WATER QUALITY AND BUSINESS ASPECTS OF SACHET-VENDED WATER IN TAMALE, GHANA

By

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B.Sc. Civil Engineering
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ABSTRACT

Microbial water quality analyses were conducted on 15 samples of factory-produced sachet water and 15 samples of hand-tied sachet water, sold in Tamale, Ghana. The tests included the membrane filtration (MF) test using mColiBlue24® medium, 3M™ Petrifilm™ test, and Hydrogen Sulfide Presence Absence (P/A H_2S) test. With the MF method, 1 factory-produced and 1 hand-tied sachet-water sample had *E.coli* counts of 5 CFU/100ml and 49 CFU/100ml respectively. Almost half (47%) of the factory-produced sachet-water samples had some total coliforms (range from 1 CFU/100ml to 115 CFU/100ml). All the 15 hand-tied sachet-water samples had total coliforms (range from 4 CFU/100ml to 2010 CFU/100ml). One sample recorded TNTC at a dilution factor of 10. The MF method showed little correlation with the 3M™ Petrifilm™ method (R=0.16). With the 3M™ Petrifilm™ test method, none of the factory-produced sachet-water samples had *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, turned out to have 100 CFU/100ml in the 3M™ Petrifilm™ test. The MF test results were considered more reliable. For the P/A H_2S test, 7% of factory-produced sachet-water samples and 27% of the hand-tied sachet-water samples returned positive results. Overall, hand-tied sachet water was found to be two times more microbially contaminated than factory-produced sachet water.

Turbidity tests done on the samples showed that 93% of the hand-tied sachet-water samples and 20% of factory-produced sachet-water samples had turbidities greater than 5 NTU - the limit set by the 1998 Ghana Standards for drinking water.

Out of 30 random passer-byes in Tamale and neighboring Savelugu that were interviewed, all drank sachet-vended water, signifying its popularity in the areas. For 37%, sachet water formed the sole supply of drinking water, even at home! 70% drank more water when away from home, 20% the same amount at home and away from home, while 10% drank more water at home. Sachet water formed the main source of water away from home. Sachet-water vendors made 100% to 400% profit.

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

DEDICATION

This thesis is dedicated to the 1.1 billion people who do not have access to clean water, particularly to the women and children who bare the brunt.

ACKNOWLEDGEMENTS

I would first of all like to give reverence to God who made all things possible.

I would also like to thank Susan Murcott, my thesis adviser, for providing a meaningful study and for the support she provided all throughout the research. I thank her for her dedication and enthusiasm to share her wealth of knowledge.

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My gratitude also goes to the MIT community for providing an enabling environment especially the GH_20 team members: Sophie Johnson and Iman Yazdani, for the great team spirit, and the Masters of Engineering class of 2007 for their comradeship.

I would like to thank the people in Ghana whom I worked with including the PHW team, World Vision, the Ghana Water Company, the Food and Drugs Board of Ghana, and especially the producers, vendors and consumers of sachet water in Tamale, who contributed to this study.

Last but not least, I thank my family: my parents David and Esther Okioga, my brother Edgar and his family, and my sisters, Kerubo, Bonareri, Moraa and Mogoi for their continued support and encouragement.

TABLE OF CONTENTS

TABLES

FIGURES

GLOSSARY OF TERMS

APHA: American Public Health Association
AWWA: American Water Works Association
BCIG: 5-bromo-4-chloro-3-indolyl-β-glucoronide
CFU: Colony Forming Units
CIA: Central Intelligence Agency
CSAE: Center for the Study of African Economies
CWSA: Community Water and Sanitation Agency
DWST: District Water and Sanitation Teams
E.coli: Escherichia coli
EPA: Environmental Protection Agency
European Community Council Directive
FAO: Food and Agriculture Organization of the United Nations
FDB: Food and Drug Board of Ghana
GAMA: Greater Accra Metropolitan Area
GHC: Ghana Cedi
GILBT: Ghana Institute of Linguistics, Literacy and Bible Translation
G-Lab: Global Entrepreneurship La
GMES: Ghana Manufacturing Enterprise Survey
GS: Ghana Standards
GSB: Ghana Standards Board
GSLS: Ghana Standard of Living Survey
GSO: Ghana Statistical Office
GWCL: Ghana Water Company Limited
High-Density Polyethylene
HT: Hand-tied
HWTS: Household Drinking Water and Safe Storage
IESWTR: Interim Enhanced Surface Water Treatment Rule
Linear Low-Density Polyethylene
MCL Maximum Contaminant Level
MCLG: Maximum Contaminant Level Goal
MDGs: Millennium Development Goals
MF: Membrane Filtration
MoWH: Ministry of Works and Housing
National Resources Defense
P/A: Presence/Absence
PFP: Porters for Peace
PHW: Pure Home Water
POE: Point-of-Entry
RPED: Regional Program on Enterprise Development
SEI: Stockholm Environment Institute
SMCLs: Secondary Maximum Contaminant Levels
Society of the Plastics Industry, Inc
SSIPWP: Small Scale Independent Private Water Provider
SWE: Small Water Enterprises
TCU: True Color Units
TNTC: Too Numerous To Count
TTC: 2,3,5-Triphenyltetrazoliumchloride
UNICEF: United Nations Children's Fund
US$: United States Dollar

USDA: United States Department of Agriculture
US-EPA: United States Environmental Protection Agency
UV: Ultraviolet
VRB: Violet Red Bile
WEF: Water Environment Federation
WHO: World Health Organization
WRC: The Water Resources Commission

1 INTRODUCTION AND PROJECT OBJECTIVES

1.1 Introduction

In 2000, 189 nations adopted the United Nations Millennium Declaration, and from that the Millennium Development Goals were made. The Millennium Development Goals (MDGs), the blueprint for the world to accelerate development and measure progress, contain a set of time-bound measurable goals and targets for combating poverty, hunger, disease, illiteracy, environmental degradation and discrimination against women. Of paramount importance in the water supply sector, is Goal 7, which aims at ensuring environmental sustainability. According the United Nations Mid-term Assessment Report (UNICEF and WHO, 2004), 80% of the world's population used an improved drinking water source in 2004, up from 71% in 1990. Although these numbers indicate the world is on track to meet the goal, there will be challenges as populations increase.

Two targets of goal 7 are:

- "To halve, by 2015, the proportion of people without sustainable access to safe drinking water and basic sanitation"
- "By 2020, to have achieved a significant improvement in the lives of at least 100 million slum-dwellers" United Nations (2006).

According to McGranahan et al (2006) water vendors can positively contribute the two targets of Goal 7 by filling in gaps in water supply provision in areas that lack access to water and also by improving livelihoods through employment generation in both rural and urban poor areas. However, according to WHO/UNICEF (2000), vended water is considered an "unimproved" source of water (Table 1.1).

This negative image has hindered initiatives to improve water provision through services offered by water vendors, along with other constraints which include pricing, water quality and supply related constraints, legal constraints, financial constraints, lack of technological innovations, and limited management capacity (McGranahan et al, 2006).

Despite these limitations, a rapidly emerging water vending business in Ghana and many other developing countries has been that of vending sachet water or bagged water, which is a cheaper alternative to bottled water. This project identifies ways that can improve the services offered by sachet-water vendors in Tamale, Ghana, that can enable the entrepreneurs to positively contribute to international goals. Focus is placed on the quality of sachet water, and the handling and distribution practices.

Because water obtained from 'improved sources' can also have a significant increase in contamination between the source and storage, the proportion of the world's population using safe drinking water is likely to be lower than that using improved drinking water sources. Pure Home Water (PHW), a social enterprise in Ghana, attempts to address the problem of providing access to safe drinking water, by marketing household drinking water treatment and safe storage (HWTS) products to low income customers in the Northern Region of Ghana. The project links the work of PHW with that of sachet-water vendors by analyzing the feasibility of marketing PHW's ceramic filter product to sachet-water vendors.

1.2 Background

1.2.1 The Global Need for Improved Water and Sanitation

According to the World Health Organization (2004), 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 diarrhoeal diseases, and 90% of these deaths are of children under 5 (WHO, 2004). Figure 1.1 shows the per-capita deaths per million related to water and sanitation in each country in 2000. Besides causing death, water-related diseases also prevent people from working and leading active lives.

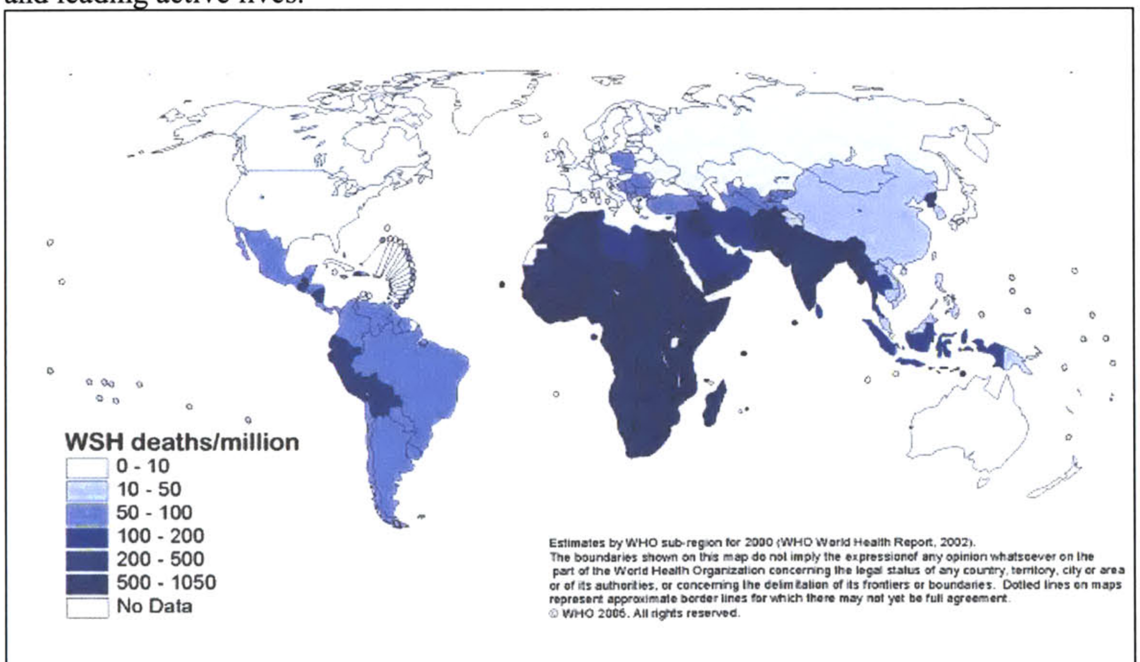

Figure 1.1: Deaths caused by unsafe water, sanitation, and hygiene for the year 2000, by country (WHO, 2002)

Table 1.1: Water supply technologies considered "improved" and "not improved"

Improved sources of drinking water	Unimproved sources of drinking water
– Piped water into dwelling, yard or plot – Public tap/standpipe – Tube well/borehole – Protected dug well – Protected spring – Rainwater collection – Bottled water*	– Unprotected dug well – Unprotected spring – Vendor-provided water – Tanker truck water – Surface water (river, stream, dam, lake, – pond, canal, irrigation channel)
*High quality bottled water is not considered "improved' because of limitations concerning the potential quantity of supplied water. It is thus considered an "improved" source of drinking water only where there is a secondary source that is "improved". (WHO/UNICEF, 2000)	

1.2.2 Ghana

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, at least 75 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).

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 diarrhoea. Diarrhoea 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 (UNICEF, 2004). The infant mortality rate currently stands at about 55 deaths per 1,000 live births (CIA, 2006). The major cause of diarrhoeal disease is lack of adequate sanitation and safe drinking water. 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).

Figure 1.2: Map of Ghana (CIA, 2006)

1.3 Pure Home Water (PHW)

PHW is a social enterprise established in Ghana to market HWTS products to low-income customers in the Northern Region of Ghana. It is the first social enterprise of its kind in Ghana that aims at giving users options to affordable and locally manufactured HWTS products through rural, school and hospital outreach, and retail sales.

The PHW project was initiated in August 2005 in the Northern Region. Figure 1.3 shows the districts in the Northern Region of Ghana where PHW works. The Conrad N. Hilton Foundation provided start-up funds for two years from 2005 to 2007, amounting to a total budget of US$ 150,000. The project's original goal was to be self sustaining by the sale of HWTS within this period, but we now know that PHW will not achieve this goal in that timeframe.

During 2006-2007 ("Year 2"), PHW has been managed by Elizabeth Wood, a recent Harvard graduate, and 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, who provide support through research, development, monitoring, and evaluation studies.

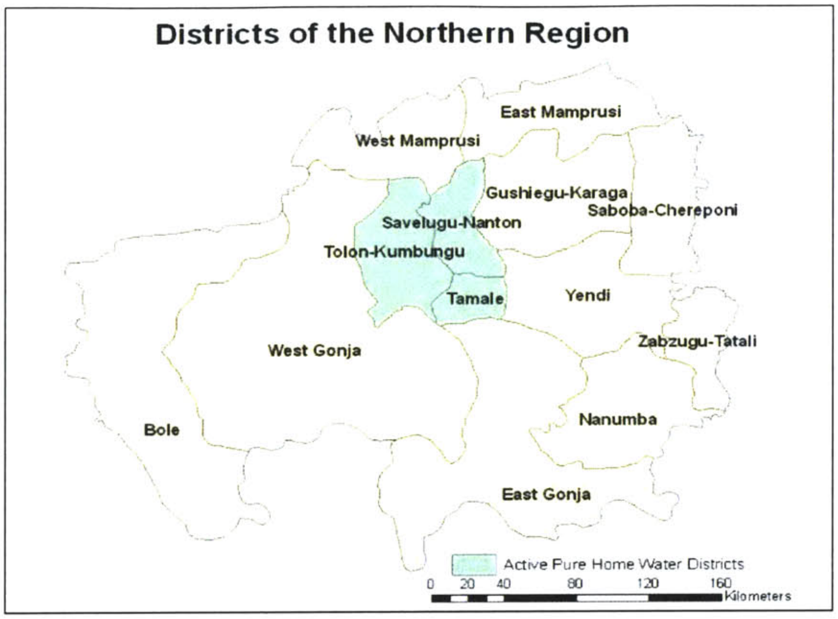

Figure 1.3: Presence of Pure Home Water in Northern Ghana (Mattelet, 2006)

1.4 The Products and Business Model of Pure Home Water

The goal of PHW is to provide "safe water to people in Northern Ghana in order to reduce or eliminate water-related diseases". The project's objectives are as follows:

- To verifiably improve water at the point-of-use by widely disseminating HWTS products in households, schools, hospitals and among leaders in targeted districts in Northern Ghana
- To create a sustainable market for HWTS through awareness-raising and education
- To establish a ceramic water filter factory and testing facility in the Northern Region of Ghana by December 2007

1.4.1 Pure Home Water Products

The initial strategy of PHW was based on marketing a large range of locally manufactured and affordable HWTS products, with the objective of giving consumers a range of options to choose from. The products consisted of solar disinfection (SODIS) systems, the modified clay pot, plastic safe storage vessels, biosand filters, Nnsupa candle filters and the Ceramica Tamakloe Filtron (CT Filtron) filter, which PHW has locally branded as the *Kosim* filter (meaning "the best of all water", in the predominant Northern Region local language – Dagbani).

Due to limited capacity and resources of its several person staff in Ghana, PHW narrowed down from a range of products to focus on promoting only the ceramic pot filter (the CT Filtron), the modified safe storage clay pot and a plastic safe storage container. The product selection was based on recommendations from the 2006 Global Entrepreneurship Lab (G-Lab) team and on performance and treatment efficiency evaluations undertaken by MIT engineering students and PHW staff, during the 2005-2006 ("Year 1"). PHW further narrowed its focus to concentrate on marketing the ceramic pot filter with the goal of setting up a filter factory and a water testing facility, where the performance of the filters produced would be assessed and the quality better controlled. The ceramic pot filter was selected as the main product due to the following factors:

- Proven user acceptability;
- Possibility of local production;
- Low cost treatment over the life of filter;
- High treatment efficiency and performance;
- "One-step" treatment and safe storage;
- Cultural compatibility with traditional ceramic clay storage vessels;
- Ability to treat water of very high turbidity, as is common in Northern Ghana.

The main problems identified with the ceramic pot filter included its relatively high initial price, filter breakage during transportation, slow filtration rate of approximately 2 liters per hour, necessity of regular weekly maintenance in order to maintain filtration rate, and the low levels of awareness of the technology.

The ceramic filter is made of a red clay and wood saw-dust mix. The mix is pressed into flower-pot-shaped filter molds using a hydraulic press, after which the units are dried and fired at approximately 830 °C. In firing the filter units, the saw dust burns and leaves pores through which water is filtered. The fired filters are then dipped into a mixture of water and colloidal silver1 (1cm^3 of 3.2% colloidal silver in 300ml of water). The colloidal silver prevents biofilm growth on the filter surface and may act as an

1 Colloidal silver is produced by passing a positive electric current through bars of silver immersed in water, thus forming positively charged ionic colloids of 0.015 to 0.005 microns. The colloids take on a positive ionic charge thus obtain their bacteriostatic capabilities. It is alleged that silver immobilizes enzyme responsible for oxygen metabolism in microorganisms and thus suffocates them. The electric charge of the silver colloids also destroys some pathogens (PFP, 2007).

The large scale production of colloidal silver impregnated ceramic filters was developed by Potters for Peace, a U.S and Nicaragua based non-profit organization, and has been applied in more than 8 countries in Africa, Central and South America and Asia. In Ghana the filters are locally manufactured by Ceramica Tamale Ltd under the C.T Filtron brand name and being marketed by PHW in Northern Ghana by the brand name Kosim.

antibacterial disinfectant. The filter unit is placed in a 40 liters plastic receptacle into which the filtrate is collected and decanted though a tap (Figure 1.4). The filters are tested to ensure that the flow rate is between 2 to 2.5 liters per hour and the filters thus ready for market and use. Figure 1.5 to Figure 1.12 show the ceramic pot filter production at Ceramica Tamakloe, Accra, Ghana and marketing and use by PHW, Tamale, Ghana.

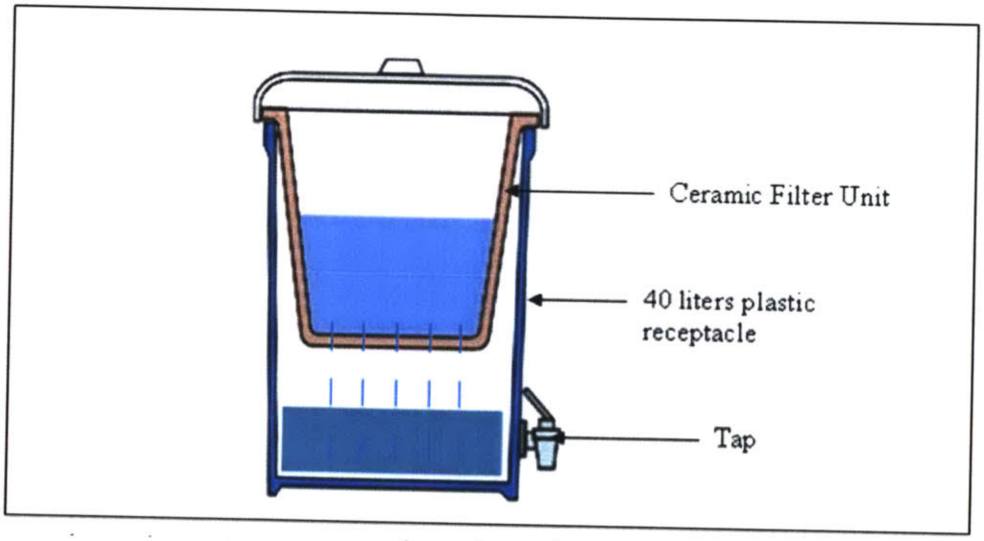

Figure 1.4: Schemata of the CT Filtron filter

Photos showing the ceramic pot filter production at Ceramica Tamakloe, Accra, Ghana and marketing and use by PHW, Tamale, Ghana

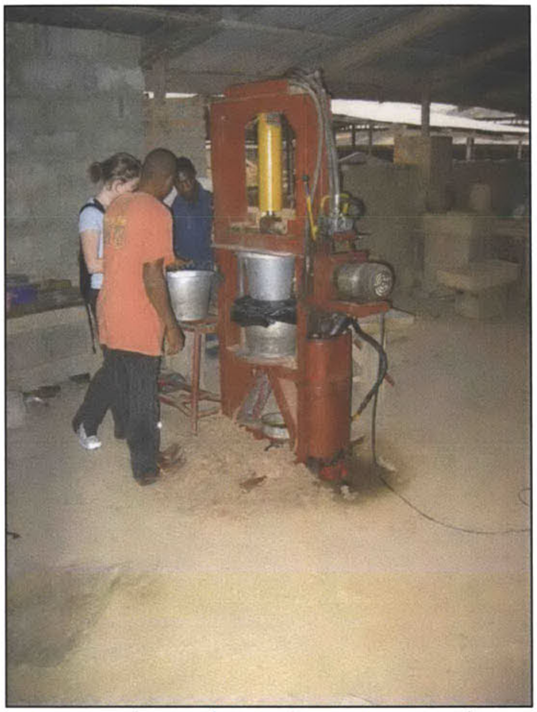

Figure 1.5: Shaping of ceramic filter units using a hydraulic press

Figure 1.6: Pressed filter extracted from mould

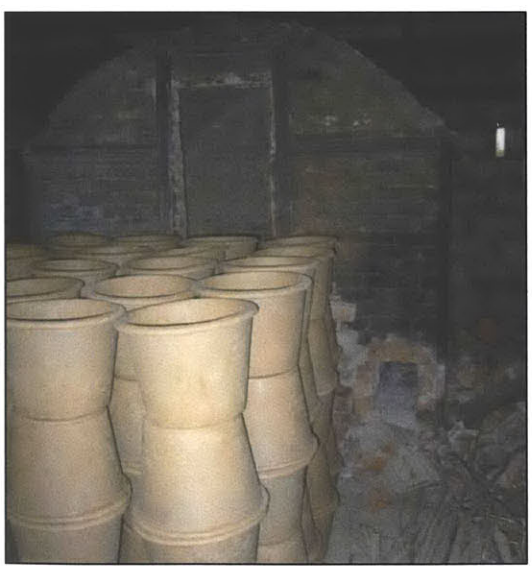

Figure 1.7: Filter awaiting firing in kiln

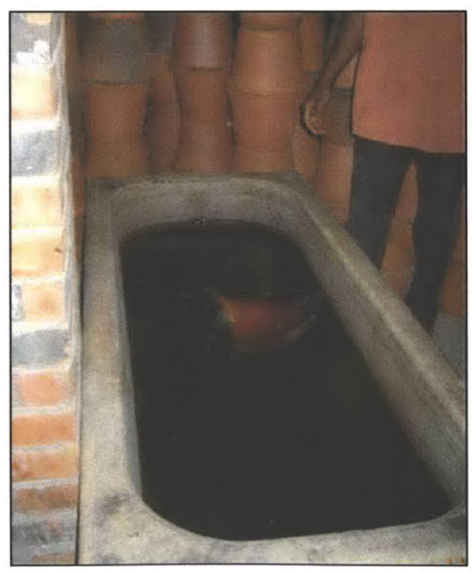

Figure 1.8: Colloidal silver treatment of fired filters

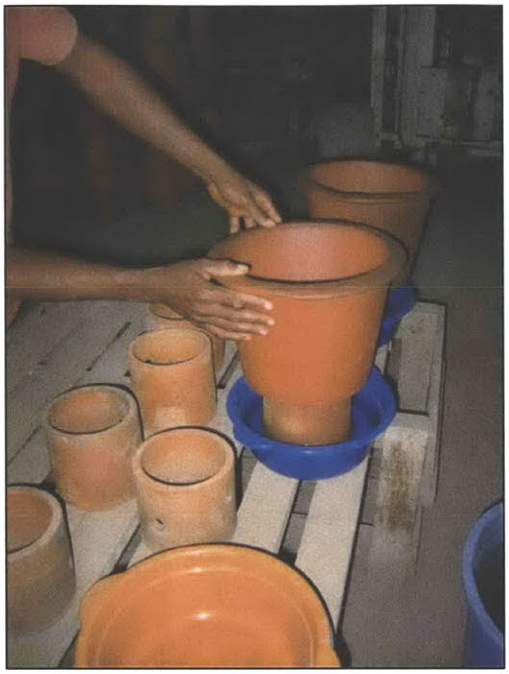

Figure 1.9:Testing filter flow

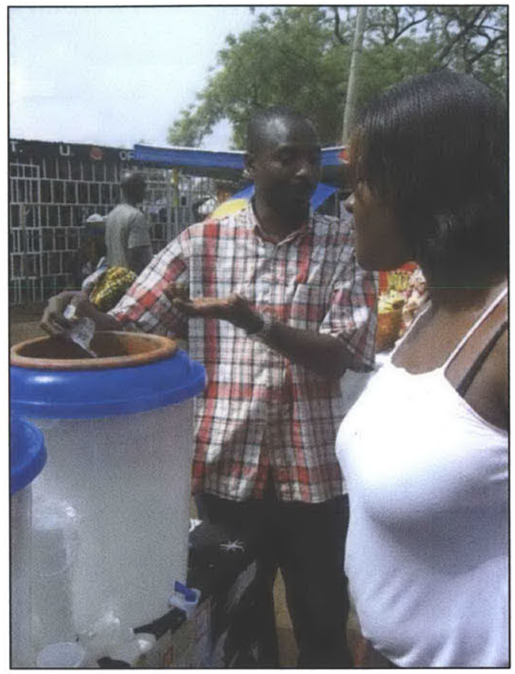

Figure 1.10: Marketing filter

Figure 1.11: Filter in use. Filtrate comparison with raw water

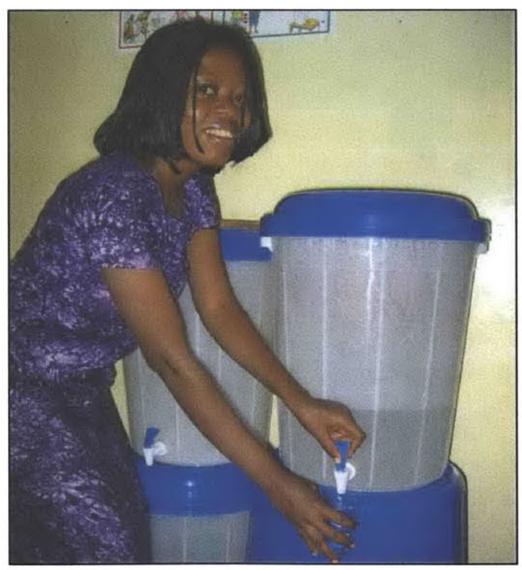

Figure 1.12: Clean water from safe storage container

1.4.2 Pure Home Water Business Model

During 2005-2006 year, PHW had set the CT filtron price at US$ 19 (GHC 170,000)[2] when bought in cash and US$ 20 (GHC 180,000) when bought on credit. The price of the filtering element was set at US$ 6.10 (GHC 55,000). However, according to surveys conducted by Peletz (2006), the willingness-to-pay for filter technologies was between US$ 8.00 (GHC 72,000) and US$ 8.90 (GHC 80,000). PHW thus realized that the ceramic pot filter would not reach the poor as it was unaffordable to many.

In August 2006 a two member Harvard-MIT Sloan Leader in Manufacturing team 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 hospitals, and a "subsidy price" for rural areas (Table 1.2). For the retail price, PHW sells to retailers for approximately US$ 11 (GHC 100,000), who then sell the filters to customers for US$ 13 (GHC 120,000). At these prices, PHW thinks it can generate profit if the filters are manufactured locally. The subsidy price was set by PHW at approximately US$ 6 (GHC 50,000) to reach rural villages [US$ 7 (GHC 60,000) when sold through community liaisons who earn a 1$ profit/sale]. The subsidy price was considered as a partial grant to target those who needed the filter most.

The Year 2 Strategy is comprised of three main elements based on the marketing approach and the target population, as follows:

Urban Outreach

In this outreach approach, business owners, referred to as retailers, located at urban centers, are approached to sell filters for a commission and at the "retail" price. 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.

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[2] The exchange rate used is US$1 = GHC 9,000.

Hospital Outreach

This outreach program is similar to the urban outreach in that filters are sold to individuals who re-sell 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.

School Outreach

In this 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 demonstration 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. Like in the Hospital Outreach Program, free filters are given out to each class for use and demonstrations, and maintained by the school liaisons.

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 leaders 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, presentations, and training sessions on use of the ceramic pot filter, distributing the filters to opinion leaders and selling them at the "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, in that they obtain user feedback information on the filter and answer questions posed by the communities.

A summary of all the key prices for the *Kosim* ceramic filter are given in Table 1.2

Table 1.2: PHW filter prices

Distribution Type	Distributor Cost	Customer Price
Hospital	US$ 11 (GHC 100,000)	US$ 13 (GHC 120,000)
Rural	US$ 6 (GHC 50,000)	US$ 7 (GHC 60,000)
Urban	US$ 11 (GHC 100,000)	US$ 13 (GHC 120,000)

Part of PHW's Year 2 Strategy is to manufacture its own ceramic filters in the Northern Region by December 2007, so as to be able reduce the costs incurred in disseminating the filters and enable the production and distribution and/or sale 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.

1.5 Objectives

Based on the success of the sachet-water industry in Ghana, which is a dynamic, and profitable new "bottom of the pyramid" industry, this 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.

1.5.1 General Objective

The overall objective of this thesis is to investigate the quality of sachet-vended water and suggest strategies for improving its water quality.

1.5.2 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.

2 WATER VENDING

2.1 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". In contrast, McGranahan et al (2006) includes both bottled and pre-packed water as a category of vended water. Kjellén and McGranahan (2006) generally refer to water vending as any form of water sale and suggest that utilities which charge for water can, strictly speaking, be referred to as water vendors. In "water literature" however, water vending is described as the "reselling or onward distribution of utility water, or water from other sources".

There are other names and labels that have been used to refer to water vendors, as well as more definitions that have been suggested. Conan (2003a) refers to water vendors as *Small Scale Independent Private Water Providers (SSIPWP)*, and distinguishes them from other water providers based on the following criteria:

- Small Scale: They are considered small scale due to the few number of employees;
- Independent: As they do not receive financial backing from government, local authorities or non-governmental organizations;
- Private – As their investment in water provision is for profit;
- Water Providers – Water provision accounts for more than 75 per cent of their business.

Conan (2003b) also refers to water vendors as *Small Scale Private Water Providers (SSPWPs)* and based on the criteria listed above, describes them as "small or medium scale entrepreneurs that have made water distribution their main source of income and who generally invest their own capital to initiate their services."

McGranahan et al (2006) refers to water vendors as *Small Water Enterprises (SWE)* and describes them as "private enterprises, usually operated by small-scale entrepreneurs (with a maximum of 50, and usually fewer employees), which earn money from sale of water."

The Water Utility Partnership (2002-2003), refers to water vendors as *resellers* and defines a water vendor as "an individual who purchases water (e.g., from a network connection or private borehole), then transports it and sells it to households and/or businesses".

2.1.1 Categories of Water Vendors

Just as there are several labels and terms used to describe water vendors, there are also several overlapping categories of water vendors. According to Whittington et al (1989) water vendors can be classified into three main groups based on their level of distribution and selling strategies. These are:

- Wholesale vendors;
- Distributing vendors;
- Direct vendors.

