphs.

4.11.1 Turbidity

Twenty per cent of the factory-produced sachet water that was tested and 93% of the hand-tied sachet water had turbidities greater than 5 NTU, the maximum turbidity level set by the 1998 Ghana Standards Board (*Figure 4.15*). The lower turbidity levels were expected in the factory-produced sachet water, given that all factory-produced sachet water passed through a series of filters before packaging. However, it is surprising that 20% of those turbidity values were above 5 NTU for the factory-produced sachet water, given that the source water was municipal water followed by multiple stages of filters from the POE systems. Divine Love, Nacool and Tropika were the brands that showed turbidity values above 5 NTU.

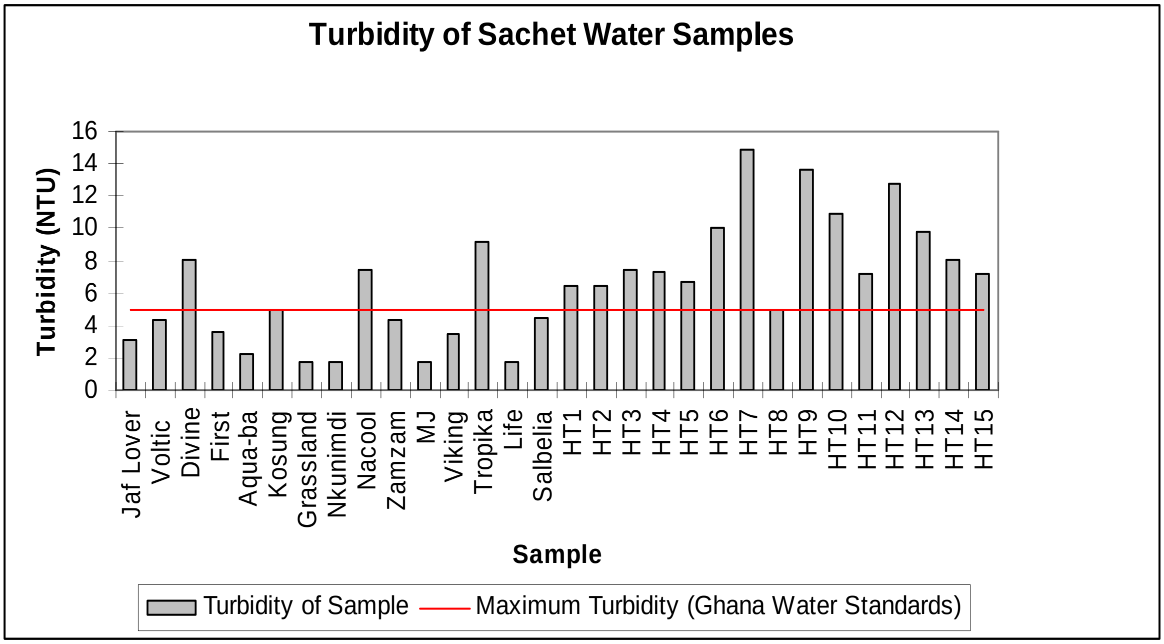


Figure 4.15 - Turbidity of sachet-water samples

4.11.2 Membrane Filtration Test Results

One factory-produced sample out of 15 tested had an *E. coli* count of 5 CFU/100ml and that was Life. All other factory-produced samples had 0 *E. coli* CFU/100ml. Almost half (47%) of the factory-produced samples showed total coliform counts that ranged from 1 CFU/100ml to 115 CFU/100ml. One of the hand-tied sachet-water samples had an *E. coli* count of 49/100ml CFU/100ml. All the hand-tied sachet-water samples had total coliform counts ranging from 4 CFU/100ml to 2060 CFU/100ml, plus one sample that had total coliforms that were too numerous to count at a 1:10 dilution. The membrane filtration results are shown in *Figure 4.16* on a normal scale and in *Figure 4.17* on a log-scale.

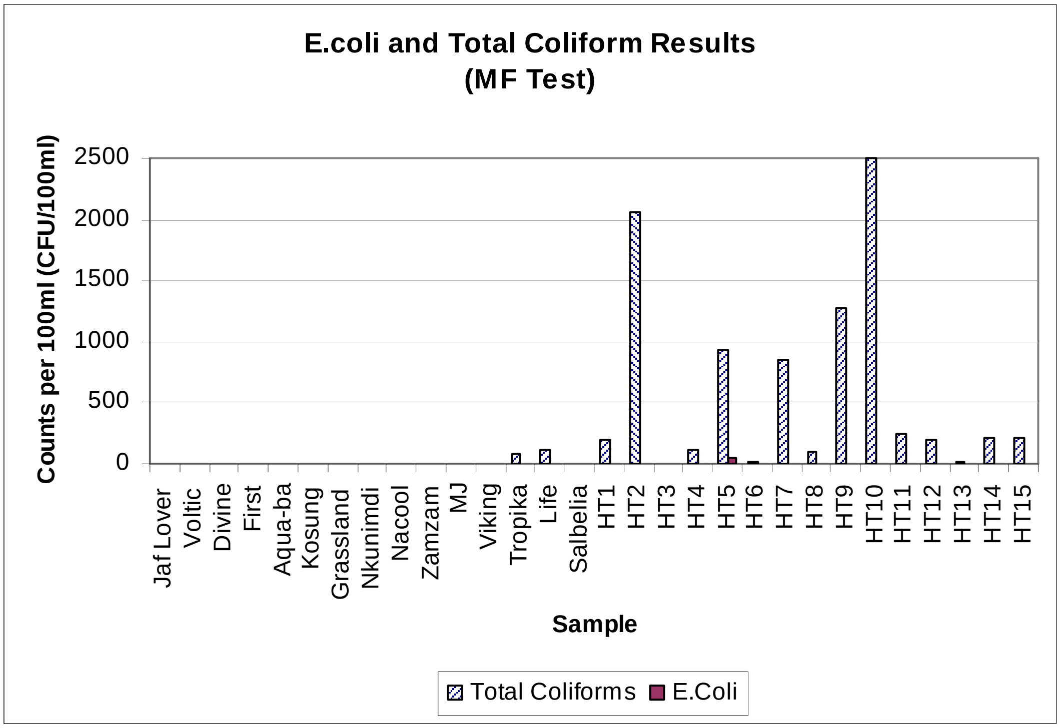


Figure 4.16 - *E. coli* and total coliform results (MF test)

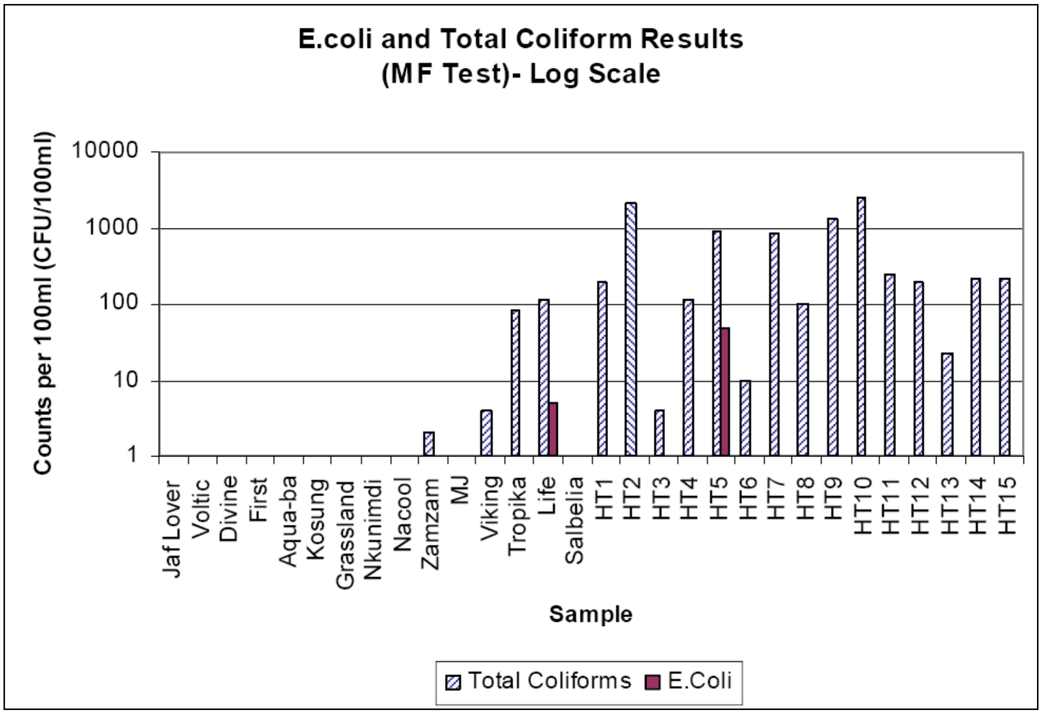


Figure 4.17 - *E. coli* and total coliform results (MF test) – log scale

4.11.3 3M™ Petrifilm™ Results

Regarding the 3M™ Petrifilm™ results, while all the factory-produced sachet water had 0 *E. coli* CFU/100ml, one brand, Tropika, had a total coliform count of 100 CFU/100ml. One sample, HT5, of the hand-tied sachet water had 100 *E. coli* CFU/100 ml and 7 samples, HT2, HT3, HT4, HT5, HT7, HT19, and HT14 showed total coliform counts that ranged from 100 CFU/100ml to 2300 CFU/100ml. All these brands also gave total coliforms and/or *E. coli* in the MF test. However the brand Life gave *E. coli* in the MF test but not in the 3M™ Petrifilm™ test. Brands that gave total coliform in the MF test but not in the 3M™ Petrifilm™ test include Grassland, Zamzam, MJ, Viking, Life, Salbelia, HT1, HT6, HT8, HT9, HT11, HT12, HT13 and HT15. The results are shown in *Figure 4.18* and on a log scale in *Figure 4.19*.

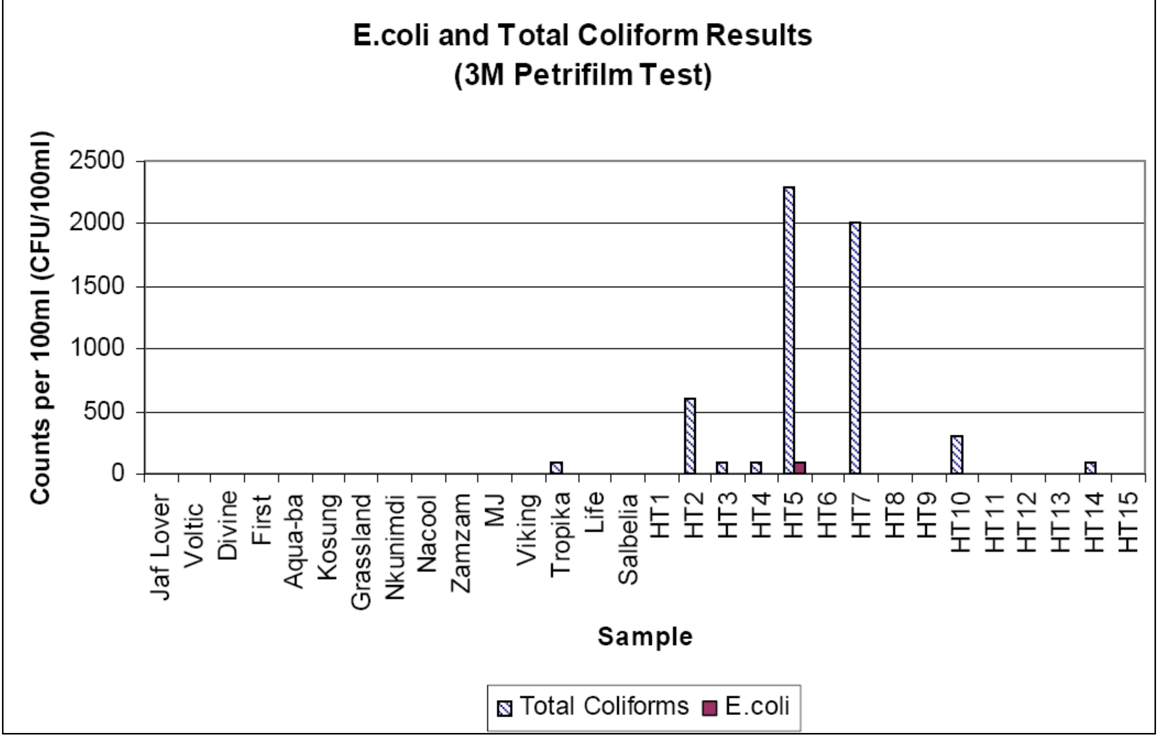


Figure 4.18 - *E. coli* and total coliform results (3M™ Petrifilm™ test)

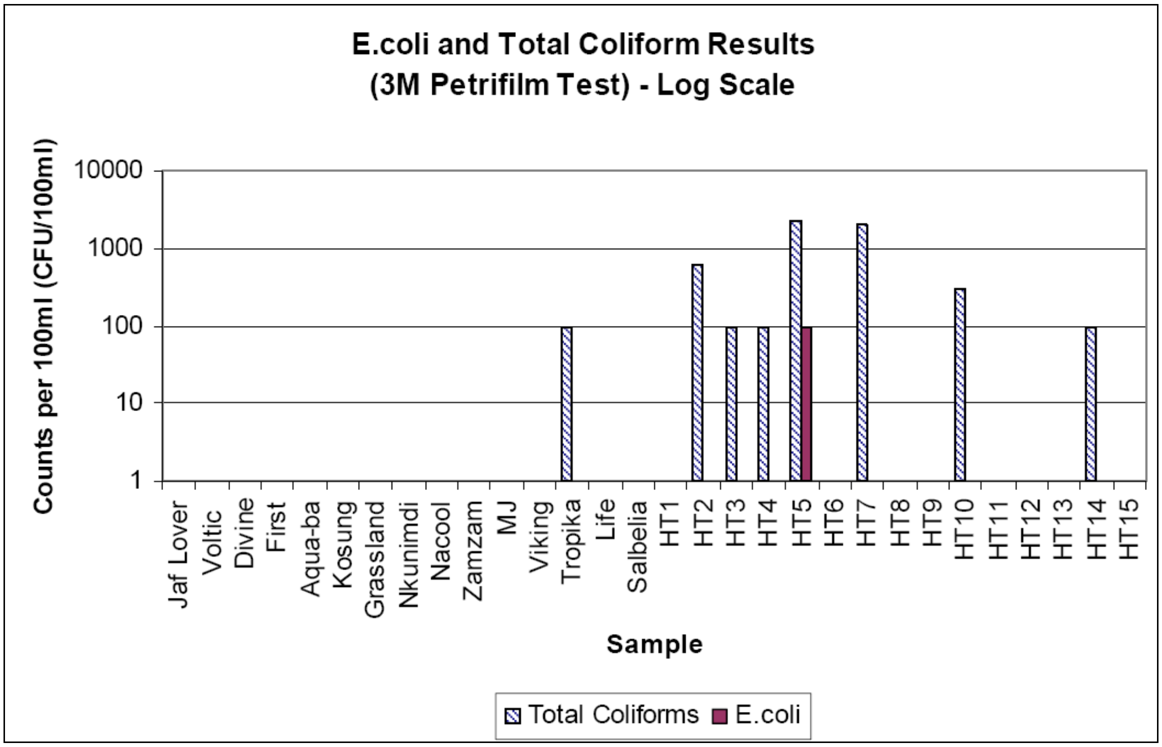
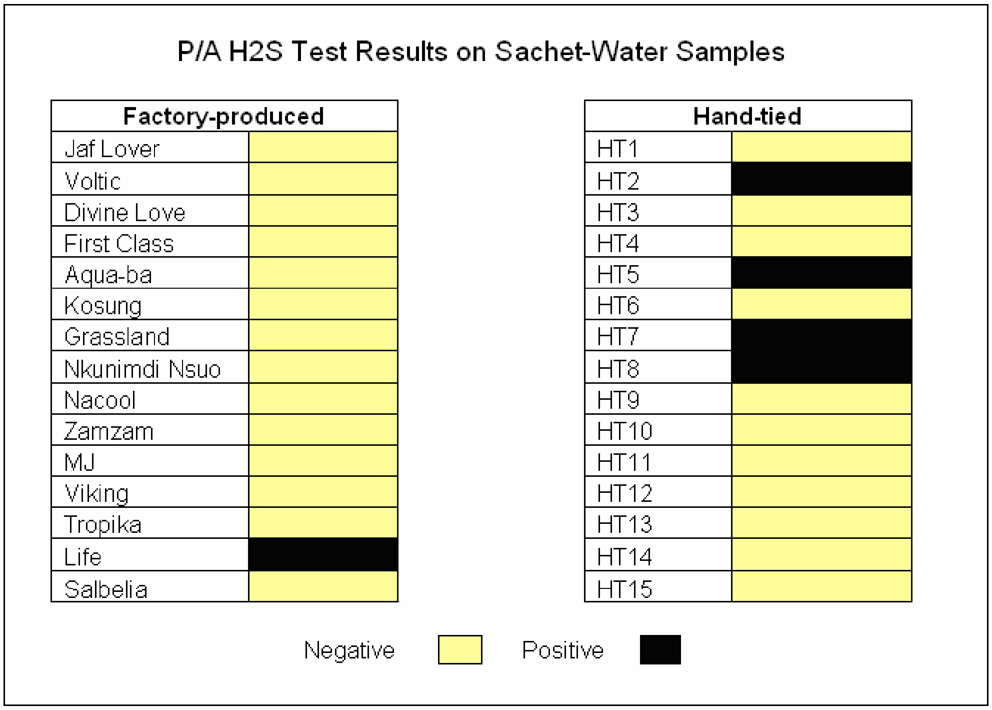


Figure 4.19 - *E. coli* and total coliform results (3M™ Petrifilm™ test) – log-scale plot

4.11.4 P/A H_2S Test

Seven percent of the factory-produced samples and 27% of the hand-tied samples returned positive results in the P/A H_2S (*Figure 4.20* and *Figure 4.21*). Again the results here showed more microbial contamination in the hand-tied sachet water.



