160

Safe Water Storage in Kenya's Modified Clay Pot: Standardization, Tap Design, and Cost Recovery

by

Suzanne E. Young

B.S. Environmental Engineering Science
Massachusetts Institute of Technology, 2004

Submitted to the Department of Civil and Environmental Engineering
in Partial Fulfillment of the Requirements for the Degree of
Master of Engineering in Civil and Environmental Engineering

at the

Massachusetts Institute of Technology

September 2005

Signature of Author: ....
Department of Civil and Environmental Engineering
June 28, 2005

Certified By: ....
Susan Murcott
Lecturer, Department of Civil and Environmental Engineering
Thesis Supervisor

Accepted By: ....
Andrew Whittle
Professor of Civil and Environmental Engineering
Chairman, Department Committee on Graduate Studies

Safe Water Storage in Kenya's Modified Clay Pot: Standardization, Tap Design, and Cost Recovery

by

Suzanne E. Young

Submitted to the Department of Civil and Environmental Engineering
on June 30, 2005 in Partial Fulfillment of the Requirements for the Degree of
Master of Engineering in Civil and Environmental Engineering

ABSTRACT

One of the main components necessary for providing safe drinking water for users who lack piped water in the home is the ability to safely store it in the home. Users in the Nyanza Province of Kenya frequently carry water from some distance or purchase vended water and traditionally store this water in their homes in clay pots. CARE/Kenya, a non-governmental organization working in conjunction with local women potters and the Centers for Disease Control and Prevention, modified these clay pots so that they fit the definition of designated safe storage water containers, which contain the following three characteristics: a narrow mouth, a lid, and a tap to prevent recontamination. Three pottery production sites were visited in order to document, analyze, and suggest improvements for the design of the modified clay pots, specifically with regards to the standardization of the size and shape of the pots, so as to allow simple and convenient standardized household chlorine dosing, and the tap design and attachment, because the current tap design is expensive and prone to leaking. The modified clay pots displayed little variability in pot dimensions, and the 20 liter modified clay pots from the Amilo location showed a less than or equal to 10% volume variability that is acceptable according to the Centers for Disease Control and Prevention household chlorine dosing procedure. A reference rope tool developed to help standardize the size of modified clay pots can be used to train new potters but is not necessary for experienced potters. The spring-operated plastic tap was found to be the most promising design to replace the current metal tap design. The material cost of the modified clay pots at the three sites was determined with some certainty to range from 202-370 KSH (US\$2.70-US\$4.90). However, labor costs, transportation costs, profit margins and the role of subsidies, if they exist, were unable to be accurately determined. Therefore, cost recovery of the modified clay pot is unclear at all three pottery sites due to insufficient data.

Thesis Supervisor: Susan Murcott
Title: Lecturer in Civil and Environmental Engineering

Acknowledgements

"Do you not know? Have you not heard? The Everlasting God, the Lord, the Creator of the ends of the earth does not become weary or tired. His understanding is inscrutable. He gives strength to the weary, and to him who lacks might He increases power. Though youths grow weary and tired, and vigorous young men stumble badly, yet those who wait for the Lord will gain new strength; they will mount with wings like eagles, they will run and not get tired, they will walk and not become weary." (Isaiah 40: 28-31)

To God, thank you for your strength, thank you that your power is made perfect in my weakness, thank you that your grace is sufficient for me.

To Susan Murcott, thank you for finding this project and for your careful reading of this thesis.

To Daniele Lantagne, thank you for your help in kick-starting this project in Kenya, careful reading of this thesis, quick replies to emails and encouragement throughout.

To CARE Kenya, thank you for hosting me in Homa Bay and making this project possible.

To Eric Adams, Cynthia Stewart, and Blanche Staton, thank you for your administrative help regarding finishing this thesis during the summer. Dr. Adams, thank you also for the last minute calculus help!

To AC, EC, and CR, thank you for your help with taking pictures, giving me access to a digital camera, and giving me access to a scanner.

To my M.Eng classmates, thank you for a fun year.

To my friends, AP, PH, JT, AC, AF, RB, KL, MC, JZ, RW, EH, CBCGB girls group and Charis home group, thank you for listening to my thesis woes, encouraging me in hard times and supporting me throughout.

To my family, Mommy, Daddy, SM, KL, and BN, thank you for loving and supporting me 100%, and for constantly reminding me not to give up and that in the end I will always be okay.