Wholesale vendors sell water from natural sources such as boreholes or from piped water networks, normally in bulk quantities, to distributing vendors or consumers. Distributing vendors sell water directly to consumers via door-to-door sales, while direct vendors have customers come to them (Figure 2.1).

Figure 2.1 Direct vendors in Tanzania

(Water Utility Partnership, 2001-2003)

Distributing vendors can further be categorized as water carriers and tankers. Water carriers mainly deliver water by non-motorized means using plastic or metal containers. They may transport water manually, by animal-power or by bicycles or carts. Water carriers mainly serve low income households that are similar to their own. Tankers use motorized means to deliver water and are able to deliver more water in terms of volume per unit time, but require a higher capital investment than carriers. Tankers normally serve high income customers or those who require bulk volumes of water. Figure 2.2

shows a water tanker that serves GILLBTs guest house in Tamale, where the author and teammates stayed. The tanker is owned by the guest house and water is purchased directly from Ghana Water Company. The capacity of the tanker is 2200 gallons and the cost per tanker load of water is US$ 18 (GHC 160,000). The tanker pumped water to an elevated tank which distributed water to the guest house buildings by gravity flow. At least two tanker loads are purchased per week by this particular guest house.

Figure 2.2: Water tanker serving GILLBT Guest House in Tamale

Collignon and Vézina (2002) categorize water vendors into three classes based on degree of investment, legality and relationship with municipal suppliers. These classes are:

- Standpipe vendors;
- Licensed water resellers and
- Unlicensed household water resellers.

Standpipe vendors are small entrepreneurs who operate standpipes installed by the water concessionaire or municipal water suppliers under a given contract. These vendors usually sell water in buckets or jerry cans with the standard volume of the containers normally being 20 liters.

Licensed water resellers are micro-entrepreneurs who also have a formal contract with the respective concessionaire. The contract allows them to resell piped water that is supplied to their homes to other consumers. Unlike standpipe water vendors, licensed water sellers generally have to invest in standpipe stations when required. They may then sell water from these stations or invest in network expansion for increased profit.

Unlicensed household water resellers are water vendors who do not have any form of legal support to carry out the sales. Though many times unlicensed household water resellers are not seen as professionals, of the three sub-categories mentioned, they provide the highest proportion of share in the market (Collognon and Vézina, 2002).

A relatively new category of water vending involves selling pre-packed drinking water. The scale of this business ranges from small-scale entrepreneurs who simply fill tap water or water from other secondary supplies in plastic bags and hand-tie or heat-seal the bags producing what can be referred to as 'hand-tied' or 'home produced' sachet water; to industry or factory-produced sachet water, that more likely treat the water sold and that are of a larger scale; and finally to larger businesses producing bottled spring or mineral water.

McGranahan et al (2006) categorize water vendors into four main classes and includes vendors of bottled and pre-packed water as a separate category. The four categories given are:

- Resales – households that are connected to piped water supplies and that sell the water supplied to their homes. Water can be sold in small volumes or through extensions to the piped networks that serve them;
- Distributing Small Scale Water Enterprises – water carriers and tankers;
- Private Supplies – water venders that sell water from supplies other than utility sources such as groundwater sources (private boreholes and wells);
- Bottled or pre-packed water – including hand-tied and factory-produced sachet water.

There is validity in all the water vending definitions that were presented in Section 2.1, and thus the definition of water vendors and water vending that is used in this thesis, is a composite of the descriptions presented and includes packaged water.

DEFINITION – WATER VENDING

For the purpose of this thesis, the <u>water vending</u> or the <u>water vendors</u> 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.

In this case, distributors generally refer to those vendors who buy large quantities of water (either packaged or unpackaged such as in the case of tankers) and sell the water to other entrepreneurs rather than the ultimate consumers or buyers. Resellers refer to vendors who buy and sell water in bulk quantities to the end consumers, while retailers refers to vendors who buy water in large quantities, but sell the water in smaller volumes to end consumers.

Figure 2.3 shows the categories of the water vendors discussed and gives a schematic representation of the relationship between the different categories. The schematic representation does not, however, give an actual representation of the hierarchy of the water vendors, as this may be location specific and may also vary among different social set-ups.

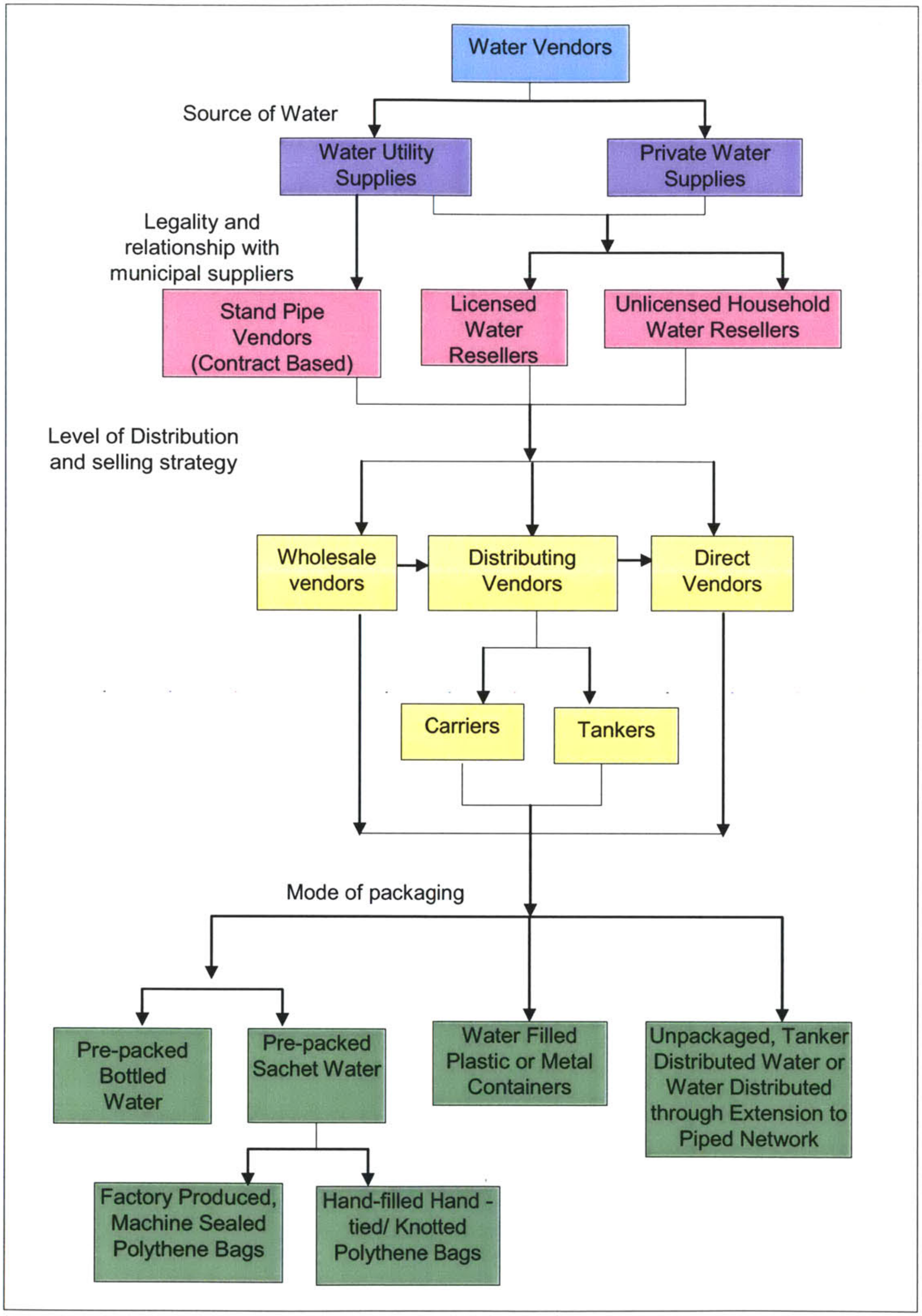


Figure 2.3: Categories of water vending

2.1.2 Water Vending Distribution Routes

Generally speaking, water supply and distribution routes mainly depend on the available sources of water. In urban areas with piped network connections, high and middle–income households are typically connected. Water vendors serving these communities re-sell piped water to low-income households that lack coverage. In peri-urban areas and areas not reached by piped water, more sources of water are tapped as the density of low income households increases, with free sources preferred. Low-income households buy as little as they must and only after having exhausted all the free sources, such as water from wells and springs. In peri-urban areas, vendors typically transport water using hand-carts and animal-drawn carts, and sell the water to middle and high-income households. Figure 2.4 shows a schematic view of the sources of water production and the diversity of water distribution to low-income residents of typical African cities (Collignon et al, 2000).

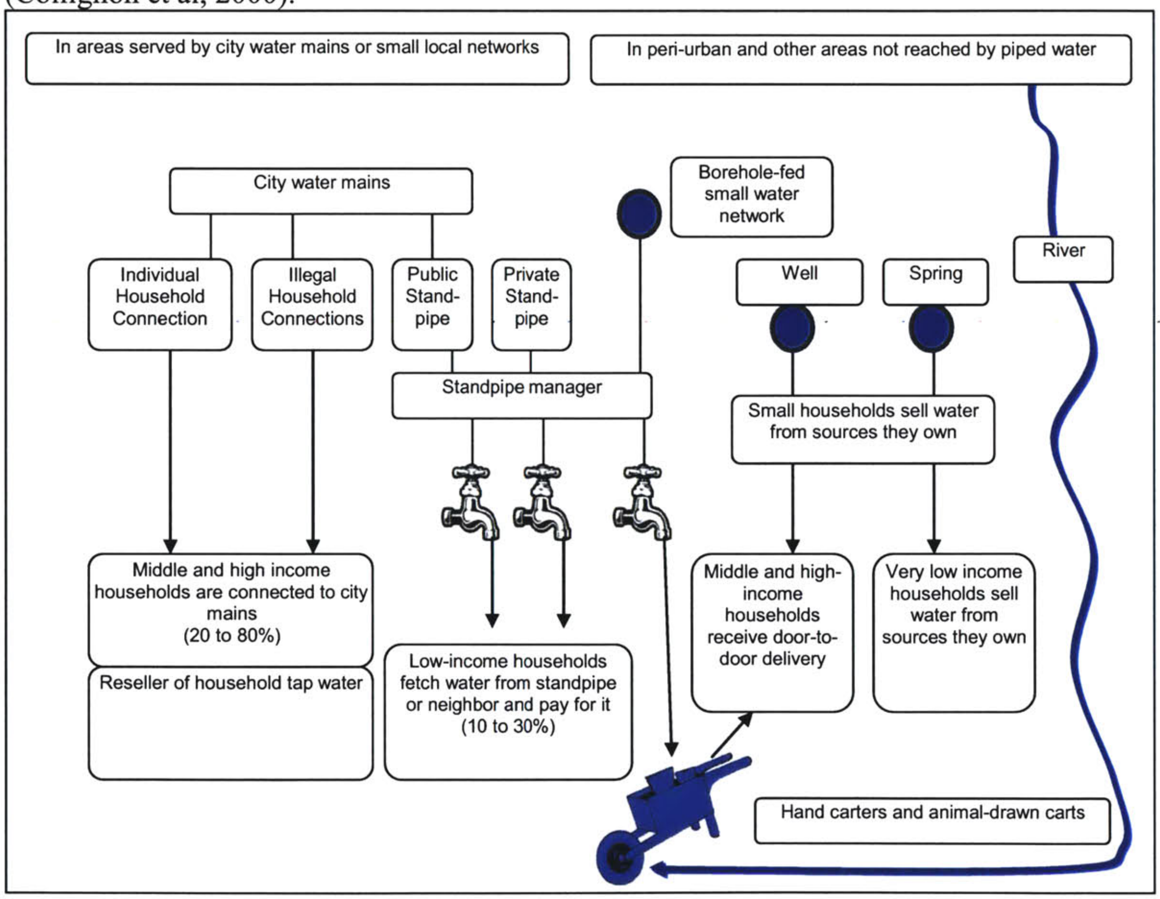


Figure 2.4 : Water supply and distribution routes (Collignon B. and Vézina, M., 2000)

2.2 Water Vending and Water Supply Policy Framework in Ghana

In order to make an analysis of sachet water and generally understand the water vending situation in Ghana, it is important to first get an overall picture of the policy framework of water supply in the country. According to World Bank/African Development Bank (2004), the *Ministry of Works and Housing (MoWH)* in Ghana is the agency responsible for policy formulation, monitoring activities and coordination for the water sector. *The Water Resources Commission (WRC)* and the *Environmental Protection Agency (EPA)*, created by an Act of Parliament in 1996, are responsible for regulating and managing utilization of water resources and for enforcing environmental laws, such as those pertaining to water resources pollution. There is currently no specific body responsible for monitoring drinking water quality of vended water and the role is shared between the Ghana Standards Board (GSB), EPA and the Food and Drugs Board of Ghana (FDB). The statutory mandate to ensure water quality is unclear.

Water and sanitation services in rural areas and towns are managed by the *Community Water and Sanitation Agency (CWSA). District Assemblies* manage project implementation and approve tariffs set by the CWSA through *District Water and Sanitation Teams (DWST).* These teams are responsible for selecting beneficiary communities for water supply projects and applying for national program benefits on behalf of the communities. Community Water and Sanitation Committees are set up to manage operations of water points, such as communal boreholes or hand pump water supply systems, and also setting tariffs.

Non-governmental Organizations (NGOs) and charitable institutions also play an important role in water supply in rural areas through capacity building, funding and implementing water supply facilities.

In small and medium towns, *Water and Sanitation Boards* are established to manage water facilities and set tariffs. Like in rural areas, *District Assemblies* approve tariffs set by the Town Water and Sanitation Boards and manage project implementation such as community-managed small pipe systems.

The *Ghana Water Company Limited* (GWCL*),* formerly the Ghana Water and Sewerage Corporation, is responsible for planning, development and operation of water supply systems in large towns and cities and some medium towns that are not under community management. GWLC currently supplies water to 59% of urban areas in Ghana. The remaining 41% mainly rely on water vendors and private sources (McGranahan et al, 2006).

In 2005, as a strategy for ensuring sustainable water supply systems in Ghana, donors, led by the World Bank, included conditions for the Government of Ghana to bring in private sector participation in the operations of the Ghana Water Company as preconditions set for the country to receive funding. This involved combining public ownership and private management through management contracts (Whitfield, 2006). In July 2005 a Dutch company, Vitens International BV, and a South African company, Rand Water

Services Pty, jointly submitted a bid for the management contract of the Ghana Water Company among other bidders. In November 2005, the two companies were awarded a 5 year contract for take over commencing in April 2006 (Norwegian Forum for Environment and Development, 2006). The World Bank provided a grant of US$ 103 million, the Nordic Development Fund US$ 5 million and the Republic of Ghana US$ 12 million (GWCL, 2007).

GWCL realizes the importance of vendors in urban areas where piped water supplies do not reach. According to McGranahan et al (2006), tanker operators in Accra have formed a Tanker Operators Association through which, GWCL attempts to regulate their operations and price. However, most vendors still do not operate under any formal agreements. Also, many vendors in the associations do not always adhere to agreements, especially during water shortages, when they take advantage of the situation to make large profits. These vendors also operate outside the territories designated in their association agreements. These "intermittently enforced regulations" encourage corruption and destabilizes the already weak regulatory framework.

2.3 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". According to the Stockholm Environment Institute (1993), "ice-water" vendors get their local name because most of them add blocks of ice to water sachets contained in ice-boxes or pots to cool the water. However, to majority, "ice-water" simply means hand-tied sachet water weather it is cooled or not.

KEY FINDINGS

In this thesis machine-sealed sachet water that is produced in industries is referred to as "<u>factory-produced</u>", while that produced by manually filling plastic bags with water and knotting the water-filled bags is referred to as "<u>hand-tied</u>" sachet water.

The main source of the sachet water in both cases is tap water. Sachet water produced in small-scale industries is mainly treated by aeration, double or single filtration using porcelain molecular candle filters or membrane filters and in rare instances, disinfection is applied. The level of treatment generally depends on the source of water. However, sometimes tap water is used without additional treatment and is sold in markets without clearance from the Foods and Drugs Board of Ghana or other bodies concerned with water quality (Dodoo et al, 2006).

Figure 2.5 shows sachet-water production in factories, while Figure 2.6 shows hand-tied sachet water being produced. The production process is discussed in Chapter 6.

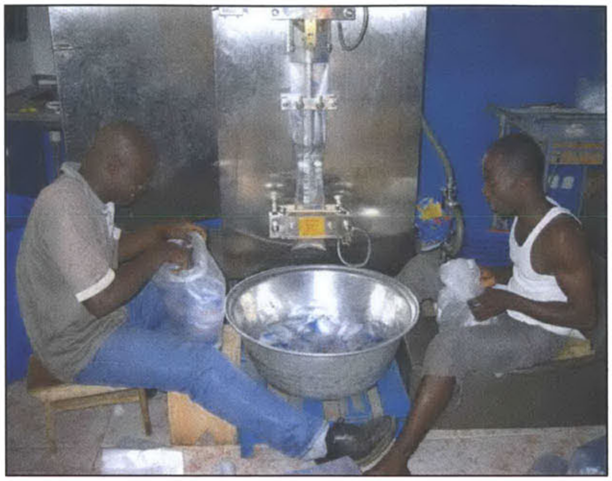


Figure 2.5 :Factory-produced sachet with sealing machine in the background

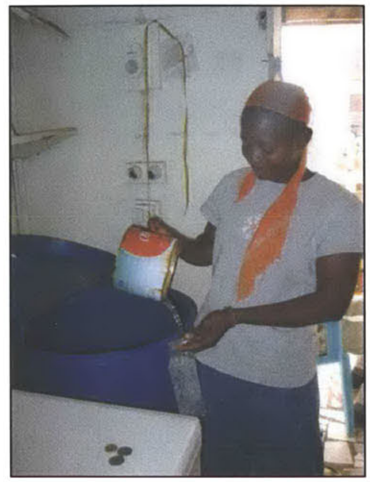


Figure 2.6: Hand-tied sachet water being manually filled

2.3.1 Previous Studies on Microbial Quality of Sachet Water in Ghana

For an overview of the indicator organisms used in microbial water quality testing, the reader is advised to make reference to Section 10.4 of Appendix IV, which gives a background to microbial water quality.

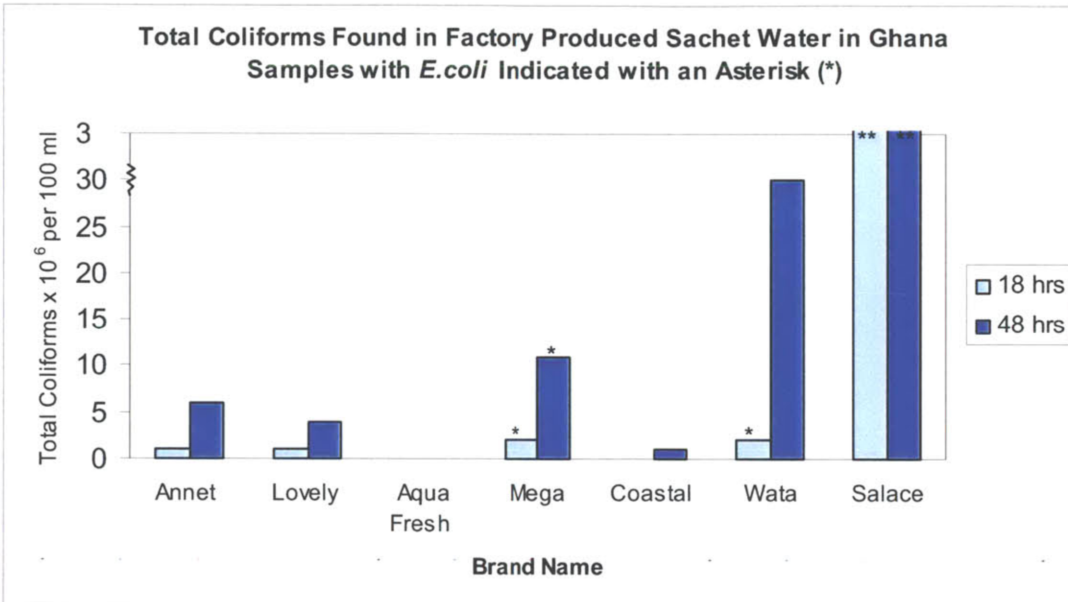
Previous research works on the quality of sachet water in Ghana include three separate studies in three locations: the Cape Coast Municipality of Ghana (in the Central Region), Kumasi (in the Ashanti Region) and the Greater Accra Metropolitan Area (GAMA). See Figure 2.7. Results of these studies are discussed briefly in this section.

Figure 2.7: Regions and major cities of Ghana (VanCalcar, 2006)

Studies conducted by Dodoo et al (2006), involved testing the quality of a total of 29 "brands" of factory-produced sachet water in the Cape Coast municipality of Ghana and using 180 random samples exposed to three different environmental conditions; the sun (40°C), room (28 °C), and in the laboratory (28 °C) . The water quality tests were carried out using the membrane filtration method with lauryl broth or algar medium, and/or by the multiple tube fermentation method. Results indicated that 45% of the brands of sachet water contained total coliform bacteria in at least one test. The total coliform counts ranged from 0 colony forming units (CFU)/100ml to 98 million CFU/100ml.

Three out of seven brands (Mega, Wata and Salace) returned positive results for *E.coli* in their analysis [indicated with a single asterisk (*) in Figure 2.8]. Figure 2.8 shows the maximum number of total coliform colonies counted for sachet water stored at a temperature of 40°C (sun exposure), that simulates the environmental conditions sachet water may be exposed to when sold in open air markets or on streets by roadside vendors.

The tests were run once per week over five weeks. Two counts, at 18 hours and 48 hours of incubation at 37°C, are shown. Only one brand out of the seven (Aqua Fresh) was free of total coliforms for tests run under the specified conditions. Two brands, Mega and Wata, incubated for 18 hours and 48 hours, showed the presence of *E.coli* as represented by an asterisk.



* *E.coli* Present

**Too Numerous to Count (TNTC)

Figure 2.8: Total coliforms found in factory-produced sachet-water. Data from Dodoo et al (2006)

A result not shown in Figure 2.8 but relevant is that samples of the brand Salace stored at room and lab environments (28 °C) showed *E.coli* while samples of this brand that were exposed to the sun (40°C) did not.

Obiri-Danson et al (2003) analyzed the quality of bottled water, factory-produced and hand-tied sachet water sold in the streets of Kumasi in Ghana, using membrane filtration. The water samples they considered included eight samples of bottled water, 88 factory-produced sachet-water samples and 40 hand-tied sachet-water samples.

While their results showed no presence of total coliforms in bottled water (0 CFU/100ml), 4.5% of the factory-produced sachet-water samples showed total coliforms (counts ranged from 10 CFU/100ml to 13 CFU/100ml for positive results) and 2.3% had fecal coliforms (2 samples both 10 CFU/100ml).

For the hand-tied sachet water 43% (17 samples) were positive for total coliforms (range from 10 CFU/100ml to 67 CFU/100ml). Twenty three percent (9 samples) showed presence of fecal coliforms (range from 10 CFU/100ml to 20 CFU/100ml). Figure 2.9 shows the percentage of positive *E.coli* and total coliform results from the samples tested.

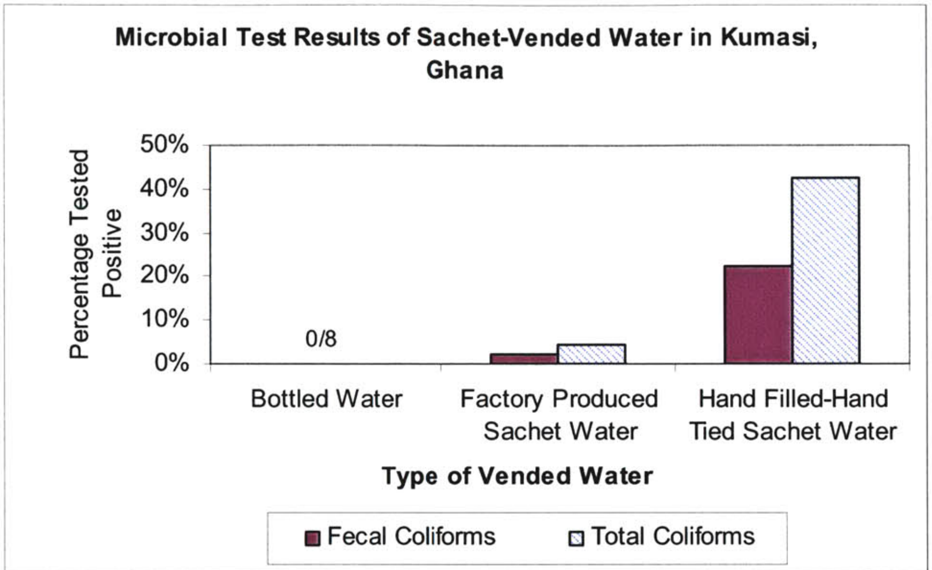


Figure 2.9: Results from microbial tests of vended water in Kumasi, Ghana. Data from Obiri-Danson et al (2003)

In the Greater Accra Region, the quality of "ice-water" sold in the streets was analyzed by SEI (1993). Here, tests were conducted to obtain the numbers of total coliform, fecal coliform and fecal streptococci. Although no fecal coliforms were detected, 78% of total coliforms were found in the range of 11-100 CFU/100ml, and fecal streptococci, 33% in the range of 11-100 CFU/100ml and 67% in the range of 101-1000 CFU/100ml, were found confirming the presence of fecal contamination (Table 2.1).

Table 2.1: Bacteria Concentration of Drinking Water from 'Ice-Water' vendors.

	Total Coliform		**Fecal Coliform**		**Fecal Streptococci**	
Counts/100ml	No.	%	No.	%	No.	%
0	0	0	42	100	0	0
1-10	5	22	0	0	0	0
11-100	18	78	0	0	14	33
101-1000	0	0	0	0	28	67
Total	23	100	42	100	42	100

(SEI, 1993)

2.4 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.

Products that have been certified by the GSB, including factory-produced sachet water, bear the "Mark of Conformity", also called the "Certification Mark" or the "Quality Mark". The procedure for obtaining certification for sachet-water factories includes submitting a complete application form together with a registration certificate for the factory. An inspection of the factory is then carried out to assess its Quality Management System and laboratory analyses of water samples taken. The sachet water is also inspected to assess the labeling requirements (GSB, 2004). According to the specifications given by the GSB (1998), all packaged drinking water is required to have the name of the product, the brand name or trade name if any, the net volume, name and address of manufacture, the batch code and the expiry date indicated by the words "BEST BEFORE".

Sachet-water factories that conform to all requirements are then issued with a license which authorizes them to use the Board's "Mark of Conformity". The license is valid for one year after which it can be renewed. The certified products are regularly audited by the GSB, both at the factory and market, to ensure that the quality is maintained. The certification mark therefore generally serves as an assurance of quality in locally produced goods in Ghana. Figure 2.10 shows the mark of conformity. The mark has a logo that bears a unique registration number for all products and a standard number that depends on the type of product.

The FDB enforces its own standards as well as those of the GSB. Although the FDB was established in 1993, it became fully operational in 1997 (USDA, 2005). The registration procedures for food products in Ghana, including sachet water, involve completing an application form and submitting it together with supporting documents that include a business registration certificate, certificate of analysis, a site master plan of the factory, and health certificates for all workers in the product line showing test results for tuberculosis, hepatitis A and E, typhoid and other communicable diseases.

Water samples are analyzed to assess the quality before registration is approved. Once the sachet water is registered with the FDB, the registration is valid for three years and is renewable by the end of the third year.

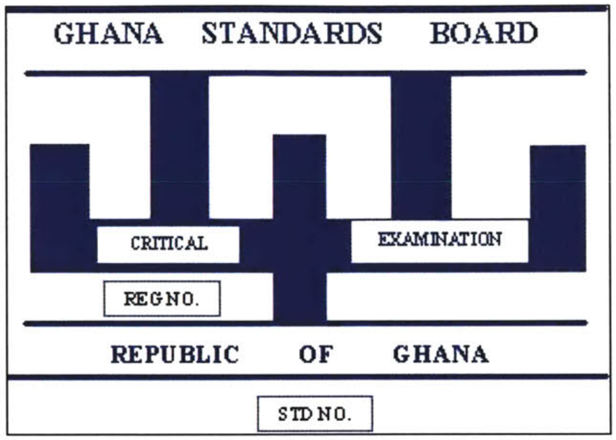


Figure 2.10: The GSB mark of conformity (GSB, 2004)

KEY FINDINGS

The Food and Drugs Board (FBD) and the Ghana Standards Board (GSB) both regulate and certify factory-produced sachet water. It is mandatory to have the factory-produced sachet water approved and registered with the Food and Drugs Board

2.5 Guidelines Set by the Food and Drugs Board (FDB) in Accra

The Food and Drugs Board of Ghana (FDB, 2005) specifies guidelines for the establishment of food industries, which also applies to factory-produced sachet water. Applications for the establishment of sachet-water factories are submitted with supporting documents which include a site plan of the production premise and an environmental permit from the Environmental Protection Agency (EPA). Other requirements and relevant documentation, as obtained from personal communication and literature provided by the FDB staff in Accra, are summarized as follows:

Personnel

The manufacturing premises are required to have, among other departments, a quality control and production department. Personnel in charge of production and quality control are required to have relevant training, experience and suitable qualifications in the production process. Based on information provided by the FDB, Accra, specific personnel information required by the FDB include the distribution of personnel as per departments and the responsibilities of each department, the key personnel and their responsibilities, the personnel health policy and the protective clothing policy of the industry being considered.

Premises and Equipment

The FDB requires documented information on the premise (nature of building) and equipment of sachet-water factories. This includes general information on interior surfaces, drainage system, ventilation, water and electrical systems. The type and make of equipment used and the maintenance and standard operating procedures, quality control as well as the equipment validation and calibration information are also required. The design and placement of equipment used is checked to ensure that it can be easily cleaned and disinfected and properly maintained and used. Floor plans that show the positions of equipment and facilities are required. As described by the FDB employees, other guidelines that relate to the premises include:

- Smooth flooring with no cracks that can possibly harbor vectors;
- Fluorescent lights with shatter proof bulbs to contain the glass particles if the bulbs should break;
- Walls coated or clad with washable material such as tiles or oil-based paints;
- Wiring and electrical connections and devices covered by electrical cover plate.

Water, Health, Safety and Hygiene

The staff working with sachet-water production (or other food and drug products) is required to undergo periodic health checks to ensure they are free of any communicable diseases. They are also required to have protective clothing, such as gloves. Other documented information required by the FDB , as related to hygiene, includes the cleaning and disinfecting agents used, the pest management strategies, the disinfection standard operating procedure and, where applicable, the effluent discharge and treatment.

Record Keeping

The FDB requires production records documenting all batches of sachet water produced and the materials and processes applied at each stage of production. Records of complaints on product quality and the corrective actions taken are also required.

Minimum Water Treatment Requirements

According to information given during the interview session with the FDB staff, the minimum water treatment requirements in sachet-water production is filtration followed by UV disinfection. At least 5 filters and one UV disinfection unit are required for each sachet machine. The filter cartridges are required to be changed at least once every 3 months.

Water Quality Tests, Licensing and Certificates

According to interview responses by the FDB, two categories of licenses are issued and are described below:

Pre-licenses: Here, the FDB carries out water quality analysis on samples of sachet water produced by unregistered factories before they are allowed to produce and market sachet water. Here, the factory owners pay for all costs incurred in carrying out the tests. A certificate of analysis is then issued as one of the required documents for registration or renewal.