P/A H2S Test Results on Sachet-Water Samples

Factory-produced	
Jaf Lover	🟨
Voltic	🟨
Divine Love	🟨
First Class	🟨
Aqua-ba	🟨
Kosung	🟨
Grassland	🟨
Nkunimdi Nsuo	🟨
Nacool	🟨
Zamzam	🟨
MJ	🟨
Viking	🟨
Tropika	🟨
Life	⬛
Salbelia	🟨

Hand-tied	
HT1	🟨
HT2	⬛
HT3	🟨
HT4	🟨
HT5	⬛
HT6	🟨
HT7	⬛
HT8	⬛
HT9	🟨
HT10	🟨
HT11	🟨
HT12	🟨
HT13	🟨
HT14	🟨
HT15	🟨

Negative 🟨 Positive ⬛

Figure 4.20 - P/A H_2S test results (individual samples)

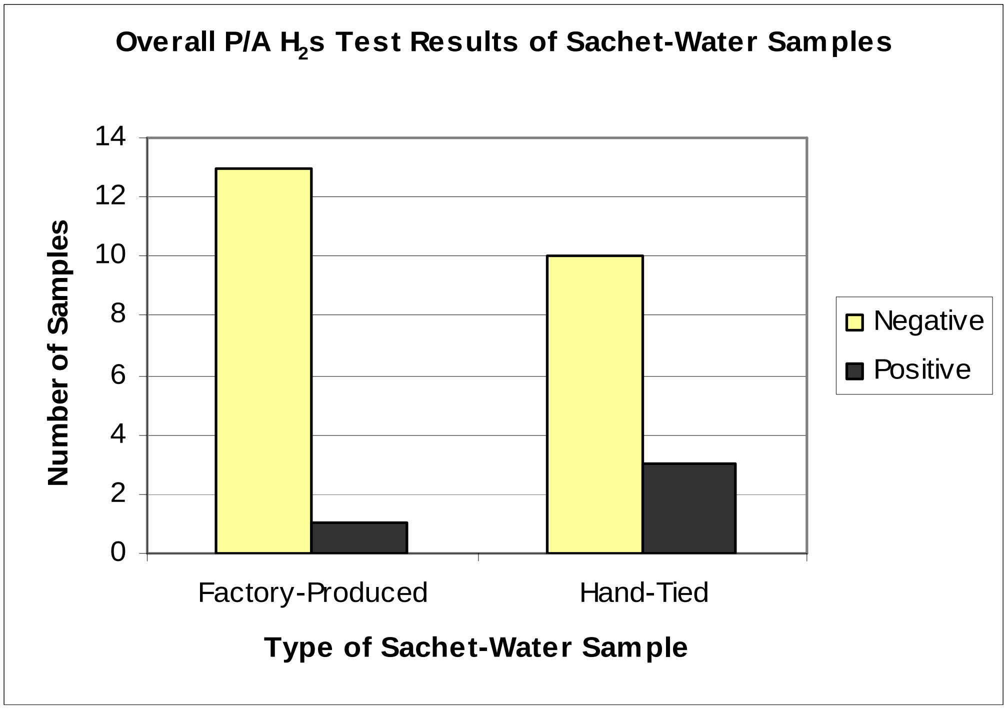


Figure 4.21 - P/A H_2S test results (overall results)

4.12 Discussion of Water Quality Results

4.12.1 Comparison between contamination found in factory-produced and hand-tied sachet water

To compare the percentage of samples contaminated for both factory-produced and hand-tied sachet-water samples, any sample that had bacteria in one or more microbial test was considered contaminated. The MF test showed the highest number of samples contaminated. This was used to compute the percentage of sachet-water samples that had bacteria (*Table 4.7*). *Table 4.7* shows that 47% of the hand-tied sachet samples tested were contaminated while all hand-tied sachet water (100%) was contaminated. Hand-tied sachet water was therefore approximately two times more contaminated than factory-produced sachet water.

Table 4.7 - Number and percentage of hand-tied and factory-produced sachet-water samples contaminated

Number and percentage of samples contaminated							
Test Method **Sample Type**	**H2S P/A**	**MF**		**3M™**		**Highest number of sample contaminated (out of 15 samples)**	**% Contaminated**
		TC	*E. coli*	TC	*E. coli*		
Factory-Produced	1	7	1	1	0	7	47%
Hand-Tied Sachet	4	15	1	7	1	15	100%

WHO (2004) suggests that it may be useful to classify drinking water systems into categories that are predefined depending on the risks associated with the drinking water, the order of priorities placed, and the local circumstance, by using the percentage of samples tested negative for *E. coli*. An example of such a classification is shown in *Table 4.8*.

Table 4.8 - Categorization of drinking-water systems based on compliance with performance and safety targets

	Proportion (%) of samples negative for *E. coli*		
	Population Size:		
Quality of Water	**<5,000**	**5,000-100,000**	**>100,000**
Excellent	**90**	**95**	**99**
Good	**80**	**90**	**95**
Fair	**70**	**85**	**90**
Poor	**60**	**80**	**85**

(WHO, 2004)

The highest count of *E. coli* recorded from the three tests conducted was 1 CFU/100ml for both factory-produced and hand-tied sachet water. This means that 93% of both the factory-produced and hand-tied sachet-water samples were negative for *E. coli* and fall in the WHO (2003) category of "excellent" water systems as shown in *Table 4.8.* There is, however, still room for improvement. All hand-tied sachet water and almost half (47%) of factory-produced sachet had total coliform in at least one test.

4.12.2 Comparison between MF and 3M™ Petrifilm™ Test results

In order to compare the results obtained in the MF method to those obtained in the 3M™ Petrifilm™ tests, a regression analysis was done on the two sets of the total coliform test results, after a constant of 10 was added to the coliform counts given in CFU/100ml in order to prevent taking logarithms of zero.

The results, given in *Figure 4.22*, showed weak or no correlation (strength of 2.5%, R=0.16). This may have been as a result of the low number of coliforms in the water tested. The small volume (1 ml per sample) tested in the 3M™ Petrifilm™ method, makes it less precise in determining counts in samples that contain low numbers of coliforms as in the case with the sachet water tested in this study. The results obtained from the membrane filtration method were thus considered to be more accurate and representative of the bacterial contamination of the water samples than those obtained from the 3M™ Petrifilm™ analysis.

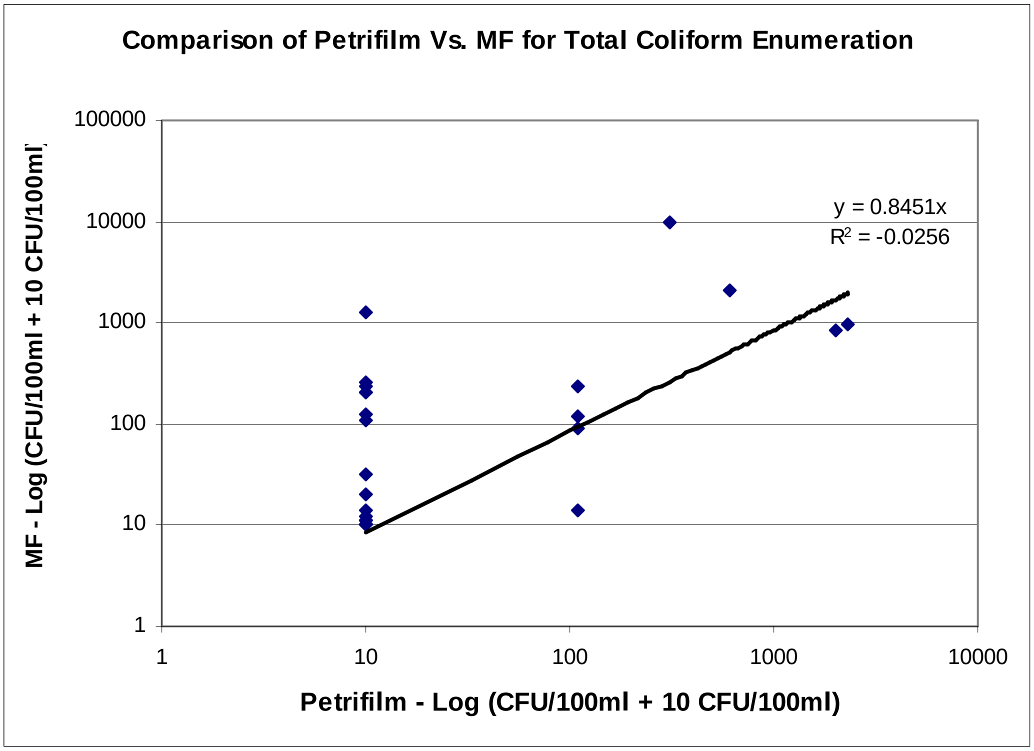


Figure 4.22 - Relationship of Log $_{10}$ coliforms determined by 3M™ Petrifilm™ test to log$_{10}$ coliforms determined by MF test

4.12.3 Strategies of improving hand-tied sachet-water quality

From the surveys, interviews and microbial water quality tests conducted, it was clear that hand-tied sachet vended water was more problematic in terms of microbial water quality and required more attention to improve the quality through treatment, as well as appropriate storage and handling methods. The quality of factory-produced sachet water was relatively more acceptable. However, considering *E. coli* counts in the drinking water alone, and following a similar method of categorizing drinking water as that presented by WHO (2004), both factory-produced and hand-tied sachet water could be categorized as "excellent" since each had 93% of samples negative for *E. coli* (*Table 4.8*). However, there is still room for improvement and the following are recommendations that can be implemented as low-cost strategies to improve hand-tied sachet-water quality which we found had higher counts of total coliforms.

4.12.3.1 Treatment and Storage

The cloth filters used for hand-tied sachet water do not adequately treat water, as can be seen by comparing water quality test results of the raw water samples to cloth filtered samples (*Figure 4.23*).

In this comparison, though tap water is used for production of both hand-tied and factory-produced sachet water, there is higher microbial contamination in the tap water used for hand-tied sachet water. This is likely due to poor storage and/or handling.

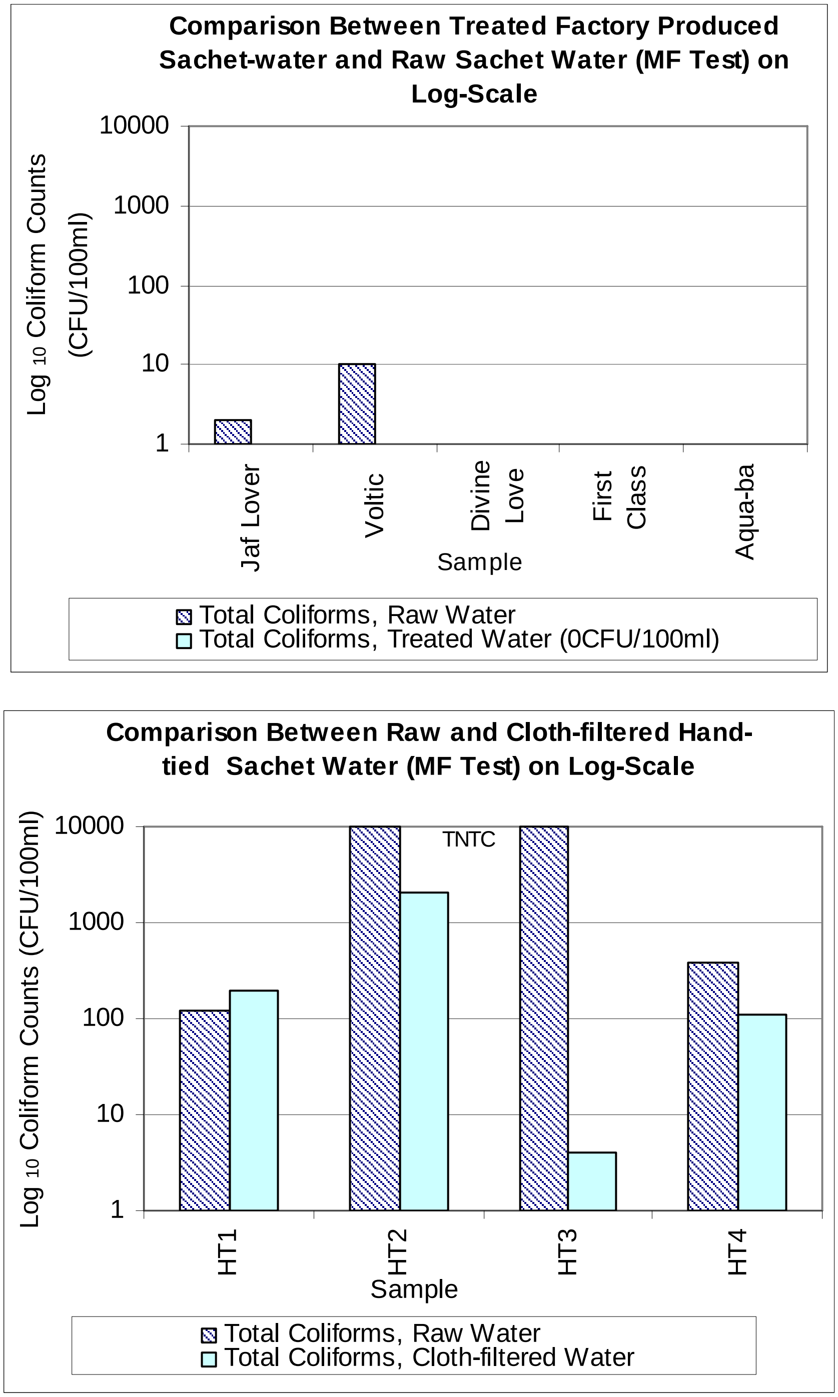


Figure 4.23 -Comparison of log $_{10}$ coliforms of treated and raw sachet water determined from MF test

Since the hand-tied sachet-water vendors did not use safe storage containers, it is likely that their method for extracting water, by pouring from one vessel to another, exacerbates the risk of contamination. Safe storage containers may thus be considered for vendors producing and selling hand-tied sachet water. The ceramic pot filter shown has the advantage of serving a dual purpose of treatment and safe storage.

Low-cost treatment methods that could complement or replace the cloth filter would include filtration through bio-sand or ceramic filters, coagulation and/or disinfection, for example by use of chlorine among other methods.

The ceramic pot filter *Figure 4.24* was used by one of the vendors for filtering hand-tied sachet water. Unfortunately, a family member had dropped the ceramic filter element, cracked it, and at the time of sampling, it was nonetheless being used. The crack that ran though the pot would likely have been the reason that the filtered water was microbially contaminated (sample HT2 on *Figure 4.17* to *Figure 4.20*). It is therefore recommended that training on maintenance of the filters be given to these vendors as part of PHWs outreach program. It is also recommended that further studies be conducted on other technically feasible low-cost options for water treatment by these vendors.

Figure 4.24 - Ceramic pot filter use in hand-tied sachet-water production

90% of the sachet-water producers/vendors self-reported that they washed their hands with soap before packaging water. They all rubbed the polythene bags they used with their hands to open the bags. To close the bags, they would knot the open end of the bags after filling with water. Handling the sachet water in this manner may have been a possible route of contamination.

To reduce the levels of contamination, and ensure proper handling of sachet water, several low-cost options for packaging water may be considered. One of them is to use a “bar-type” heat sealer as shown in *Figure 4.25*. For such sealers, if electricity is not available, the sealing bars could be modified to allow the bags to be directly heated with an open flame fueled by gas, or other liquid or solid fuels (this could make an excellent undergraduate engineering design challenge). Low-cost manually operated packaging machines include electric wire-type or bar-type heat sealers that have a thermostat for adjusting the sealing temperature, and an adjustable timer for controlling the time of heating as shown in *Figure 4.27*. The cost of electric sealers is approximately US$ 50 to US$ 200, depending on their width/size and method of operation. Some packaging machines can be operated by a pedal such as the hand/pedal operated sealing machine shown in *Figure 4.28*.

Non-electric heating bars, used for the bar-type sealer, can be produced by local metal workers from recycled metal waste or scrap. Metals such as iron and its alloys are ideal due to their high strengths and relatively low cost. In Ghana the market price of a ¼’’ iron rod (6mm) is approximately US$ 0.4/kg (GHC 3,500/kg) (GhanaWeb, 2007). This is equivalent to US$ 0.1/m (GHC 875/m), considering an iron density of 7860kg/m^3. The plastic sachets sealed using the heating bars should preferably be purchased as a film roll, rolled around a tube (in the same way as paper towels, for example).

4.12.3.2 Packaging and Handling

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Sealing can also be done by simply using a lit wax candle and a hacksaw blade or flat piece of thin metal as illustrated in *Figure 4.29*. Here, the edge of the plastic bag is lightly folded over the metal piece or teeth of the hacksaw blade and passed through the candle flame. Once the metal piece or hacksaw blade is removed, the seam should be checked to ensure that the bag is well sealed. This method may be more suitable for solid substances rather than liquids, due to high chances of poor seals.

To further prevent contamination when bagging water manually, the roll of plastic used should be continuous tube rolls, which should not be cut into smaller sections of individual sachet bags before filling and sealing. Instead the rolls should be continuously filled with water and double sealed with a gap between the seals whereby the individual sachets produced can be separated but cutting between the seals as illustrated in *Figure 4.26*.