Contents

List of Figures

List of Tables

Chapter 1

General Introduction

1.1 Introduction

One of the main components necessary for providing safe drinking water is the ability to safely store it in homes of users that do not have a piped water supply at all times. Whether the water is obtained from an improved source, such as a protected well; cleaned, such as by using filters or a coagulant; or disinfected through SODIS, household chlorination, or some other method, the potential for contamination in transport and storage undermines and can negate the resources spent ensuring the water is safe to drink at the improved source.

People in the Nyanza Province of Kenya (Figure 1-1), located along the shores of Lake Victoria, have a tradition of storing their water in wide-mouth clay pots (Figure 1-2). Users prefer using clay pots because of the evaporative cooling effect such vessels have on water and because the clay makes the water palatable (Bovin and Morohashi, 2004). However, the wide mouths encourage the drawing of water with cups, and often, the hands holding the cups are contaminated. So, even pristine water stored improperly can be easily contaminated, leading to incidences of diarrheal disease, mainly in children under the age of five.

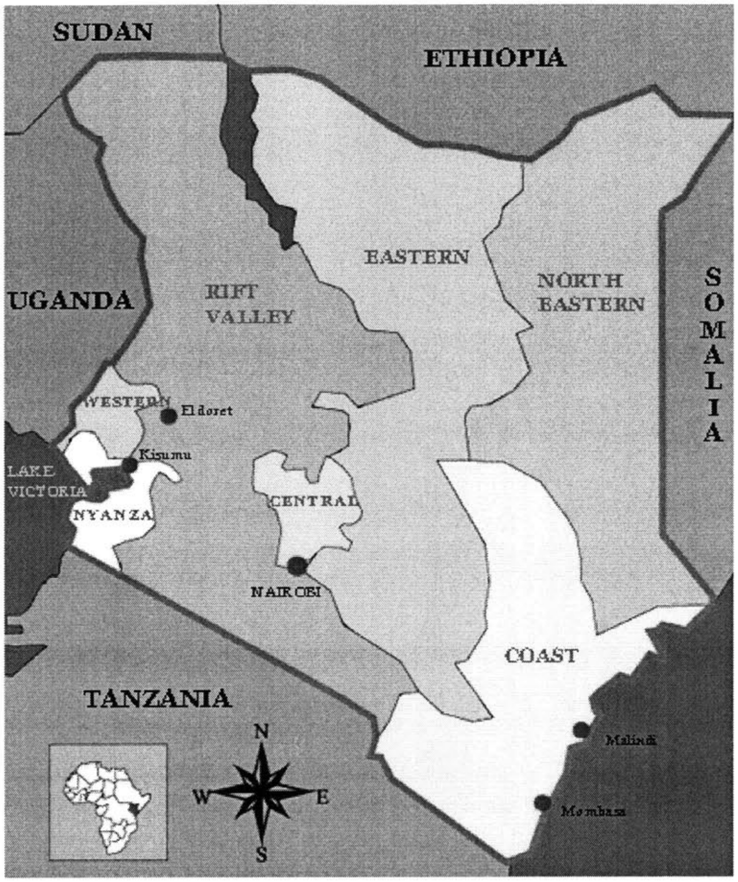


Figure 1-1. A provincial map of Kenya showing the location of Nyanza Province on the shores of Lake Victoria (western border).
(Source: United Nations Development Programme-Kenya/ GEF-SGP, 2004)

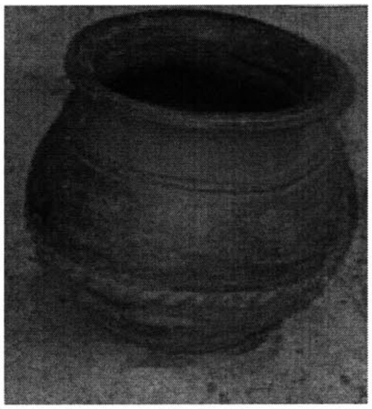


Figure 1-2. Wide-mouth clay pot.
(Source: CARE Kenya, 2003)

One approach to minimizing potential contamination routes in storage is the use of a designated safe water storage container. Safe Water System (SWS) containers are designed to eliminate potential routes of contamination when used properly, by providing a fully enclosed container with a tap that enables safe access to water. The Centers for Disease Control and Prevention (CDC) defines a safe storage container as having the three following characteristics: 1) narrow mouth; 2) lid; and 3) a tap to prevent recontamination (CDC, 2005).