Post-licenses: This is carried out randomly on sachet-water samples produced by registered sachet-water factories to ensure that production of quality water is maintained. Post-licensing is carried out at the expense of the FDB. It is sometimes based on customer complaints. The FDB carries out punitive measures, such as license withdrawal, if samples tested are not of quality.

A product certificate is issued for factories that meet the water quality requirements. According to information provided during the study visit, three certificated are therefore required for factory-produced sachet water: One certifying the product is of quality (certificate of analysis), one to certify the premises are up to standard and the third to certify that the factory workers handling sachet water are of good health. The premise certificate and certificate of analysis must always be displayed in the factories.

2.6 Plastic Material Used for Sachet-water Production

The plastic bags used in hand-tied sachet-water production are made of transparent, linear low-density polyethylene (LLDPE) film grade plastics. This type of plastic is very flexible and can elongate easily under stress, making it possible for hand-tied sachet-water vendors to knot the bags. On the other hand, the bags used for packaging factory-produced sachet water are made of high-density polyethylene (HDPE), which is slightly more opaque than the LLDPE used for hand-tied sachet water, has a higher tensile strength (more difficult to elongate), and can withstand higher temperatures (Polyprint, 2007). The two types of plastics are made from the distillation of crude oil and the principal raw material is ethylene gas (monomer) as shown in Table 10.1 of Appendix I, which shows the origin of these and other commonly-used plastics.

2.7 Toxicity/Safety of using Food-grade Plastics for Packaging

The use and manufacture of plastic is a much-debated issue as regards to its advantages and disadvantages, especially as it relates to impacts on the environment and public health. While the subject of use of plastics in water vending has not been extensively researched in this thesis a brief discussion is in order.

Toxic chemicals used in the production of low density polyethylene (LDPE) include benzene, chromium oxide, cumene hydroperoxide, and tert-butyl hydroperoxide, while those used in the production of HDPE include chromium oxide, benzoyl peroxide, hexane and cyclohexane (Wirka, 1988). Studies however show that many chemical residues in plastics that are considered to be toxic do not necessarily migrate into food stuff. For example, studies done by Fordham et al (1994), to analyze element residues used as polymerizations aids in food-contact plastics and their migration into food simulants (3% acetic acid, 15% ethanol and olive oil) showed that migration of these residues was less than limits proposed by the European Community Council Directive (EEC, 1992), and generally less than 1mg/kg under varying conditions of temperature and time (40°C/10 days and 100 °C/2 hours).

A number of pesticides and plasticizers are suspected endocrine disruptors[3] based on limited studies on animals (NRDC, 1998). Di (2-ethylhexyl) phthalate is an example, and is used (95%) as a plasticizer in the production of polyvinyl chloride (PVC) and vinyl chloride resins (U.S. Dept. of Health and Human Services, Public Health Service, Agency for Toxic Substances and Disease Registry, 1993). Goettlich (2006), lists, among PVC plastics, other suspected endocrine disruptors which include health and beauty aids (cosmetics, sunscreens, perfumes, soaps); pharmaceuticals (birth control pills); dental sealants; solvents; surfactants; and pesticides. More specific research in the area is recommended for plastics used in the sachet-water industry in contact with water and under similar environmental conditions. Studies on the feasibility of recycling plastic waste generated from sachet-water packaging are also recommended. Plastic recycling codes (resin identification codes) that were developed by the Society of the Plastics Industry, Inc. (SPI) in the United States are shown in Table 10.2 of Appendix I, while Table 10.3 of Appendix I, shows various recycling symbols used.

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[3] An endocrine disruptor is a synthetic chemical that imitates hormones in the body of humans and other species and/or blocks them, thus disrupting normal bodily functions. The functions can be disrupted through "altering normal hormone levels, halting or stimulating the production of hormones, or changing the way hormones travel through the body, thus affecting the functions that these hormones control" (NRDC, 1998).

2.8 The Water Vending Business: Strengths and Limitations

Water vending often occurs in developing countries due to inadequacy in water service provision from utility networks (Zafoff, 1984). Water utilities have often been unable to deliver services efficiently due to the following reasons:

- Inability to expand existing services relative to the rapid population growth. This has resulted to intermittent supplies of water, poor water quality and low water pressures.
- Limited availability of funds required for increasing supply coverage in urban and rural areas. This inhibits and discourages new developments.
- Lengthy process in planning, design and implementation of piped systems. This has led to substandard interim solutions.
- Unwillingness of water utilities to provide services in squatter settlements that are often located in marsh lands, flood plains, and other areas that offer limited returns on investments required.
- Unavailability of funds, skilled personnel and spare parts required for operation and maintenance operations in rural areas.
- Unrealistic design standards that often need to be scaled down in instances where it is more realistic to spread out resources rather than concentrate resources for fewer people to meet standards.
- Unwillingness to charge/unwillingness to pay the full cost of water.

Strengths of water vendors are several. Water vendors generally provide services in areas that lack water and those that have inadequate and intermittent supplies. They play an important role in complementing services provided by official water utilities, by providing water in areas that have little prospects of being served by utility supplies.

According to Kjellén and McGranahan (2006), water vending also positively contributes to employment generation in local communities and often provides more jobs within the water sector than official water utilities.

However, McGranahan et al (2006) highlights some key limitations faced by water vendors with reference to studies conducted for Accra, Ghana:

Limited Supplies- Tanker operators in Accra ostensibly have restrictions based on the number of days and hours they can operate, the points at which they can fill their tanks, and the areas in which they are allowed to sell water.

Pricing – Water vendors are charged a commercial tariff, much higher than domestic tariffs. The amount charged by tank operators is a sum of the commercial tariff, transport, income tax and profit, which frequently translates into higher vendor prices in comparison to utility supplies. For example, utility supplies in Tamale cost US$ 0.5/m^3 whereas tanker water costs approximately US$ 3/m^3 (Table 10.7 of Appendix I).

Financial constraints - Water vendors normally do not have access to credit for investments required. They are therefore limited in their mode of operation.

Water Quality – There is lack of water quality awareness among many water vendors and their customers, therefore, the quality of water is typically assessed by observing color, odor and taste of water. Also, the means of water storage and extraction further presents a challenge in assuring water quality.

Management– Many water vendors do not keep proper records of their sales, incomes and expenditures and sometimes do not separate their water sales from water they use domestically. This makes it difficult for them to ascertain their profit margins.

Recognition – Despite the role they play in water supply, water vendors do not often receive support or formal recognition and thus their activities and charges are not properly regulated. However, as we have already described in Section 2.4, in Ghana, the FDB and the GSB regulate and certify factory-produced sachet water but not hand-tied sachet water.

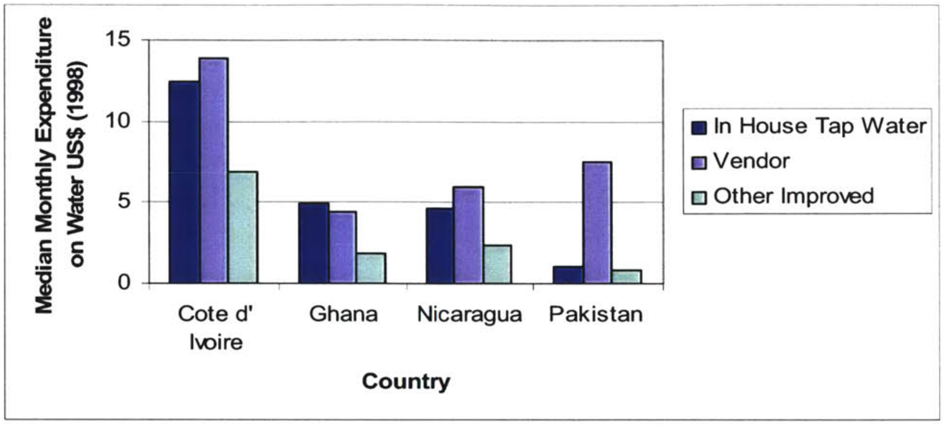
2.8.1 Water Vendors: Coverage and Price

Although it is difficult to estimate the percentage of the world's population that relies on water vendors, it is clear that in many cities and smaller urban centers in sub-Saharan Africa, and in low income nations in Asia and Latin America, water vendors play a much more important role than large-scale water companies in terms of the number of people they reach and especially the low-income households they serve (UN-HABITAT, 2005).

According to Briscoe (1985), as quoted by Cairncross and Kinnear (1991), approximately 20 to 30 percent of the urban populations in developing countries depend on water vendors. However, more recent studies by Komives et al (2000) show that from surveys conducted in a sample of 15 countries between 1988 and 1998, for which information on water vendors is available for four countries: Cote d'Ivoire, Ghana, Pakistan, and Nicaragua, only 2.4% of households depend on water vendors as their primary source of drinking water. In Ghana, the population that primarily depends on vended water is only 1%. Figure 2.11 shows that in three of the four countries mentioned, households using water vendors spend, on average, more that those connected to pipe water or those using improved sources. In contrast, households in Ghana that rely on water vendors spend approximately 10% less than those with "in-house" tap water, according to Komives et al (2000).

While vendors may generally sell water at higher prices, this is not necessarily always true. Studies conducted by Solo (1999) showed that individual provider charges ranged from one-tenth to eight times those of the public providers. Where much higher charges are reported, it is also worth noting that most public water companies' prices are subsidized, and the actual price may be paid through other taxes. According to UN-

HABITAT (2005), the price charged by vendors also strongly depends on the ease or difficulty by which vendors can get water close to their customers.



"Other improved sources" include yard taps, public taps, wells, and rainwater collection

Figure 2.11: Median monthly household expenditure on water, by households relying on different primary drinking water sources

(Komives et al, 2000)

2.8.2 Relative Competencies in Water Vending

Despite the challenges water vendors face, they have unique competencies in their business. Those that are also applicable to sachet-water vendors are described below.

Demand responsiveness - The water vending business is generally demand driven. Though water vendors are sometimes accused of supplying water at high prices, they do so in direct response to consumer demand and willingness to pay.

Customer service quality - Water vendors form personal relationships with their clients and are keen in creating customer loyalty especially when competing with public operators that offer subsidized rates (Solo, 1999). According to McGranahan et al (2006) they also have potential advantages in reaching the poor in service provision through:

- Providing services in remote areas;
- Selling small affordable quantities of water to customers who cannot afford to buy large quantities;
- Giving customers credit and being flexible with different payment modalities;
- Adapting their service according to the physical and social setup of their client communities.

Local knowledge – Local knowledge of the community and society enable the vendors to understand their customers' needs and respond appropriately to them.

Lower rates - Water vendors often lower their price when actively competing for markets.

Varied services – In some areas, sachet-water entrepreneurs offer a wide range of products including flavored water and other similar products. Knowing their markets and customer habits gives them an advantage of discovering and developing new products.

Capacity to grow with demand - Water vendors increase their service delivery as demand grows. Their expansion does not depend on external funds and large capital costs. They are also able to "stake a fast claim" in developing areas as they know about new settlements well before municipal planners and other stakeholders do. This puts them ahead of their competitors (Solo, 1999). According to McGranahan et al (2006) they also have the advantage of being able to serve markets with low entry and investment costs.

Capacity to reach the poor - Water vendors disregard issues such as security of tenure, income levels, and population size and are thus able to reach slum dwellers and marginalized groups (Solo, 1999).

Innovative in their use of local resources and flexible in technologies - Unlike large-scale companies, which are easily discouraged by risks and costs associated with new technologies, small scale entrepreneurs are keen in introducing innovative technologies, market approaches and administrative systems (Solo, 1999). These entrepreneurs are also innovative in their use of local resources (McGranahan et al, 2006). This enables them to minimize costs required in delivering their products and services.

Profit-driven - Water vendors set their prices to cover their costs, unlike public sector companies that tend to undercharge, making it difficult for them to increase their coverage and serve poorer population groups (McGranahan et al, 2006).

Job creation - Water vending provides a range of job types, from unskilled to skilled. Since it is labor intensive, a variety of unskilled labor is required, for example, vending water in the streets. In the case of community run water-vending kiosks and tankers, skilled jobs would, for example, include managing the Kiosks and driving vehicles.

3 WATER QUALITY STANDARDS AND GUIDELINES

Different countries and international organizations have proposed water quality standards to ensure safe drinking water. In this chapter, water quality standards and guidelines set by WHO, the GSB and US EPA are compared with regard to specific parameters of interest, including turbidity and pH (physical water quality) and *E.coli* and total coliforms (microbial water quality). The word "standards" is used to refer to legally enforceable threshold values for the water parameters analyzed, while "guidelines" refer to threshold values that are recommended and do not have any regulatory status.

3.1 Water Quality Requirements for Drinking Water – Ghana Standards

The Ghana Standards for drinking water (GS 175-Part 1:1998) indicate the required physical, chemical, microbial and radiological properties of drinking water. The standards are adapted from the World Health Organizations Guidelines for Drinking Water Quality, Second Edition, Volume 1, 1993, but also incorporate national standards that are specific to the country's environment.

3.1.1 Physical Requirements

The Ghana Standards set the maximum turbidity of drinking water at 5 NTU. Other physical requirements pertain to temperature, odor, taste and color. Temperature, odor and taste are generally not to be "objectionable", while the maximum threshold values for color are given quantitatively as True Color Units (TCU) or Hazen units. The Ghana Standards specify 15 TCU or 15 Hazen units for color after filtration. The requirements for pH values set by the Ghana Standards for drinking water is 6.5 to 8.5 (GS 175-Part 1:1998).

3.1.2 Microbial Requirements

The Ghana Standards specify that *E.coli* or thermotolerant bacteria and total coliform bacteria should not be detected in a 100ml sample of drinking water (0 CFU/100ml). The Ghana Standards also specify that drinking water should be free of human enteroviruses.

3.2 WHO Drinking Water Guidelines

3.2.1 Physical Requirements

Although no health-based guideline is given by WHO (2006) for turbidity in drinking water, it is recommended that the median turbidity should ideally be below 0.1 NTU for effective disinfection. WHO (2006), also, does not specify any health-based guideline value for pH of water, although it indicates that in a typical distribution system, the normal range will vary from 6.5 to 8 depending on the composition of water and material used in the system.

3.2.2 Microbial Requirements

Like the Ghana Standards, no *E.coli* or thermotolerant bacteria should be detected in a 100 ml sample of drinking water as shown in Table 3.1.

Table 3.1: Guideline values for verification of microbial quality

Organisms	Guideline Values
All water directly intended for drinking	
E.coli or thermotolerant coliform bacteria[bc]	Must not be detectable in any 100-ml sample
Treated water entering the distribution system	
E.coli or thermotolerant bacteria[b]	Must not be detectable in any 100-ml sample
Treated water in the distribution system	
E.coli or thermotolerant 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 fecal pollution, the count of the 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.
(WHO,2006)

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 3.2.

Table 3.2: 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)

3.3 US EPA Drinking Water Standards

The United States Environmental Protection Agency (US EPA, 2006) distinguishes between "primary contaminants", those such as microbial, chemical and radionuclides that affect human health, and "secondary contaminants" that relate to the physical/aesthetic quality of water.

3.3.1 Physical Requirements

From January 1, 2002, as part of the US EPA Interim Enhanced Surface Water Treatment Rule (IESWTR), turbidity for drinking water must never exceed 1 NTU for all samples of water tested, and 0.3 NTU in 95% of daily samples in any month. US EPA generally recommends that turbidity of water should not, at any time, go above 5 NTU. Systems that filter must also ensure that the turbidity does not go higher than 1 NTU (0.5 NTU for conventionally filtered water) in at least 95% of the daily samples in any month.

pH guidelines are given by US EPA as "National Secondary Drinking Water Regulations", among 14 other secondary contaminants. The pH range recommended is between 6.5 and 8.5. The National Secondary Drinking Water Regulations, unlike National Primary Drinking Water Regulations, are generally non-mandatory water quality standards and thus EPA does not enforce "secondary maximum contaminant levels" or "SMCLs" set for the given contaminants. The SMCLs are established only as guidelines to assist public water systems in managing their drinking water for aesthetic considerations, such as taste, color and odor. These contaminants are not considered to present a risk to human health at the SMCL.

3.3.2 Microbial Requirements

US EPA prescribes regulations which limit the amount of certain contaminants in water, based on parameters that include the Maximum Contaminant Level (MCL) and the Maximum Contaminant Level Goal (MCLG). The MCL is described as the "the highest level of a contaminant that is allowed in drinking water", while the MCLG is "the level of a contaminant in drinking water below which there is no known or expected risk to health". The MCLs are enforceable standards that are set to be as close to the MCLG as possible using the best and most economically feasible treatment technology. The MCLGs incorporate a factor of safety and are not enforceable (US EPA, 2006).

Table 3.3 shows that while the MCLG for total coliforms in drinking water is 0 CFU/100ml, the MCL requires no more than 5% of the total monthly samples give positive results for total coliform. The 5% leeway set by the MCLs makes the US EPA standards for total coliform unique when compared to the Ghana Standards and WHO guidelines which specify 0 CFU/100ml in analysis of all drinking water samples. US EPA allows for the leeway since total coliforms do not necessarily mean that water is contaminated, as they include both fecal-related species and species that are found throughout the environment.

Table 3.3: List of contaminants and their MCLs as given by US EPA

Contaminant	**MCLG**	**MCL**
Total Coliforms (including fecal coliform and *E. Coli*)	0	5%[1]
Turbidity	n/a	< 1 NTU for all samples and <= 0.3 NTU in 95% daily samples in any month (IESWTR)
pH[2]	6.5 – 8.5	

[1] More than 5.0% samples total coliform-positive in a month. (For water systems that collect fewer than 40 routine samples per month, no more than one sample can be total coliform-positive per month). Every sample that has total coliform must be analyzed for either fecal coliforms or E. coli. If two consecutive samples turn positive for total coliform, and one is also positive for *E.coli* fecal coliforms, the system has an acute MCL violation.
[2] pH values set by National Secondary Drinking Water Regulations
(US EPA, 2006)

Table 3.4 summarizes the drinking water requirements given by the GSB (1998), the WHO Water Quality Guidelines (2006) and US EPA Drinking Water Standards. From the parameters listed, the most significant is *E.coli* counts, which should be 0 in all cases.

Table 3.4: Summary of water quality requirements for turbidity, pH, E.coli, thermotolerant coliforms and total coliforms

Parameter	Ghana Standards	WHO	US EPA
Turbidity	Max. 5 NTU	Median 0.1 NTU (for effective disinfection)	< 1 NTU for all samples and <= 0.3 NTU in 95% (IESWTR)
pH	6.5 - 8.5	6.5 - 8.5	6.5 - 8.5
E.coli or thermotolerant (fecal) bacteria (CFU/100ml)	0	0	0
Total Coliform (CFU/100ml)	0	0	MCLG: 0 MCL: <10 for all samples and 0 for 95%

4 METHODOLOGY

4.1 Microbial Water Quality Tests

The GSB (GSB, 1998) specify that the appropriate number of samples to be obtained for each lot of packaged water considered for water quality analysis should vary from 15 to 24 as indicated in Table 10.24 of Appendix I. 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.

All water quality tests were conducted at a temporary lab that was set up in a guesthouse private kitchen where the author and the rest of the MIT team stayed while in Tamale. Distilled, bottled or boiled water was used to meet sterile water requirements. Studies done by Obiri-Danson et al (2003) indicated that all samples of bottled water tested were free of microbial contamination (0 CFU/100ml for both *E.coli* and total coliforms), which implies that using bottled water as sterile water could not have been a major source of error for the tests conducted in this study. Blanks were consistently run of this water and (with one days exception on distilled water that was obtained from World Vision labs and potentially contaminated by the collection container) came out blank. Sampling for all tests was done in a similar way as described in Section 4.1.1.

4.1.1 Sample Collection

Sampling Equipment:

- 100ml Whirl-Pak® bags with sodium thiosulfate tablet
- Ice-packs and cooler bag

Raw water samples used in sachet-water production, in all cases, municipal tap water samples, were collected using 100ml Whirl-Pak® bags that contain sodium thiosulfate ($Na_2S_2O_3$). The sodium thiosulfate tablet contained in one bag is capable of neutralizing 100ml of a chlorinated water sample (HACH, 1999). The neutralization by sodium thiosulfate ensured that no residual chlorine would interfere with the microbial analysis. The raw water samples were taken by first flushing the tap to ensure that only water representative of the source was sampled. Since sachet water was already bagged, these samples were transported in their original sachet-packs and water samples only transferred to the Whirl-Pak® bags at the testing lab, so that the sodium thiosulphate tablet contained in the Whirl-Pak® bags would neutralize any chlorine in the sachet water. All samples collected were transferred to the testing lab in ice packs and cooler bags to ensure low temperatures (2-8°C) were maintained at all times. When testing within 4 to 6 hours was not possible, the samples were transferred to a refrigerator and tested within 24 hours.

4.1.2 Membrane Filtration Method (MF) using mColiBlue24®

In the Membrane Filtration (MF) method, water of a known volume (usually 100ml) is passed through a sterile filter paper with 0.45 microns pore diameter. These pores are small enough to filter out bacteria. The filter paper is then transferred to a Petri dish which contains a pad saturated with medium. For this study, mColiBlue24® broth (ready-to-use broth sold in plastic ampules) was the media for coliform growth.

mColiBlue24® is a nutritive membrane-filtration media that simultaneously detects total coliforms and *E. coli* within 24 hours. The media is lactose based and contains inhibitors to selectively inhibit growth of non-coliform cells (HACH, 2003). Total coliforms are "highlighted" by non selective dye, 2,3,5-Triphenyltetrazoliumchloride (TTC), which produces red colonies. *E.coli*, on the other hand, are "highlighted" through the action of β-D-glucuronidase enzyme and/or 5-bromo-4-chloro-3-indolyl-β-glucoronide (BCIG or X-Glu). Red and blue colonies combined are total coliforms while blue colonies alone are *E. coli*. The media is provided in 2ml ready-to-use ampules, which have a shelf life of one year when stored under temperature conditions between 2-8 °C. The detection limit (or sensitivity) is one CFU coliform bacteria or *E. coli* per 100ml of sample (HACH, 1999).

The Petri dish is incubated at 35°C ± 0.5°C for 24 hours, during which coliforms, if present, multiply and grow in size, and can thus be identified and counted. Visible coliforms form since dye present in the media causes the coliforms to appear colored. For drinking water, the counts are reported as coliform forming units per 100ml of water (CFU/100ml). The ideal range of coliforms per plate is 20 to 80 CFU/100ml, but not more than 200 CFU/100ml for any filter (APHA et al, 1998). Where necessary, various dilutions were applied to obtain coliform counts within the given range, otherwise the counts when greater than 200 CFU/100ml were recorded as "too numerous to count" (TNTC).

When non-recyclable Petri dishes are used, the total cost of the test, which includes the Petri dish with absorbent pad, filter paper, and broth, is US$ 2.52 [0.36 (Petri dish with absorbent pad) + 0.47 (filter paper) + 1.69 (broth)].

When recyclable Petri dishes are used, the cost of the recyclable Petri dishes is not included as it is not consumable. The total cost of the test using recyclable Petri dishes is approximately US$ 2.53 [0.37 (absorbent pad) + 0.47 (filter paper) + 1.69 (broth)], plus the 1-time cost of stainless steel recyclable dish, which cost US$ 8 per dish. Individual costs are listed in Table 10.22 of Appendix I.

Testing Apparatus

- Incubator capable of operating at 35°C ±0.5 °C;
- Vacuum pump;
- Millipore membrane filtration stainless steel funnel unit and flask;
- Pre-sterilized 45 mm filter papers of 0.45μm pore diameter;
- Petri dishes of 50 mm with or without absorbent pads (with base plate labeled);
- Pre-sterilized absorbent pads (for Petri dishes without absorbent pads);
- Lab supplies: Graduated cylinders, stainless steel forceps and disposable pipette tips, 2 squeeze bottles, one for sterilized water and the other methanol;
- Automatic pipette;
- Magnifying glass (3X and 10X);
- Candles and lighters for flame sterilization;
- Boiling equipment (pots, stove or burner);
- Stop watch;
- Bleach disinfectant.

Reagents

- Methanol for flame sterilization;
- Isopropylene for sterilization of working surface;
- mColiBlue24® pre-packed culture medium;
- Sterilized water (boiled, distilled or bottled water).

Sterilization

Before testing the water samples, all the Petri dishes, pipette tips, and measuring cylinders were sterilized by boiling in water for 10 to 15 minutes and left to cool at ambient temperature before use. Isopropylene was used to clean all working surfaces as well as the outer wrap of sachet-water packets. The forceps were flame sterilized (by candle flame) before every use. The Millipore stainless steel, portable filtration unit was sterilized by soaking the wick attached to its lower plate with methanol, igniting the methanol and immediately capping the filtration unit. The methanol ignition produces formaldehyde, which sterilizes the unit. The unit was left closed for 15 minutes for effective sterilization to take place.

Preparation of Petri Dishes

To prepare the Petri dish, a sterile absorbent pad was placed in a Petri dish (with labeled base plate) using flame sterilized forceps. In some cases, disposable Petri dishes, bought with absorbent pads were used. Otherwise, recyclable Petri dishes made of stainless steel were used. The mColiBlue24® medium was added evenly on to the absorbent pad after inverting it two to three times to mix it. Excess liquid was poured off.

Preparing Sample Dilution

For water samples that were suspected to have high counts of total coliform and *E.coli* counts above the 20 to 80 range, mainly the hand-tied sachet water, dilutions of 1:10 and 1:100 were used. For the 1:10 dilutions, a sample of 10ml was pipetted using the automatic pipette and this was placed in a graduated cylinder that contained 90ml of sterilized (bottled or boiled) water. Similarly for the 1:100 dilutions, 1ml of the sample was pipetted into 99ml sterile water.

Filtration

Using sterile forceps, a sterile membrane filter paper was placed in the filtration unit over the porous plate of the receptacle with the grid side up. Well mixed samples of 100ml were then filtered under a partial vacuum. After filtration, sterilized water in the squeeze bottle was used to rinse the interior surface of the funnel 3 times with 20 to 30 ml water. The rinsing ensured that coliform that could have been stuck on the sides of the vessel would be washed onto the filter paper.

The membrane filter was then removed using sterile forceps and placed, with the grid side up, on the prepared Petri dish by applying a slight "rolling motion". The sample was then incubated for 24 hours at a temperature of 35°C ± 0.5 °C, upside-down (inverted with the base side up) to prevent steam from forming on the filter thus making it difficult to read the samples.

Sterile water was also run through the filtration unit, before each sample, as a blank to make sure there was no contamination. If blank samples contained coliforms, as they did on several occasions, the corresponding tests were repeated. In some cases, where coliforms in the samples were much larger than those in the blanks, instead of repeating the test, the actual coliform count was taken to be the difference between the coliforms in the sample and those in the blank. While it may have been ideal to also ran blanks between dilutions, because of time constraints not all tests done on sample dilutions were preceded by blanks. In all cases however, the lowest dilutions were first tested and the filter unit always sterilized after testing a given series of dilutions, of the same sample.

A magnifying glass was used to determine colony counts on the filter papers.

All waste material generated from the tests were soaked in disinfectant bleach, and allowed to stand for 30 minutes to 24 hours before they were disposed of in the garbage.

Interpretation of results

Red and blue colonies combined indicated the sample had total coliforms, while blue colonies indicated *E.coli*. The absence of red or blue colonies indicated that the sample contained no total coliforms or *E.coli*.

The coliform density was directly given by the number of coliforms counted based on the formula below:

$$CFU/100ml = \frac{N \times 100}{V}$$

Where:
N = the number of colonies counted;
V = the sample volume in ml.

In cases where no colonies were observed, the coliform colonies were reported as 0 CFU/100ml.

Averaging Counts

For duplicate tests that were carried out on samples with varying dilutions, the average values of colonies counted were obtained after multiplying the counts with appropriate dilution factors. 57% of the samples tested (17/30) were also run as duplicates. Where duplicated samples were taken with some results being TNTC, only the average of the countable colonies was obtained. In cases where the "blanks" that preceded samples being tested had more coliforms than samples run subsequently, the colony counts in samples associated to those blanks were disregarded (spoiled samples). Nevertheless, when blanks tested had colonies, but the sample test that followed had none, the corresponding sample was taken to have 0 CFU/100ml.

4.1.3 3M™ Petrifilm™ Test

Petrifilm™ plates were initially developed for use in testing bacteria in food and dairy products. However studies conducted by Vail et al (2003) showed that the tests are also useful in water testing. Vail et al compared the results obtained in testing environmental water samples using the 3M™ Petrifilm™ test with other standard methods, including membrane filtration tests. When compared to the membrane filtration method using mColiBlue24®, the 3M™ Petrifilm™ results were highly correlated, with a correlation factor, R>0.9, and equivalent, with a slope of approximately 1.0, as shown in Figure 4.1. Mattelet (2006), obtained similar results in her correlation of the 3M™ Petrifilm™ test and mColiBlue24® MF test, based on environmental samples tested in Tamale, Ghana, the same study site as this author's.

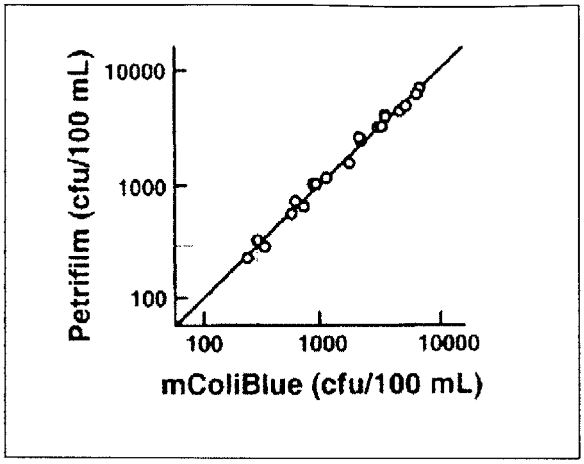


Figure 4.1: Comparison between Petrifilm™ and mColiBlue methods (Vail et al, 2003)

The 3M™ Petrifilm™ test uses sample-ready plates that, like the membrane filtration test, can identify both *E.coli* and total coliforms simultaneously. The Petrifilm™ plates have a circular growth area of approximately $20cm^2$, with a grid background that facilitates counting colonies.

The plates consist of a plastic film, which is coated with Violet Red Bile (VRB) nutrients, a gelling agent, an indicator of glucuronidase activity BCIG, which has the ability to synthesize glucuronidase, a common trait in *E.coli*, and a tetrazolium indicator that enables colonies to be counted. Gas produced by lactose fermenting coliforms and *E.coli* is trapped by the top film.

E.coli are capable of growing in media containing VRB nutrients, and 97% produce β-glucuronidase, which reacts with the BCIG indicator dye in the Petrifilm™ and causes the colonies to turn blue to red. *E.coli*, if present, are thus identified by blue colonies with entrapped gas (gas bubbles) within one colony diameter. Total coliform colonies, if present in samples being tested, are identified as red and blue colonies combined, with entrapped gas within one colony diameter.

The ideal counting range of total colony population in the 3M™ Petrifilm™ test is 15 to 150. Since the plate circular growth area is approximately $20cm^2$, for colonies with more than 150 colonies, the estimated count per Petrifilm™ plate can be obtained by determining the average number of colonies per square on the plate grid, and multiplying the average by 20. Colonies that entirely cover the plate grid, causing it to be red or pink in color, are recorded as TNTC. The tests cost approximately US$ 1.68 per plate or sample.