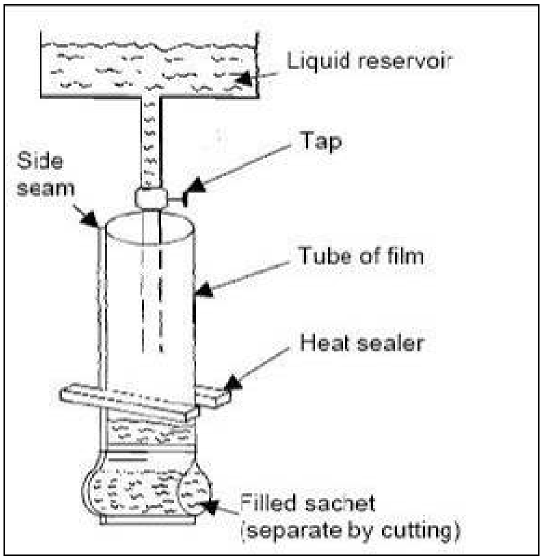

Figure 4.25 - Simple bar-type heat sealer (either manual or electric) (Fellows, 1997)

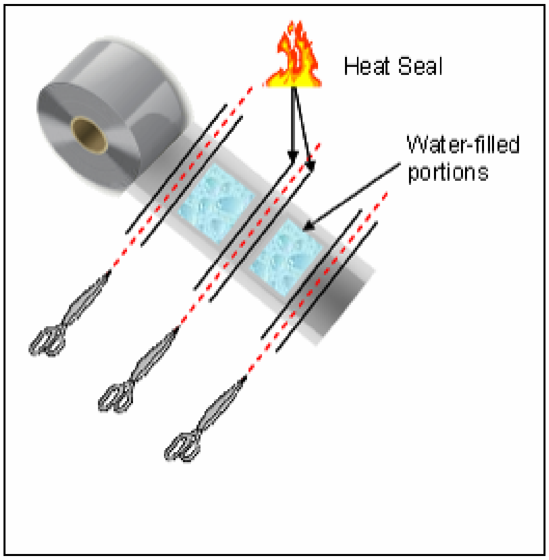

Figure 4.26 - Recommended sealing procedure

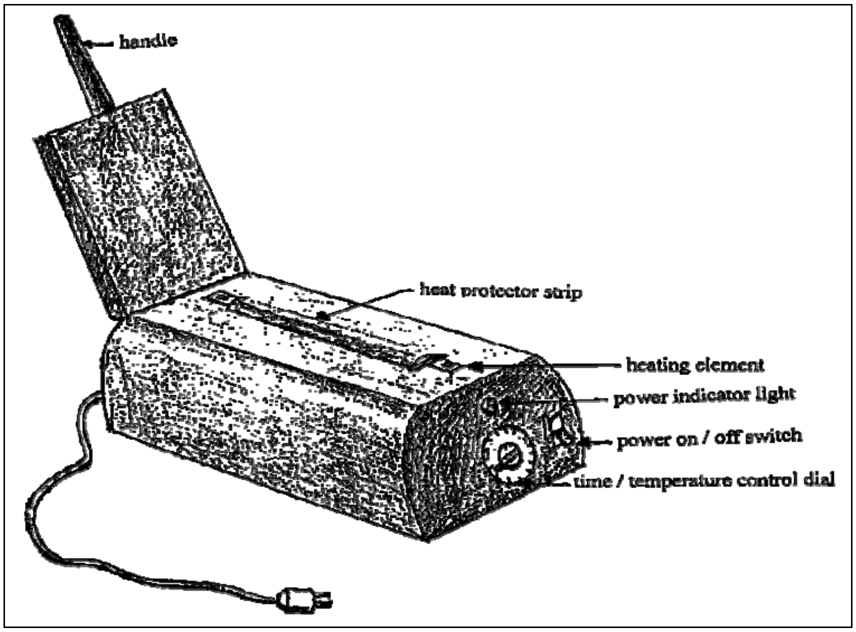

Figure 4.27 - Electric heat sealer for sealing plastic films (Fellows, 1992)

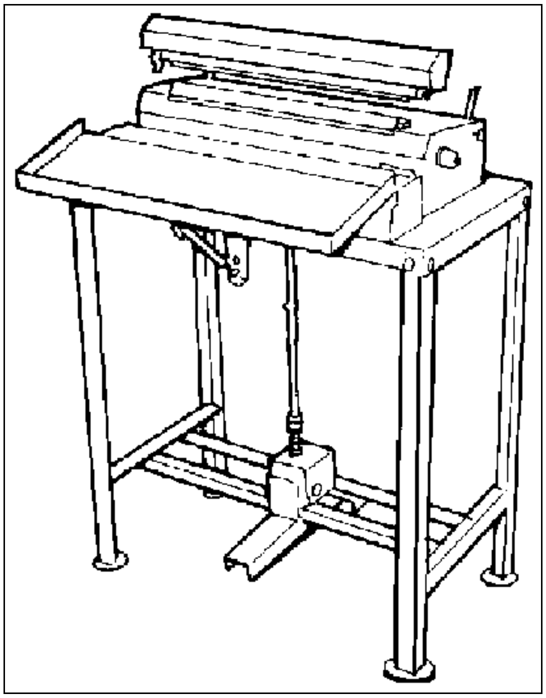

Figure 4.28 - Hand/pedal operated sealing machine (Fellows, 1992)

Figure 4.29 - Candle and hacksaw blade method of sealing plastic bags (FAO, 1994)

Various sources of heat are given in *Table 4.9*. This table compares different energy sources qualitatively according to a number of criteria including:

- Energy per unit weight required;
- Cost per unit of energy;
- Heating equipment cost;
- Efficiency of heating:
- Flexibility of use:
- Risk of contaminating food and;
- Labor and handling cost.

As shown in the table, electricity and gas would have the lowest risk of contaminating sachet water.

Table 4.9 - A Comparison of different sources of heat for sealing sachets

Criteria	Electricity	Gas	Liquid fuels	Solid Fuels
Energy per unit weight or volume[a]	**not applicable**	**low**	**high**	**moderate to high**
Cost per unit of energy[b]	**moderate to high**	**high**	**moderate to high**	**low**
Heating equipment cost	**low**	**low**	**high**	**high**
Efficiency of heating	**high**	**moderate to high**	**moderate to low**	**low**
Flexibility of use	**high**	**high**	**low**	**low**
Fire or explosion hazard	**low**	**high**	**low**	**low**
Risk of contaminating food	**low**	**low**	**high**	**high**
Labor and handling cost	**low**	**low**	**low**	**high**

[a] Heating values (in kJ/kg x 10^3) for gas = 1.17-4.78, for oil = 8.6-9.3, for coal = 5.26-6.7, for wood = 3.8-5.26.
[b] Depending on presence of national hydro-electric schemes, coal mines or afforestation projects (Fellows,1997)

According to Fellows (1992), all kinds of plastic films coated with cellulose can be sealed using a heat sealer. The different types of heat sealers have varying widths of the heated bar or wire and level of control over temperature and/or time of heating. A seal of approximately 3-5mm is recommended for liquids and therefore bar-type sealers would be preferred to wire-types. For whichever type of sealer is used, to ensure proper sealing, there should be no particle such as dust in the inside of the plastic bag where the seal is made (a challenge in the Northern Region, Ghana, where Harmattan, during November to late March or April, means pervasive dust everywhere).

4.13 Survey Results

4.13.1 Customer Survey

From the customer survey we found that the customers selected specific sachet-water brands on:

- The water quality – 20%;
- Taste – 17%;
- The product name – 10%;
- The market reputation – 7%;
- The packaging – 3%;
- Convenience in reaching the vendors (place) - 3% and
- Price – 3%.

The question presented was not applicable to the remaining 37% that did not buy specific factory-produced sachet brands (27%) or those who only bought hand-tied sachet water (10%).

All the interviewees felt that the quality of service of sachet-water vendors was always good (70%) or usually good (30%).

While all the interviewees thought that the price of hand-tied sachet water was either cheap (23%) or affordable (77%), 33% felt that factory-produced sachet water was expensive. It was interesting to note that for 37% of the interviewees, sachet water formed the sole supply of drinking water, even at home! The same percentage used both sachet and tap water for drinking water in their homes. 70% of the respondents drank more water when away from home, 20% drank the same amount at home and away from home, while 10% drank more water at home.

A concern that was also investigated had to do with the disposal of the sachet plastic bags. Twenty seven percent of those interviewed always disposed of the bags by littering, and 20% sometimes littered. This suggests a need to encourage proper disposal of the plastic bags as a responsibility of all stakeholders, as well the need to encourage recycling of the bags.

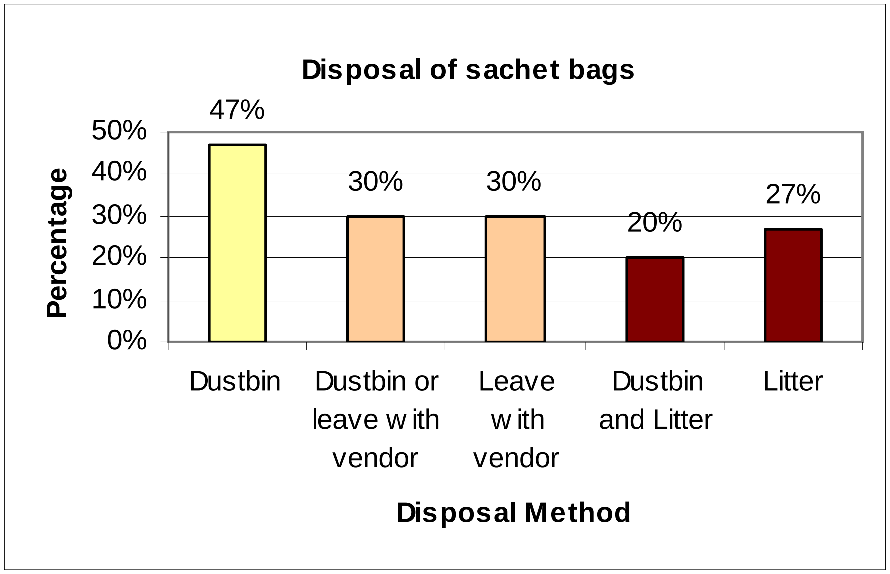

Figure 4.30 - Sachet plastic bag disposal methods

4.13.2 Road-side Vendors Survey

All road-side vendors interviewed were women and girls whose ages varied from less than 15 to 40 years. There were no male sachet-water vendors seen and therefore none were interviewed. 50% of the vendors sold their water specifically at Tamale's main taxi station, the market place and bus stops (OA and STC), 20% at the main taxi station and market place, 10% only at the market place, and another 10% around Tamale's main mosque area. 10% did not have a specific selling location.

70% of the respondents selected these areas as they had more customers (more people traffic) in the given locations. Half of the interviewees stated that taxi drivers were their main customers, which was probably one of the reasons they concentrated their sales at the main taxi station in Tamale.

All the vendors sold hand-tied sachet water at US$ 0.02 (GHC 200) and factory-produced sachet water at US$ 0.04 (GHC 400) and sold an amount that added up to between US$ 1 to US$ 5.5 (GHC 10,000 to 50,000) per day from sachets they sold. Two of the sellers interviewed were the owners of the business, 7 were employed by family members (mainly grandmother or mother) and 1 was employed by a lady she lived with (who was not a related to her in any way). The vendors worked 2 to 12 hours a day and up to 7 days a week. These girls and women earned between zero (60%) to US$ 0.60 (GHC 5000) per day (20%), indicating that most of the vendors were being exploited in the business[6]. Since majority of the vendors were very young girls 40% < 15 years old and

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[6] UNICEF (2007) differentiates between Child work and Child Labor as follows: Child Work: "Children's participation in economic activity - that does not negatively affect their health and development or interfere with education". Child labor: "All children below 12 years of age working in any economic activities, those aged 12 to 14 years engaged in harmful work, and all children engaged in the worst forms of child

40% 16 to 20 years old, it was worthwhile to note whether they had a chance to attend school. 50% of the vendors interviewed reported that they were attending either regular school during morning hours, as school did not usually last through mid afternoon, or less formal “Arabic schools” in the evenings when they were not working. Article 32 of the UN Convention on the Rights of the Child (1990) protects the child “from economic exploitation and from performing any work that is likely to be hazardous or to interfere with the child's education, or to be harmful to the child's health or physical, mental, spiritual, moral or social development”, (UNICEF, 2007b). The definition of the child in Article 1 of the Convention is a person below the age of 18 years. The United Nations High Commissioner for Human Rights (1993), recognizes that the Convention does not provide us with a definition of “economic exploitation” and suggests that economic exploitation be broken down into two elements: Economic, which implies “the idea of a certain gain or profit through the production, distribution and consumption of goods and services” and exploitation, which means “taking unjust advantage of another for one's own advantage or benefit. It covers situations of manipulation, misuse, abuse, victimization, oppression or ill-treatment”.

The source of water used for hand-tied sachet-water production for the road-side vendors was primarily tap water (80%). The remaining was water from distributing vendors (10%) and tankers (10%). The water was treated by settling, cloth or sponge filtration or a combination of both. None of the road-side vendors used safe storage containers and all but one washed their hands with soap. The vendors were, however, willing to invest US$ 1 to US$ 28 (GHC 10,000 to 250,000) on water treatment systems.

Retailers of factory-produced sachet water would purchase sachet water directly from the sachet-water factories at approximately US$ 0.02 and resell the water at US$ 0.04, indicating they would also obtain 100% profits of the resale.

4.14 Feasibility of Marketing PHW Products to Sachet-Water Vendors

PHW has, in the past, generally aimed at promoting HWTS products specifically for use in individual households, with the organization’s goal being “to provide safe water to people in Northern Ghana in order to reduce or eliminate water related diseases”. In the Year 2 Strategy, PHW has broadened its reach by targeting schools, hospitals in addition to individual households in urban and rural areas. While this may have resulted in the consumers having access to improved water in homes, schools and hospitals, a gap still remains in ensuring that people also have clean water when they are away from home or from school, and as they transit between their final destinations.

Due to the hot day-time temperatures in Ghana, ranging from 24 ºC to 35 ºC throughout the year, it was also not surprising to note that people consumed more water during the day when they were away from home (*Section 4.13.1*). Since this was the case, promoting

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labor...these involve children being enslaved, forcibly recruited, prostituted, trafficked, forced into illegal activities and exposed to hazardous work.”

safe water practices and safe water consumption in areas away from home would have a significant impact in providing clean water, especially to those that buy hand-tied sachet water, which we found to be microbially contaminated.

From the surveys conducted, a total of 53% of the sample population that drank vended water drank hand-tied sachet water (including those who drank both hand-tied and factory-produced water), indicating that well over half the population might be at risk from drinking contaminated water, because it is mostly hand-tied sachet water that we found to be microbially contaminated (*Figure 4.31*).

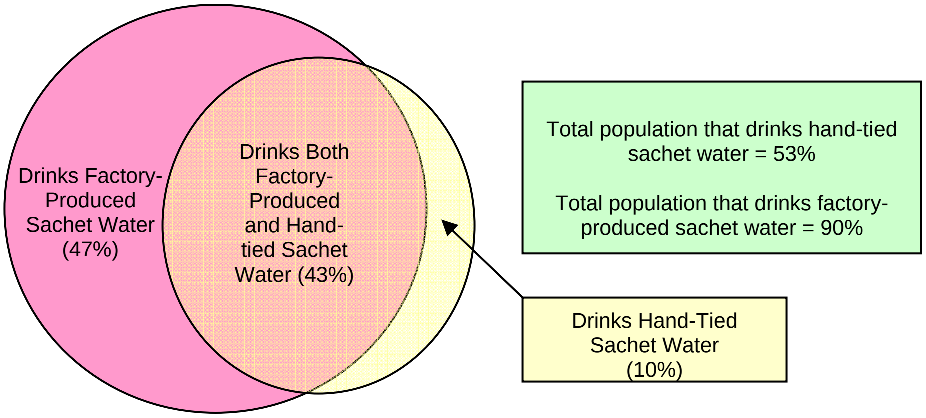

Figure 4.31 - Venn diagram showing percentage of people who drink factory-produced and hand-tied sachet water

Pure Home Water's ceramic pot filter and/or their safe storage container product with a spigot for drawing water hygienically were identified as viable options for treatment and safe storage for hand-tied, sachet water. However, with the given filter flow rate of 2 liters per hour, at least 5 filters (total cost of US$ 65 or GHC 585,000 using the urban retail price of US$ 13 per filter) would be required for the average production and sale of 100, 500ml sachets per day, with about 5 hours set aside for packaging. The willingness-to-pay for water treatment systems was, however, a maximum of US$ 28 (GHC 250,000), which would only cover the cost of two complete filter sets at the current retail price of US$ 13 (GHC 120,000).

The high production capacity and relatively sophisticated treatment methods already applied by factory-produced sachet-water industry clearly indicate that it would not be feasible to market any of the HWTS products of PHW to these producers. However a few lessons can be drawn from the vendors based on the marketing strategies applied, as discussed in the next section.

4.14.1 4P's applied by Sachet-Water Vendors

Product: Here we consider the water quality, for both hand-tied and factory-produced sachet water, and the brand name and company reputation of factory-produced sachet water.

From interviews directed to customers of sachet water, 80% felt that the water quality of factory-produced sachet water was good and only 33% felt the same for hand-tied water. The fact that factory-produced sachet water was generally considered to be "pure water" may have been a reason why 90% of the interviewees bought it despite it being more expensive when compared to hand-tied sachet water (90% also includes those who bought both hand-tied and factory-produced sachet water). Reasons for choosing specific sachet-water brands included the quality of the physical product itself, convenient availability, the brand name and company reputation. 40% of the respondent preferred "Voltic" sachet water. Voltic, which has been in the Ghana market for the longest time, was established in 1995 and holds 65% market share in Ghana (Voltic-Group, 2006). In Tamale, it has been in operation since the year 2000.