This study focuses on a safe water storage container called the "modified clay pot" (Figure 1-3), which was developed by the non-governmental organization (NGO) CARE/Kenya, working in conjunction with local women potters and the CDC. Despite their improvements to the wide-mouth clay pot to make it into a safe storage container (narrowing the mouth, adding a lid, and attaching a tap), the design of the modified clay pot needs further improvement (Quick, 2004). The metal tap leaks, and is very expensive, costing nearly the same amount as all of the other materials combined. In addition, the size and shape are non-standard. A standard size is essential for proper chlorine dosing, and a standard shape is ideal to ease tap attachment.

This thesis begins in Chapter 1 with a brief introduction to water in Kenya, the Safe Water System (SWS), the modified clay pot, and the role of CARE/Kenya regarding the modified clay pot. The research objectives are stated in Chapter 2, followed by a literature review in Chapter 3, the methodology in Chapter 4, a spotlight on the focus group results in Chapter 5, a discussion and results of standardization in Chapter 6, a discussion and results of the tap design and attachment in Chapter 7, a cost recovery analysis in Chapter 8, and conclusions in Chapter 9.

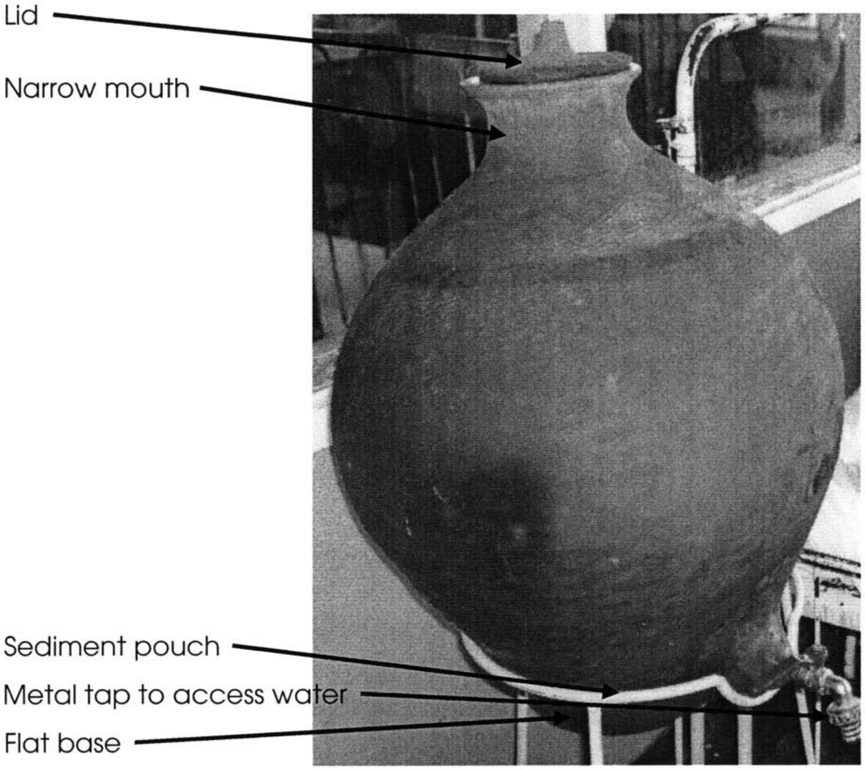


Figure 1-3. The modified clay pot.
(Source: Murcott, 2004)

1.2 Water in Kenya

Kenya is a country struggling to meet the water demand of its 31.5 million people. Only 57% of the population has access to an improved water supply (e.g. piped household connection, public standpipe, borehole, protected dug well, protected spring, or rainwater collection), and 31% of the population has to travel over half an hour to fetch water (Gordon, 2004).

Two thirds of Kenya is arid or semi-arid; therefore, access to water in many areas is very limited. Women spend several hours daily collecting water, a resource that is shared with animals that drink from it and contaminate it.

In Nyanza Province, only 14% of people receive their drinking water from a piped supply. The percentage of people using unimproved open water sources such as springs, streams, and rivers amounts to nearly 58% (Central Bureau of Statistics, 2003). In such open water systems, the likelihood of contamination is significantly higher than for piped and treated water systems.