The advantages of the test include the simplicity of use and storage, reliability and reasonable accuracy and relatively low cost. Unlike the membrane filtration test, the 3M™ Petrifilm™ does not require apparatus such as a filtration unit and pump. The main disadvantage of 3M™ Petrifilm™ test for water testing is the small volume of 1ml per sample that can be tested, which makes it less precise in determining counts in samples containing low numbers of coliforms (Morgan et al , 2003; Mattelet, 2006).

Apparatus and reagents

- 3M™ Petrifilm™ plates and spreader;
- Incubator 35°C ± 0.5°C;
- Automatic pipette and sterile pipette tips;
- Magnifying glass with light bulb attached (3X and 10X);
- Isopropylene.

Sterilization

The working surfaces and spreader were disinfected by wiping with isopropylene.

Testing Procedure

The Petrifilm™ plate was placed on a level surface with grid side up. The top film was then lifted and 1ml of sample pipetted. Care was taken to ensure that the pipette was held perpendicular to the plate and the sample inoculated at the center. The top film was then rolled onto the bottom film and the spreader was used to distribute the sample over the circular area by placing it on the top film (with flat side down) and applying gentle pressure. The spreader was then lifted and the gel left for approximately 1 minute to solidify before lifting the plates.

The plates were incubated in stacks of no more than 20 plates, with the grid side down and for 24 hours at a temperature of 35°C ± 0.5°C. A magnifying glass with a light bulb attached was used for lighting and magnifying to enhance the detection of colonies. *E.coli* colonies were identified as blue colonies with gas bubbles, while total coliforms as the sum of red and blue colonies with gas bubbles.

Samples that were not within the circular "foam dam" are not counted, because according to the 3M™ interpretation guide (undated), they are removed from the "selective influence of medium". Colonies counted were recorded as CFU per 1ml and converted to CFU/100ml by multiplying by 100.

For this test, no dilutions were carried out on the samples.

4.1.4 Presence/Absence Method – Hydrogen Sulfide Producing Bacteria Presence/Absence Test

Unlike the Membrane Filtration and 3M™ Petrifilm™ test methods that give quantitative results for microorganisms present in water, the presence/absence (P/A) test is a qualitative test that indicates presence or absence of microorganisms.

The hydrogen sulfide Presence/Absence test (P/A H_2S) is used to detect fecal contamination in drinking water associated with hydrogen sulfide producing bacteria. The presence of hydrogen sulfide producing bacteria is detected by the reaction of hydrogen sulfide with iron in the medium used, to produce iron sulfite, which precipitates as a black insoluble substance (WHO, 2002). Color changes are observed first after 24 hours, and if no color change occurs, samples are incubated for another 24 hours. If the samples do not change in color after a total of 48 hours, results are recorded as negative.

P/A H_2S tests are generally temperature-versatile, such that samples can be incubated at a broad range of ambient temperatures. P/A H_2S studies done by Pillai et al (1999), using the H_2S paper strip method, showed that though higher temperature ranges between 28 °C and 37 °C gave the fastest results in P/A H_2S tests, temperatures in the range of 15°C and 44 °C gave results within 24 to 48 hours. The same studies also showed that the time required for positive results to show depended on the concentration of fecal coliforms or H_2S bacteria. Here when fecal counts were greater than 400 CFU/100ml, with incubating temperature of 37 °C, 36 hours were required for positive results to show and 48hrs when the incubating temperature range was between 22 °C to 28 °C. When fecal counts were as low as 11 CFU/100ml, and with incubating temperature at 37 °C, 90 hours were required for positive H_2S results to show. At lower incubation temperatures no positive results showed at all (Low, 2002). For tests that were conducted in this study, incubation was carried out at ambient temperature, which in Ghana, during January, ranged from approximately 24 °C to 35 °C.

As shown in Figure 4.2, the specific test organisms present in a positive P/A H2S test are not all coliforms and H_2S producing bacteria is therefore associated with fecal contamination and total coliforms. Positive results obtained are however mainly associated with fecal contamination (Hirulkar, 2006).

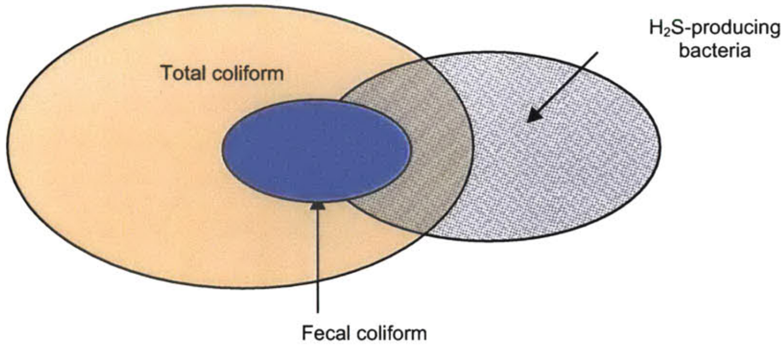


Figure 4.2: Illustration of the relationship between total coliform, fecal coliform and hydrogen sulfide bacteria (Low, 2002)

For the tests conducted in this thesis, Presence/Absence H_2S PathoScreen™ medium for 20ml samples was used. The PathoScreen™ medium is used to "screen" certain bacteria, such that results obtained only give an indication of fecal contamination. The H_2S isolated-bacteria include *Citrobacter freundii, Salmonella typhimurium, Proteus mirabilis, Proteus vulgaris, Clostridium perfingens,* and certain species of *Arizona, Klebsiella*, and *Edwardsiella* (Manja et al., 1982). Of these, fecal/themotolerant bacteria include species of *Klebsiella*, and *Citrobacter,* which also have species that fall in the coliform group (Figure 10.4 of Appendix IV). Non-coliform bacteria include species of *Salmonella, Proteus, Clostridium, Arizona* and *Edwardsiella.*

The PathoScreen™ media is purchased as a dehydrated powder in foil packs (pillows) and tests 20ml or 100ml samples per individual pack. The test costs approximately US$ 0.76 per sample tested for the 100ml sample size. For the 20 ml sample-size that was used, the test costs approximately US$ 0.27 per sample (Table 10.23 of Appendix I).

Advantages of the P/A H2S test include its relatively low cost and simplicity (minimal analytical skills). The wide range of temperatures requirements in the P/A H2S test also implies that in areas with favorable ambient temperatures, incubators may not be necessary for the tests.

However, according to Sobsey and Pfaender, (2002), a drawback to the test is that there are some uncertainties about how reliable, specific and sensitive the tests are in detecting fecal contamination in drinking water. Reliability refers to a measure of how valid the tests results obtained are, in the case of H_2S tests, unreliable results would be those that gave false positives or false negatives (undetected target error). Specificity refers to the ability for tests to give a positive response to specific organisms, in the case of H_2S tests, the aim would be to have tests more specific to organisms of fecal origin. Sensitivity refers to the lower limit of detection. According to Low (2002), "the sensitivity of a H2S test refers to the number of coliform forming units (CFU) required to produce a positive result per 100ml of sample". The sensitivities reported are on the order of 1-10 total coliforms CFU/100m. For example, 8-10 total coliforms CFU/100ml according to Manja et al (1982) and 1 total coliforms CFU/100ml according to Pillai et al (1999).

Apparatus and reagents

- 30 ml glass sampling bottles;
- PathoScreen Medium;
- Boiling equipment;
- Isopropylene;
- Permanent marker.

Testing Procedure

Before conducting the P/A H_2S tests, the 30ml glass sampling bottles were sterilized by boiling for 10 to 15 minutes and left to cool to ambient temperature. A line indicating the 20ml volume was then marked on all the sampling bottles with a permanent marker and water samples poured up to this mark. The PathoScreen Medium pillow was cleaned with isopropylene to ensure no possibility of contaminating the medium by handling, after which it was opened and poured into the measured 20ml sample. After shaking the samples to ensure the medium was well mixed, the samples were incubated at ambient temperature (approximately 24 °C to 35 °C), and results checked at 24 and 48 hours.

Interpretation of results

Color change from yellow to black indicated positive results (presence of H_2S producing bacteria) and no change indicated negative results.

4.2 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 information obtained from these interviews is described in more detail in section 6 of this thesis.

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 and the results are included in Appendix III. Several predetermined responses were included in the original questionnaires, but only options that had response frequencies greater than 1, meaning those that were applicable to one or more interviewee, are presented in the results appended.

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 sachet 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 (Figure 6.16).

5 SOURCE AND TREATMENT OF TAP WATER USED BY SACHET-WATER VENDORS IN TAMALE

5.1 Tamale Water Treatment and Supply System (Water Treatment Works)

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.

Two scientists, Ismaila Sayed and Evans Okot, from the Ghana Water Company provided a ½ day guided tour of the water intake structure and the Dalun water Treatment Plant to the author and her supervisor S. Murcott. This section describes the treatment processes we observed there including coagulation, flocculation, settling and sludge disposal, filtration, disinfection, post liming and finally distribution. The Ghana Water Company labs in Tamale and at Dalun, where water quality tests are conducted, were also visited.

The White Volta River water is treated at the Dalun Water Treatment Plant, approximately 35 km north west of Tamale. The intake point at the village of Nawuni is shown in Figure 5.1, while Figure 5.2 shows a scenic view of the White Volta Tributary at Nawuni, taken from the intake structure. Inside the structure are two pumps which drive water from the river to the treatment plant. Each pump has a capacity of approximately 10,600m^3/day (2.8 million gallons per day).

The main objective of a water treatment system is to take water from the best available source and to subject it to processing to ensure that is safe for human consumption (potable) and it is aesthetically acceptable to consume (palatable). The most common water treatment processes in conventional water treatment plants include coagulation (with rapid mixing), flocculation, sedimentation, filtration and disinfection. In addition, other treatment processes are applied depending on specific pollutants present in water, such as hardness, manganese, iron, fluoride and many other parameters, depending on the local circumstances.

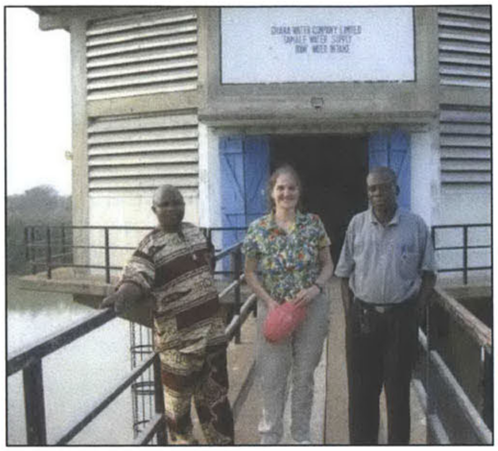


Figure 5.1: Intake structure at Nawuni

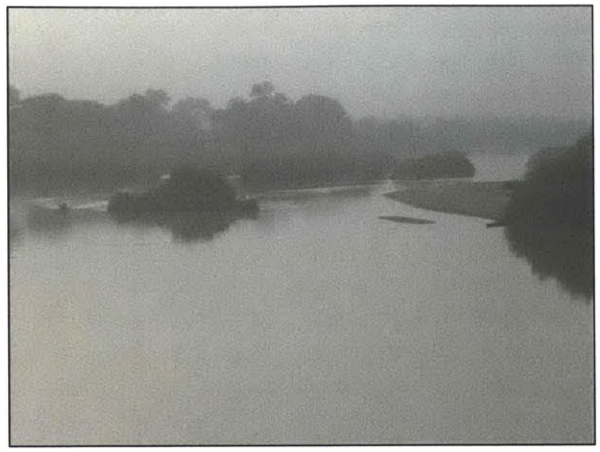


Figure 5.2: White Volta Tributary at Nawuni

5.1.1 Coagulation and Flocculation

A significant portion of dispersed solids in surface water are colloids, which are particles that range from one millimicron to one micron. Colloids have a relatively large surface area per unit volume of particles. They therefore have a tendency of adsorbing ions from surrounding water and thus develop an electrostatic charge. Because of the charge they carry, they repel each other and persist as small particles. These particles do not settle by force of gravity (Reynolds and Richards, 1996).

Coagulants are thus added to destabilize the electrostatic charges carried by the colloids. According to Smethurst (1988) most coagulants are salts of aluminium and iron that act by double decomposition, involving "the mutual interchange of groups". The final products in the double decomposition are hydroxides in the form gelatinous precipitates or flocs.

At the Dalun Water Treatment Plant, coagulation is carried out by feeding a known, predetermined concentration of aluminium sulfate solution into a coagulation chamber, followed by rapid mixing to disperse it effectively throughout the water. The aluminium solution is fed through solution feeders to distribution chambers.

The aluminium sulfate solution is mainly bought in granular-form, in the case of Dalun, made from a dry powder manufactured by Kemira Kemi AB. The granular-form is then mixed with water as shown in Figure 5.3 to form a feed solution. The aluminiun feed solution is stored in tanks (Figure 5.4) after which it is passed through a gravel filter bed (Figure 5.5) before being distributed through pipes to the distribution chamber and subsequently the coagulation/flocculation chamber. Filtering the solution ensures that the distribution pipes are note chocked with dissolved chunks of dry granules.

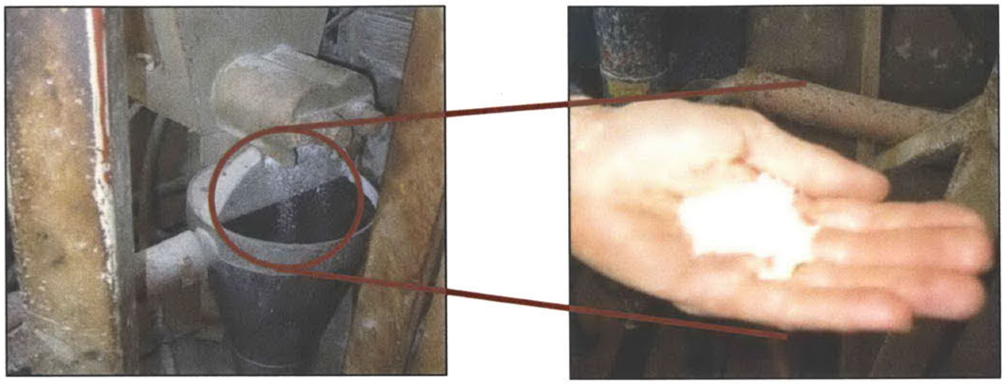


Figure 5.3: Dry aluminium sulfate powder

Figure 5.4: Aluminium sulfate solution

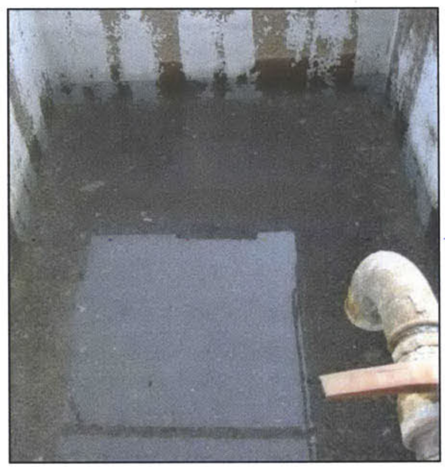


Figure 5.5: Filtering of aluminium sulfate solution

The aluminium sulfate distribution chamber, which feeds the aluminium sulfate solution to the coagulation/flocculation chamber, is shown in Figure 5.6. Note the hose in the center, which delivers the aluminium sulfate solution.

Figure 5.6: Aluminium sulfate injected for required coagulation

Rapid mixing of the coagulant is carried out mechanically by electrically driven propellers mounted on an overhung shaft that is attached to the coagulation/flocculation chamber as shown in Figure 5.7. Flocs form in the same chamber after the rapid mixing process, aggloromating the minute flocs into larger flocs that can easily settle. The mixing intensity is extremely important during coagulation/flocculation, such that the extent of agitation must be determined before hand and controlled. The required mixing velocity should ideally be rapid enough to allow flocs to grow, but slow enough so as not to cause floc breakup.

The concentration of coagulant (dosage), as well as the mixing intensity, is predetermined through jar tests. Knowing the optimum dosage ensures that the chemicals are used efficiently and the cost of treatment is reduced. The quality of water is also ensured. In the jar test procedure, 1 or 2 liter water samples are added to a series of beakers and different dosages (for example 0 mg/l, 10 mg/l, 50 mg/l etc) of coagulants added. To simulate the actual treatment process, the samples are rapidly mixed to evenly disperse the coagulant and then gently agitated to allow floc formation. The samples are then allowed to settle. The optimum dose and mixing speed is thus obtained from the test results and replicated proportionally at the actual treatment plant.

Important parameters noted in the jar tests include the time taken to form flocs, the settling characteristics, turbidity, color and the final pH of the settled water (Reynolds and Richards). The factors that influence coagulation are summarized in Table 5.1. The different types of coagulants that are typically applied, besides aluminium sulfate, include ferric chloride, ferric sulfate, ferric aluminium sulfate and also potentially synthetic polymers, although these tend to be more expensive and therefore may not be commonly used on developing countries. The coagulant characteristics and physical characteristics given in Table 5.1 can easily be determined in jar tests and controlled in the actual treatment plant. The raw water characteristics will often vary, even within the same environment for example during rainy seasons vs. dry seasons, and therefore regular jar testing is required. The frequency of sampling and jar testing depends on the quality of raw water and variation of water characteristics. Jar tests are carried out at least daily for the Dalun Water Treatment Plant (Sayed, 2007).

Figure 5.8 shows the jar test being performed at the Tamale Ghana Water Company Lab, using a jar stirrer with six paddles. Coagulant aids, in the form of polyelectolyte polymers, are also added when necessary.

Figure 5.7:Flocculation/ coagulation chamber with mechanical mixer suspended on a horizontal shaft

Figure 5.8: Jar test demonstration at the Ghana Water Company laboratory in Tamale

Table 5.1: Factors affecting coagulation

Coagulant Characteristics	Physical Characteristics	Raw Water Characteristics
Coagulant type	Settling time	Suspended solids
Coagulant dose	Mixing intensity	Temperature
Proper solution make-up and dilution	Mixing time	pH
Proper coagulant age	Coagulant addition point	Alkalinity
	Proper coagulant feed	Presence of micro-organisms and other colloidal species, ionic constituents (sulfate, fluoride, sodium, etc)

(Murcott, 2006)

5.1.2 Sedimentation and sludge disposal

Sedimentation is the process of separating suspended particles that are heavier than water by gravitational settling. At the Dalun water treatment plant, sedimentation takes place after flocculation in four circular sedimentation tanks with upward flow. The sedimentation tanks are circled by weirs through which the supernatant flows as it rises upwards, as shown in Figure 5.9. The tanks have sludge rakes at the bottom that scrape out settled sludge. The rakes are mechanically operated by a circular motion induced by a central drive shown in Figure 5.10. To facilitate sludge removal, the bottom of the sedimentation tanks slope towards the center where sludge is collected. Sludge removal is by suction withdrawal whereby the sludge is pumped out and disposed via an outlet chamber. This is shown in Figure 5.11 and Figure 5.12. The supernatant is then directed to rapid sand filters where further treatment takes place.

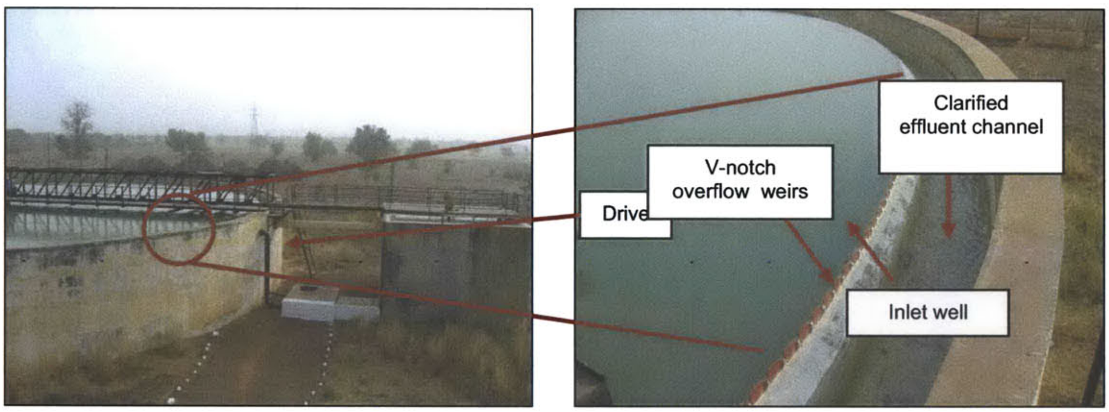


Figure 5.9: Sedimentation tanks and overflow weirs

Figure 5.10: Sedimentation tanks showing inlet well and drive

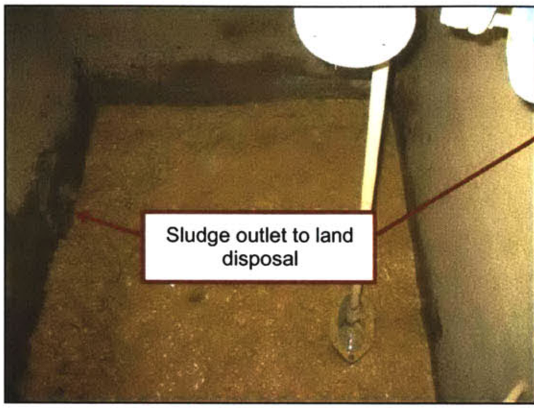


Figure 5.11:Sludge from sedimentation tank – pump on, taken nearly empty, outlet visible

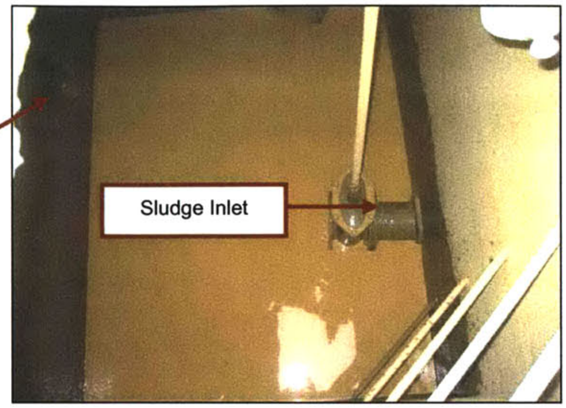


Figure 5.12: Sludge from sedimentation tanks – pump off, both inlet and outlet visible

5.1.3 Filtration

Two common types of filtering processes are slow sand filtration and rapid sand filtration. Their difference is based on the principles by which they operate. Slow sand filters treat water by four mechanisms:

- Mostly by mechanical straining;
- Attachment to previously removed particles;
- Biological predation;
- Natural die off (Haarloff and Cleasby, 1991; Weber-Shrink and Dick, 1997).

The most significant feature of slow sand filters is the top biological layer of the filter bed, know as the *schmutzdecke*, where microorganisms form a mat-like structure in the top layer of the sand that feeds on and breaks down pathogens in water.

Slow sand filters are less energy intensive when compared to rapid sand filters. They are also simple to design and operate and have minimal requirements for expensive chemicals. They develop minimal sludge handling problems and do not demand close monitoring by an operator. These advantages make them appropriate for developing countries. However slow sand filters require larger area, large quantities of filter medium, manual cleaning, and raw water of low turbidities, ideally less than 50 NTU (Vigneswaran and Visvanathan, 1995).

Since surface water has high turbidity, rapid sand filters are more suited for these waters. Turbidities of up to 2000 NTUs have been measured for surface water in Ghana, for example at the Dalun Water Treatment Plant (Sayed, 2007).

Rapid sand filters require less surface area (about 25 to 150 times less) when compared to slow sand filters because they operate under pressure, and are commonly used in municipal water treatment plants as the final clarifying step. For water that has turbidities greater than 10 to 20 NTU, pre-treatment through flocculation and sedimentation has to be provided (Vigneswaran and Visvanathan, 1995). The primary mechanism for rapid sand filtration is by depth removal. Rapid sand filters must be backwashed regularly through energy supplied by pumps.

There is also a less common water filtration method known as multistage filtration that aims to overcome the limitations of slow sand filters to cope with raw water such as that with high turbidities. Multi-stage filters are a combination of slow sand filters and gravel filters. The slow sand filters act as a polishing step, while the gravel filters are used as roughing filters for pretreatment as shown on Figure 5.13 (Galvis, 1999).

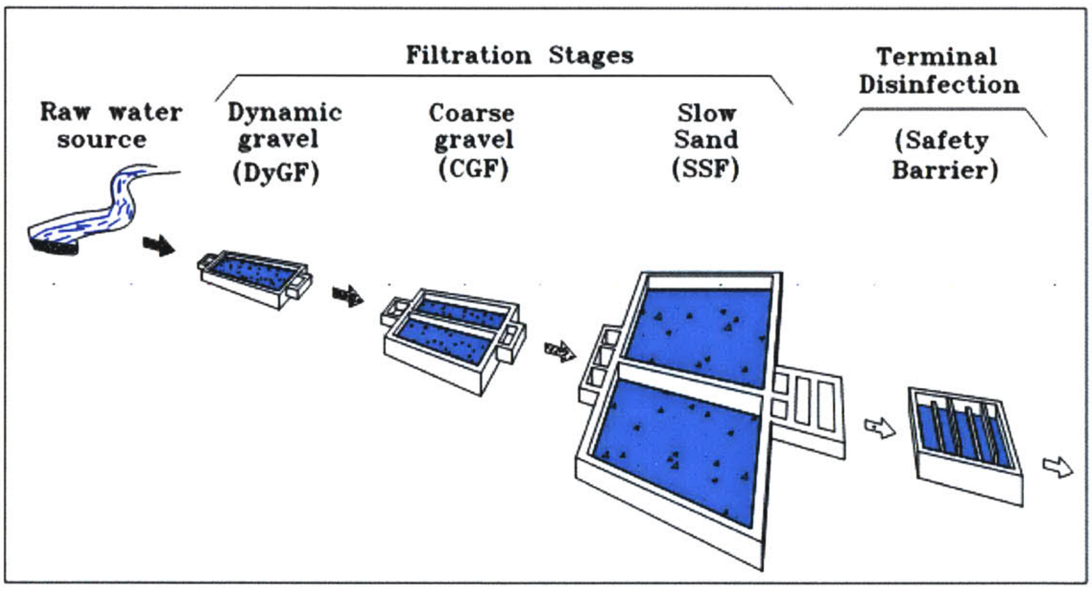


Figure 5.13: General layout of a multistage filtration water treatment plant (Galvis, 1999)

At the Dalun Water Treatment Plant, water is filtered through rapid sand filters after coagulation, flocculation and settling. Four filters are provided, each comprised of a 1m deep single layer of sand. Two of these filters are shown in Figure 5.14. When the available head cannot maintain the required rate of filtration, (typically 4 to $10m^3/m^2/hr$) the filters are cleaned. The filter run (operation period before cleaning) generally varies from 8 hours to 3 days depending on the raw water quality. Head loss and poor filtrate quality are primary indications that the filters need to be cleaned. The filters are cleaned by backwashing for 10 to 15 minutes.

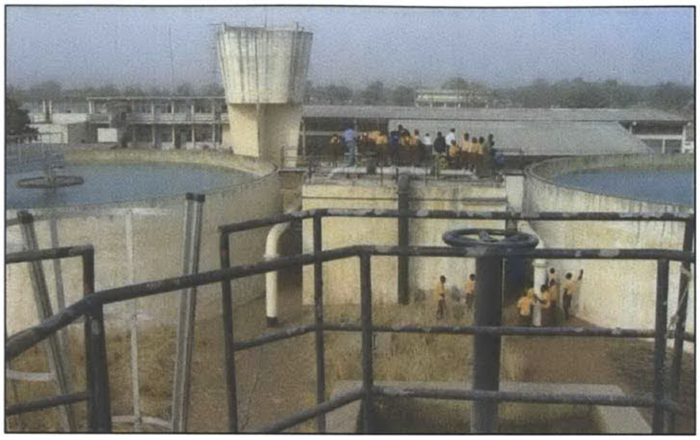


Figure 5.14: Sand filters

5.1.4 Disinfection

Disinfection is the process by which pathogenic organisms are destroyed or otherwise inactivated. Common disinfection techniques for large scale water treatment include chlorination, ultraviolet (UV) disinfection and ozonation. At the Dalun Water Treatment Plant, disinfection is carried out through direct solution feed of chlorine gas through a chlorinator. The chlorine gas is stored as liquefied gas in chlorine cylinders. As a backup during breakdown of the chlorine gas disinfection system, chlorinated lime (calcium hypochlorite) is instead applied. Figure 5.15 shows a chlorine cylinder, meters and feeder pipes used for the disinfection system.

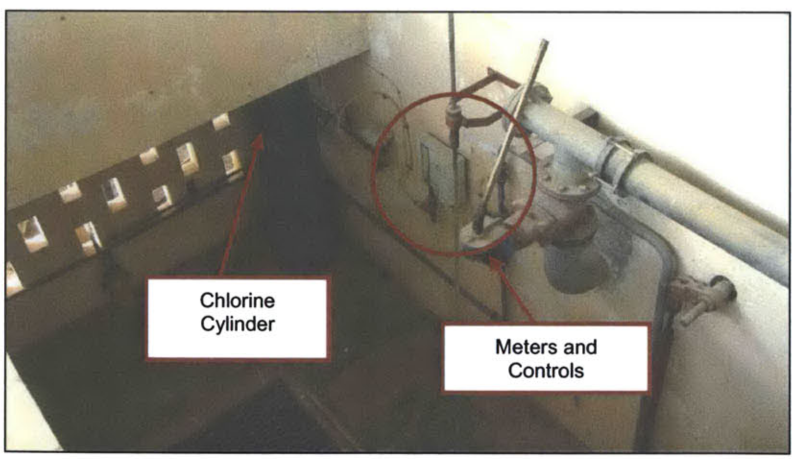


Figure 5.15: Storage cylinder (at the corner) that contains the chlorine gas and meters that control amount dosed into the treated water

5.1.5 Post lime addition

Since aluminium sulfate used in coagulation significantly reduces the pH of water to acidic levels, post lime addition is carried out at Dalun to raise the pH. Lime is only added after chlorination in order not to hinder disinfection whereby microorganisms are protected by flocs of lime. The main reason that lime is added is for corrosion control in the distribution pipes. The lime is prepared in slurry handling tanks shown in Figure 5.16 and Figure 5.17 and fed into the chlorinated water (Sayed, 2007).

Figure 5.16: Handling tanks mix and meter lime

Figure 5.17: Lime slurry in the feed tank (handling tank)

5.1.6 Distribution

The estimated water production from the treatment plant is approximately 19,560m^3/day or roughly 20,000m^3/day (5.2 million gallons per day). The treated water is temporarily stored in an underground tank (Figure 5.18), and distributed to Tamale.

Figure 5.18: The treated water is stored in under-ground tanks (perimeter marked by white painted stones) prior to pumping into the distribution pipes to homes and businesses

The water supply coverage is currently about 65% in Tamale (Table 5.2). This percentage corresponds to the areas covered by the distribution pipe network and does not include stand pipes which have mostly been disconnected due to poor maintenance and misuse (Ndebugri, 2007). By approximating the total population served as 198,250, the total production of 19,560m^3/day equates to a per capita water use of approximately 100 liters/person/day.

The number of domestic/household and commercial connections is approximately 7000, only 42% are metered (Ndebugri, 2007). More specific numbers are given by Benjamin (2007), who states that in Tamale, "5,237 of 8,961 domestic and private community connections and 131 government, local council, and municipal connections are not metered, or almost 60 percent".