Price: Sachet water, being a cheaper alternative to bottled water (which costs 5 times more than factory-produced sachet water and 12 times more than hand-tied sachet water) was purchased and drunk by all those interviewed and this was a good indication of the role price played.

Place: Only 10% of the customers surveyed walked more than 100m to buy sachet water, pointing out that convenience in reaching vendors played an important part in sales. Road-side vendors particularly sold around taxi stations, where the majority of their customers (taxi drivers and/or passengers) were located.

Promotion: The promotional methods applied for factory-produced sachet water included radio commercials, free samples and promotional materials such as T-shirts. Hand-tied sachet-water vendors mainly relied on building good customer relations to sell their products.

4.15 Conclusions and Recommendations on Sachet Vended Water

4.15.1 Water Quality Tests

4.15.1.1 Turbidity

Ninety three percent of the hand-tied sachet water and 20% of factory-produced sachet water had turbidities greater than the limit set by the GSB (1998) of 5 NTU. The maximum turbidity limit that the Ghana Water Company aims to achieve for water treated at the Dalun Water Treatment Plant is 0-2 NTU, while the average actually achieved is 3 NTU.

4.15.1.2 Microbial Test

With the MF method (using mColiBlue24® medium), 1 factory-produced and 1 hand-tied sachet-water samples had *E. coli* counts of 5 CFU/100ml and 49 CFU/100ml respectively. Forty seven percent of the factory-produced sachet water had total coliforms that ranged from 1 CFU/100ml to 115 CFU/100ml. All the 15 hand-tied sachet-water samples had total coliforms in the range of 4 CFU/100ml to 2010 CFU/100ml. One sample recorded TNTC at a dilution factor of 10.

With the 3M™ Petrifilm™ test, all samples of the factory-produced sachet water had no *E. coli* and only one sample had total coliforms with 100 CFU/100ml. The hand-tied sachet-water sample with 49 *E. coli* CFU/100ml in the MF test had 100 CFU/100ml with the 3M™ Petrifilm™ test. Forty seven percent of the hand-tied sachet-water samples had total coliform that ranged from 100 CFU/100ml to 2300 CFU/100ml.

The MF method showed little correlation with the 3M™ Petrifilm™ method (R=0.16).

With the P/A H_2S test, 7% of factory-produced sachet water and 27% of the hand-tied sachet water returned positive results.

Overall, all hand-tied sachet water was found to be two times more contaminated than factory-produced sachet water on the basis of all tests combined.

From the three tests carried out to obtain the microbial quality of sachet water, the membrane filtration method was considered the most reliable in determining microbial quality of water with low bacterial contamination, due to its sensitivity and ability to give quantitative results. The main constraint was the need for careful sterilization.

From the results, it can be concluded that hand-tied sachet water can and should be improved. The ranking done in *Table 4.7* shows that all samples of hand-tied sachet water had either *E. coli*, total coliform, or both in at least one test. PHW's ceramic filter was found to be a feasible option for treatment and storage of hand-tied sachet water and the bar type heat sealer a low cost alternative for packaging sachet water.

Making it mandatory that sachet-water producers to be registered with the FDB is a good step towards ensuring water quality for sachet water sold in the market. However, the regulations set by the FDB need to be enforced. The vendors selling hand-tied sachet water also need to be regulated as they did not operate under any rules or regulations.

4.15.2 Source Water and Prior Treatment Process of Sachet-vended Water

The source of tap water used for sachet-water production in Tamale is the White Volta. This water is treated at the Dalun Water Treatment Plant through coagulation, flocculation, sedimentation, filtration, disinfection and post liming. For factory-produced sachet water, the water is again treated by a POU system that makes use of filtration and in some cases UV disinfection before it is packaged. For hand-tied sachet water, the water is filtered with a cloth or sponge or simply not treated further.

4.15.3 The Sachet-Water Business

Out of the 30 random passer-byes in Tamale that were interviewed by the author, all drank sachet water. The sachet-water business was found to be very profitable, whereby business owners of every vendor-level involved received 100% or more profit. While the operation and maintenance cost for factory-produced sachet water was approximately US$ 4200 per month, the income generated was US$ 8400 per month, or double the costs. The capital cost computed was US$ 7300. The salaries of technical workers and drivers (US$ 61 and US$ 64 respectively) were comparable to the general monthly wages paid to unskilled workers in the manufacturing sector (approximately US$ 52 to US$ 55). However the casual workers obtained half the average wage (approximately US$ 25 per month).

Retailers of factory-produced sachet water and the producers themselves made 100% profit. Vendors that produced hand-tied sachet water sold each sachet at US$ 0.02. Assuming that the only costs associated with production was the cost of tap water and the polythene bags used to package the water, approximately US$ 0.004 was spent for each sachet produced. This amounted to a 400% profit. Though the profits were much higher than that obtained by those who sold factory-produced sachet water, and the retailers involved, the production and number of sales was not as high. While hand-tied sachet-water producers sold between 30 to 200 sachets of water per day, produces of factory-produced sachet water sold an average of 15,000 sachets per day.

4.15.4 Pure Home Water Strategy

We find in this portion of the study that it is feasible for PHW to extend its outreach to producers of hand-tied sachet water, with the possibility of selling 1-2 PHW filters to these vendors, based on their reported willingness to pay, and potentially more units as their business continues to bring in customers and profits. There is a need for education and training among these vendors in both filter maintenance, as was observed by one of the vendors who continued to use a broken filter that did not properly serve its purpose, as well as in safe storage and hygienic practices, such as hand-washing with soap.

What PHW could learn from the sachet-water industry (factory-produced) include good record keeping of sales made and automatic stamping of each filter to keep track of the numbers produced once they start producing filters.

CHAPTER 5: SOLAR DISINFECTION OF DRINKING WATER

BY
IMAN YAZDANI

5.1 Research Objectives

The objective of this portion of the team's effort is to determine the technical feasibility of the SOLAIR method of solar disinfection of drinking water in the Northern Region of Ghana. Previously, SOLAIR had been tested in only one location (South Africa). This section of the team's efforts sought to repeat the SOLAIR procedure under different solar radiation and meteorological conditions in West Africa.

This topic of research is in line with PHW's intention to offer a variety of HWTS products as it continues to grow, including the possibility of offering a solar disinfection product as a viable HWTS system, in the future. In particular, the use of larger (2-25L) high density polyethylene (HDPE) containers (SOLAIR) as an alternative to smaller (0.5-2L) polyethylene terephthalate (PET) bottles (SODIS) for solar disinfection of drinking water will be investigated.

5.2 Solar Disinfection of Water

Solar water disinfection uses the sun's (solar) energy, which is an abundantly available and renewable resource, to kill pathogenic microorganisms that are present in raw water. It is a simple, low-cost and environmentally sustainable water treatment solution, particularly at the household level (EAWAG, 2002). This method of water purification will be discussed in the following sections.

5.2.1 Theory behind Solar Water Disinfection

5.2.1.1 Solar Radiation

The sun continuously emits large amounts of solar radiation, or energy. This solar radiation can be broken down into sub-sections of energy radiated at different wavelengths. The diagram below depicts this energy band:

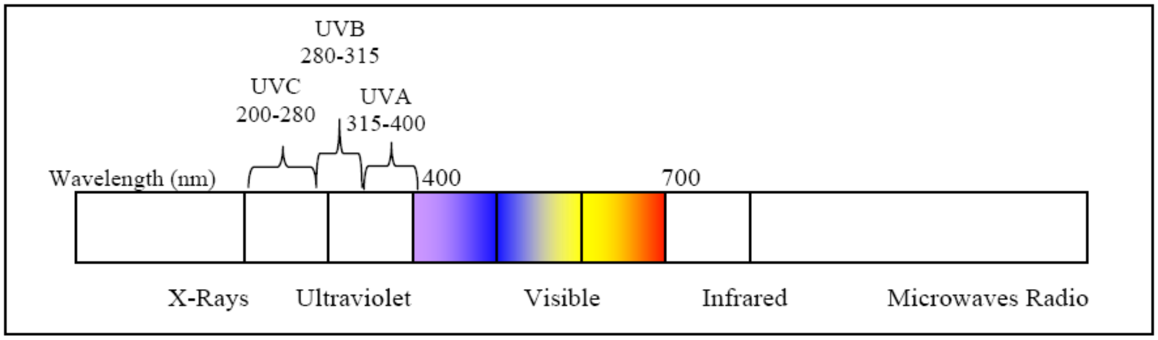

Figure 5.1 – Radiation bands vs. wavelengths (Flores-Cervantes, 2003)

The UV band can be broken down into UV-A, UV-B and UV-C. Most of the UV-B and UV-C light is absorbed by the ozone (O_3) layer in the earth's upper atmosphere and, hence, very little reaches the surface of the earth. UV-A rays, however, reach the earth's surface, and it is this range of light that has been shown to have a lethal effect on many of the pathogens present in water; the exact disinfection of which will be discussed in detail later on.

In addition, the infrared range of light is absorbed by water, which raises its temperature, thereby creating a "pasteurization" effect in the water (EAWAG, 2002).

The location on earth will affect the favourability of solar disinfection (*Figure 5.2*). The most-favourable zone lies between the 15^{o} and 35^{o} parallels of latitude. This is because these regions are frequently semi-arid and have limited cloud coverage, thus allowing the most amount of direct radiation to reach the surface.

The next most favourable zone lies between the equator and 15^{o} latitude. Incoming solar radiation is reduced since this zone is more humid, which leads to greater cloud formation. Nevertheless, solar radiation is still high in these regions (Acra, 1984). It is pertinent to note that the Northern Region of Ghana lies within the most-to-moderately favourable zone.

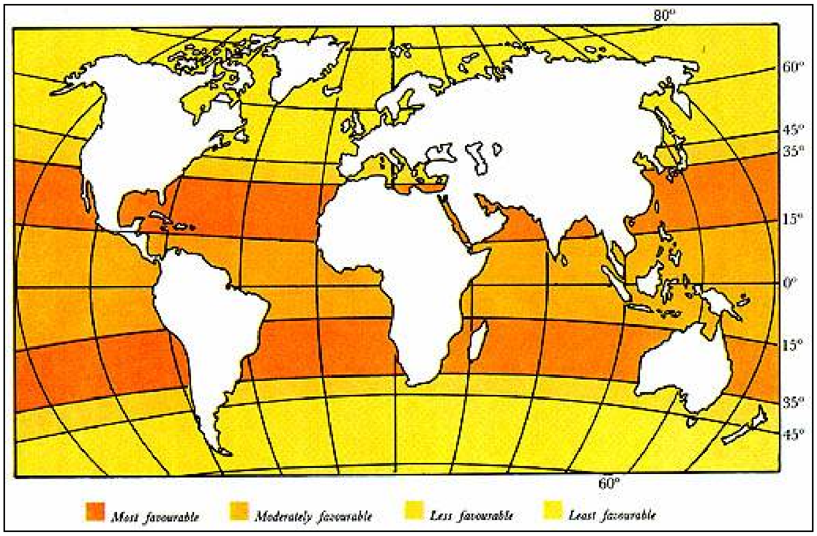

Figure 5.2 – Feasibility of solar disinfection based on worldwide location (Acra, 1984)

The effect of clouds on incoming radiation available for solar disinfection is simply illustrated in the *Figure 5.3*, where the shaded bars represent the % of UV-A radiation reaching the earth's surface and the unshaded bars show the % of radiation in the visible spectrum reaching the ground. These bars are plotted against varying degrees of cloudiness:

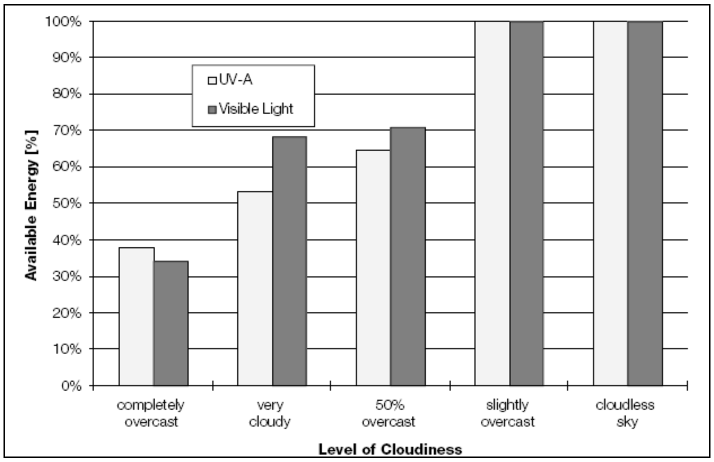

Figure 5.3 – Effect of cloudy skies on available solar energy (EAWAG, 2003)

5.2.1.2 The Disinfection Process

There are 2 main forms of disinfection that are caused by exposure of water to solar radiation. Inactivation of pathogens is caused by:

1) **UV-A radiation**
   a. Direct alteration and mutation of pathogen cell deoxyribonucleic acid (DNA).
   b. Indirect breakdown of pathogen cells due to the photo-oxidative effect.

2) **Infrared radiation**
   a. High temperatures (>50°C) eliminates some sensitive microorganisms.

A detailed description of each process follows.

DNA Alteration due to UV-A

This primary disinfection process is due to the UV-A radiation, which directly affects the DNA structure of several of pathogens found in water. The radiation causes cells to mutate which ultimately results in cellular death. Any repair mechanism that the cells may have are overpowered at a threshold of $500W/m^2$ total[7] solar radiation, applied for approximately 6 hours (EAWAG, 2002). The disinfection of the following list of microorganisms has been documented(EAWAG, 2002):

It should be pointed out that solar disinfection does not *sterilize* the water. Organisms that are not harmful to human health, algae for example, may still remain in the water (EAWAG, 2002).

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[7] *Total* radiation is the radiation emitted by *all* spectrums of light.

Photo-Oxidative Disinfection & Effect of Dissolved Oxygen Concentration

UV-A radiation can lead to the formation of reactive oxygen free radicals and hydrogen peroxides if there is sufficient dissolved oxygen (DO) in the water (Miller, 1998). These radicals then oxidize cellular components of the pathogens, such as enzymes, nucleic acids and membrane lipids, which kills the microorganisms (Reed, 1997). Although this process is secondary to the direct destruction of the pathogens by UV-A, it will nevertheless augment the disinfection process. Therefore, the presence of dissolved oxygen plays an important role in destroying the microorganisms. *Figure 5.4* graphically compares the inactivation of bacteria, *E. coli* in this case, under both aerobic and anaerobic conditions:

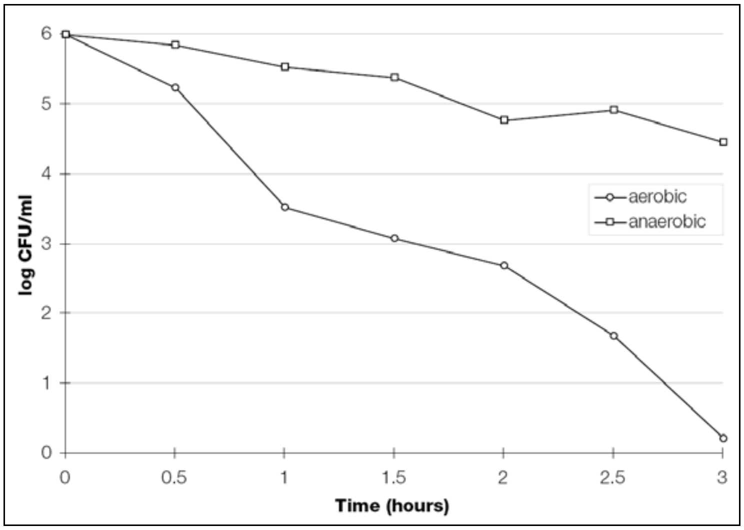

Figure 5.4 – Inactivation of *E. coli* under aerobic and anaerobic conditions (EAWAG, 2003)

Thermal Inactivation & Effect of Temperature

Infrared radiation is absorbed by water, causing the water to heat up. Heating water to between 50°C and 60°C for one hour has the same effect as boiling the water, which would kill 99.9% of microorganisms (EAWAG, 2003). Thus, the temperature of water plays a large role in increasing the rate of disinfection. *Figure 5.5* depicts the combined effect of both UV-A disinfection and thermal inactivation:

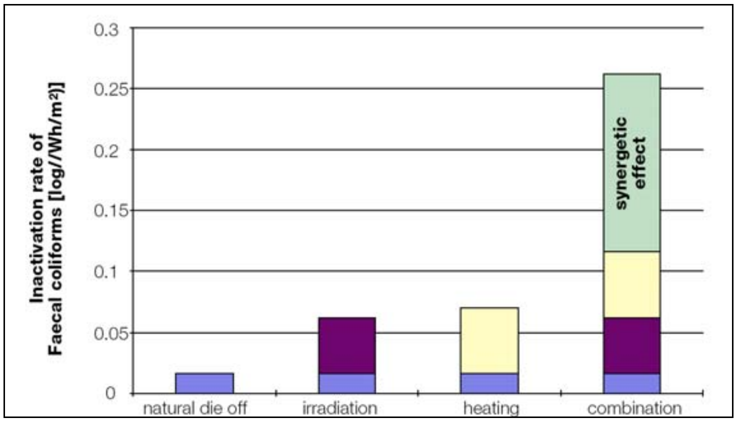

Figure 5.5 – Combined effect of UV-A and thermal radiation on solar disinfection (EAWAG, 2003)

To explicate the effect of temperature on the disinfection process, EAWAG state that at a temperature of 30^{o}C, 6 hours of mid-latitude midday sunshine (radiation fluence of 555W.hr/m^2 in the 350-450nm UV-A wavelength spectrum ≡ 3000W.hr/m^2 in the entire wavelength spectrum) is required to achieve a 3-log reduction of harmful bacteria (fecal coliforms). At a temperature of 50^{o}C, however, this reduction is seen at an equivalent exposure time of just 1 hour (or 140W.hr/m^2 of UV-A radiation for 6 hours) (EAWAG, 2002).

Effect of Turbidity & Water Depth

Turbidity is the "decrease in the transparency of a solution due to the presence of suspended and some dissolved substances, which causes incident light to be scattered, reflected, and attenuated rather than transmitted in straight lines; the higher the intensity of the scattered or attenuated light, the higher the value of turbidity" (Ziegler, 2002). Turbidity can be measured in Nephelometric Turbidity Units (NTU). Tests have shown that turbid water reduces the effectiveness of solar disinfection, since the suspended particles scatter the radiation by deflecting it in all directions. An increase in water depth also reduces the amount of radiation able to pass through the entire water column. *Figure 5.6* shows the % of UV-A radiation remaining in the water column at a certain depth of water, given varying turbidities:

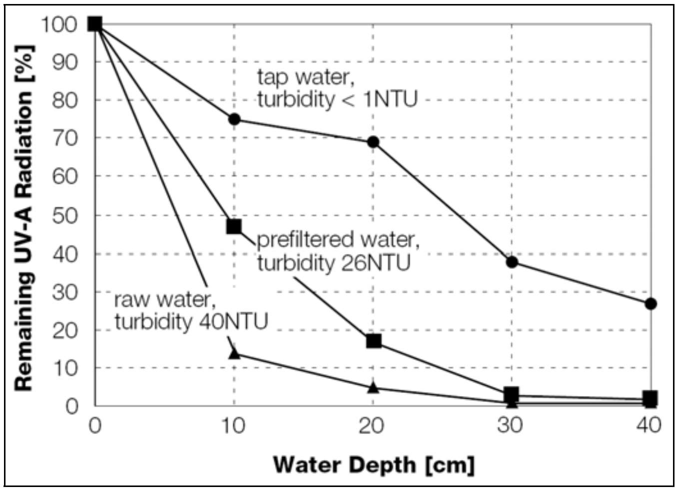

Figure 5.6 – Effect of turbidity & water depth on solar disinfection (EAWAG, 2003)

Turbidity reduces the intensity of the solar radiation, protects microorganisms from being irradiated by concealing them, and hence, reduces the overall disinfection efficiency. It is, therefore, highly recommended that the turbidity of the water measure no more than 30NTU. If turbidity is >30NTU, it is necessary for a pre-disinfection turbidity removal step to be implemented (EAWAG, 2002). Methods of turbidity removal will be discussed in greater detail in sections to follow, as this will be of great importance due to the high turbidity of some surface waters in Northern Ghana (Foran, 2006).

5.2.1.3 Microbial Indicators

In order to test the efficiency of solar disinfection systems, EAWAG and SANDEC, along with most other SODIS researchers, have used indicator organisms. An ideal indicator organism meets these criteria:

- Present in high number in human faeces,
- Detectable by simple methods,
- Does not grow in natural waters,
- Persistent in water and similar to other water-borne pathogens.

It was, therefore, found that the *E. coli* fecal coliform suitably matched these criteria thereby making it a good indicator organism for verifying the quality of solar disinfected water. One particular advantage of measuring *E. coli* is that it is possible to do this with portable field equipment under the difficult conditions that exist in some developing countries.

Total coliform bacteria and *total bacterial* counts cannot be used as an index of faecal contamination. However, they can be used as an indicator of treatment effectiveness (WHO, 2004). Therefore, total coliform is used as an indicator by the MIT MEng teams, for technology testing, since frequently one finds no *E. coli* in influent water, leading to effluent values that show no improvement.

5.2.2 Solar Disinfection Systems

5.2.2.1 SODIS

The acronym SODIS has become synonymous with solar disinfection. However, solar disinfection of drinking water can take many forms, for example solar cookers are being used to disinfect drinking water in Kenya and elsewhere, and SOLAIR is yet another example. In this report, SODIS is defined as the technology that entails the solar disinfection of small quantities of water in transparent plastic bottles or bags.

The SODIS technology considers all the solar disinfection variables, as discussed previously, and combines them in order to provide a safe, disinfected product. SODIS comprises numerous stages which will now be discussed at greater length.

Choice of Characteristic Vessel

The two main types of vessel recommended for SODIS are plastic polyethylene terephthalate (PET) *bottles* and thick, clear, plastic polyethylene *bags*, since both are good transmitters of UV-A light. Polyvinylchloride (PVC) bottles are also effective light transmitters but are not recommended since they contain a high number of artificial additives which may harm human health. Some types of glass bottle can also be used. The type of glass to be chosen largely depends on the concentration of iron oxide in the glass (EAWAG, 2002). The following table provides a comparison between the various vessel types:

Table 5.1 – SODIS vessel comparison

	Advantages	Disadvantages
PET bottles	☐ Low weight ☐ Chemically stable ☐ Durable ☐ Neutral in taste ☐ Low cost	☐ Treats small quantities ☐ Limited heat resistance ☐ Ageing effects (eg. scratches) ☐ Plastic is an environmental problem
Glass bottles (Corex,Pyrex,Vycor)	☐ Ageing resistant ☐ Limited ageing	☐ Treats small quantities ☐ High cost ☐ Heavy ☐ Easily smashed
Polyethylene bags	☐ Low weight ☐ Small bulk ☐ Fast & efficient disinfection	☐ Treats small quantities ☐ Limited heat resistance ☐ Ageing effects (eg. scratches) ☐ Plastic is an environmental problem ☐ Treated water smells of plastic ☐ Not durable

In order to optimize solar disinfection efficiency it is recommended that the vessel have a volume of less than 2L and that the depth of the water column facing the sun is less than 10cm. SODIS efficiency will also be augmented if the vessel is placed on a reflective surface (to increase effective UV-A radiation) (Kehoe, 2000) or if the bottle is placed on a dark surface (to increase temperature and, hence, thermal inactivation) (EAWAG, 2002). Usually, the choice of characteristic vessel is determined by local availability.

SODIS Method

As previously stated, the water to be disinfected should have a turbidity of <30NTU. If the original turbidity is higher than this value, the water needs to be pre-filtered or coagulated.

The SODIS procedure, as recommended by EAWAG/SANDEC (2002), is as follows:

> *Water is poured into the selected vessel up to the half way point of the container. The receptacle is shaken vigourously for up to 1 minute to increase the dissolved oxygen concentration in the water. This will increase the rate of photo-oxidative disinfection occurring in the water. The vessel is then filled to the top with water. It is important to fill the container to the brim, in order to avoid the formation of air bubbles which can reduce radiation penetration*[8].
>
> *The bottle is now exposed to the sun for a duration ranging from 3 hours to 2 days (duration is dependent on location, altitude, cloud cover, time of day etc.). The exact exposure time needs to be properly verified before solar disinfection is undertaken.*

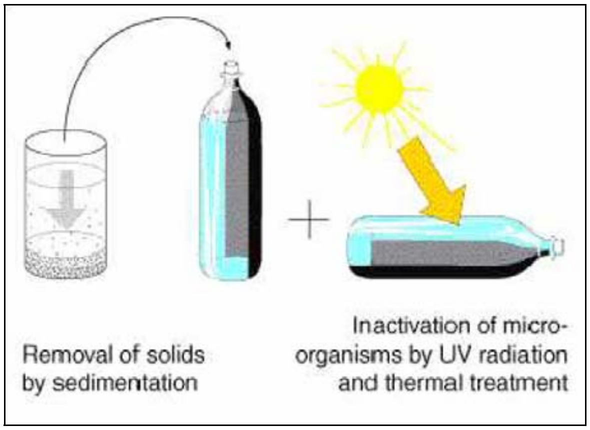

Figure 5.7 – SODIS put simply (Flores-Cervantes, 2003)

Assuming such verification has occurred and proper procedures have been followed, the resultant water is now ready for safe consumption. Great care should be taken to prevent recontamination of the water by practicing effective safe storage methods of the treated water and by cleaning the bottles before re-use.

5.2.2.2 SOLAIR

SOLAIR is a modification of the SODIS technology which substitutes the typical SODIS vessel types (PET or glass bottles, polyethylene bags) with larger HDPE containers.

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[8] This procedure can be found at http://www.sodis.ch/Text2002/T-Howdoesitwork.htm & http://www.sodis.ch/Text2002/T-FAQ.htm .

Whereas SODIS vessels are 0.5-2L, SOLAIR containers are typically 2-25L. SOLAIR is a solar disinfection system on which **particular emphasis** is placed on the inactivation of pathogens by the **photo-oxidative process**. SOLAIR uses both UV radiation and oxygen to purify water. In essence, SOLAIR is a variation of the SODIS system, modified to make it more applicable and practical, especially in a rural context. SOLAIR was developed by Meyer et al. (1999, 2000, 2001) whose research was conducted in rural South Africa.

Choice of Characteristic Vessel

Meyer et al. (2000) wished to use a container that is representative of those commonly used in rural South African communities. The UV intensities inside HDPE plastic containers of various colours (translucent, white, red, blue, yellow, black) were measured:

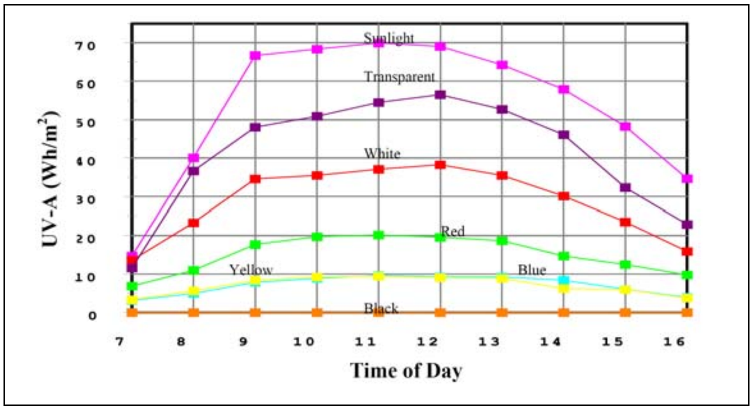

Figure 5.8 – UV-A radiation in different coloured containers (Meyer, 2001)

The transparent or white containers would be the most suitable for SOLAIR as these let through the most UV light. The translucent containers, which allow the second highest amount of UV radiation through, were chosen for the field tests by Meyer et al. as this type of container would be more readily available in the local communities.

The volume of the container will also affect the efficiency of the disinfection process:

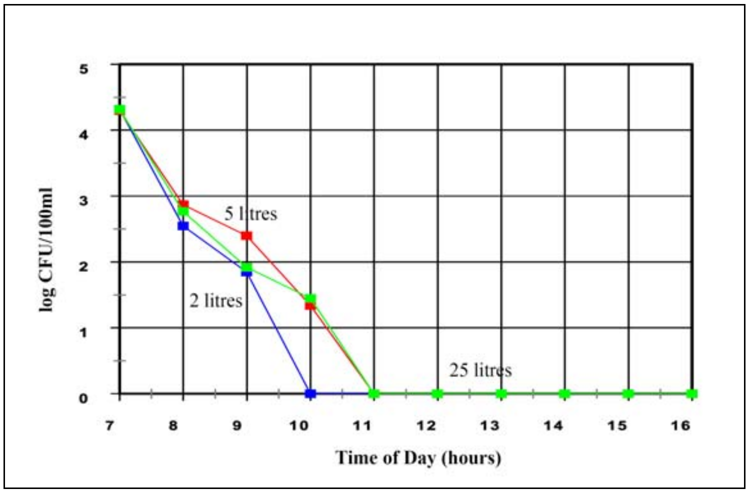

Figure 5.9 – Effect of volume of container on SOLAIR *E. coli* reduction efficiency (Meyer, 2001)

It can be seen from Meyer's data shown in *Figure 5.9* that the 2L volume showed a complete reduction in *E. coli* over 3 hours whilst the 5L and 25L showed this complete reduction in 4 hours. It is interesting to note that despite the inherently large difference in volume between the 5L and 25L containers, both containers display the same disinfection efficiency.

SOLAIR Method used in Field Tests in South Africa

As with SODIS, so too in SOLAIR, the turbidity of the water should be reduced to below 30NTU before solar disinfection occurs.
Furthermore, "intermittent vigorous shaking is important to dissolve and distribute the oxygen throughout the whole volume of water and to ensure the contact of all organisms in the water with the absorbed ultraviolet light"[9] (Meyer, 1999).

The SOLAIR method used in field testing by Meyer (1999) is as follows:

> *The container is first filled with water, up to the about the ¾ mark of the container. The vessel should then be closed and shaken vigorously for 5 minutes, in order to increase the amount of dissolved oxygen (DO) concentration in the water. As with SODIS, the purpose of increasing the DO concentration in the water is to ensure there is enough oxygen that can be converted into free radicals by the UV light. These free radicals will then destroy the microorganisms.*
>
> *The container is then placed in direct sunlight and shaken every hour thereafter. As previously stated, the shaking not only aides the dissolution and distribution of oxygen in the water, but also re-distributes the pathogen population to various*

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[9] With regard to SODIS, EAWAG (2003) states that "aeration can be achieved by stirring the raw water vigorously before filling the SODIS containers or by shaking the half-filled containers thoroughly and filling them completely before sunlight exposure. Especially stagnant water drawn from ponds, cisterns and possibly wells should be aerated to enhance the inactivation of microorganisms by SODIS".

parts of the water column, which brings them in contact with the varying radiation intensities in the container (Meyer, 1999).

Field Test Results

Field tests were performed by Meyer et al. (2000) at one site in rural South Africa. A 25L white receptacle was used in the tests. The following coliform reduction results were obtained for the SOLAIR system, compared with 2 experimental control set-ups:

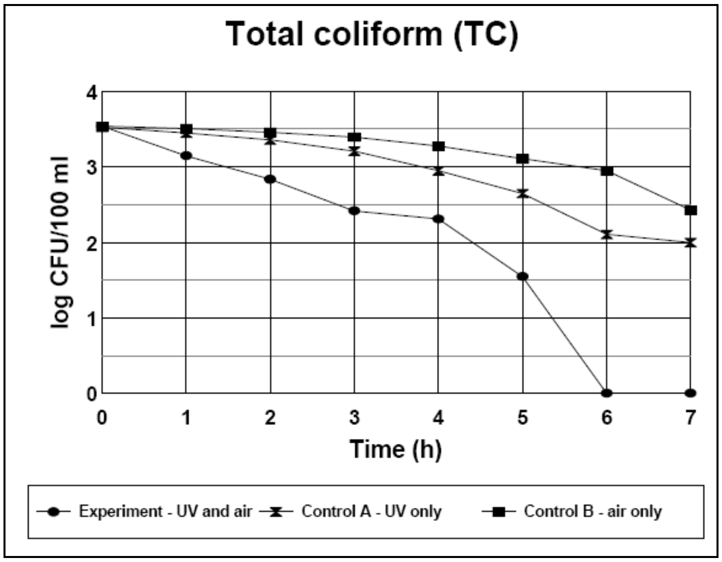

Figure 5.10 – Total coliform concentrations over SOLAIR experimental duration (Meyer, 2000)
-Control A was de-oxygenated, by bubbling nitrogen through it, and placed in direct sunlight.
-Control B was kept in a dark room (Meyer, 2000).

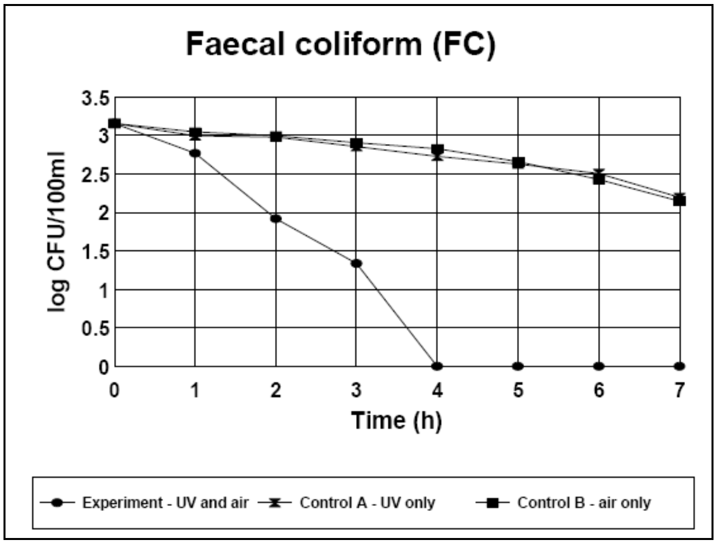

Figure 5.11 – Fecal coliform concentrations over SOLAIR experimental duration (Meyer, 2000)

After a 24 hour lag period following the successful completion of these SOLAIR tests, no re-growth of bacteria was observed indicating that these cells were irreversibly damaged or killed by the disinfection process (Meyer, 2000).

It is important to note that Control A was an *anaerobic* system, whilst SOLAIR is aerobic. No comparison between two *aerobic* systems (one with shaking and one with no shaking) was done in Meyer's study. Therefore, the ability to increase the DO concentration, which translates into a potential increase in photo-oxidative disinfection, in a natural source (aerobic) water, by shaking, was not investigated.

In a separate experiment, Meyer (2001) showed SOLAIR achieving complete disinfection over 8 hours, using water with a turbidity of 280NTU. The turbidity was *artificially* increased to 280NTU using calcium carbonate.