Table 5.2: Population Served by Water Supplied by the Ghana Water Company

District	Population	%Supplied	Population Served
Tamale	305,000	65%	198,250
Yendi	40,336	65%	26,218
West Gonja	139,260	85%	118,371
Total	484,596		342,839

Population data obtained from Wikipedia (2007)

The Tamale water supply system is currently being expanded to produce a total of 44,000 m^3 /day. This is intended to serve a population of about 500,000 people. The expansion works include installation of two new vertical shaft pumps, reinforcement and extension of the distribution system, adding transmission mains and a booster station, constructing a new treatment facility with the capacity of 19,000 m^3/day (5 million gallons per day) at Dalun, and four 4,200m^3/day (1.1 million gallons) reservoirs. The expansion project is jointly financed by the Ghana and Dutch governments and is estimated to cost 50,000,000 Euros (US$ 68.2M). 50% of the cost is grant contribution from the Government of Ghana. The project implementation is being carried out by a British multinational contractor, Messrs Biwater (GWCL, 2007). The total length of the main transmission lines will be approximately 30km and the distribution pipelines an additional 95km. The pipe diameter from the intake to the Dalun Treatment works will be 600mm. The pipe diameter from the water treatment to the storage reservoir will be 700mm (Benjamin, 2007).

6 SACHET-WATER PRODUCERS IN TAMALE, GHANA

6.1 Factory-Produced Sachet Water

Five producers of factory-produced sachet water in Tamale were visited and interviewed by the author during January 2007. The factories visited were Divine Love, Voltic, First Class, Jaf Lover, and Aqua-ba. Semi-structured interviews were conducted with employees and owners of the respective factories, 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. Since the responses largely varied, the specific responses are not included in this report, but rather discussed in general.

6.1.1 Water Treatment

The source of water used for sachet-water production is tap water from the Ghana Water Company Dalun Water Treatment Plant. At the sachet-water factory, the water supplied 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 thesis, "sachet machines" is used. A typical set-up of a sachet-water factory is shown in Figure 6.1, 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 6.1: Typical sachet-water factory set-up

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 6.2 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.

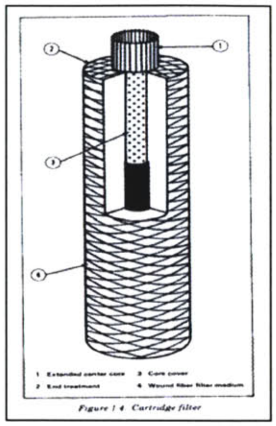


Figure 6.2: Yarn filter cartridge (GlobalSecurity, 2007)

Wound filters can also contain a layer of activated granular carbon as shown in Figure 6.3. The outer-most layer is wound yarn, followed by the activated carbon layer and finally an inner winding which is a polishing step.

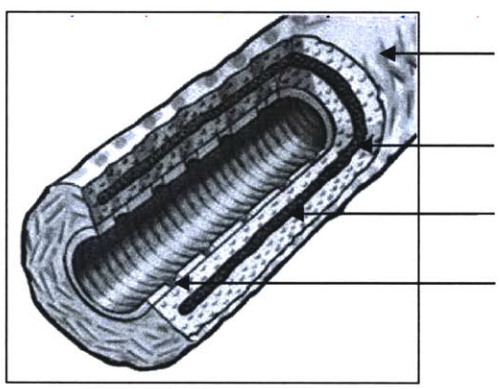


Figure 6.3: Yarn filter cartridge with granular carbon layer (KTH Sales, Inc., 2007)

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 6.4). 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.

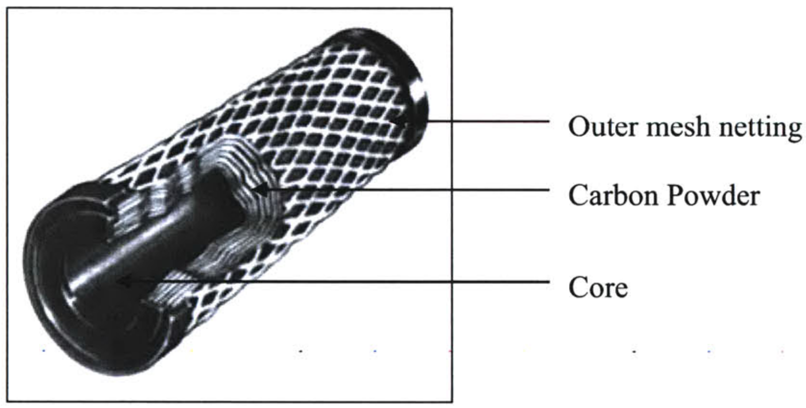


Figure 6.4: Matrix carbon filter (KTH Sales, Inc., 2007)

Table 10.25 of Appendix I gives the directly quoted remarks found on the labels of cartridges, produced by various manufacturers, and explains the types of contaminants the filters cartridges are designed to remove.

Divine Love, Voltic and Aqua-ba used filtration and UV disinfection to treat water, while First-class and Jaf-Lover only used filtration. The different stages of treatment were applied together as a single line-system, whereby water generally flowed from a storage tank, through the filters and finally through the UV disinfection units. Two different filter configurations are shown in Figure 6.5 and Figure 6.6. Figure 6.5 shows cylinders with sand and carbon filter media and Figure 6.6 filters which make use of filter cartridges. Figure 6.7, Figure 6.8 and Figure 6.9 show the actual filter cartridges used.

To ensure minimum re-contamination of treated water, piping from the POE system is connected directly to the packaging machine and final sachet-water product. There was no pipe outlet provided in between, so as to avoid possible contamination.

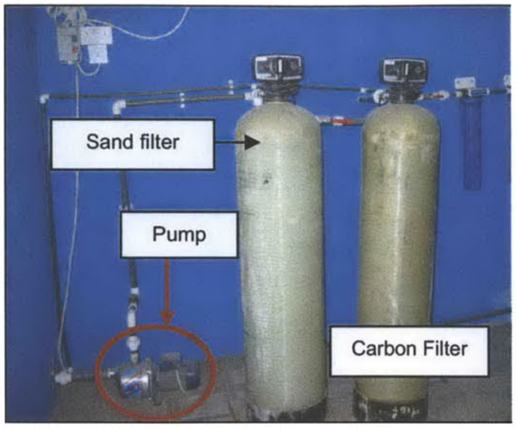


Figure 6.5: Sand and carbon filters. Filter media in cylinders

Figure 6.6: Series of yarn, fiber, granular carbon and carbon matrix filters. Arrow shows flow direction

Figure 6.7: Yarn filter cartridge (used)

Figure 6.8: Fiber filter cartridge (used)

Figure 6.9: Matrix carbon filter cartridge (used)

The treatment methods applied by each of the factories are summarized in Table 10.8 of Appendix I. Since some filter casing used were opaque, it was not possible to record the specific types of filter cartridges used for each factory visited.

6.1.2 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 6.1.

Table 6.1: 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 $\approx$7,500

6.1.3 Packaging

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

6.1.4 The Sachet-water 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.

A schematic diagram, with labeled parts of the machine is shown in Figure 10.1 to Figure 10.3, and the legend is given in Table 10.26, both given in Appendix II.

The particular model shown can produce 1500 to 2100 bags of sachet water per hour. The packing capacity (volume per sachet-bag) can be adjusted to the required volume, generally 200-500ml, with a packaging precision of ± 1%. The required volume can be obtained by either adjusting the length between the horizontal seal, or using an appropriate film width. The films can be purchased in varying widths of 180mm, 240mm, 320mm, or 360mm. The sachet machine is able to print the date of production on sachets produced.

Before operating the machine, the vertical sealing temperature is adjusted to 140°C - 170°C and the horizontal sealing temperature to 200°C -250°C, depending on the type of film material used and its thickness. Higher temperatures, than the given range, may damage the sealers.

The machine weights about 300kg and measures about 850mm(L) x 750mm(W) x 1700mm(H) (Hualian Machinery Co. Ltd, China, 2007).

6.1.5 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 "adjusting device for film roller" given as part 25 of Figure 10.2 and Figure 10.3 of Appendix II, and shown in Figure 6.10. 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 (Section 2.4). 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 6.11. An additional length of roll, of about 0.5m, was heat-sealed longitudinally as shown in Figure 6.12, 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 6.13. 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 6.14. 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 6.15).

Figure 6.10: Loading of polythene rolls in sachet machine

Figure 6.11: Polythene rolls adjusted by folding on base board of bag former

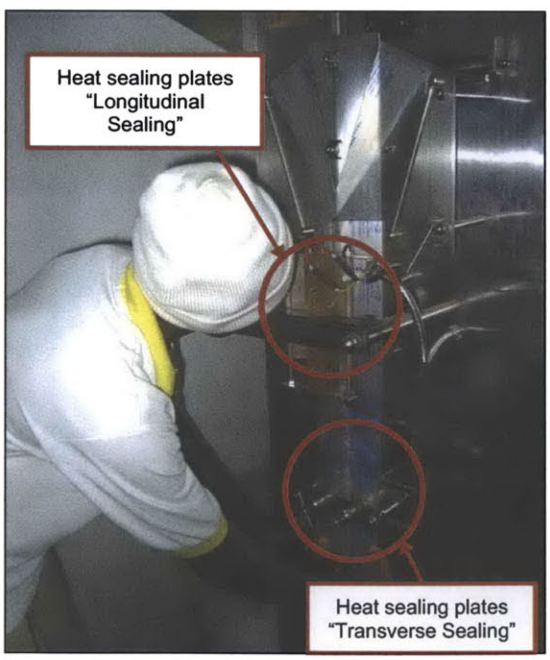


Figure 6.12: 0.5m of sachet rolls sealed longitudinally and at one end

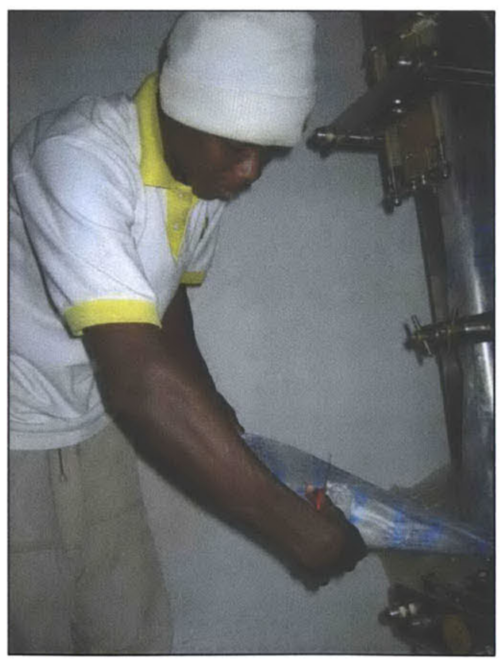


Figure 6.13: Final adjustment of roll and trimming below seal

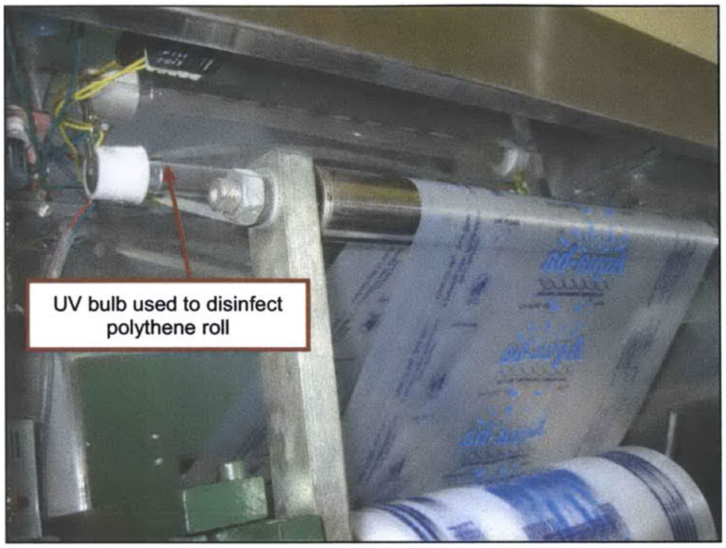


Figure 6.14: UV-bulb in sachet machine used to disinfect polythene roll

Figure 6.15: Automatic Counter(Shown blown up)

6.1.6 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 6.2, 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 6.2: 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 6.3: 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.

6.1.7 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). Both operated in a similar manner as described in Section 6.1.4 and Section 6.1.5.

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. These were categorized into filtration components (Table 10.11 of Appendix I) and UV disinfection units (Table 10.12 of Appendix I). According to the owner of the shop, each UV bulb lasted approximately 1 year.

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.

The calculation that was performed in obtaining this amount is given in Table 10.15 of Appendix I.

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 costs of some tanks of various sizes are given in Table 10.9 of Appendix I, which shows that 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).

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 6.4). The methodology that was followed in computing the salaries is given in Table 10.16 of Appendix I.

Table 6.4 :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 6.4 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 6.5 and Table 6.6 for the years 1987 to 1992 and 1992 to 1998 respectively.

In Table 6.5, 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 6.5: 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 6.6 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 6.6: 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)

Cost of Raw Water

All the five factories visited were strategically located around Jisonaayili town (shown in Figure 6.16), 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 as obtained in Table 10.5 of Appendix I.

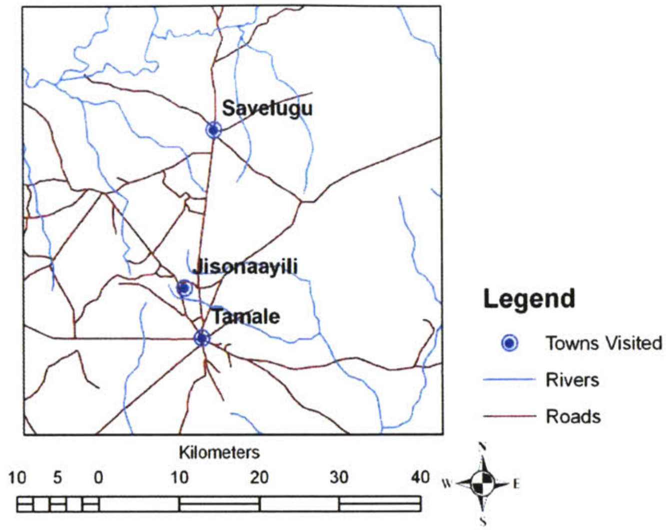


Figure 6.16: Jisonaayili, Tamale and Savelugu towns, Northern Region of Ghana

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.

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.

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.

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).

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.

Total Costs

The total investment cost was computed as approximately US$ 7300 (Table 10.13 of Appendix I), while total monthly expenses as approximately US$ 4200 (Table 10.14 of Appendix I).

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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.

KEY FINDINGS – FACTORY PRODUCED SACHET WATER

- ***An average of 15,000 factory-produced sachets are produced per factory per day in Tamale area***
- ***The cost of 1 sachet (0.5liters) is $0.02 per sachet in bulk purchase, $0.04 individual sachet***
- ***Sachet water factories make up to 100% profit in the business in Tamale***

6.2 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.

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 sachet 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 6.17 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.

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. Table 10.9 of Appendix I gives costs of polyethylene tanks, while Table 10.10 of Appendix I gives estimated costs of other typical storage containers used.

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

Figure 6.17: 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.

Table 10.4 of Appendix I shows the approximate cost of vended water in Tamale, while Table 10.5 of Appendix I shows the cost of piped-water as given by GWCL. The tables show that 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.

KEY FINDINGS- HAND-TIED SACHET WATER VENDORS

- ***An average of 30 to 200 sachets are bagged by each hand-tied sachet-water vendor everyday***
- ***The cost of one sachet (0.7liter) is $0.02 per individual sachet***
- ***Hand-tied sachet water vendors make up to 400% profit on their sales***

7 WATER QUALITY TESTS AND SURVEYS: RESULTS AND ANALYSIS

7.1 Water Quality Results

This section discusses the results of tests that were conducted on sachet-water samples. The test results are summarized in the form of graphs in this section as well as tabulated in Appendix I (see Table 10.17 to Table 10.18).

7.1.1 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 7.1). 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.

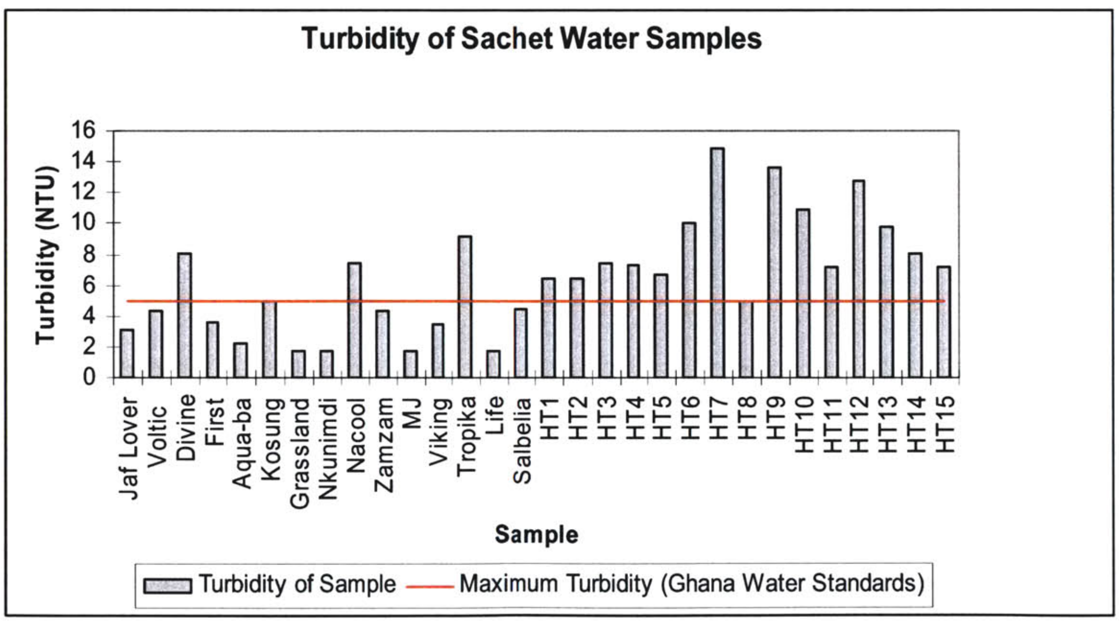


Figure 7.1: Turbidity of sachet-water samples

7.1.2 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 7.2 on a normal scale and in Figure 7.3 on a log-scale. Because total coliform counts less than 100 CFU/100ml are not visible in Figure 7.2, due to the wide range of values represented on a small scale, and counts of 1 CFU/100ml are not represented in Figure 7.3 on the log-scale plot, the reader is also advised to refer to the tabulated results given in Appendix I.

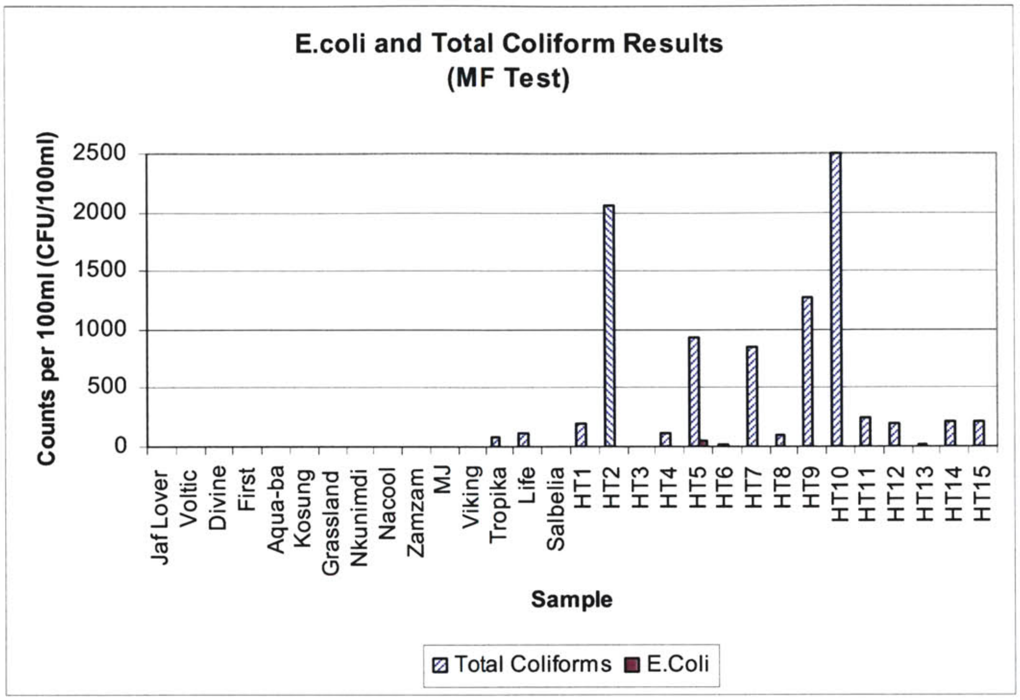


Figure 7.2: E.coli and total coliform results (MF test)

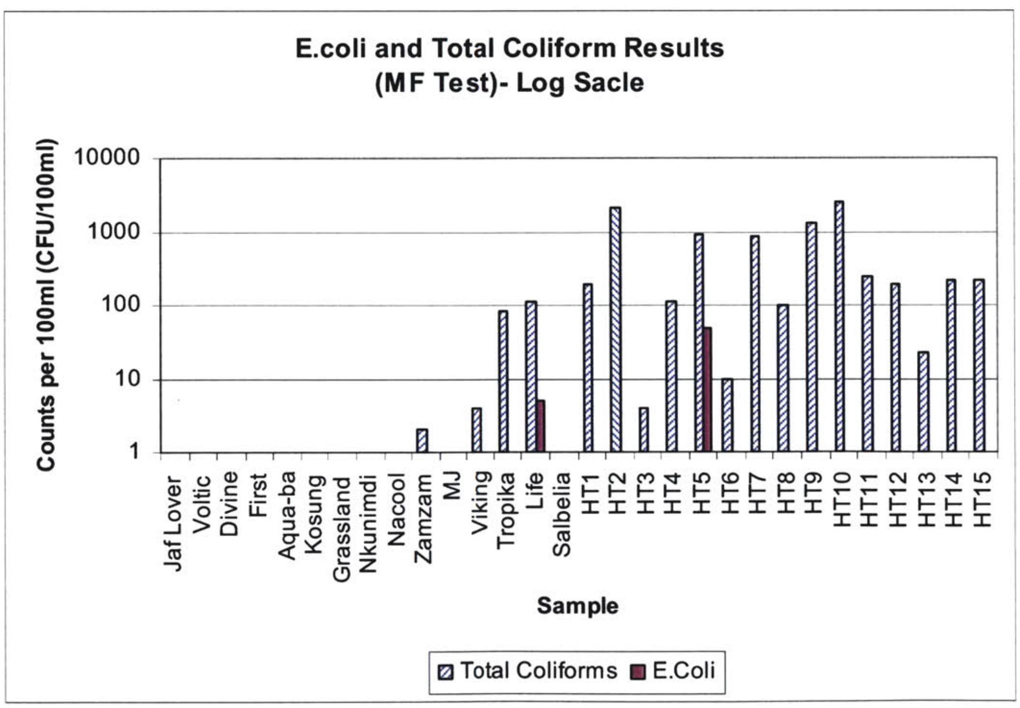


Figure 7.3: E.coli and total coliform results (MF test) – log scale

7.1.3 3M™ Petrifilm™ Results

As regards to 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 7.4 and on a log scale in Figure 7.5.

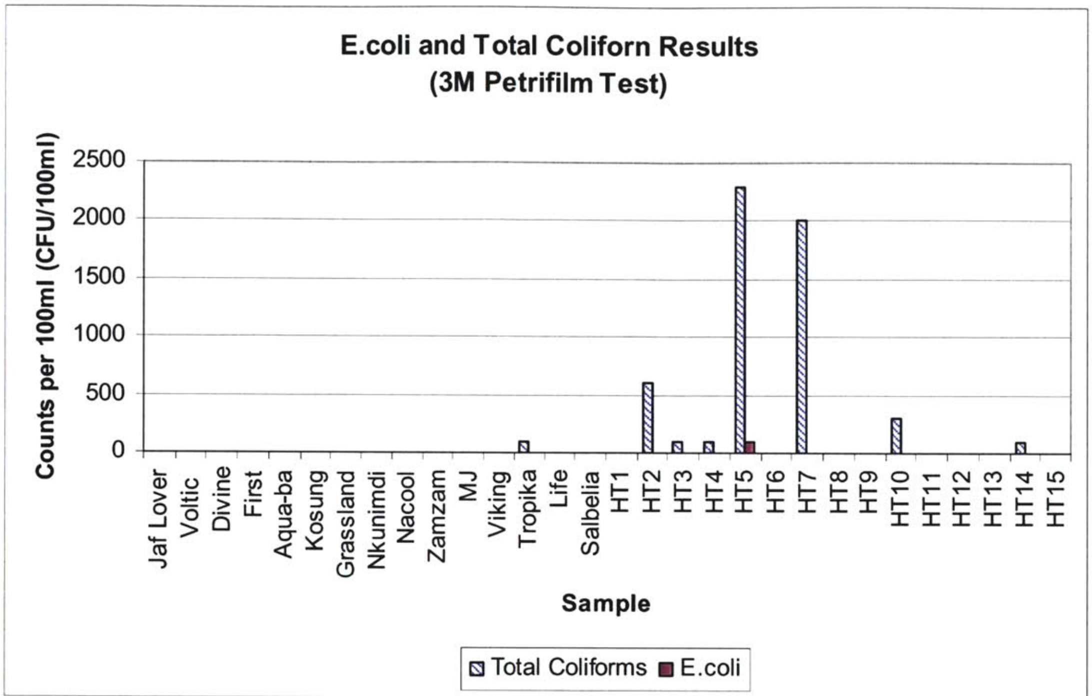


Figure 7.4: E.coli and total coliform results (3M™ Petrifilm™ test)

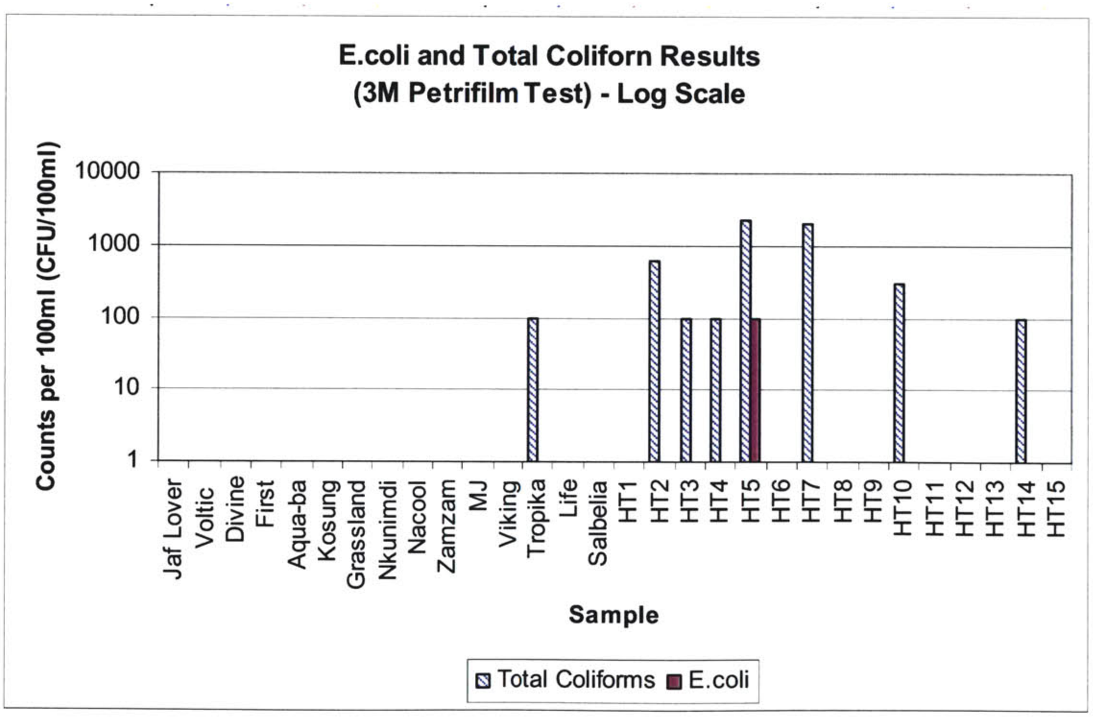


Figure 7.5: E.coli and total coliform results (3M™ Petrifilm™ test) – log-scale plot

7.1.4 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 7.6 and Figure 7.7). Again the results here showed more microbial contamination in the hand-tied sachet water.

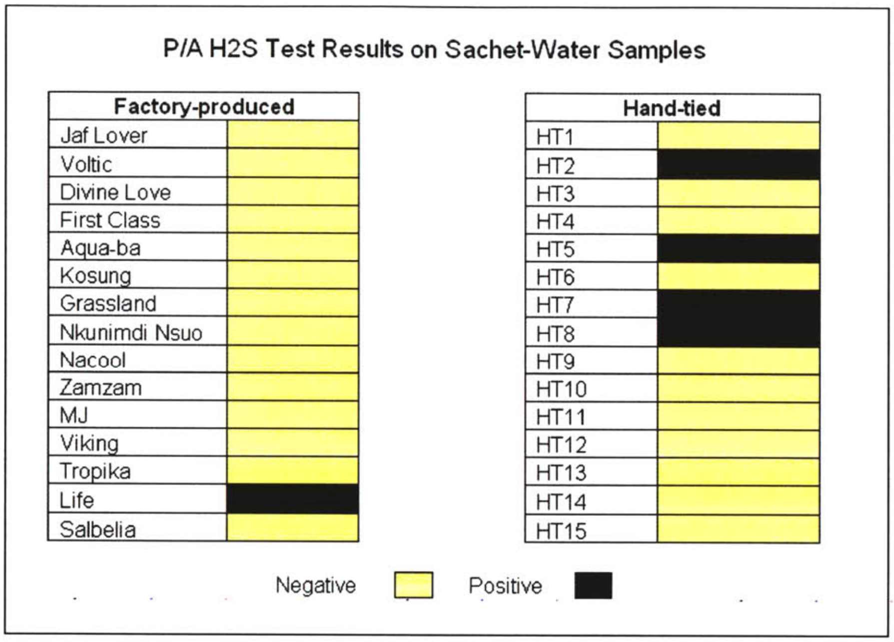


Figure 7.6: P/A H_2S test results (individual samples)

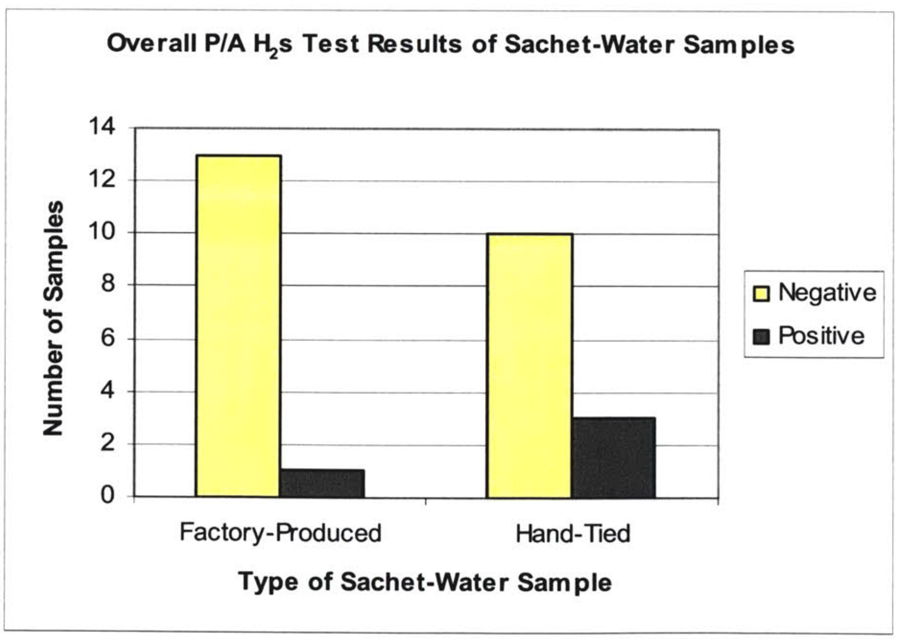


Figure 7.7: P/A H_2S test results (overall results)

7.2 Discussion of Water Quality Results

7.2.1 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. Table 10.21 of Appendix I assigns a value of "1" for each sample that had bacteria from the corresponding test and "0" to those that did not. We see that every sample that turned out positive in either the 3M™ Petrifilm™ test or P/A H_2S test also turned positive in the MF test. The MF test thus showed the highest number of samples contaminated. This was used to compute the percentage of sachet-water samples that had bacteria (Table 7.1). Table 7.1 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 7.1: Number and percentage of hand-tied and factor- produced sachet-water samples contaminated

Number and percentage of samples contaminated							
Test Method / Sample Type	H_2S 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%

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 is equivalent to saying 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 3.2.