Conclusions

Meyer et al. (2001) drew the following conclusions:

- SOLAIR is applicable and effective in volumes of water between 2L and 25L, based on results obtained in South Africa.
- White/translucent HDPE containers are reasonable transmitters of UV light, and can be used.
- Visible turbidity (say, <30NTU) should be removed before performing SOLAIR disinfection.
- The containers should be kept closed, with a lid, and must be exposed to full and direct sunlight at all times.
- Intermittent vigorous shaking is very important during the disinfection process. This dissolves and disperses the diffused (some oxygen enters the vessel by diffusion through the container) and dissolved oxygen throughout the entire water column and ensures contact of all microorganisms in the water with the UV light entering the receptacle.
- A minimum of 4 hours irradiation is required for effective fecal coliform disinfection in sub-tropical latitudes. Exposure time is dependent on the various factors, as discussed in previous sections of this chapter.
- Unlike chlorination or other chemical disinfection processes, no residual disinfectant is available after the SOLAIR process. Therefore, secondary contamination of the water should be prevented through the practice of safe storage and good hygienic practices.

5.2.2.3 System Comparison

The table below compares the advantages and disadvantages of the SODIS and SOLAIR systems:

Table 5.2 – Comparison of SODIS and SOLAIR

	Advantages	Disadvantages
SODIS	☐ Low cost ☐ Simple ☐ Widely known & studied; practiced in 34 countries (Murcott 2007) ☐ Proven through health impact studies (Conroy 1996; Rose 2006)	☐ Treats small quantities (<2L) ☐ Requires many small, transparent bottles or bags, which can be impractical and laborious and may not readily provide sufficient quantities of safe water, depending on family size and need ☐ Bottles and bags could pose an environmental problem ☐ Containers are less durable and need frequent replacement ☐ Inadequate user knowledge and implementation can lead to poor use of system so *education is key*
SOLAIR	☐ Low cost ☐ Can use containers that are representative of those commonly used by many local communities world-wide (eg. white jerry can-type containers). ☐ Treats larger quantities (2-25L), making it more practical and less laborious ☐ Containers are more resilient ☐ Simpler and more practical in a rural context	☐ Requires intermittent shaking [according to Meyer (1999, 2000, 2001)] of container which may be laborious ☐ Not widely studied ☐ Inadequate user knowledge and implementation can lead to poor use of system so *education is key*

Considering the aforementioned advantages and disadvantages, it can be seen that SOLAIR has potential benefits that could make it a more feasible and practical method of solar disinfection than SODIS. This is chiefly due to the ability to use a larger water container, and one that is more likely to be available in a rural setting (translucent/white jerry can-type container).

5.2.3 Experimental Setup

5.2.3.1 SOLAIR

The SOLAIR experiments were carried out using two 10L translucent HDPE containers, whose original use was to store cooking oil, purchased from the market in Tamale, Ghana. One was used for SOLAIR (sunlight & shaking), whilst the other was used as a control (sunlight & no shaking):

Apparatus

- Two 10L translucent HDPE containers
- 100 micron monofilament nylon filter[10]

Figure 5.12 – SOLAIR experimental set-up

Procedure

1. Clean the containers thoroughly with detergent and rinse several times.
2. Fill each container up to ~3/4 mark with raw water, passing water through the nylon cloth filter in order to remove the guinea worm copepods.
3. The "SOLAIR" container is shaken vigourously for 5 minutes prior to the start of the experiment, as per the method of Meyer (1999). This is intended to increase the dissolved oxygen concentration in the water. The "control" container is not to be shaken.
4. Place both containers, upright, in direct sunlight for 7 hours.
5. Shake the SOLAIR container vigourously for 1 minute every hour, for 7 hours, as done by Meyer (1999).
6. Collect 100ml water samples from both containers on an hourly basis. These samples are tested for *E. coli* and total coliform using the Membrane Filtration

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[10] Cloth obtained from Decotex, Inc. 63 East Main Street, Pawling, NY 12564, URL: http://decotexinc.com/mono.htm .

and 3M Petrifilm™ methods. Ensure that the water in each container is well mixed prior to removing hourly samples, so that particulate settling does not skew results and that representative samples are extracted.

5.2.3.2 SODIS

The SODIS experiment was carried out as follows:

Apparatus

- 2L transparent (with slight blue tint) PET bottle

Procedure

1. Clean the bottle thoroughly.
2. Half-fill the bottle with the water to be disinfected and shake vigourously for about a minute. Top up the container with the water.
3. Place the bottle in direct sunlight, with the bottle lying on its longest side.
4. Test for coliform at 0, 3 and 6 hours after the start of the experiment.

5.3 Results & Discussion

5.3.1 Prevailing Meteorological Conditions

The winter months (November to February) in Ghana generally see a dry and dusty wind blowing through the country, from the direction of the Sahara desert south-west towards the Gulf of Guinea. This is known as the *Harmattan* wind. As a result, a thick haze of dust forms in the atmosphere, thereby limiting visibility. The heavy amounts of fine dust particles in the air interact with sunlight by *scattering* radiation back to space, as well as *absorbing* radiation (Sokolik 1996; Colarco 2002). Since winter is the dry season in Northern Ghana, the sky is cloudless for the most part.

The percentage UV absorbed by the dust, and, hence, not able to reach the earth's surface, is difficult to accurately quantify due to the differing shapes and sizes of dust particles (Colarco, 2002). The Ozone Monitoring Instrument (OMI) Aerosol Index (AI), which is provided by the Total Ozone Mapping Spectrometer (TOMS) unit of the United States National Aeronautics and Space Administration (NASA), is a scale depicting the amount of aerosol particulate in the atmosphere (*Figure 5.13*). It is formally defined as "how much the wavelength dependence of backscattered UV radiation (360nm wavelength) from an atmosphere containing aerosols (Mie scattering[11], Rayleigh scattering[12], and absorption) differs from that of a pure molecular atmosphere (pure

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[11] "Scattering of light by particles small enough to render the effect selective so that different colours are deflected through different angles" (Encyclopaedia Britannica 2007).

[12] "Any scattering produced by spherical particles whose diameters are greater than 1/10 the wavelength of the scattered radiation" (NOAA 2007).

Rayleigh scattering)” (NASA, 2005). In simpler terms, the AI provides a *qualitative* measure of the amount of UV absorbing aerosol particles in the earth’s atmosphere.

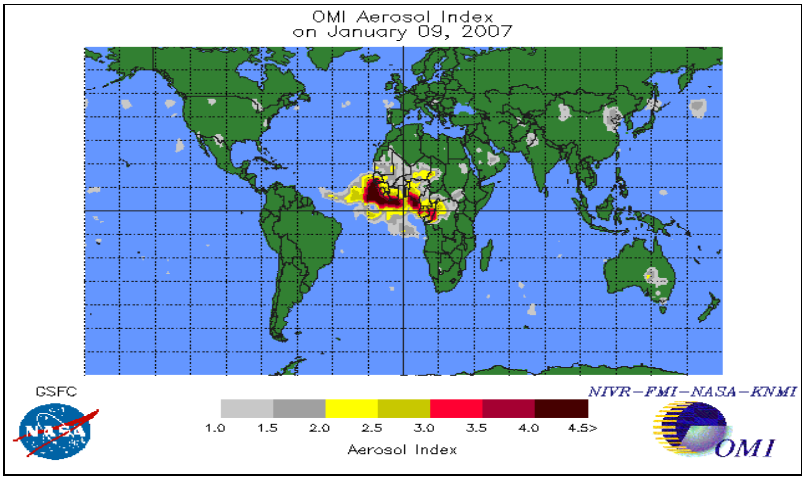

Figure 5.13 – A typical OMI Aerosol Index map: January 09, 2007 (NASA, 2007)

5.3.2 Radiation

5.3.2.1 Peaks, Averages & Trends

Hourly radiation measurements were taken on different days in Tamale, Northern Region, Ghana (*Figure 5.14*). Average and peak radiation intensity values, as well as approximate OMI AI values are presented in T*able 5.3*.

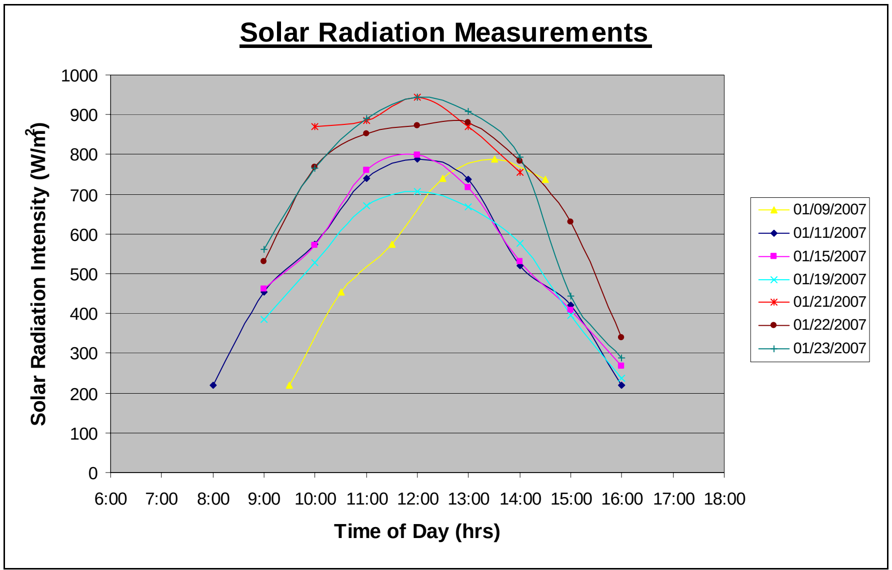

Figure 5.14 – Total[13] solar radiation measurements taken in January 2007 in Tamale, Ghana

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[13] *Total* radiation is the radiation emitted by *all* spectrums of light.

Table 5.3 – Average, peak daily radiation and OMI Aerosol Index Values

Date	Average Intensity (W/m^2)	Peak Intensity (W/m^2)	~ OMI Aerosol Index (for Tamale, Ghana)
01/09/2007	607	788	2.00
01/11/2007	557	788	3.00
01/15/2007	593	799	3.00
01/19/2007	551	707	4.00
01/21/2007	878	945	1.75
01/22/2007	746	881	2.00
01/23/2007	739	944	2.00
Mean	**667**	**836**	**2.50**

The high variability ($p<0.0001$)[14] of the radiation measurements on a day-to-day basis is indicative of the fickle nature of the dust haze. A model can be derived to quantify the radiation intensities in terms of the OMI AI (*Figure 5.15*), despite the AI being a ratio of absorption of UV light (360nm) *only*, as mentioned previously.

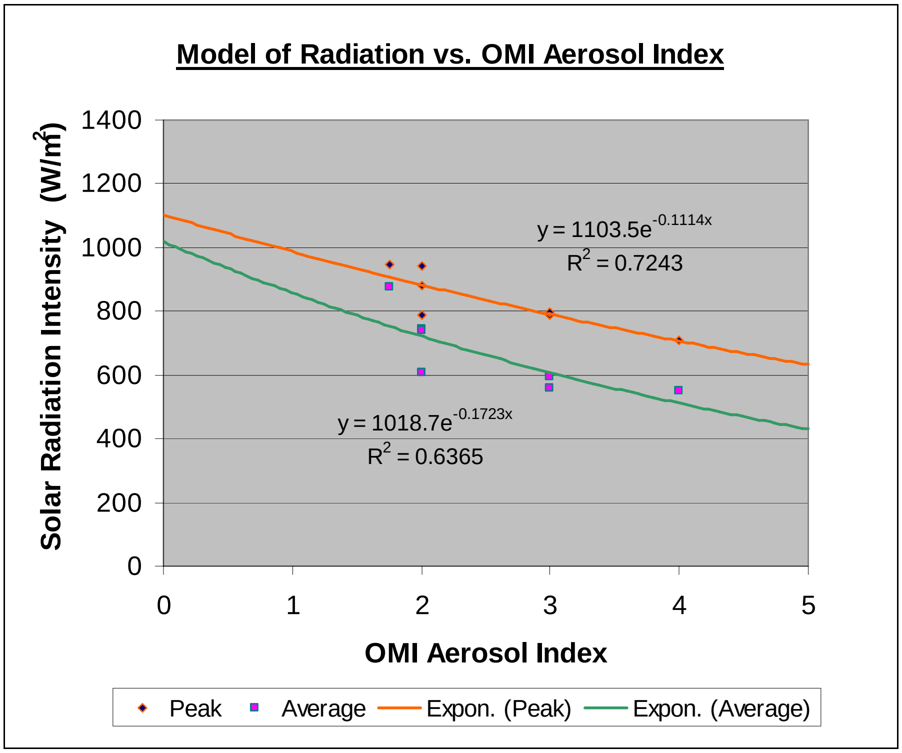

Figure 5.15 – Total solar radiation measurements taken in January 2007 in Tamale, Ghana

The peak potential radiation in Tamale, at noon on a cloudless mid-January day, was calculated as $1164 W/m^2$. The equation derived for the peak radiation is:

$$I_p \approx 1100e^{-0.11AI}$$

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[14] Probability calculated using a one sample *t* test which compares the mean of the peak radiation values with the expected peak value of $1164 W/m^2$.

where $\mathbf{I_p}$ *is peak radiation intensity (W/m^2)*
AI *is OMI Aerosol Index (0<AI<5.0)*

For an AI of zero, the above equation yields $I_p = 1100 W/m^2$, a value which is comparable to the peak potential radiation. The average radiation can then be represented as follows:

$$\mathbf{I_{avg} \approx 1000e^{-0.17AI}}$$

where $\mathbf{I_{avg}}$ *is average radiation intensity (W/m^2)*
AI *is OMI Aerosol Index (0<AI<5.0)*

5.3.2.2 Inside HDPE Container

In order to determine the amount of radiation inside an HDPE container, the pyranometer was placed at the bottom of an upright, translucent 10L HDPE receptacle and radiation measurements were taken (*Figure 5.16*). An average (% penetration averaged out over the day) of 53% of the incoming radiation penetrates the container. Interestingly, radiation penetration varies non-linearly with incoming radiation. It was noticed that penetration was lowest when radiation was at a peak. This could be because less surface area of the container is exposed to the sun's face when the sun is at its zenith. Based on this prediction, a recommendation would be for future experiments to be conducted with the largest surface of the container exposed at a correct angle to the sun for the specific latitude.

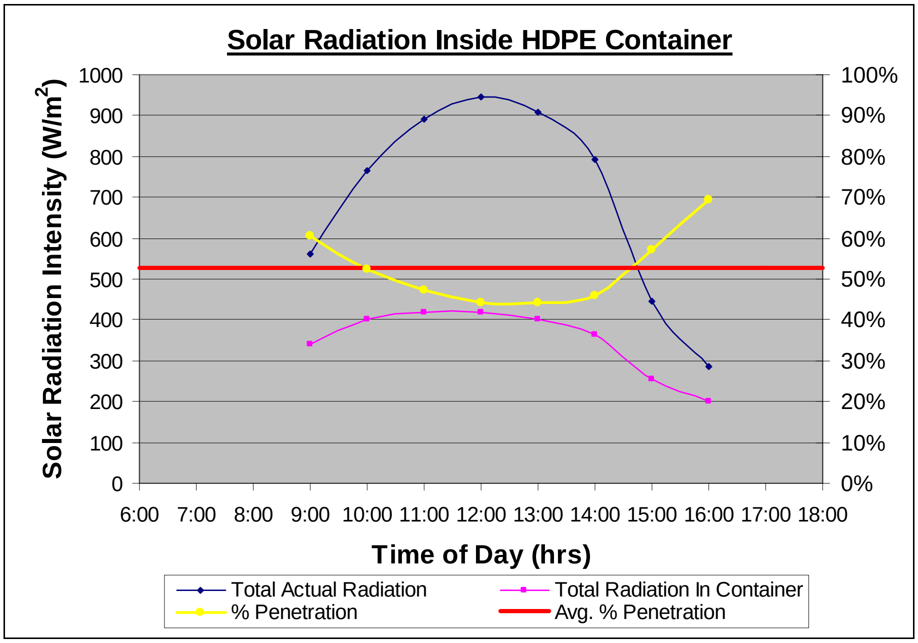

Figure 5.16 – Total solar radiation measurements taken inside a 10L translucent HDPE container in January 2007 in Tamale, Ghana

A radiation penetration of about 90% through a 1.5L PET (SODIS) bottle was observed.

5.3.3 Turbidity

In the Northern Region of Ghana the surface waters, which are used as drinking water by some of the population, have turbidity levels ranging from around 20NTU to more than 2000NTU. Turbidity values recorded by Foran (2006) in June-July 2006 during the rainy season, and by the author in January 2007 during the dry season, from various drinking water sources in Northern Region, Ghana, and which were collected and used experimentally by the MIT teams, are presented in *Table 5.4 & Table 5.5* respectively:

Table 5.4 – Turbidity, *E. coli*, total coliform readings of surface waters in June-July 2006 in Northern Region, Ghana (Foran, 2006)

Location	Pre-Alum			Post Alum		
	Turbidity [TU]	TC /100ml	EC /100ml	Turbidity [TU]	TC /100ml	EC /100ml
Ghanasco Muali Dam	~1600	6621	169	<5	6	0
Kaleriga Dam	>2000	13475	754	<5	26	4
Bipelar Dam	38	21667	100	~6	10.5	4.5
St. Mary's Dam	>2000	52110	1650	<5	7.5	6
Dungu Dam	400	4540	133	<5	108	0
Libga Dam	75	500	0	<5	3	0
Bunglung Dam	300	5117	200	<5	.5	0
Diare Dam	23	3417	0	<5	2.5	0
Libga Dam	50	1408	50	<5	0	0
Gbanyami Dam	~1000	19150	367	<5	0	0
Vitting Dam	~125	12767	1400	<5	0	0

Table 5.5 – Turbidity of source waters in January 2007 in Northern Region, Ghana

Location	Turbidity [NTU]
Ghanasco Muali Dam	817
Libga Dam	23
Datoyili Dam	115
Unprotected Well (Shishegu)	12.5

The results by Foran (2006) in *Table 5.4* show that a large percentage of the coliform in dam waters in the Northern Region of Ghana is attached to the particulates, thereby inferring that the majority of the coliform will be shielded from UV disinfection.

5.3.4 SOLAIR

5.3.4.1 SOLAIR Results with High Turbidity Water

Meyer (2001) showed that at a turbidity of 280NTU, using SOLAIR, complete *E. coli* removal was achieved after 6 hours exposure to sunlight, which is only 1 hour longer than 100% *E. coli* removal from a low turbidity water (1.5NTU). The author's SOLAIR experiments in Ghana were conducted on water collected from Datoyili dam. The water had a high initial turbidity (136NTU for the experiment and 108NTU for the control) due to the presence of a large amount of suspended fine clay particulates. *Table 5.6* provides a summary of the key physical experimental conditions for water tested from Datoyili dam, namely the total radiation fluence the containers were exposed to and the temperature, pH and turbidity of the water:

Table 5.6 – Physical properties of experiments: water from Datoyili Dam (01/11/2007)

		Experiment (UV & Shaking)	**Control A (UV & No Shaking)**
Total Fluence ($W.hr/m^2$)		4453	4453
Avg. Intensity (W/m^2)		557	557
Temperature (^oC)	**Avg.**	36.0	36.0
	Max.	42.0	42.0
Turbidity (NTU)	**Start**	136	108
	End	--	--
pH	**Start**	5.75	5.75
	End	--	--

The maximum temperature attained was less than the threshold temperature of 50^oC at which the synergetic disinfection caused by both cell breakdown due to UV, and pasteurization due to temperature, is most prominent (Wegelin 1994; Sommer 1997). Therefore, one can assume that disinfection due to pasteurization was negligible compared to disinfection due to direct UV and photo-oxidative disinfection. The water had an initial turbidity of >100NTU.

Figures 5.17 & 5.18 plot hourly log CFU/100mL (Colony Forming Units) counts for total coliform (TC) and *E. coli* (EC), respectively, for one day. Log CFU/100mL values at the start of the experiments are on the order of 4.0 TC and 3.5 EC. Both the experiment (SOLAIR) and the control (no shaking) showed <1.0 log reduction of TC and EC over 7 hours using the Membrane Filtration method. The 3M Petrifilm™ and H_2S tests confirm these results. Comparing the SOLAIR and control results (p=0.26)[15], there is no significant difference with regard to the *degree* of disinfection.

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[15] Probabilities comparing disinfection were calculated using the paired *t* test. For each group, both the reduction in the number of TC and the number of EC were included in order to have sufficient data to perform the test.

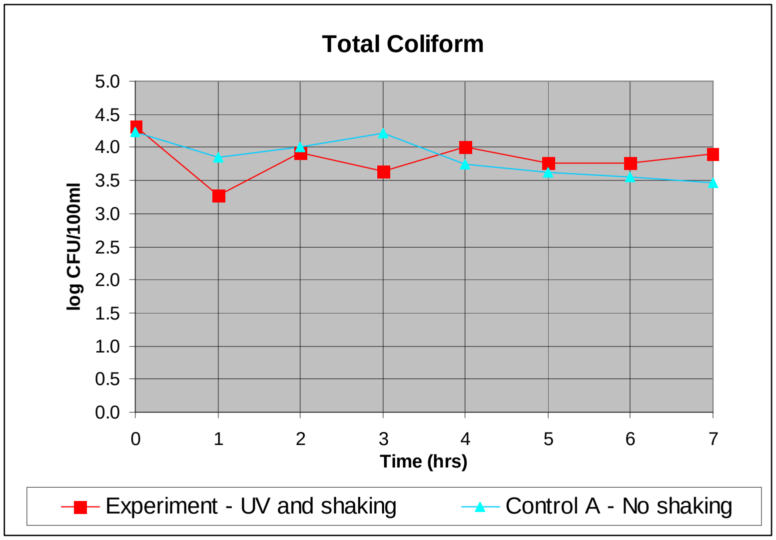

Figure 5.17 – Graph of log CFU/100mL (TC) vs. time for water with turbidity >100NTU

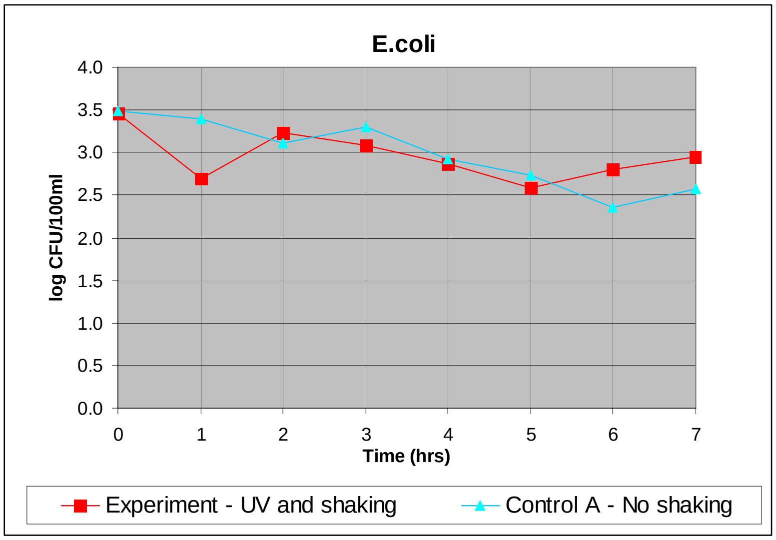

Figure 5.18 – Graph of log CFU/100mL (EC) vs. time for water with turbidity >100NTU

Discussion

The results show a low rate of coliform reduction of <1.0 log. The relatively low average radiation intensity of 577W/m^2 (compared to a potential peak radiation of about 100W/m^2) coupled with the high turbidity most likely accounts for this.

It is highly probable that a large percentage of incoming UV radiation was absorbed and scattered by the Harmattan haze, as is evinced by the average recorded radiation on the day (01/11/2007, *Table 5.6*) being half of the potential maximum radiation on a clear day. Furthermore, only half of this radiation is able to penetrate the walls of the container, as shown in *Figure 5.16*.

High levels of particulates in water, measured as turbidity, limit radiation penetration through the water. Furthermore, bacteria are attached to particles and are shielded from radiation. As mentioned in *section 5.3.3*, a large percentage of the coliform in dam waters in the Northern Region of Ghana is attached to the particulates, thereby inferring that the majority of the coliform will be shielded from UV disinfection (Foran 2006). Despite the turbidity concentration, it would still be expected that a greater degree of disinfection be observed in the SOLAIR container, compared with Control A, due to shaking the container which keeps dissolved oxygen (DO) levels raised, based on the Meyer et al. (2000) results which assume an increase in photo-oxidative disinfection. However, the results show that this is not the case, and that the SOLAIR and Control A display similar disinfection. An explanation for this is that there is enough air above the air-water interface in the container that the water is *almost saturated* with DO even without shaking and, hence, shaking can only make a marginal improvement. Lab tests performed by the author back at the Massachusetts Institute of Technology, in April 2007, support this claim, which is depicted in *Figure 5.19*:

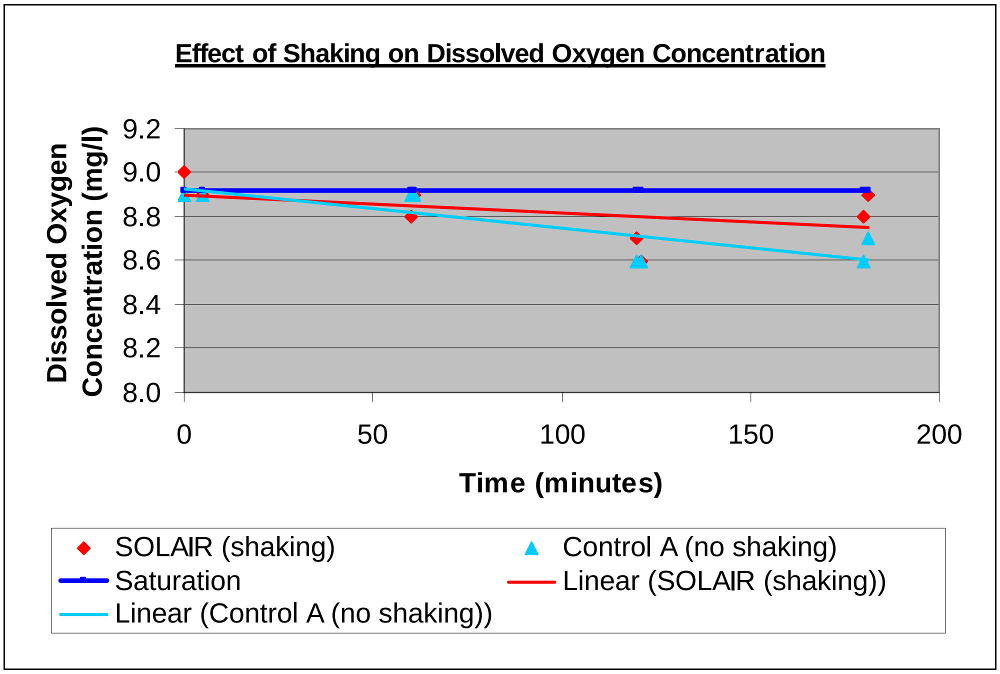

Figure 5.19 – Effect of shaking on dissolved oxygen concentration in water

The most likely reason for the slight reduction in coliform is, therefore, disinfection by direct UV cellular breakdown, closest to the walls of the container.

Although Meyer (2001) showed successful results at a turbidity of 280NTU, the turbidity was *artificially* increased using calcium carbonate in those experiments. Since the turbidity introduced was artificial, it is possible that the coliform were not attached to the particulates. Therefore, the coliform were not shielded by the calcium carbonate particles which could explain the high rate of disinfection in the case of the artificially adjusted water.

5.3.4.2 SOLAIR Results with Low Turbidity Water

Water measuring approximately 12NTU turbidity (*Table 5.7*) was collected from an unprotected well at Shishegu, Tamale. The lowest average radiation (551W/m^2) of those measured during January was experienced on this day. Again, pasteurization will be negligible due to the relatively low maximum temperature (38^{o}C) of the water in the containers.

Table 5.7 – Physical properties of experiments: water from unprotected well at Shishegu (01/19/2007)

		Experiment (UV & shaking)	**Control A (UV & No shaking)**
Total Fluence (W.hr/m^2)		3855	3855
Avg. Intensity (W/m^2)		551	551
Temperature (^{o}C)	**Avg.**	33.0	33.0
	Max.	38.0	38.0
Turbidity (NTU)	**Start**	12.5	12.5
	End	11.5	12.7
pH	**Start**	5.25	5.25
	End	5.25	5.25

Log CFU/100mL values at the start of the experiments are on the order of approximately 5.0 TC and 3.0 EC (*Figures 5.20 & 5.21*). Both the SOLAIR and Control A showed ~1.0 log reduction of TC over 7 hours. Log EC reduction was ~1.0 for SOLAIR and ~1.5 for the control. Again, it can be seen that complete disinfection was not achieved and that SOLAIR did not display a statistically significant increase in the degree of disinfection compared with the control ($p=0.57$). This general trend is confirmed via Membrane Filtration performed on 01/15/2007 using another low turbidity source water collected from Libga dam (<20NTU), as well as by the 3M Petrifilm™ and H_2S test results.

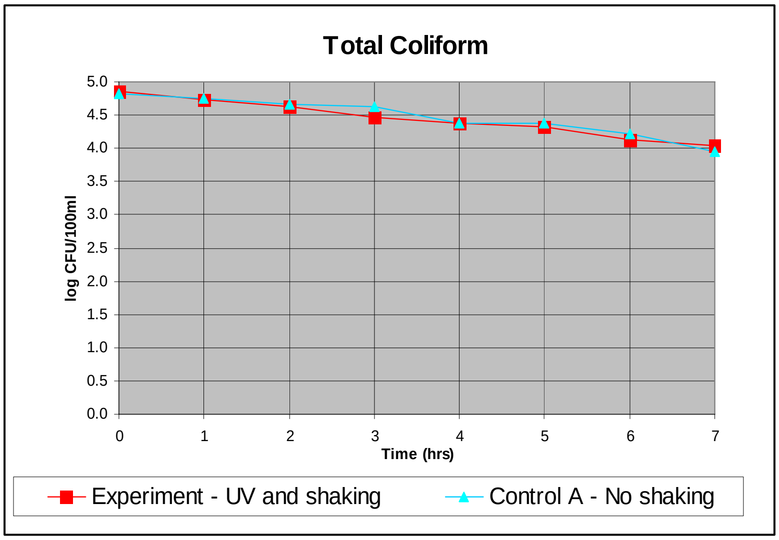

Figure 5.20 – Graph of log CFU/100mL (TC) vs. time for water with turbidity <20NTU (at 551W/m^2)

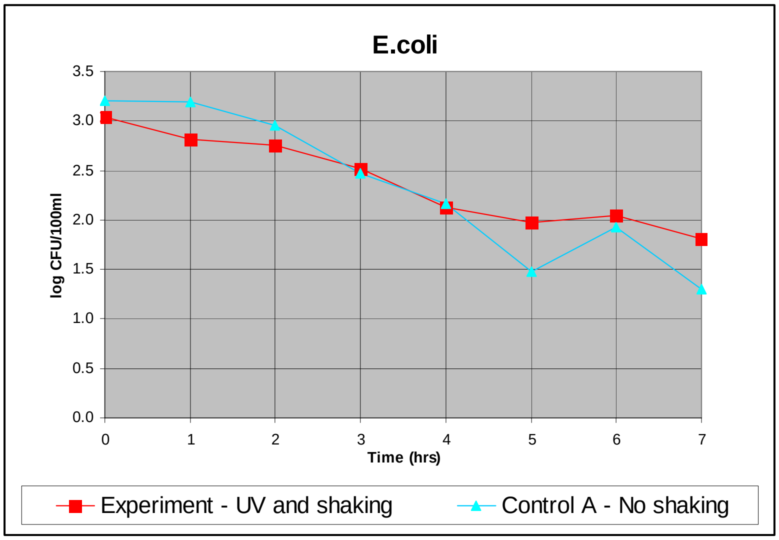

Figure 5.21 – Graph of log CFU/100mL (EC) vs. time for water with turbidity <20NTU (at 551W/m^2)

Experiments using water with a similar turbidity of <20NTU, using a mix of various source waters, were also conducted, on a separate day, with exposure to an average radiation which was higher at 746W/m^2:

Table 5.8 – Physical properties of experiments: mix of various source waters (01/22/2007)

		Experiment (UV & Shaking)	Control A (UV & No Shaking)
Total Fluence (W.hr/m^2)		5224	5224
Avg. Intensity (W/m^2)		746	746
Temperature (^{o}C)	**Avg.**	37.5	37.5
	Max.	43.0	43.0
Turbidity (NTU)	**Start**	16.1	16
	End	19.5	17.6
pH	**Start**	5.25	5.25
	End	5.25	5.25

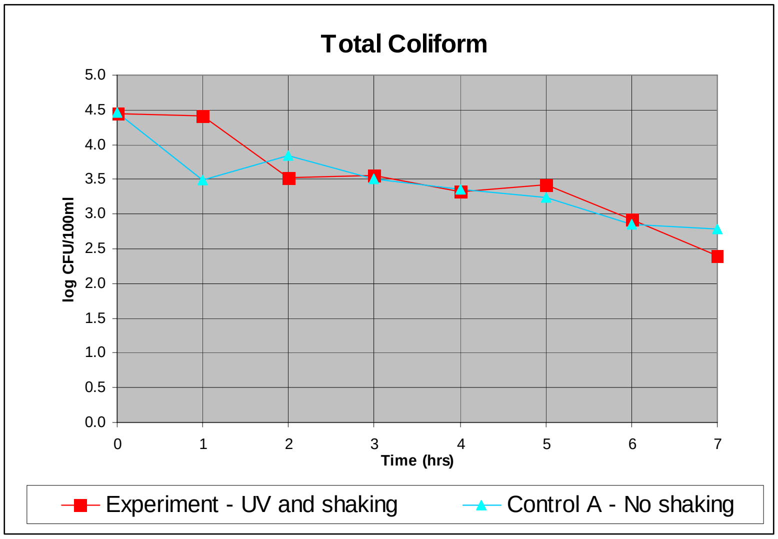

Figure 5.22 – Graph of log CFU/100mL (TC) vs. time for water with turbidity <20NTU (at 746W/m^2)

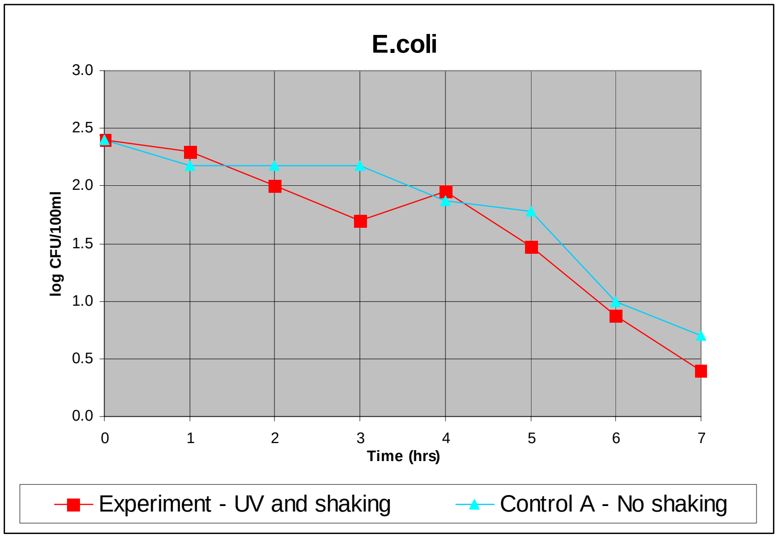

Figure 5.23 – Graph of log CFU/100mL (EC) vs. time for water with turbidity <20NTU (at 746W/m^2)

This set of experiments, which corresponded to one of the highest recorded average radiations of 746W/m^2, also showed the highest rate of disinfection out of all the experiments conducted. A 2.0 log reduction in both TC and EC was observed for both SOLAIR and the control. However, it can be seen that *complete* disinfection was not achieved. Furthermore, as before, the rate of disinfection for SOLAIR is *not* significantly different (p=0.50) from that of Control A.