KEY FINDINGS

Hand-tied sachet water was two times more microbially contaminated than factory-produced sachet water

7.2.2 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 7.8, 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.

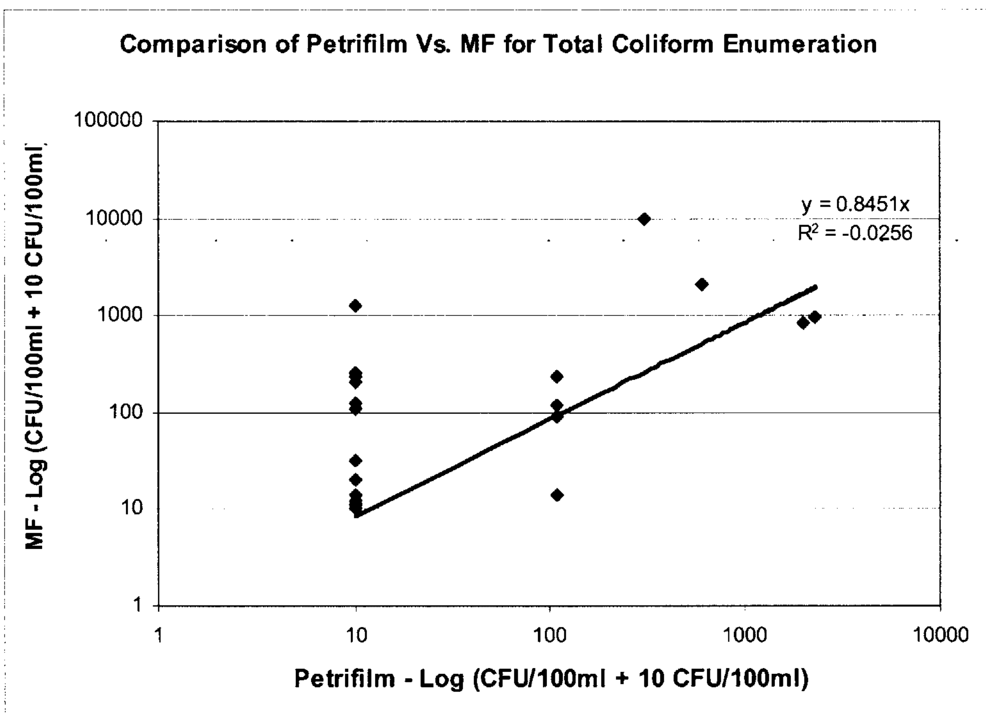


Figure 7.8: Relationship of Log $_{10}$ coliforms determined by 3M™ Petrifilm™ test to log$_{10}$ coliforms determined by MF test

7.2.3 Comparison of Water Quality Test Results with those Obtained from Previous Studies

In comparing the results of sachet-water quality obtained in this study with previous studies for factory-produced sachet water, the results were much lower than those reported by Dodoo et al (2006) from tests carried out on 180 samples of 29 brands of factory-produced sachet water in the Cape Coast municipality of Ghana over a 5-year period. Dodoo et al (2006) recorded total coliform counts as high as 98 million CFU/100ml and found 45% of the samples contaminated. Nonetheless the percentage found by Dodoo et al is closely comparable to the 47% microbially contaminated factory-produced sachet water found in this study.

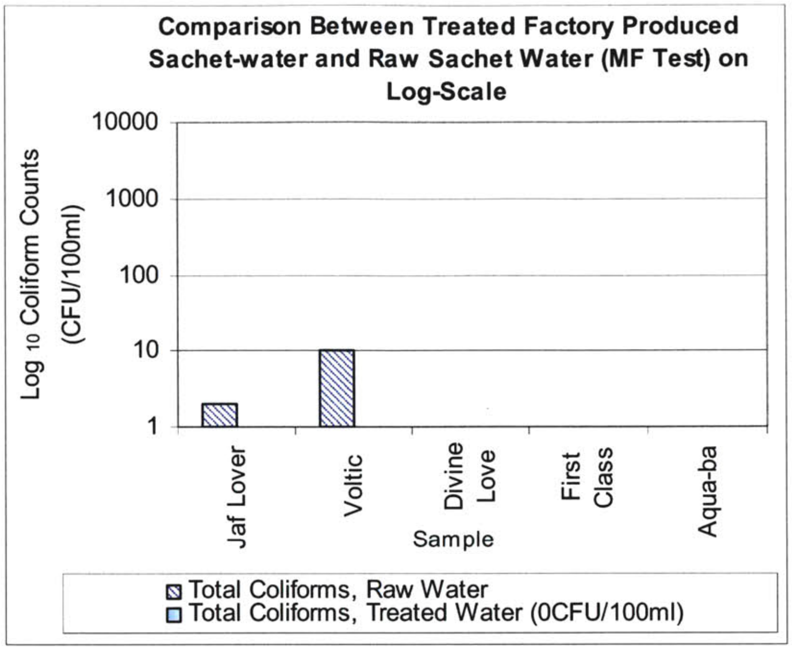
7.2.4 Strategies of improving hand-tied sachet water quality

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 3.2). 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.

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 7.9).

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.



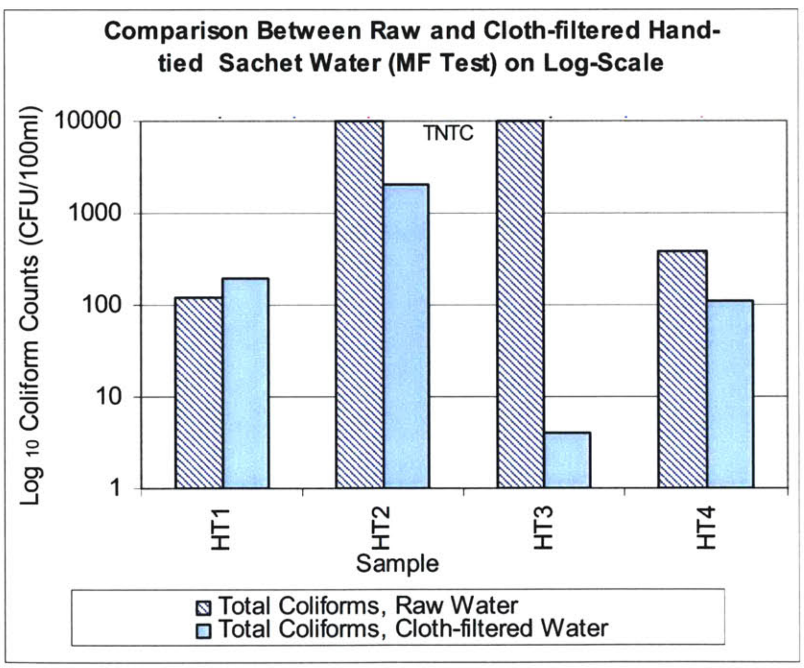


Figure 7.9: Comparison of log $_{10}$ coliforms of treated and raw sachet water determined from MF test

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 7.10 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 7.3 to Figure 7.6). 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.

KEY FINDINGS

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- ***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.***
- ***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.***

Figure 7.10: Ceramic pot filter use in hand-tied sachet-water production

Packaging and Handling

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 7.11. 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 7.13. 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 7.14.

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).

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 7.15. 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 7.12.

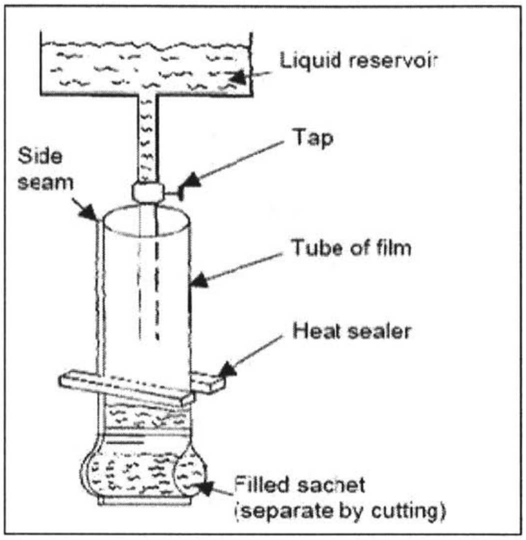

Figure 7.11: Simple bar-type heat sealer (either manual or electric) (Fellows, 1997)

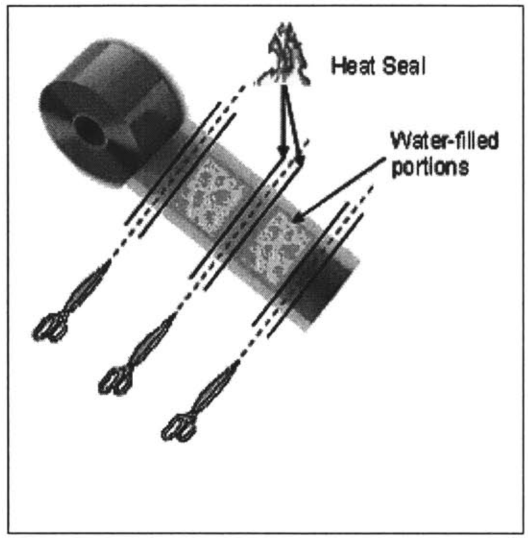

Figure 7.12: Recommended sealing procedure

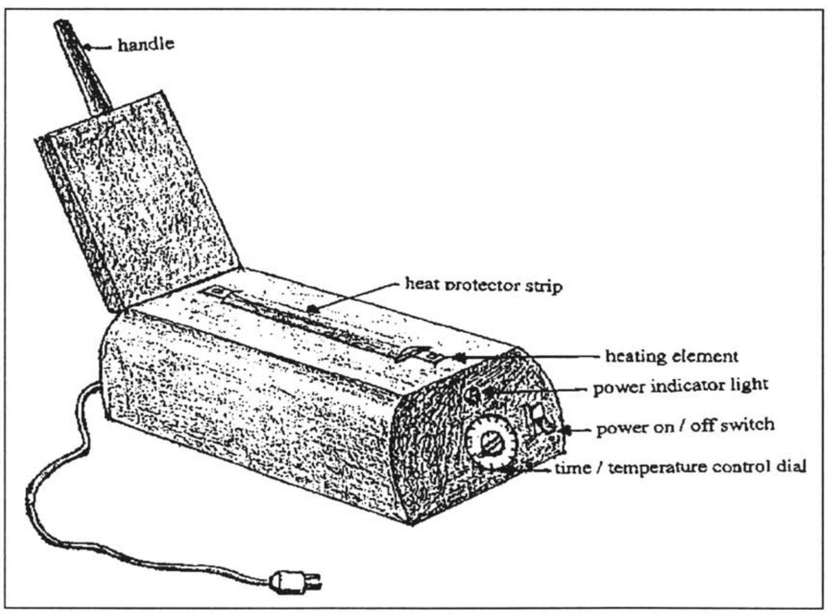

Figure 7.13: Electric heat sealer for sealing plastic films (Fellows, 1992)

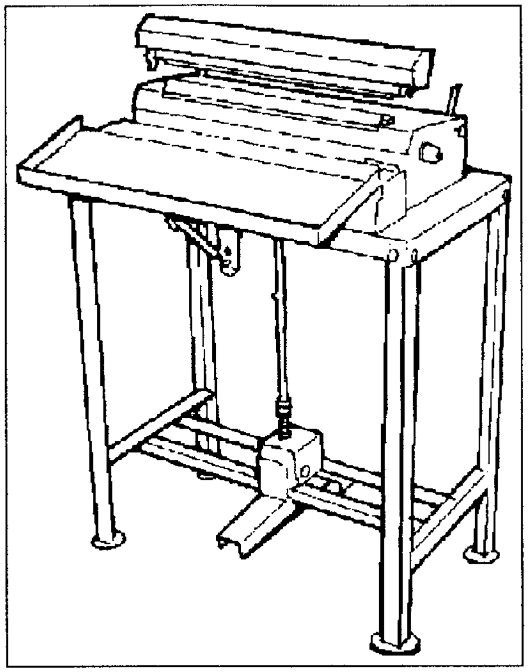

Figure 7.14: Hand/pedal operated sealing machine (Fellows, 1992)

Figure 7.15: Candle and hacksaw blade method of sealing plastic bags (FAO, 1994)

Various sources of heat are given in Table 7.2. 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 7.2: 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).

7.3 Survey Results

7.3.1 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.

KEY FINDINGS

- ***For 37%, sachet water formed the sole supply of drinking water, even at home!***
- ***Sachet water formed main source of drinking water away from home***
- ***70% drank more water when away from home, 20% the same amount at home and away from home, while 10% drank more water at home***
- ***47% would always or sometimes litter to dispose of the plastic bag***

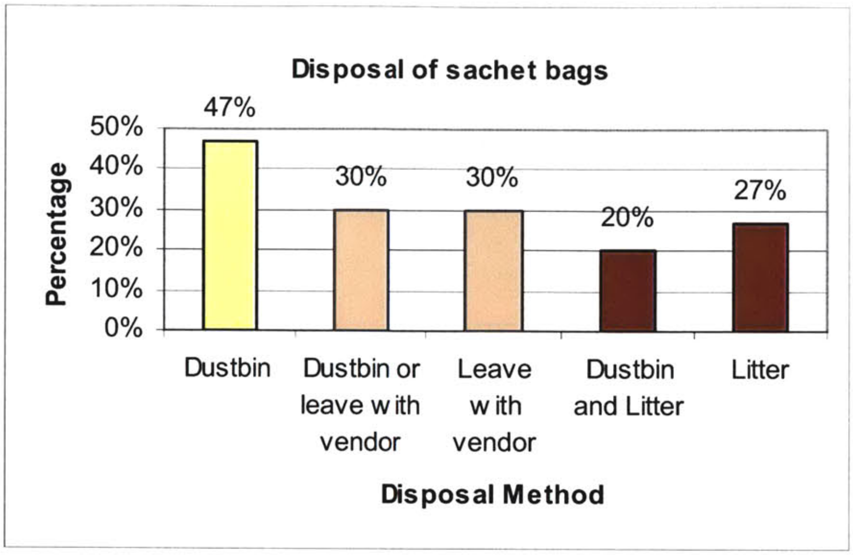

Figure 7.16: Sachet plastic bag disposal methods

7.3.2 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[4]. Since majority of the vendors were very young girls (40% < 15 years old and 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.

KEY FINDINGS

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".

Like the 5 hand-tied sachet-water producers who were initially interviewed at their production premise (Section 6.2), 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

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

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.

KEY FINDINGS

Retailers of factory-produced sachet water made 100 percent profit.

7.4 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 °C to 35 °C 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 7.3.1). Since this was the case, promoting 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 sachet 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 7.17).

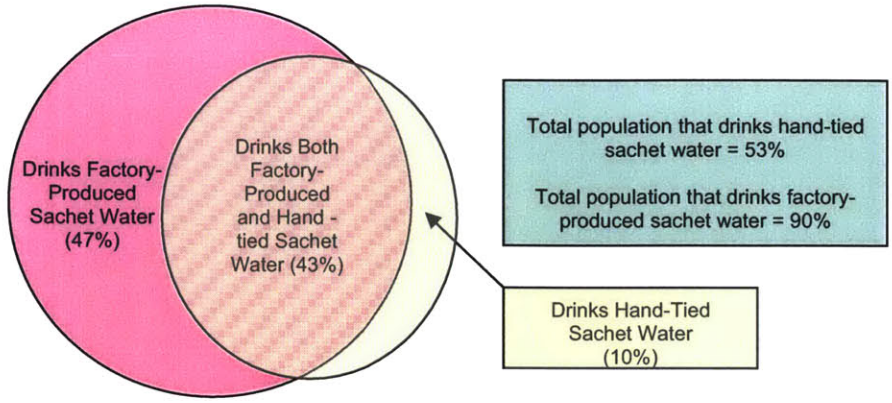

Figure 7.17: Venn diagram showing percentage of people who drink factory-produced and hand-tied sachet water

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.

KEY FINDINGS

With a filtration rate of 2 liters per hour, about 5 ceramic pot filters would be required per vendor producing hand-tied sachet water to improve turbidity and bacterial quality of sachet water

7.4.1 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 sachet 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.

8 CONCLUSIONS AND RECOMMENDATIONS

8.1 Water Quality Tests

8.1.1 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.

8.1.2 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 7.1 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 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, as some were not observed in the sachet-water factories visited. For example, as can be seen in Table 10.8 of Appendix I, not all factories disinfected sachet water during the treatment process although they were required to do so, and not all had a minimum of 5 filters. The vendors selling hand-tied sachet water also need to be regulated as they did not operate under any rules or regulations.

8.2 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.

8.3 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.

8.4 Pure Home Water Strategy

We find in this 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.

8.5 Avenues and Recommendations for Future Masters of Engineering Research Projects

- Detailed study of the Dalun Water Treatment Plant and water quality assessment of the distribution system, as several factors may contribute to presence of microbes in the distribution system and at the point of use;
- Further development and testing of low-cost packaging systems for hand-tied sachet water;
- Solid waste management and recycling/re-use of plastic bags, including a study to investigate the potentials of using sachet plastic waste for fuel alternatives, as is already being considered by PHW and feasibility of using biodegradable plastics for sachet-water production;
- A study on the potential of using solar disinfection to treat bagged water.

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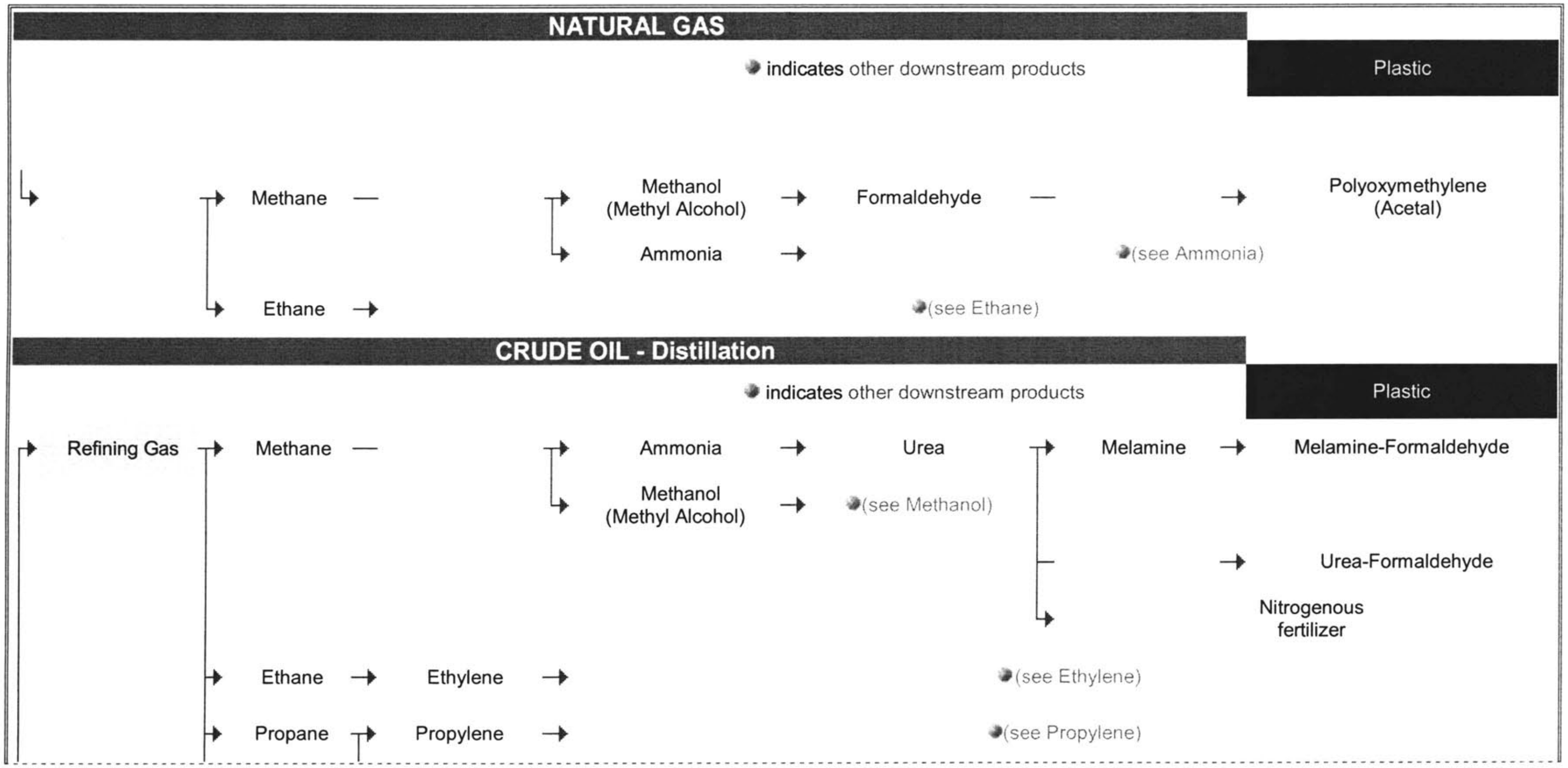
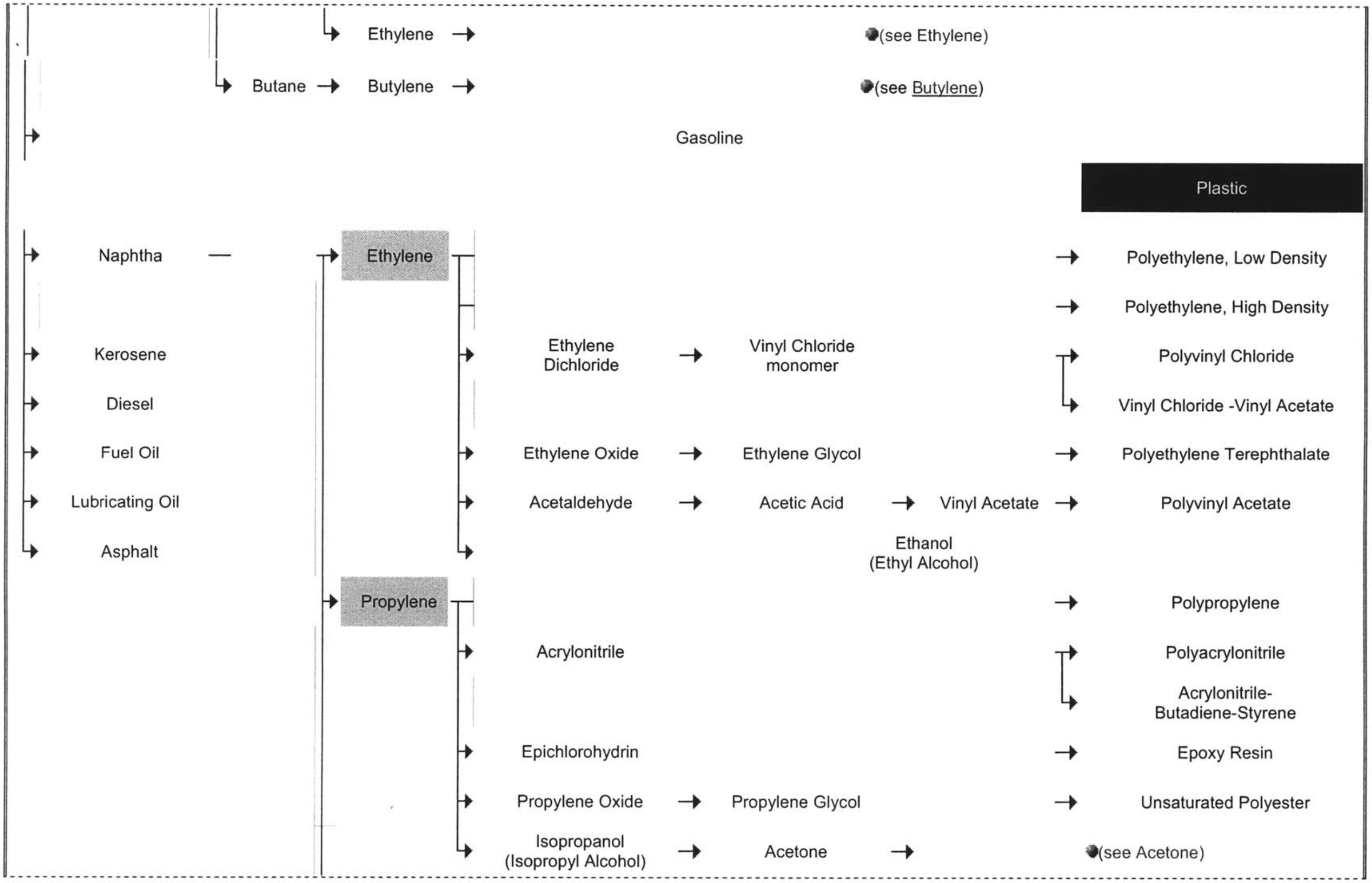
10 Appendix

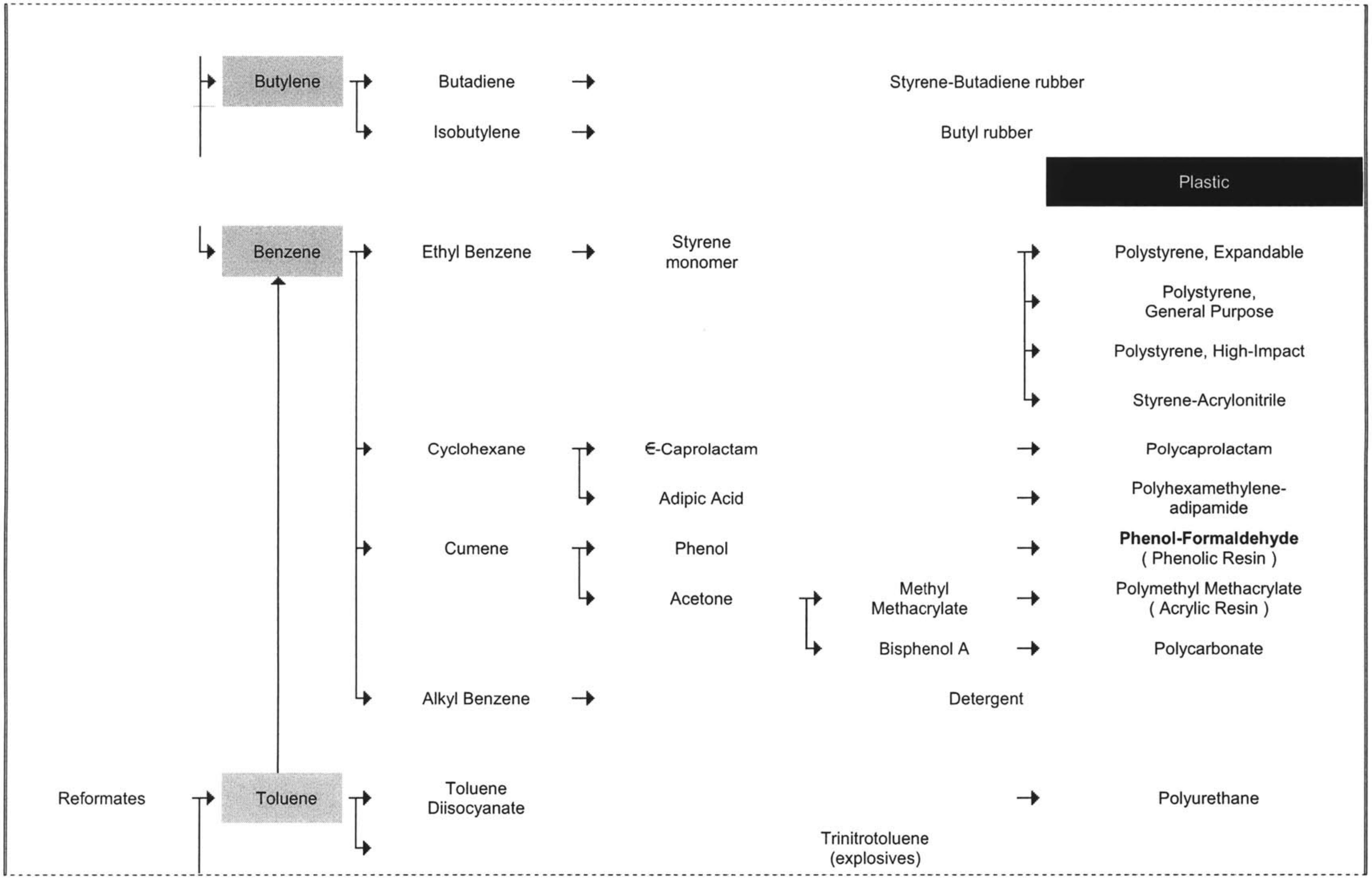
10.1 Appendix I: Tables

Table 10.1: Origin of Commonly Used Plastics

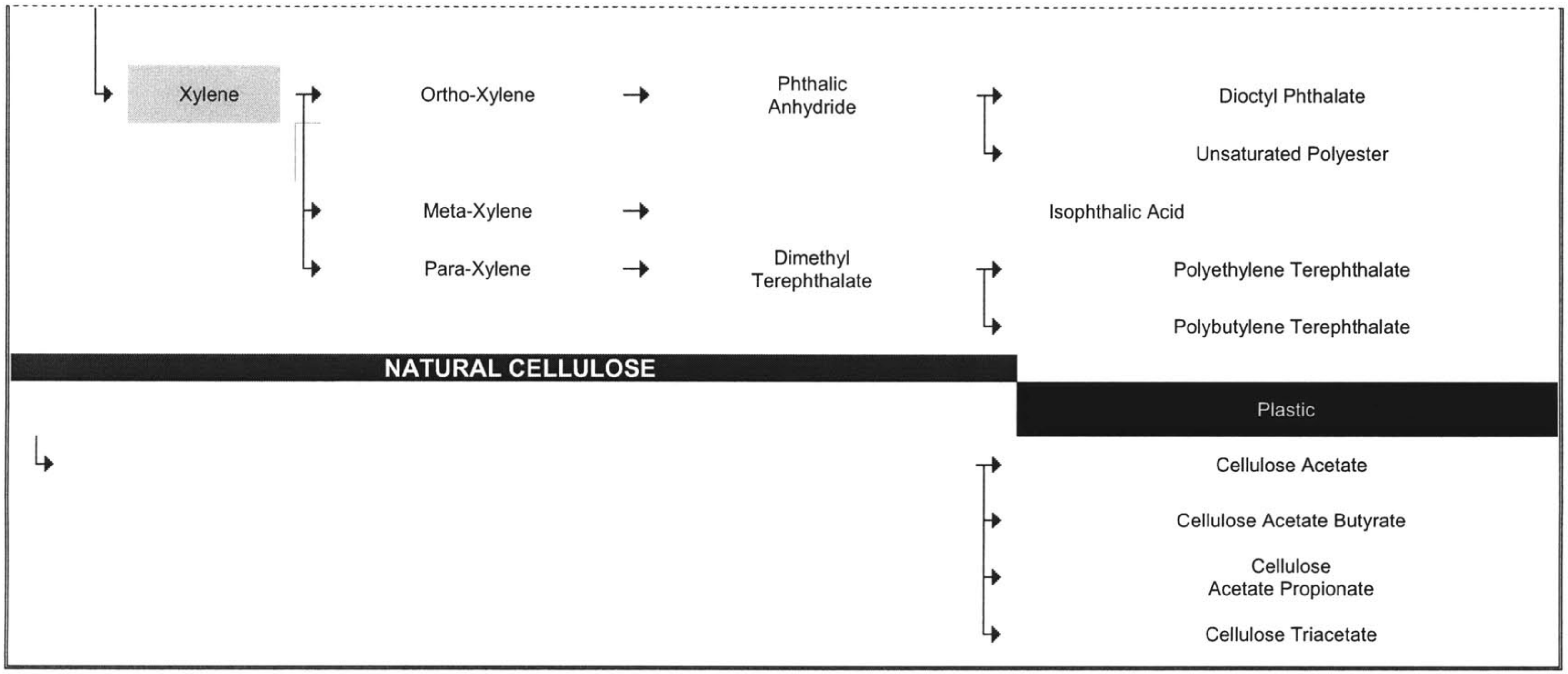




Ethylene
(see Ethylene)
Butane
Butylene
(see Butylene)
Gasoline
Plastic
Naphtha
Ethylene
Polyethylene, Low Density
Polyethylene, High Density
Kerosene
Ethylene Dichloride
Vinyl Chloride monomer
Polyvinyl Chloride
Diesel
Vinyl Chloride -Vinyl Acetate
Fuel Oil
Ethylene Oxide
Ethylene Glycol
Polyethylene Terephthalate
Lubricating Oil
Acetaldehyde
Acetic Acid
Vinyl Acetate
Polyvinyl Acetate
Asphalt
Ethanol (Ethyl Alcohol)
Propylene
Polypropylene
Acrylonitrile
Polyacrylonitrile
Acrylonitrile-Butadiene-Styrene
Epichlorohydrin
Epoxy Resin
Propylene Oxide
Propylene Glycol
Unsaturated Polyester
Isopropanol (Isopropyl Alcohol)
Acetone
(see Acetone)



Butylene
Butadiene
Styrene-Butadiene rubber
Isobutylene
Butyl rubber
Plastic
Benzene
Ethyl Benzene
Styrene monomer
Polystyrene, Expandable
Polystyrene, General Purpose
Polystyrene, High-Impact
Styrene-Acrylonitrile
Cyclohexane
Є-Caprolactam
Polycaprolactam
Adipic Acid
Polyhexamethylene-adipamide
Cumene
Phenol
Phenol-Formaldehyde (Phenolic Resin)
Acetone
Methyl Methacrylate
Polymethyl Methacrylate (Acrylic Resin)
Bisphenol A
Polycarbonate
Alkyl Benzene
Detergent
Reformates
Toluene
Toluene Diisocyanate
Polyurethane
Trinitrotoluene (explosives)



(Export911,2007)

NOTE:
The production process may differ for the given plastics.
Hence, other origins of plastics may not be shown in the above flow charts.

Table 10.2 Recycling plastic codes

1	PETE **Polyethylene Terephthalate** Product examples: bottles for soft drink, soy sauce, and cooking oil
2	HDPE **High Density Polyethylene** Product examples: pails; containers for liquid detergent and fruit juice
3	V **Polyvinyl Chloride** Product examples: pipes; bottles for shampoo and mineral water
4	LDPE **Low Density Polyethylene** Product examples: shopping bags; house wares
5	PP **Polypropylene** Product examples: household storage containers
6	PS **Polystyrene** Product examples: foam products like drinking cup and food tray
7	**OTHER** **Other type of less commonly used plastics** Product examples: bottles for ketchup and syrup

(Export911, 2007)

Table 10.3: Recycling symbols

	
	
	**Reversed mobius loop ---** means that the product contains recycled material. The recycled material can be 100% to as little as 5% post-consumer waste.
	**Percentage of recycled material ---** means that the recycled product contains 20% post-consumer waste

(Export911, 2007)

Table 10.4: Cost of tanker and distributor-vended water in Tamale

Source	Unit of measure	Cost per unit (GHC)	Cost per liter (GHC)	Cost per liter (US$)
Tankers	3000 gallons	450,000	40	0.004
Tanker (with own tanker)	2200 gallons	160,000	19	0.002
Distributing vendors	20 liters	1500	75	0.008
Distributing vendors	200 liters	8500	42.5	0.005
		Average	240	0.027

Table 10.5: Cost of pipe-water in Tamale (Ghana Water Company)

Type	Range (m^3)	Cost per 1000 liter (GHC)	Cost per liter (GHC)	Cost per liter (US$)
Domestic use	1 to 20	4031	4.031	0.0004
	>21	5528	5.528	0.0006
Commercial use	-	6911	6.911	0.0008
Public Institutions	-	6220	6.220	0.0007
Boreholes	-	5759	5.759	0.0006
Premises no connection	-	4031	4.031	0.0004
Average		5.413		0.001

(GWCL, 2004, Internal letter to the Regional Chief Managers, ref. RRD 14 00-2/67, regarding "Tariff Adjustments")

Table 10.6: Cost of packaged water in Tamale

Cost of bagged water	Unit of measure	Cost per unit (GHC)	Cost per liter (GHC)	Cost per liter (US$)
Voltic – wholesale	20 sachets per bag, each sachet 500 ml	4500	450.00	0.050
Others – wholesale	30 sachet per bag, each sachet 500 ml	5000	333.33	0.037
Single sachet – voltic – retail	1 sachet, 500 ml	500	1000.00	0.111
Single sachet – others – retail	1sachet, 500 ml	400	800.00	0.089
Hand-tied	1 sachet, 700 ml	200	285.71	0.032
Bottled water (wholesale)	12, 1.5 liter bottles	70000	3888.89	0.432
Bottled water (retail)	1, 1.5 liter bottle	7000	4666.67	0.519

Table 10.7: Average cost of water to consumers in Tamale

Average cost of water to consumers	Cost per liter (GHC)	Cost per liter (US$)
Pipe water (Domestic use only)	4.78	0.0005
Tanker	29.42	0.0033
Distributing vendors	58.75	0.0065
Sachet water (factory-produced)	645.83	0.0718
Sachet water (hand-tied)	285.71	0.0317
Bottled water	4277.78	0.4753
Boreholes	5.759	0.0006
Standpipes	4.031	0.0004

(Tanker and Distributing vendors) Average cost US$ **0.005**

(Sachet water (factory-produced)) Average of cost per liter of 1st four rows of Table 10.6

Table 10.8: Treatment applied in factory-produced sachet-water

Factory	Treatment Applied before packaging
Divine Love	3 10'' filters, 1 cartridge-type 20'', UV water sterilizer
Voltic	1 sand filter (media in cylinder), 1 carbon filter (media in cylinder), 2 10'' cartridge type filters, 2 20'' cartridge-type filters, 1 No. 20'' UV water sterilizer
First Class	4 10'' cartridge-type filters
Jaf Lover	5 10'' cartridge-type filters
Aqua-ba	1 sand filter (media in cylinder), 1 carbon filter (media in cylinder), 5 10'' cartridge-type filters, 3 20'' cartridge-type filters (placed outside factory), 1 20''UV water sterilizer

Table 10.9: Costs of polyethylene storage tanks

Tank Size (liters)	Cost of tank (GHC)	Cost of tank (US$)	Cost per liter (GHC)	Cost per liter (US$)
1800	2,520,000.00	280.00	1,400.00	0.16
1400	1,875,000.00	208.33	1,339.29	0.15
1000	1,470,000.00	163.33	1,470.00	0.16
700	1,115,000.00	123.89	1,592.86	0.18
200	440,000.00	48.89	2,200.00	0.24
Average cost per liter			1,600.43	0.18

Table 10.10: Costs of water storage containers

Description	Capacity (Liters)	Cost (GHC)	Cost of tank (USD$)	Cost per liter (GHC)	Cost per liter (US$)
Drum	200	400,000	44.44	2000	0.22
Bucket	80	100,000	11.11	1250	0.14
Bucket	50	70,000	7.78	1400	0.16
Traditional clay pot	10	54,000	6.00	5400	0.60
Average cost per liter				2513	0.28

(Wahabu S.S and Murcott S, personal communication, May 05, 2007)

Table 10.11: Cost of filtration components

Description	**Cost (GHC)**	**Cost (US$)**
Filter Housing		
Filter Housing, 20"	280,000	31.11
Filter Housing, 10"	146,000	16.22
Filter Cartridges		
Wound Polypropylyne		
0.5 Micron Filter, 10"	40,000	4.44
1 Micron Filter, 10"	25,000	2.78
5 Micron Filter, 10"	17,000	1.89
Granular Carbon Filters		
Granular Carbon Filters, 10"	75,000	8.33
Granular Carbon Filters, 20"	130,000	14.44
Matrix Carbon Filter		
1 micron, 10"	70,000	7.78
Polypropylene Fiber Cartridge		
1 micron, 10"	30,000	3.33
5 micron, 10"	20,000	2.22

Table 10.12:Cost of UV disinfection units

Description	**Cost (GHC)**	**Cost (US$)**
UV treatment unit, 40"	16,000,000	1,777.78
UV treatment unit, 20"	4,000,000	444.44
UV bulb, 20"	380,000	42.22
UV bulb, 10"	190000	21.11

Table 10.13: Approximate capital costs required for factory-produced sachet water

Item	Unit	Unit Cost (US$)	Approximate quantity	Cost (US$)
SACHET FILLING AND PACKAGING MACHINE	No.	3,333.33	1	3333.33
FILTER UNITS				
Filter Housing				
Filter Housing, 20"	No.	31.11	0	0
Filter Housing, 10"	No.	16.22	5	81.1
Filter Cartridges				
Wound Polypropylyne				
0.5 Micron Filter, 10"	No.	4.44	1	4.44
1 Micron Filter, 10"	No.	2.78	0	0
5 Micron Filter, 10"	No.	1.89	1	1.89
Granular Carbon Filters				
Granular Carbon Filters, 10"	No.	8.33	1	8.33
Granular Carbon Filters, 20"	No.	14.44	0	0
Matrix Carbon Filter				
1 micron, 10"	No.	7.78	1	7.78
Polypropylene Fiber Cartridge	No.			0
1 micron, 10"	No.	3.33	1	3.33
5 micron, 10"	No.	2.22	0	0
UV UNITS				
UV treatment unit, 40"	No.	1,777.78	0	0
UV treatment unit, 20"	No.	444.44	1	444.44
UV bulb, 20"	No.	42.22	0	0
UV bulb, 10"	No.	21.11	1	21.11
15,000 liters Storage Tanks	No.	1350	2	2700
Stands (100 capacity storage)	No.	111.11	5	555.55
License	No.	111.11	1	111.11
			Grand Total	7272.41

Table 10.14: Operation and maintenance costs

Item	**Units per time**	**Unit Cost (US$)**	**Units per month**	**Cost per month (US$)**
Raw Water	m3 per day	0.998	450	449.1
Packaging bags + printing	per individual sachets	0.0074	450,000	3330
Chlorine Tablets	Pack per 2 years	27.78	1/16	1.75
Electricity	-	-	-	8
Rent	m2 per month	0.6664	25	16.66
License	per renewal per 3 years	111.11	1/36	3.09
Salaries				
Technical Operators	per person per month	61.11	2	122.22
Drivers	per person per month	63.89	1	63.89
Casual Workers	per person per month	24.86	5	124.3
Treatment (Consumables)				
0.5 Micron Filter, 10"	no. per 3 months	4.44	1/3	1 1/2
5 Micron Filter, 10"	no. per 3 months	1.89	1/3	0.63
Granular Carbon Filters, 10"	no. per 3 months	8.33	1/3	2.776667
1 micron, 10"	no. per 3 months	7.78	1/3	2.593333
1 micron, 10"	no. per 3 months	3.33	1/3	1.11
UV bulb, 10"	no. per years	21.11	1/12	1.76
			Total Costs per month	4129

Table 10.15: Computation of cost of printing polythene bags used in sachet-water production

According to the technician (referred to as "engineer") in charge at Voltic, one roll of polythene weighed 13.8kg, including 1kg of an inner support the polythene is rolled on. The weight of the polythene alone was thus 12.8 kg. The cost of printing 2 colors on the polythene was approximately US$ 2.5 per kg (GHC 22,500 per kg).

One roll of polythene (12.8kg polythene) was able to produce 315 bags of sachets, with 20 individual sachets per bag. This is therefore equivalent to 492 individual sachets per kg. The equivalent cost a printed polythene bag for one individual sachet according to information provided by Voltic was thus US$ 0.005 per individual sachet (45.7GHC).

According to information given by Divine Love owners, the printing cost of the polythene bags was US$ 2.78 per kg (GHC 25,000). These bags were printed in Accra and thus additional costs were also incurred in transporting the bags to Tamale. The bags were transported by a local bus, the STC bus, and according to the information provided, transportation cost amounted to US$ 3.33 per 100 kg (GHC 300,000), including taxi costs and tips. The total cost of printing and transporting the bags was therefore US$ 311.11 per 100 kg (GHC 2,800,000). According to the interviewee, one kg of polythene bag would approximately produce 15 bags of 30 individual sachets. The cost of a printed polythene bag for one individual sachet based on this information was US$ 0.007(GHC 62.2).

Taking the average of costs computed above, the cost of a printed polythene bag for one individual sachet was computed to be US$ 0.006 (GHC 54).

Since the sachets were packaged in bigger bags of 20, 25 and 30 individual sachets, the cost of the bigger bag was factored into the US$ 0.006 for individual printed bags calculated above. The packaging bags cost US$ 3.56 (GHC 32,000), per 100 bags. Taking 25 to be the average number of individual sachets per bag, the cost factored into each individual sachet was therefore US$ 0.0014 (GHC 12.8) and the total packaging cost per individual sachet was thus calculated as US$ 0.0074 (GHC 66.8).

The total amount required per month for packaging material was therefore 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 day.

Table 10.16: Computation of sachet-water factory employee salaries

Aqua-ba gave information on the salaries paid to the technical operation staff, which in their case was US$ 61 per month (GHC 550,000). Voltic and First-class gave information based on the driver monthly salaries, which were US$ 78 (GHC 700,000) and US$ US$ 50 (GHC 450,000) respectively. The average of the two is US$ 63.89 (GHC 575,000). Divine-love, Jaf-lover, Voltic and First-class provided their factory-worker salary information. Divine-love and Jaf-lover paid this category workers based on the number of bags produced. Divine-love paid US$ 0.028 per bag of 30 sachets produced (GHC 250) while Jaf-lover paid US$ 0.022 per bag of 30 sachets (GHC 200). From the information on daily sachet-water production provided in Table 6.1 of Appendix I, these salaries were converted to an equivalent average monthly salary of US$ 19.44 (GHC 250 *21,000/30 = 175,000) for Divine Love and US$ 13.33 (GHC 200*18,000/30 = 120,000) for Jaf Lover. Voltic and First class paid monthly salaries to this category of workers. Voltic paid US$ 39 (GHC 350,000) while First-class paid a salary that ranged from US$ 22 to 33 (GHC 200,000 to 300,000), depending on experience.

Table 10.17: Microbial analysis results

				MEMBRANE FILTRATION					3M™ PETRIFILM™				H_2S		TURBIDITY	pH
Date	Sample No.	Brand	Dilution Factor	Red CFU (Plate Count)	Blue CFU (Plate Count)	Ave.TC CFU/100ml)	Ave. E.coli CFU/100ml))	Comments	Red Colonies (Plate Count)	Blue Colonies (Plate Count)	TC (CFU/ 100ml)	E.coli (CFU/ 100ml)	24 hrs	48 hrs	Turbidity (NTU)	pH
1/9/2007	1a-B	Jaf Lover		0	0			Blank								
1/9/2007	1a-S	Samples from	1	2	0	2	0	Raw	0	0	0	0	N	N	4.16	
1/9/2007	1b-B	Producer		0	0			Blank								
1/9/2007	1b-S		1	0	0	0	0	Treated/ packaged	0	0	0	0	N	N	3.16	
1/9/2007	2a-B	Voltic		0	0			Blank								
1/9/2007	2a-S	Samples from	1	10	0	10	0	Raw	0	0	0	0	N	N	4.63	
1/9/2007	2b-B	Producer		0	0			Blank								
1/9/2007	2b-S		1	0	0	0	0	Treated/ packaged	0	0	0	0	N	N	4.28	
1/11/2007	3a-B	Divine Love		0	0			Blank								
1/11/2007	3a-S	Samples from	1	0	0	0	0	Raw	0	0	0	0	N	N	9.52	5.5
1/11/2007	3b-B	Producer		0	0			Blank								
1/11/2007	3b-S		1	0	0	0	0	Treated /packaged	0	0	0	0	N	N	8.07	6.5
1/9/2007	4a-B	First Class		1	0			Blank*								
1/9/2007	4a-S	Samples from	1	0	0	0	0	Raw	0	0	0	0	N	N	8.50	
1/9/2007	4b-B	Producer		3	0			Blank*								
1/9/2007	4b-S		1	0	0	0	0	Treated /packaged	0	0	0	0	N	N	3.59	
1/16/2007	5a-B	Aqua-ba		1	0			Blank*								
1/16/2007	5a-S	Samples from	1	0	0	0	0	Raw	0	0	0	0	N	N	15.9	
1/16/2007	5b-B	Producer		0	0			Blank								
1/16/2007	5b-S		1	0	0	0	0	Treated /packaged	0	0	0	0	N	N	2.27	5.5
1/16/2007	5c-B			0	0	0	0	Blank								

1/16/2007	5c-S		1	0	0			Shelved (Since Oct/06)	0	0	0	0	N	N	0.66	5.5
1/15/2007	6a-B	Kosung		2	0			Cont Sw								
1/15/2007	6a-S		1	1	0			Spoiled Sample								
1/19/2007	6b-B			27	0			Cont Sw								
1/19/2007	6b-S		1	2	0			Spoiled Sample								
1/21/2007	6c-B			0	0			Blank								
1/21/2007	6c-S		1	0	0	0	0	Treated/packaged	0	0	0	0	N	N	4.96	5.5
1/15/2007	7a-B	Grassland		8	0			Cont Sw								
1/15/2007	7a-S		1	0	0			Treated/ packaged								
1/21/2007	7b-B			0	0			Blank								
1/21/2007	7b-S		1	1	0	1	0	Treated/ packaged	0	0	0	0	N	N	1.76	5.5
1/15/2007	8a-B	Nkunimdi Nsuo		1	0			Blank*								
1/15/2007	8a-S		1	0	0	0	0	Treated/ packaged	0	0	0	0	N	N	1.76	5.0
1/17/2007	9a-B	Nacool		2	2			Cont Sw								
1/17/2007	9a-S		1	CONF	0			CONF Colonies								
1/21/2007	9b-B			23	0			Blank*								
1/17/2007	9b-S		1	0	0	0	0	Treated /packaged	0	0	0	0	N	N	7.5	8.5
1/15/2007	10a-B	Zamzam		CONF	0			Blank*								
1/15/2007	10-aS		1	CONF	0			Spoiled Sample								
1/17/2007	10a-B			0	0			Blank								
1/17/2007	10-aS		1	CONF	CONF			CONF Colonies								
1/21/2007	10b-B			1	0			Blank*								
1/21/2007	10b-S		1	1	0			Spoiled Sample								
1/23/2007	10c-B			1	0			Blank*								
1/23/2007	10c-S		1	0	0	2	0	Treated /packaged								
1/23/2007	10c-B			0	0			Blank								
1/23/2007	10c-S			3	0			Treated /packaged	0	0	0	0	N	N	4.35	5.5

1/17/2007	11a-B	MJ		8	0			Blank*								
1/17/2007	11-aS		1	32	0			Spoiled Sample								
1/21/2007	11b-B			0	0			Blank								
1/21/2007	11b-S		1	1	0	1	0	Treated/ packaged	0	0	0	0	N	N	1.74	5.5
1/17/2007	12a-B	Viking		0	0			Blank								
1/17/2007	12-aS		1	4	0	4	0	Treated/ packaged	0	0	0	0	N	N	3.45	5.5
1/19/2007	13a-B	Tropika		0	0			Blank								
1/19/2007	13-aS		1	102	0			Treated/ packaged								
1/19/2007	13b-B			0	0			Blank								
1/19/2007	13b-S		1	62	0	82	0	Treated /packaged	1	0	100	0	N	N	9.13	5.5
1/19/2007	14a-B	Life		32	0			Blank*								
1/19/2007	14-aS		1	3	0			Spoiled Sample								
1/19/2007	14b-B			0	0			Blank								
1/19/2007	14b-S		10	12	1			Treated /packaged								
1/19/2007	14c-B			0	0			Blank								
1/19/2007	14c-S		100	1	0	115	5	Treated/ packaged	0	0	0	0	P	P	1.74	5.0
1/23/2007	15a-B	Salbelia		0	0			Blank								
1/23/2007	15-aS		1	1	0			Treated/ packaged								
1/23/2007	15b-B			0	0			Blank								
1/23/2007	15b-S		1	0	0	1	0	Treated/ packaged	0	0	0	0	N	N	4.52	5.5
1/9/2007	16a-B	HT1	1	1	0			Blank*								
1/9/2007	16a-S	(Samples from	1	121	1	120	0	Raw	0	0	0	0	N	N	8.85	
1/9/2007	16b-B	Producer – Joyce)	1	1	0			Blank*								
1/9/2007	16b-S		1	196	0	195	0	Treated/ packaged	0	0	0	0	N	N	6.43	
1/11/2007	17a-B	HT2		0	0	2060		Blank								
1/11/2007	17a-S	(Samples from	1	TNTC	0			Raw	4	0	400	0	N	N	7.45	
1/11/2007	17b-B	Producer - Peace)		0	0			Blank								
1/11/2007	17b-S		1	20	0			Treated/ packaged								

1/23/2007	17c-B			7	0			Cont Sw								
1/23/2007	17c-S		10	213	0			Spoiled Sample								
1/23/2007	17c-B			0	0			Blank								
1/23/2007	17c-S		100	41	0			Treated/ packaged	6	0	600	0	N	N	6.49	
1/10/2007	18a-B	HT3	1	0	0			Blank								
1/10/2007	18a-S	(Samples from	1	TNTC	0			Raw	18	0	1800	0	N	P	6.28	
1/10/2007	18b-B	Producer Mariama)	1	0	0			Blank								
1/10/2007	18b-S		1	4	0	4	0	Treated/ packaged	1	0			N	N	7.47	
1/10/2007	19a-B	HT4	1	0	0			Blank								
1/10/2007	19a-S	(Samples from	1	387	0	387	0	Raw	48	0			N	P	6.3	
1/10/2007	19b-B	Producer Hamshau)	1	0	0			Blank								
1/10/2007	19b-S		1	111	0	111	0	Treated/ packaged	1	0	100	0	N	N	7.33	
1/10/2007	20a-B	HT5		0	0			Blank								
1/10/2007	20a-S	(Samples from	1	TNTC	94			Raw	38	2	3800	200	N	N	6.57	
1/10/2007	20b-B	Producer - Esther)		0	0			Blank								
1/10/2007	20b-S		1	TNTC	101			Treated/pac kaged								
1/23/2007	20c-B			0	0			Blank								
1/23/2007	20c-S		10	78	0			Treated/ packaged								
1/23/2007	20d-B			0	0			Blank								
1/23/2007	20d-S		100	10	0	939	49	Treated/ packaged	22	1	2300	100	N	P	6.71	
1/15/2007	21a-B	HT6		0	0			Blank								
1/15/2007	21a-S		10	1	0	10	0	Treated/ packaged	0	0	0	0	N	N	10.1	5.5
1/15/2007	22a-B	HT7		0	0			Blank								
1/15/2007	22a-S		10	85	0	850	0	Treated/ packaged	20	0	2000	0	P	P	14.9	5.5
1/15/2007	23a-B			0	0			Blank								
1/15/2007	23a-S	HT8	10	10	100	100		Treated/ packaged	0	0	0	0	P	P	4.92	5.5
1/17/2007	24a-B	HT9	0	0	0	1280	0	Blank								

1/17/2007	24a-S		10	128	0			Treated /packaged								
1/17/2007	24b-S		1	TNTC	0			Treated/ packaged	0	0	0	0	N	N	13.7	5.5
1/17/2007	25a-B	HT10		0	0			Blank								
1/17/2007	25a-S		10	TNTC	0			Treated/ packaged								
1/17/2007	25b-S		1	TNTC	0	TNTC	0	Treated/ packaged	3	0	300	0	N	N	10.9	5.5
1/17/2007	26a-B	HT11		0	0			Blank								
1/17/2007	26a-S		10	25	0			Treated/ packaged								
1/17/2007	26b-S		1	TNTC	0	250	0	Treated/ packaged	0	0	0	0	N	N	7.15	5.5
1/17/2007	27a-B	HT12		0	0			Blank								
1/17/2007	27a-S		1	110	0			Treated/ packaged								
1/17/2007	27b-S		10	28	0	195	0	Treated/ packaged	0	0	0	0	N	N	12.8	5.5
1/17/2007	28a-B	HT13		0	0			Blank								
1/17/2007	28a-S		1	33	0			Treated/ packaged								
1/17/2007	28b-S		10	1	0	22	0	Treated/ packaged	0	0	0	0	N	N	9.78	5.5
1/17/2007	29a-B	HT14		0	0			Blank								
1/17/2007	29a-S		10	24	0			Treated packaged								
1/17/2007	29b-B			0	0			Blank								
1/17/2007	29b-S		100	2	0	220	0	Treated/ packaged	1	0	100	0	N	N	8.01	6.0
1/17/2007	30a-B	HT15		0	0			Blank								
1/17/2007	30a-S		10	4	0			Treated/ packaged								
1/17/2007	30b-B			0	0			Blank								
1/17/2007	30b-S		100	4	0	220	0	Treated/ packaged	0	0	0	0	N	N	7.22	6.0

Note: Cont SW: Contaminated sterile water
CONF: Confluent
TNTC: Too numerous to count

Table 10.18: Results - MF

Sample No.	**Brand**	**Total Coliforms (CFU/100ml)**	**E-coli (CFU/100ml)**
1	Jaf Lover	0	0
2	Voltic	0	0
3	Divine Love	0	0
4	First Class	0	0
5	Aqua-ba	0	0
6	Kosung	0	0
7	Grassland	1	0
8	Nkunimdi Nsuo	0	0
9	Nacool	0	0
10	Zamzam	2	0
11	MJ	1	0
12	Viking	4	0
13	Tropika	82	0
14	Life	115	5
15	Salbelia	1	0
16	HT1	195	0
17	HT2	2060	0
18	HT3	4	0
19	HT4	111	0
20	HT5	939	49
21	HT6	10	0
22	HT7	850	0
23	HT8	100	0
24	HT9	1280	0
25	HT10	TNTC	0
26	HT11	250	0
27	HT12	195	0
28	HT13	22	0
29	HT14	220	0
30	HT15	220	0

Table 10.19: Results - 3M™ Petrifilm™

Sample No.	Brand	Total Coliforms (CFU/100ml)	E-coli (CFU/100ml)
1	Jaf Lover	0	0
2	Voltic	0	0
3	Divine Love	0	0
4	First Class	0	0
5	Aqua-ba	0	0
6	Kosung	0	0
7	Grassland	0	0
8	Nkunimdi Nsuo	0	0
9	Nacool	0	0
10	Zamzam	0	0
11	MJ	0	0
12	Viking	0	0
13	Tropika	100	0
14	Life	0	0
15	Salbelia	0	0
16	HT1	0	0
17	HT2	600	0
18	HT3	100	0
19	HT4	100	0
20	HT5	2300	100
21	HT6	0	0
22	HT7	2000	0
23	HT8	0	0
24	HT9	0	0
25	HT10	300	0
26	HT11	0	0
27	HT12	0	0
28	HT13	0	0
29	HT14	100	0
30	HT15	0	0

Table 10.20: Results - P/A H_2S

Sample No.	Brand	24hrs	48 hrs
1	Jaf Lover	Negative	Negative
2	Voltic	Negative	Negative
3	Divine Love	Negative	Negative
4	First Class	Negative	Negative
5	Aqua-ba	Negative	Negative
6	Kosung	Negative	Negative
7	Grassland	Negative	Negative
8	Nkunimdi Nsuo	Negative	Negative
9	Nacool	Negative	Negative
10	Zamzam	Negative	Negative
11	MJ	Negative	Negative
12	Viking	Negative	Negative
13	Tropika	Negative	Negative
14	Life	Positive	Positive
15	Salbelia	Negative	Negative
16	HT1	Negative	Negative
17	HT2	Positive	Positive
18	HT3	Negative	Negative
19	HT4	Negative	Negative
20	HT5	Positive	Positive
21	HT6	Negative	Negative
22	HT7	Positive	Positive
23	HT8	Positive	Positive
24	HT9	Negative	Negative
25	HT10	Negative	Negative
26	HT11	Negative	Negative
27	HT12	Negative	Negative
28	HT13	Negative	Negative
29	HT14	Negative	Negative
30	HT15	Negative	Negative

Table 10.21: Comparison made on test results by assigning "1" to all samples that showed total coliforms and "0" to those that did not

Factory-produced sachet water				Hand-tied sachet water			
	MF	3M	H_2S		MF	3M	H_2S
Jaf Lover	0	0	0	HT1	1	0	0
Voltic	0	0	0	HT2	1	1	1
Divine Love	0	0	0	HT3	1	1	0
First Class	0	0	0	HT4	1	1	0
Aqua-ba	0	0	0	HT5	1	1	1
Kosung	0	0	0	HT6	1	0	0
Grassland	1	0	0	HT7	1	1	1
Nkunimdi Nsuo	0	0	0	HT8	1	0	1
Nacool	0	0	0	HT9	1	0	0
Zamzam	1	0	0	HT10	1	1	0
MJ	1	0	0	HT11	1	0	0
Viking	1	0	0	HT12	1	0	0
Tropika	1	1	0	HT13	1	0	0
Life	1	0	1	HT14	1	1	0
Salbelia	1	0	0	HT15	1	0	0
Total Contaminated	7	1	1	Total Contaminated	15	7	4

Table 10.22: Cost of consumables for MF test

Item	Description	Product number	Unit	Units in pack	Cost per pack (US$)	Cost per unit (US$)
Filter paper	47-mm diameter, 0.45-µm pore size	1353001	No.	200	94.9	0.47
m ColiBlue24 ® Broth	2ml Plastic Ampules	2608450	No.	50	84.5	1.69
Absorbent*	47 mm sterile pads	AP10047S0	No.	100	37.0	0.37
Petri Dish, with absorbent pad	9 x 50 mm, suitable for 47 mm membrane filters	1471799	No.	100	35.5	0.36

(HACH, 2006)
*(Millipore, 2007, personal communication May 04, 2007)

Table 10.23: Cost of consumables for HACH Pathoscreen™ P/A test

Item	Description	Product Number	Units	Units in Pack	Cost per Pack (US$)	Cost per Unit (US$)
HACH Pathoscreen™ Medium Pillows	20-ml sample	2610796	No. (of pillows)	100	26.5	0.27
PathoScreen™ Medium, P/A Pillows	100-mL sample	2610696	No. (of pillows)	50	37.80	0.76

(HACH, 2006)

Table 10.24: Scale of sampling of packaged drinking water

Number of units in lot	Number of units to be selected
Up to 1000	15
1001 to 3000	17
3001 to 10,000	18
Above 10,000	24

Table 10.25: Remarks on the cartridge labels of different types of filters

Description	Manufacturers	Treatment Remarks on Product Label	Other Remarks on Product Label
Granular Activated Carbon Cartridge	Kunshan Fangshi Plastics & Electronic Factory, China	"Granular Active Carbon Cartridge: (For the) Removal of odor, chlorine and halide. With high removal efficiency of common organic matter. The processed water flow~~ing~~(s) through all the carbon to ensure ~~the~~ maximum absorption efficiency"	"Caution: For drinking water applications. Do not use where the water is unsafe or with water of unknown quality"
Granular Activated Carbon Cartridge	M85, USA	"GAC Cartridge Filter"	"This cartridge should be installed with the gasket at the top of the unit showing. Remove outside wrapper before installation. After installation, filter should be flushed with sufficient water to remove all traces of carbon fines. Filter should, be changed every six months or sooner if bad taste and/or odor return." This filter should not be used where the water is micro biologically unsafe or with water of unknown quality without adequate disinfection before and/or after the filter. The "O" ring in the housing should be replaced and lubricated with a very high light coating of white petroleum jelly to prevent leakage."