Discussion

The two sets of experiments conducted using water with turbidity <20NTU can be compared side-by-side. Results show that on the day with a higher level of radiation (01/22/2007), a statistically significant increase in the disinfection rate was not observed (p=0.16).

Very little, if any, increase in disinfection was noticed with shaking. As before, it is likely that the limiting factor in the photo-oxidative reaction is the DO concentration (or lack thereof), in the water. If the disinfection due to temperature is assumed to be negligible, then the results lead to the conclusion that disinfection occurs mainly by cellular breakdown due to the direct effect of UV radiation, with some photo-oxidative disinfection occurring, aided by the **initial** DO present in both containers.

5.3.5 SODIS

Having observed the poor performance of SOLAIR, with respect to disinfection efficiency, under the solar and meteorological conditions of Northern Region, Ghana in January, it was decided to test the hypothesis that this was mainly because of *low levels of UV-A radiation* reaching the surface of the earth, as a result of the dust haze. Ideally, a UV radiation sensor would have provided concrete results (only a *total* radiation pyranometer was available); the unavailability of which led to a less sophisticated method for proving this, via a SODIS experiment.

The SODIS experiment was conducted, as per the methodology section of this part of the team's efforts. SODIS is *known* to show a 3.0 log reduction in TC for a water with turbidity <30NTU, exposed to a total radiation of 500W/m^2 for about 5 hours (EAWAG 2002). The lack of effectiveness of a SODIS experiment would support the conclusion that the dust haze was causing the low UV-radiation efficacy.

Table 5.9 – Physical properties of SODIS experiment: mix of various waters (01/23/2007)

		SODIS
Total Fluence (W.hr/m^2)		4805
Avg. Intensity (W/m^2)		739
Temperature (°C)	**Avg.**	43.5
	Max.	53.0
Turbidity (NTU)	**Start**	13.4
	End	12.6
pH	**Start**	5.25
	End	5.25

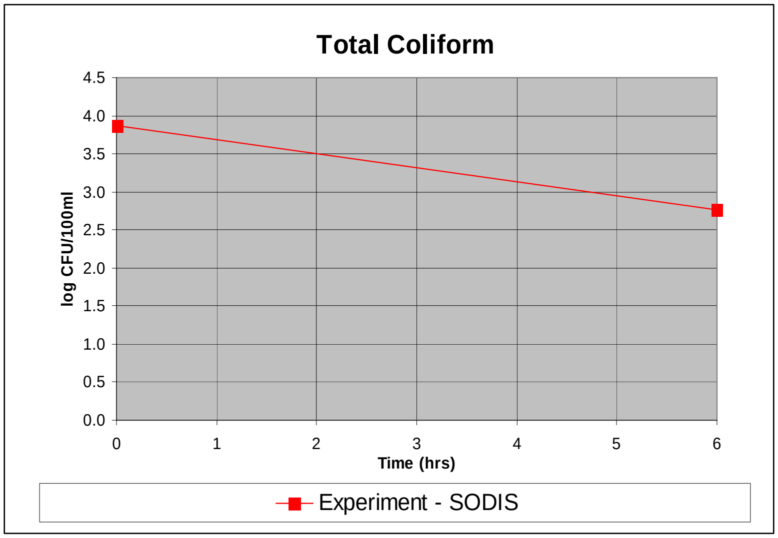

Figure 5.24 – Graph of log CFU/100mL (TC) vs. time for SODIS experiment

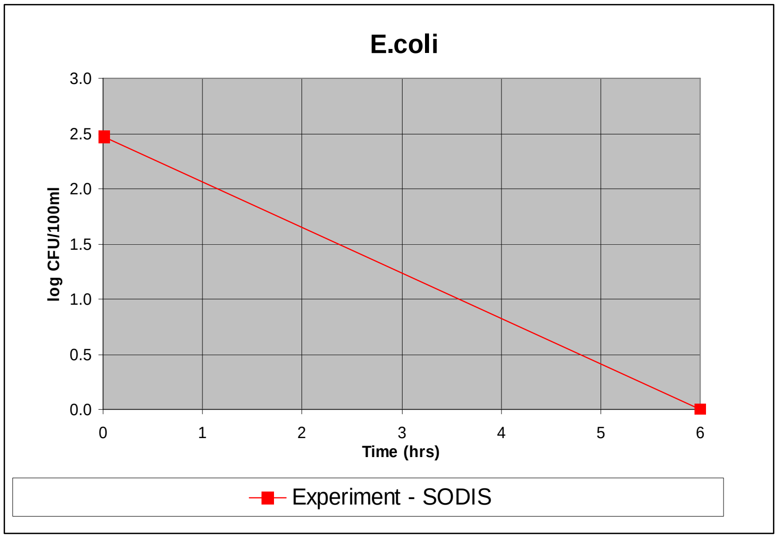

Figure 5.25 – Graph of log CFU/100mL (EC) vs. time for SODIS experiment

The water in the SODIS bottle reached a maximum temperature of 53°C, with an average temperature of 43.5°C. Therefore, it is expected that synergetic disinfection occurred for a portion of the experiment. The water was exposed to an average total radiation of about 800W/m^2 for 6 hours, well above the minimum limits required for a 3 log reduction in total coliform. Results show that, although *E. coli* was completely removed, there was only a ~1.0 log reduction in TC. Calculations show that there is an approximate loss of UV, in the wavelength range between 350nm and 450nm, of 80% due to scattering and absorption by the dust in the haze. This loss is approximate and only applicable to the prevalent meteorological conditions on the day of the SODIS experiment. However, under the assumption that AI is directly proportional to UV, days with lower average radiation values experience a higher loss in UV radiation.

5.3.6 Discussion & Comparisons

Comparing the results for a water with turbidity >100NTU with water that has turbidity <20NTU, it is clear that there is higher total coliform and *E. coli* reduction in the latter case, both experiments having been exposed to similar radiation fluences.

The SODIS experiment showed that, although the recommended *total* radiation conditions for a 3.0 log reduction of total coliform (EAWAG, 2002) had been met, a high percentage of the UV radiation was prevented from reaching the earth's surface by the Harmattan dust haze. Hence, this is likely a major reason that SOLAIR did not show complete reduction in TC or EC.

A key conclusion of this study is that there was no significant difference between SOLAIR and Control A (no shaking) (p=0.82). As mentioned previously, shaking does not increase the DO concentration in the water to sufficient levels, if at all, to augment photo-oxidative disinfection. An explanation for this is that there is enough air above the air-water interface in the container that the water is *almost saturated* with DO even without shaking and, hence, shaking can only make a marginal improvement. Meyer et al. (2000) showed that SOLAIR shows a significantly higher degree of disinfection compared with an **anaerobic** system (*see section 5.2.2.2*). However, there is no comparison between two **aerobic** containers (one with shaking and one with no shaking) as given in this study. Therefore, because the author's experimental conditions varied from Meyers' on these key parameters (meteorological conditions, control experiments used) an exact side-by-side comparison of results is not possible.

Another conclusion is that similar coliform reduction displayed by both SOLAIR and the control, therefore, indicates that disinfection was chiefly as a result of *direct cellular breakdown* by UV radiation, assuming disinfection by pasteurization was negligible, with some photo-oxidative disinfection occurring, aided by the **initial** DO present in both containers.

5.4 Conclusion

The SOLAIR results obtained in Tamale, Ghana over the month of January show that complete solar disinfection of water over the course of 7 consecutive hours of solar exposure, did **not** take place in SOLAIR or SODIS containers. This is true for both high turbidity (>100NTU) and low turbidity (<20NTU) waters.

It is believed that the primary reason for the low degree of disinfection is the scattering and absorption of UV radiation by the aerosol particles present in the seasonal Harmattan (Sahara dust) haze, which thereby reduces the amount of UV light that reaches the earth's surface. Calculations showed that the amount of UV reaching the surface of the earth was approximately 20% of the peak potential expected on a clear (cloudless and hazeless) day.

Using radiation measurements, a model relating the peak total radiation intensity versus the OMI Aerosol Index (AI) was derived:

$$\mathbf{I_p \approx 1100e^{-0.11AI}}$$

where $\mathbf{I_p}$ *is peak radiation intensity (W/m^2)*
AI *is OMI Aerosol Index (0<AI<5.0)*

The average total radiation can then be represented as follows:

$$\mathbf{I_{avg} \approx 1000e^{-0.17AI}}$$

where $\mathbf{I_{avg}}$ *is average radiation intensity (W/m^2)*
AI *is OMI Aerosol Index (0<AI<5.0)*

Incomplete SOLAIR disinfection of the water did take place. Recapping, the main forms of disinfection that are caused by exposure of the water to solar radiation are due to:

1) **UV-A radiation**
    a. Direct alteration and mutation of pathogen cell deoxyribonucleic acid (DNA).
    b. Indirect breakdown of pathogen cells due to the photo-oxidative effect.

2) **Infrared radiation**
    a. High temperatures (>50^{o}C) eliminates some sensitive microorganisms.

The maximum temperature attained in all SOLAIR experiments performed in Ghana was less than the threshold temperature of 50^{o}C at which the synergetic disinfection caused by both cell breakdown due to UV, and pasteurization due to temperature, occurs. Therefore, one can assume that disinfection due to pasteurization was negligible compared to that due to direct UV and photo-oxidative disinfection.
Furthermore, there was no distinct difference between SOLAIR (radiation & hourly shaking) and the control experiment (radiation & no shaking). Shaking does not increase the DO concentration in the water to sufficient levels, if at all, to augment photo-oxidative disinfection. Laboratory tests performed substantiate this claim. An explanation for this is that there is enough air above the air-water interface in the container that the water is *almost saturated* with DO even without shaking and, hence, shaking can only make a marginal improvement. Similar coliform reduction displayed by both SOLAIR and the control, therefore, indicates that the 1.0-2.0 log reduction that did take place was chiefly as a result of *direct cellular breakdown* by UV radiation, assuming disinfection by pasteurization was negligible, with some photo-oxidative disinfection occurring, aided by the **initial** DO present in both containers.

Although some disinfection did take place, the *recommended* WHO guideline of an *E. coli* count of zero colony forming units (CFU) per 100ml water was not met by SOLAIR (*Table 2.2*). It can be concluded, therefore, that this solar disinfection process, using translucent 10L HDPE containers, in January in the Northern Region of Ghana, does not produce a safe drinking water and should not be pursued in this context.

5.5 Recommendations

The hazeless conditions in summer (between the months of April to September) in Northern Region, Ghana may be more conducive to the success of SOLAIR. It is, therefore, recommended that further technical studies, if any, be conducted, in the absence of the Harmattan haze. Furthermore, containers should be placed parallel, not perpendicular to, the surface, or at a correct angle to solar radiation (~10^{o}). Subsequent results obtained will then, more likely, be comparable to those given by Meyer et. al (2000). Since it has been shown that an increase in photo-oxidative disinfection is not likely with shaking, research into augmenting pasteurization could be looked into. This may be possible by using darker coloured containers, in order to raise the temperature of the water being held.

Should future studies on SOLAIR or an associated system prove *technically* successful, the *social* acceptance of the treatment system in this region of Ghana would need to be considered. Furthermore, use of the system would have to be limited to hazeless months, which adds another hurdle in the way of this “simple” process.

CHAPTER 6: CONCLUSION

The Master of Engineering projects aimed to help Pure Home Water both monitor and evaluate its current program and also move forward with research and development of new simple low-cost technologies and promising marketing strategies. It is hoped that these projects will help PHW in its efforts to bring safe drinking water to people in the Northern Region of Ghana.

- Johnson's monitoring and evaluation study found that PHW is reaching those that need the filter the most and that the filters are performing well in the field. The filters are acceptable to users, and PHW's price is within reach of most households.
- Okioga, realizing that there is a great need for safe water *away* from the home, researched the sachet water vending business. She found significant contamination in hand-tied sachet water samples, and she suggests that vendors could use PHW's ceramic filters and bar type heat sealers to create a safer product.
- Since PHW seeks to expand its product line in the future, Yazdani tested the SOLAIR solar disinfection method in the Northern Region. SOLAIR did not result in complete solar disinfection of water, pointing to the direction of future research in this arena – specifically towards the aspects of water quality and meterological (Harmattan haze) conditions.

Although this work focused on PHW in Northern Region, Ghana, the results could certainly be useful in other areas of the world that face similar drinking water issues.

The ex-United Nations Secretary-General, Kofi Annan, candidly comments on how "we shall not finally defeat AIDS, tuberculosis, malaria, or any of the other infectious diseases that plague the developing world until we have also won the battle for safe drinking-water, sanitation and basic health care" (WHO, 2005). It is our hope that this small research effort can contribute towards winning this battle.

CHAPTER 7: REFERENCES

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Appendix A – Methodology of Microbial Testing

A.1 – Membrane Filtration Test

Apparatus

- Millipore MF field unit
- mColiBlue24® broth ampule (nutrient medium)
- Petri dish
- Absorbent pad
- 0.45µm filter paper
- Sterile water (distilled/bottled)
- 100ml sterile Whirl-Pak© bag
- Tweezers
- Rubbing alcohol
- Methanol
- Handheld magnifying glass

Procedure

1. *Collect* the sample:
    - Using a Whirl-Pak© bag, collect a 100ml sample of the water to be tested (from either the SOLAIR container or the control container).
      To minimize error, the final TC count should lie between 20 and 200. In order to achieve this, dilute accordingly (Standard Methods, 1999).

2. *Sterilize* the lab bench and immediate surroundings using rubbing alcohol.

3. *Sterilize* the Millipore MF filter holder:
    - Flame-sterilize by soaking the cloth rim of the filter holder with methanol, before igniting the methanol and tightly placing the filter cup over the funnel. Sterilization is accomplished by formaldehyde, which is a product of the incomplete combustion of methanol. Leave the cup on for 15 minutes then remove and rinse the funnel thoroughly with sterile water (Standard Methods, 1999).

4. *Prepare* the *Petri dish*:
    - Carefully place an absorbent pad onto a sterile Petri dish using flame-sterilized tweezers.
    - Pour 1 plastic mColiBlue24® broth ampule onto the pad, ensuring the pad is evenly soaked. Pour off excess broth, leaving approximately one drop behind.

5. Begin *Membrane Filtration*:

- Using the tweezers, place 0.45µm filter paper over the filter and clamp in funnel.
- Pour and vacuum through, using the hand pump, the 100ml sample of water.
- Rinse the walls of the funnel with sterile water a few times to ensure complete flushing of the sample.

6. *Remove* the filter paper and *incubate*:
    - Remove the filter paper and place this onto the absorbent pad that has been soaked with the mColiBlue24® broth. Ensure there are no air bubbles between the filter paper and the pad.
    - Close the lid of the Petri dish and invert.
    - Incubate the sample for 24 hours at 35°C (95°F).

7. *Count* results:
    - Remove the Petri dish and count the number of blue and red colonies formed with the aid of a handheld magnifying glass (10x magnification). The blue colonies represent *E. coli* whilst the sum of the red and blue gives the total coliform in the sample. The results are reported as Colony Forming Units (CFU/100ml) and can be calculated using the following equation:

$$\frac{\text{Number of Indicator Organisms Counted}}{\text{Millilitres of Sample}} \times 100 = \text{No. of Indicator Organisms per 100ml}$$

A.2 – 3M Petrifilm™ Test

Apparatus

- 3M Petrifilm™ EC plate
- 1-5mL pipette
- Sterile pipette tip
- 3M spreader/press

Procedure

1. *Sterilize* the lab bench and immediate surroundings using rubbing alcohol.

2. *Inoculate* the 3M Petrifilm™ plate with the sample:
    - Place the plate on a flat surface and lift top cover.

- Pipette a 1mL sample onto the centre of the plate.
- Carefully roll down the top cover, ensuring there are no air bubbles.
- Gently press down on the plate with the spreader (flat side down).
- Lift spreader and wait at least 1 minute for gel to solidify.

3. *Incubate* the plate:
    - Incubate the plates at 35°C±1°C for 24±2 hours, with the clear side up, in stacks of no more than 20.

4. *Count* results:
    - Blue colonies surrounded by gas bubbles represent *E. coli* whilst total coliform is the summation of both red and blue coloniessurrounded by gas bubbles. Red colonies without surrounding gas bubbles are non-coliform bacteria and should not be counted (3M Microbiology, 2001).

A.3 - Hydrogen Sulfide Presence/Absence Test

Apparatus

- 20ml glass bottle
- HACH PathoScreen™ Medium powder pillow for 20mL sample
- Rubbing alcohol to sterilize immediate surroundings

Procedure

1. Sterilize the glass bottles and caps by placing in boiling water.
2. Add a 20mL sample to the bottle.
3. Add the contents of one PathoScreen™ Medium powder pillow to the sample.
4. Immediately cap the bottle and shake thoroughly.
5. Place the bottle in a location with a constant temperature within the range 25-35°C (77-95°F) for 24 to 48 hours. Ambient conditions may be used in warm climates.
6. Evaluate the reaction after 24 hours. If the colour has changed from yellow to black the result is **positive**. A positive result indicates the presence of hydrogen sulfide reducing bacteria. If sample is still yellow, incubate for a further 24 hours and re-evaluate. If there is no colour change the result is **negative** (HACH, 2003).