Matrix Carbon Cartridge ("Extruded Block Activated Carbon Cartridge")	Kunshan Fangshi Plastics & Electronic Factory, China	"Extruded Block Activated Carbon Cartridge: The filter is composed of long service life carbon block and high efficiency filter net, have filtration performs of double function. The filter can eliminate color, smell, chlorine, and halide. The filter can remove extremely tiny matter (sand, silt, suspended substance and colloid)."	"Caution: For drinking water applications. Do not use where is unsafe or with water of unknown quality".
Polypropylene Fiber Cartridge	VZV, Water Quality, USA	"5 Micron Sediment Filter. Polypropylene Replacement Cartridge For (the) removal of: Sand, silt, dirt, and rust particles. For water use only. Housind(g)s.	"Maximum water temperature 125 F(52 C).
Fiber Cartridge	Kunshan Fangshi Plastics & Electronic Factory, China	"Sedi~~n~~(m)ent Cartridge. (For the) Removal of sand, silt suspended substance(s), colloid(s), rust and particle(s) in source water. Major series of high efficiency. Low pressure drop special liquid filtering cartridges. The filter could be cleaned repeated(ly) in order to extend service life.	"Caution: For drinking water applications. Do not use where is unsafe or with water of unknown quality".

10.2 Appendix II: Sachet Machine

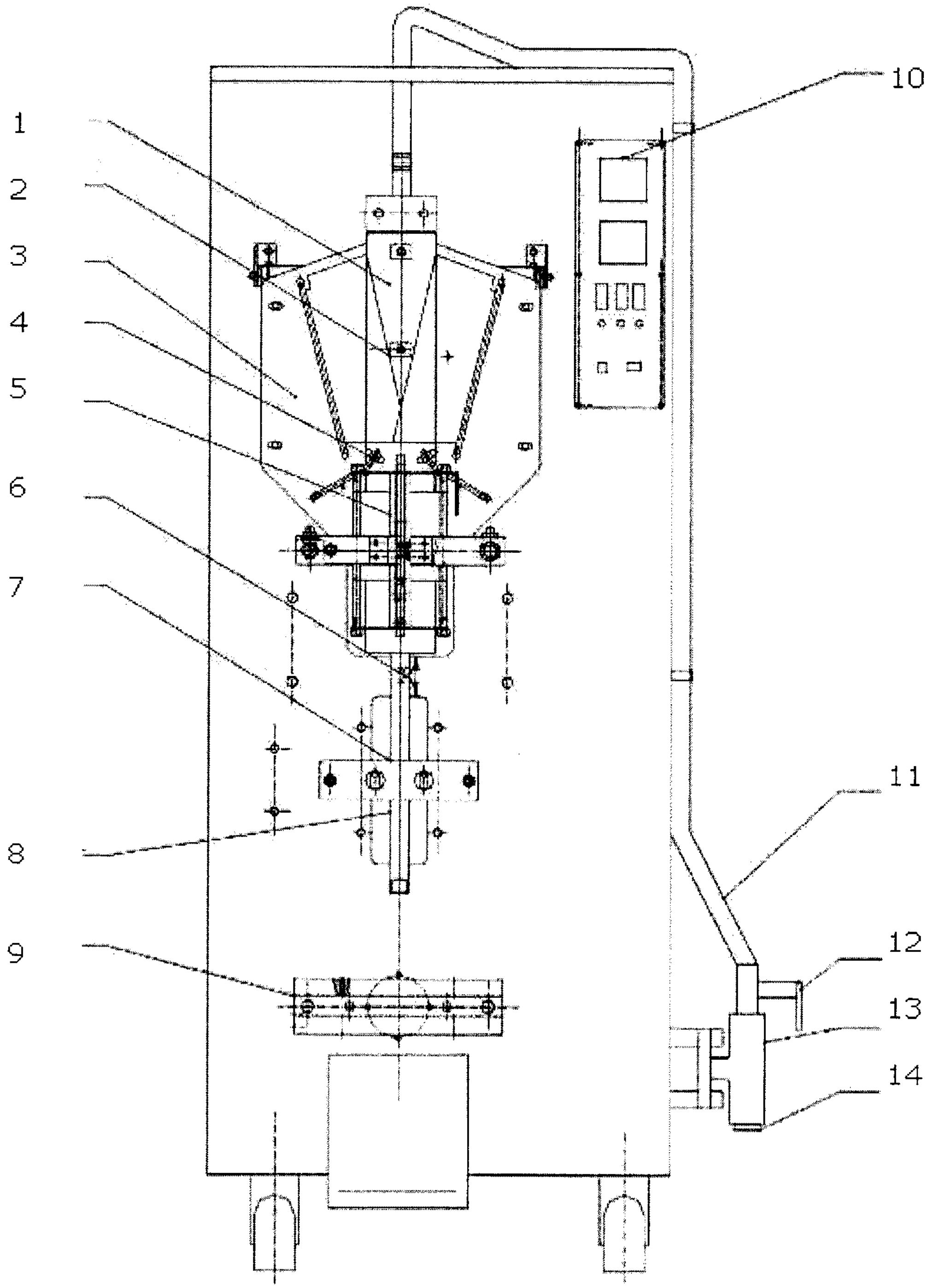


Figure 10.1: Schematic Diagram of a Sachet Machine (Front)
(Hualian Machinery Co. Ltd, China., 2007)

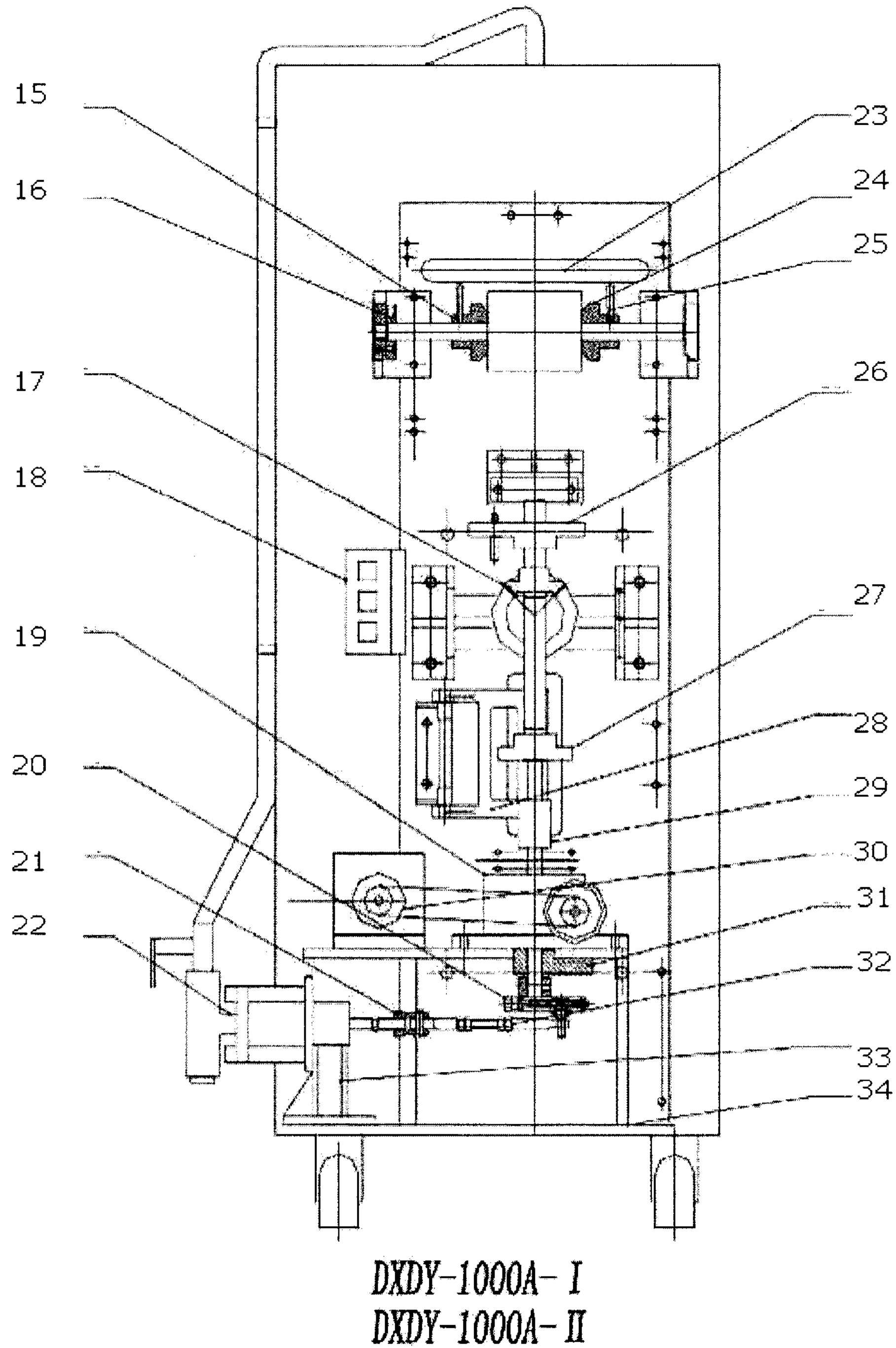


Figure 10.2 Schematic Diagram of a Sachet Machine (Back of DXDY-1000A-I and DXDY-1000A-II)

(Hualian Machinery Co. Ltd, China., 2007)

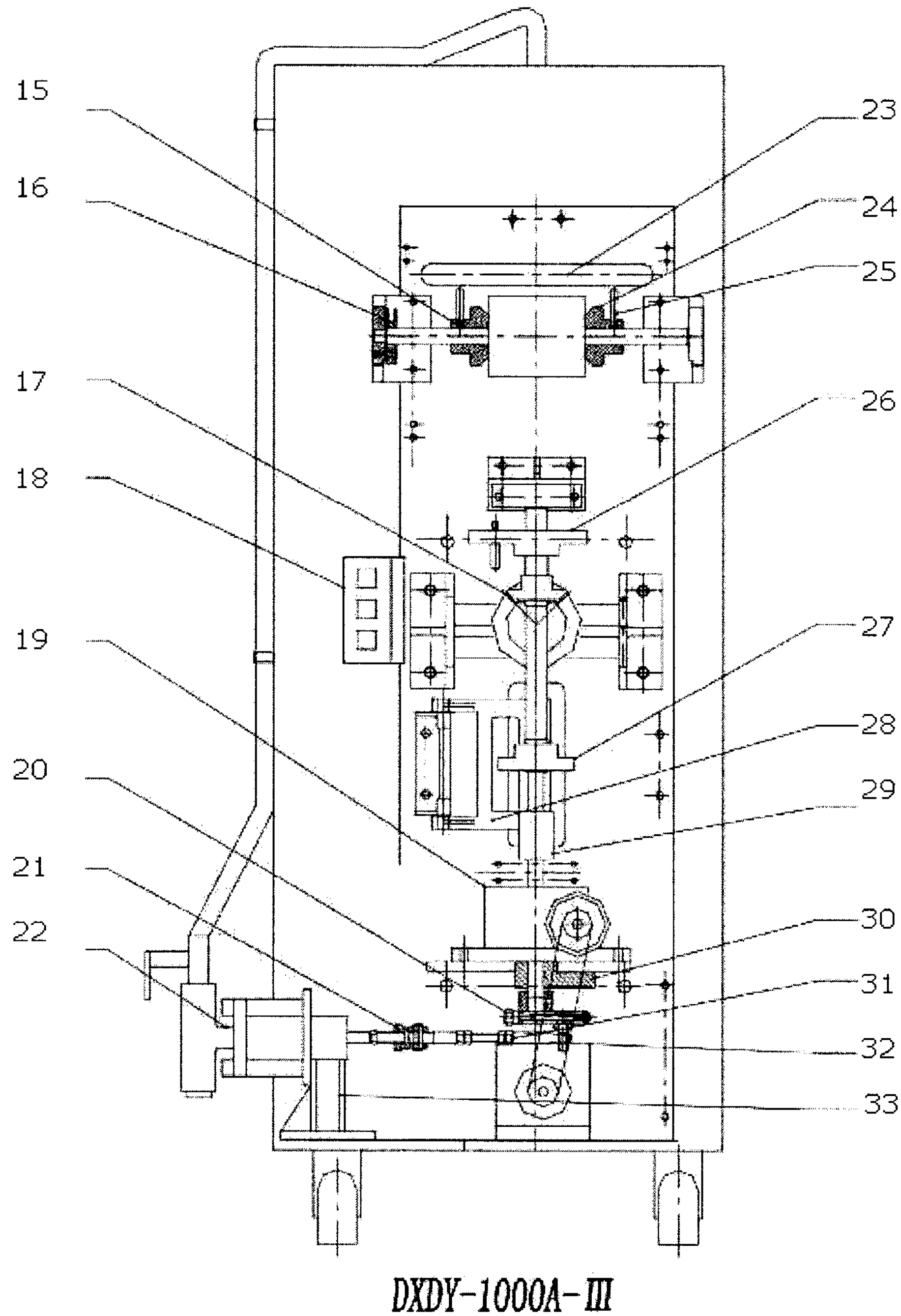


Figure 10.3: Schematic Diagram of a Sachet Machine (Back of DXDY-1000A-III)
(Hualian Machinery Co. Ltd, China., 2007)

Table 10.26: Legend of schematic diagram of the sachet machine

NO	Name	NO	Name
1	Central plate of the bag-former	18	Electronic switchboard
2	Folder plate of the bag-former	19	Speed reduce tension device
3	Base board of bag-former	20	Pump adjusting screw
4	Press bag wheel	21	Pump piston sleeve contractor
5	Copper block for vertical heat-sealing	22	Pump
6	Central tube	23	Film guide roller
7	Moving block and frame	24	Positioning head of the film roller
8	Guide	25	Adjusting device for film roller
9	Horizontal sealing device	26	Cam for vertical sealing
10	Control panel	27	Cam for dragging film
11	Product indeed tube	28	Rock plate for dragging film
12	Three-way valve	29	Coupling
13	Upper check valve	30	Cam for speed reduce and motor
14	Lowe check valve	31	Bending knob for pump
15	Roll shaft	32	Motor
16	Film roller tension device	33	Pump base
17	Bag direction knob	34	Base for speed reducer and motor

(Hualian Machinery Co. Ltd, China., 2007)

10.3 Appendix III: Questionnaires

10.3.1 Questionnaire Directed to Sachet-water Customers

GENERAL INFORMATION

Interviewee Description

	Frequency	Percentage
Passer-by	22	73.3
Business owner	8	26.7
Total	30	100.0

Location of Interview

	Frequency	Percentage
Tamale	21	70.0
Savelugu	9	30.0
Total	30	100.0

Sex of Interviewee

	Frequency	Percentage
Male	18	60.0
Female	12	40.0
Total	30	100.0

Age of Interviewee

Response	Frequency	Percentage
<=15	1	3.3
16-20	7	23.3
21-40	16	53.3
41-60	5	16.7
>60	1	3.3
Total	30	100.0

TYPE OF SACHET WATER PURCHASED

Do you buy sachet water?

Response	Frequency	Percentage
Yes	30	100.0
No	0	0.0
Total	30	100.0

If 'Yes' what type do you buy?

Response	Frequency	Percentage
Hand-tied	3	10.0
Factory-produced	14	46.7
Both	13	43.3
Total	30	100.0

Which brand of factory-produced sachet water do you prefer to buy?

Response	Frequency	Percentage
Voltic	12	40.0
Zamzam	1	3.3
Aspect	1	3.3
Jaf-Lover	3	10.0
Standard-water	1	3.3
Aqua-ba & Divine Love	1	3.3
No specific preference	8	26.7
N/A	3	10.0
Total	30	100.0

Why do you prefer to buy the brand specified?

Response	Frequency	Percentage
Better quality	6	20.0
Better packaging	1	3.3
Better taste	5	16.7
Cheaper and better taste	1	3.3
Convenient to reach vendor	1	3.3
Likes the name	3	10.0
Been in market for long	2	6.7
N/A	11	36.7
Total	30	100.0

PERCEPTION ON PRICE

What do you feel about the price of hand-tied sachet water?

Response	Frequency	Percentage
Cheap	7	23.3
Affordable	23	76.7
Total	30	100.0

What do you feel about the price of factory-produced sachet water?

Response	Frequency	Percentage
Cheap	3	10.0
Affordable	15	50.0
Expensive	10	33.3
N/A (Not able to comment)	2	6.7
Total	30	100.0

PLACE

How far do you go to access the sachet water?

Response	Frequency	Percentage
En route final destination	8	26.7
Delivered	5	16.7
<100m	10	33.3
>100m	3	10.0
En route final destination or delivered	4	13.3
Total	30	100.0

PERCEPTION ON PRODUCT AND SERVICES

What do you feel about the service quality of sachet-water vendors?

Response	Frequency	Percentage
Always good	21	70.0
Usually good	9	30.0
Total	30	100.0

What do you feel about the quality of hand-tied sachet water?

Response	Frequency	Percentage
Good	10	33.3
Fair	2	6.7
Poor	6	20.0
Uncertain	12	40.0
Total	30	100.0

What do you feel about thc quality of factory-produced?

Response	Frequency	Percentage
Good	24	80.0
Fair	3	10.0
Poor	2	6.7
Uncertain	1	3.3
Total	30	100.0

Do you buy water from a particular vendor(s)?

Response	Frequency	Percentage
No	14	46.7
Yes	14	46.7
Sometimes	2	6.7
Total	30	100.0

If 'yes', what makes you choose to buy from the particular vendor(s)?

Response	Frequency	Percentage
Trusted quality of water	7	23.3
Convenient to reach	7	23.3
Offers credit	1	3.3
Friendlier/good attitude	1	3.3
N/A	14	46.7
Total	30	100.0

What kind of improvements would you suggest for the vendors?

Response	Frequency	Percentage
Improve packaging for hand-tied sachet water	3	10.0
Improve quality/taste of hand-tied sachet water	4	13.3
Improve packaging and increase volume of for hand-tied sachet water	1	3.3
Allow customers to pick sachets themselves when they buy and not to dip sachets in melted ice	1	3.3
Improve quality/taste of both factory-produced and hand-tied sachet water	1	3.3
Improve quality of factory-produced sachet water	1	3.3
Improve taste of factory-produced sachet water	3	10.0
Reduce price of factory-produced sachet water	1	3.3
Increase quantity and reduce price of factory-produced sachet water	1	3.3
None	14	46.7
Total	30	100.0

SOURCES AND AMOUNT OF WATER AT HOME/AWAY FROM HOME

What other sources of water you drink when away from home?

Response	Frequency	Percentage
Pipe/tap water	4	13.3
Bottled water	1	3.3
Pipe/tap and well water	2	6.7
Pipe/tap and bottled water	1	3.3
None other	22	73.3
Total	30	100.0

How many days per week do you work (away from home)?

Response	Frequency	Percentage
5	4	13.3
6	11	36.7
7	7	23.3
Not defined	8	26.7
Total	30	100.0

How many hours a day do you work (away from home)?

Response	Frequency	Percentage
4 to 8	7	23.3
9 to 13	8	26.7
14 to 18	3	10.0
Not defined	12	40.0
Total	30	100.0

What is main source of drinking water at your home?

Response	Frequency	Percentage
Pipe/tap water	5	16.7
Sachet water	11	36.7
Bottled water	1	3.3
Pipe/tap water and sachet water	11	36.7
Pipe/tap water and vendor/tanker water	1	3.3
Pipe/tap water and dug-outs	1	3.3
Total	30	100.0

About how much water (glasses/ sachets of water) do you drink at home everyday? (Ans. Converted to equivalent liters)

Response	Frequency	Percentage
0-1.0litre	8	26.7
1.1 to 2.0 liters	18	60.0
2.1 to 3.0 liters	2	6.7
3.1 to 4.0 liters	1	3.3
4.1 to 5.0 liters	1	3.3
Total	30	100.0

About how much water (glasses/ sachets) do you drink when away from home everyday?

Response	Frequency	Percentage
0-1.0litre	2	6.7
1.1 to 2.0 liters	11	36.7
2.1 to 3.0 liters	12	40.0
3.1 to 4.0 liters	1	3.3
4.1 to 5.0 liters	4	13.3
Total	30	100.0

Respondent drinks more water:

	Frequency	Percentage
At home	3	10.0
Away from home	21	70.0
Same at home and away from home	6	20.0
Total	30	100.0

OTHER – ENVIRONMENTAL CONCERNS

Where do you dispose of the sachet bag?

Response	Frequency	Percentage
Dust bin	14	46.7
Leave with vendor	1	3.3
Litter	8	26.7
Dust bin or leave with vendor	1	3.3
Dust bin or litter	6	20.0
Total	30	100.0

10.3.2 Questionnaire Directed to Road-side Sachet-water Vendors

GENERAL INFORMATION

Sachet water type

	Frequency	Percent
Hand-tied	3	30
Factory-produced	1	10
Hand-tied and factory-produced	6	60
Total	10	100

Brand of pure-water

	Frequency	Percent
Jaf Lover	1	10
Grass land	1	10
Ko Sung	1	10
Viking	2	20
Voltic	1	10
First class	1	10
N/A (Hand-tied sachet water)	3	30
Total	10	100

Sex of vendor

	Frequency	Percent
Female	10	100
Total	10	100

Age of vendor

	Frequency	Percent
<=15	4	40
16 to 20	4	40
21 to 40	2	20
Total	10	100

PLACE/PROMOTION

At what locations do you sell your sachet water?

Response	Frequency	Percent
No specific location	1	10
Mosque area	1	10
Market place	1	10
Taxi area and bus stop	2	20
Taxi area, bus stop and market place	5	50
Total	10	100

Why do you choose to sell at the specified places/locations/streets?

Response	Frequency	Percent
More sales/customers	7	70
Other business/activity conducted in the area	1	10
Not specified	2	20
Total	10	100

Who are your main customers?

Response	Frequency	Percent
No specific set of customers	3	30
Taxi drivers	5	50
Market sellers/vendors	1	10
Pedestrians	1	10
Total	10	100

PRICE

How much do you sell the hand-tied sachet water for? (GHC)

Response	Frequency	Percent
200	9	90
N/A (does not sell hand-tied sachet water)	1	10
Total	10	100

How much do you sell the factory-produced sachet water for? (GHC)

Response	Frequency	Percent
400	7	70
N/A (does not sell factory-produced sachet water)	3	30
Total	10	

About how much is generated per day from your sales?

Response	Frequency	Percent
<10,000	1	10
10,000 to 19,000	3	30
20,000 to 29,000	1	10
30,000 to 39,000	3	30
50,000	1	10
Don't Know	1	10
Total	10	100

BUSINESS STRUCTURE

Who owns the business?

Response	Frequency	Percent
Member of family	7	70
Non-member of family	1	10
Self	2	20
Total	10	100

If employed how much are you paid per day?

Response	Frequency	Percent
0	6	60
5,000	2	20
Owner	2	20
Total	10	100

How many days per week do you work?

Response	Frequency	Percent
5	1	10
6	4	40
7	5	50
Total	10	100

How many hours per week do you work?

Response	Frequency	Percent
<4	2	20
4 to 8	7	70
9 to 12	1	10
Total	10	100

HAND-TIED SACHET WATER: WATER TREATMENT AND SAFE STORAGE

Where do you package the hand-tied sachet water?

	Frequency	Percent
At home	10	100
Total	10	100

Where is the water you pack sourced from?

Response	Frequency	Percent
Tap/pipe water	8	80
Tanker	1	10
Other distributing vendor	1	10
Total	10	100

How do you treat the water?

Response	Frequency	Percent
Cloth filter	6	60
Sponge filter	3	30
Settling and sponge filter	1	10
Total	10	100

Where is the water stored after it is sourced?

Response	Frequency	Percent
20 liters plastic buckets	5	50
20 liters metal buckets and 20 liters jerry cans	1	10
200 liters metal drum	1	10
200 liters plastic drum	2	20
200 liters plastic drum and 20 liters metal basin	1	10
Total	10	100

Are the storage vessels narrow mouthed?

Response	Frequency	Percent
No	10	100

Are the storage vessels always covered?

Response	Frequency	Percent
No	2	20
Yes	8	80
Total	10	100

How do you draw water from the storage containers to into the sachets?

Response	Frequency	Percent
Cup/scoop with handle	8	80
Cup/scoop with handle and without handle	2	20
Total	10	100

HANDLING PRACTICES

How do you open the sachet bags to be able to fill them with water?

Response	Frequency	Percent
Rub bag together by hand	10	100

Do you wash your hands before bagging the water?

	Frequency	Percent
Yes	10	100

Do you wash your hands with soap before bagging the water?

Response	Frequency	Percent
No	1	10
Yes	9	90
Total	10	100

CAPACITY/WILLINGNESS TO TREAT WATER

How much are you prepared to spend on water treatment and safe storage products for your water?

Response	Frequency	Percent
10000	1	10
12000	1	10
50000	1	10
250000	2	20
Not sure	5	50
Total	10	100

Do you attend school or work on another kind of job when you are not selling sachet water

	Frequency	Percent
Arabic school in the evenings	2	20
Regular school in the morning	3	30
Other job	1	10
No school or other job	4	40
Total	10	100

10.4 Appendix IV: Water Quality Notes: Indicator Organisms

In testing the microbial quality of water, it is difficult to analyze the numerous pathogenic species that may be present, each of which requires a specific and technically difficult analysis. The difficulties and complex nature of tests involved therefore makes it impractical to test for bacteria directly and instead, indicator organisms are used. Indicator organisms are bacteria whose presence in water signals the presence of pathogens. Indicator organisms are usually not pathogenic but are "present in water when other pathogens present and absent when pathogens are absent" (Hatch, 2003). Indicator organisms should have the following characteristics:

- They should be present when the pathogenic organism concern is present and absent in clean water.
- They should be present in fecal material in large numbers.
- They should behave in a manner similar to the respective pathogens and respond to the environment in a similar way, for example, have the same growth and death rate
- They should be easy to isolate, identify and count.
- They should come from the same source as the pathogen (Vigneshwran and Visvanathan, 1995).

Total Coliform Bacteria

Total coliform bacteria are often used as indicator organisms for water quality testing. They include a wide range of aerobic and facultative anaerobic, Gram-negative, non-spore-forming bacilli (rod shaped bacteria) capable of growing in the presence of relatively high concentrations of bile salts with the fermentation of lactose and production of acid or aldehyde within 24 hours and at 35 to 37 °C. Traditionally, the total coliform group belong to the Enterobacteriaceae family, which generally include genera *Escherichia, Citrobacter, Klebsiella and Enterobacter.*

Fecal Coliforms (Thermotolerant Coliforms)

Fecal coliforms are a sub-group of total coliforms, which can ferment lactose at higher temperatures that range from 44 to 45 °C. The predominant genus in most water bodies is thermotolerant forms of *Escherichia*, *Citrobacter*, *Klebsiella* and *Enterobacter*.

A characteristic that makes *Escherichia coli (E.coli)* unique from the other thermotolerant coliforms is the ability they have to produce indole from tryptophan or by the producing enzyme β-Glucuronidase. Though there is some evidence of *E.coli* growth in tropical soils, they are rarely found in the absence of faecal pollution, and occur in very large numbers in human and animal faeces. Most strains of *E.coli.* are themselves harmless and live in the intestines of healthy humans and animals. An example of a harmful strain is *E.* coli O157:H7, which produces a powerful toxin and can cause severe illness (US EPA, 2006b). Generally, the presence of *E.coli* is not a health threat in itself but rather an indication that there may potentially be a harmful bacteria present in the water tested. While water can contain total coliforms without *E.coli, E.coli* cannot be present in water without total coliforms.

Fecal coliforms are considered to be more directly associated with fecal contamination from warm-blooded animals when compared to other members of the coliforms. However, microbial tests are known to sometimes produce positive results for *E.coli* in water samples that are not fecally contaminated (Hatch, 2003).

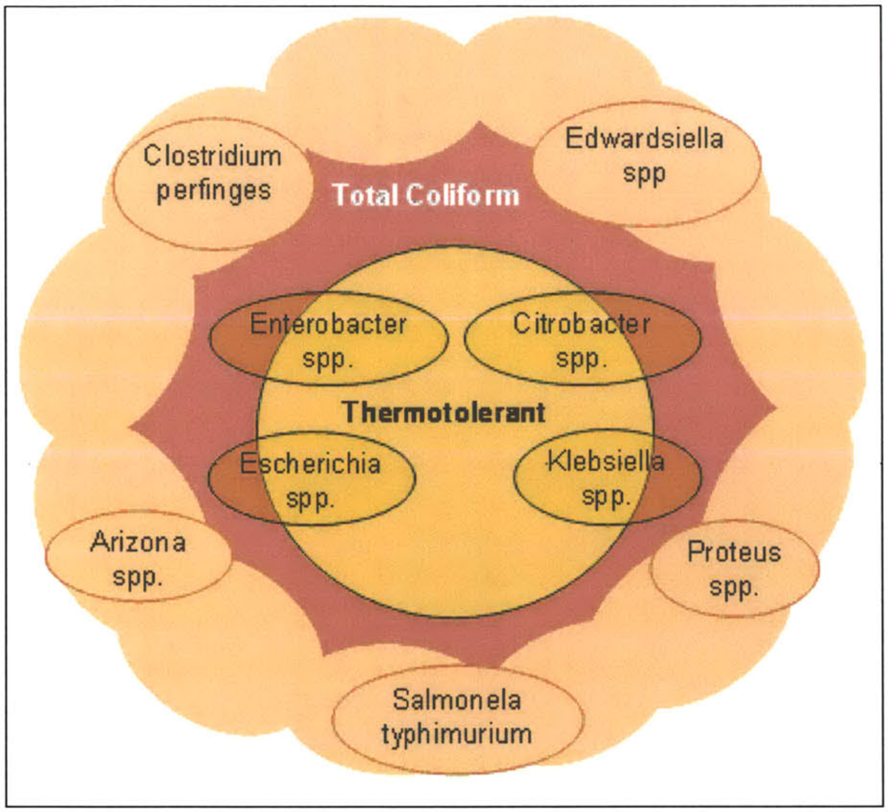


Figure 10.4: Schemata of Major Classes of Enteric Bacteria

Useful Contacts

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