One simple and cost effective solution to treating contaminated drinking water and storing it safely is the Safe Water System (SWS) intervention.

1.3 Safe Water System

According to the Centers for Disease Control and Prevention's (CDC) Safe Water System web site (2005), "Safe Water System (SWS) is a water quality intervention that employs simple, inexpensive and robust technologies appropriate for the developing world. The objective is to make water safe through disinfection and safe storage at the point of use. The intervention consists of three steps:

1) Point-of-use treatment of contaminated water using sodium hypochlorite solution purchased by a local manufacturer or in the community;
2) Safe water storage in plastic containers with a narrow mouth, lid, and a tap to prevent recontamination; and,
3) Behavior change techniques, including social marketing, community mobilization, motivational interviewing, communication and education. These activities increase awareness of the link between contaminated water and disease, the benefits of safe water, and hygiene behaviors, including the purchase and proper use of the water storage vessel and disinfectant."

Quick et al. (2002) field tested a Safe Water System intervention that consisted of water treatment, safe storage, and community education in Kitwe, Zambia. They tested a random selection of 166 intervention households and 94 control households and found that diarrheal disease risk for individuals in intervention households was 48% lower than for controls. Semenza et al. (1998) also found that the use of SWS reduced diarrheal disease incidence by 85% in Uzbekistan. For this particular thesis, the focus is safe water storage not in plastic containers as in Zambia and Uzbekistan, but in clay containers, also with a narrow mouth, lid, and a tap to prevent recontamination. This container is known as the "modified clay pot".

1.4 Modified clay pot

The modified clay pot (Figure 1-3) includes the following features recommended by the CDC: a narrow mouth, a lid, and a tap to access water. In addition, the modified clay pot has the benefits of a flat base for easy water extraction and a space at the bottom (below the tap) to retain sediment. The form, color, and function of the traditional clay pot are essentially retained. However, there are several weaknesses associated with the modified clay pot's design. These include fragility of the structure, leakage around the metal tap, and a non-standard size as a result of manual molding. Because CARE/Kenya is promoting treatment of water with a 1% sodium hypochlorite solution at the household level, a standard size is essential to choose the proper dose. Moreover, from an affordability standpoint, there is interest to replace the metal tap with a different type of tap because the metal tap itself costs about the same as the entire clay pot.

A brief history of CARE/Kenya's role in conceptualizing and disseminating the modified clay pot is found in the next section.

1.5 CARE/Kenya

CARE/Kenya has been one of the non-governmental organizations (NGOs) implementing the SWS program in Kenya. CARE is an international NGO that has contributed to poverty reduction in Kenya for the past 32 years. After conducting a baseline survey in February 2000 that revealed that 99% of the target population stored their drinking water in traditional wide-mouth clay pots, CARE/Kenya started a unique adaptation of the SWS intervention (Mwaki, 2005). Although the second step of the SWS intervention calls for the use of safe water storage in plastic containers with a narrow mouth, lid, and a tap, CARE/Kenya found that the target community preferred clay pots because of their cooling effect on water, a key point considering the hot climate of the region. Common 20-liter plastic jerry cans are used, however, to collect and transport water from the sources in the target region of Nyanza Province.

In response to the community's preference, CARE/Kenya's SWS team designed a modified clay pot with features similar to the improved plastic container. This proved a rigorous exercise, especially the molding of the pot to both incorporate the SWS features and keep a similar design to the wide-mouth clay pot. During the re-designing of the pot in August 2000, the SWS team contacted a local pottery group known as the Oriang Women's Pottery Group to make the modified clay pots on behalf of CARE/Kenya.

When the first batch of pots were ready to be sold at the market, the demand was already much greater than the limited supply. The features of the improved pots, including the metal taps and lids, appealed to the local community, increasing demand. At this point, the CARE/Kenya SWS team recognized the need to scale up the production by identifying additional pottery groups across the region, thereby decentralizing the production.

In 2003, the SWS team identified a local pottery group known as the Amilo Community Based Organization (CBO) to be trained in the SWS intervention. This group eventually started manufacturing the modified clay pots in addition to supplying the chlorine for water treatment.

At this same time, the SWS intervention greatly expanded to other districts across the Lake Victoria region. When CARE/Kenya held training sessions about SWS, one of the implementing partners, Society for Women and AIDS in Kenya (SWAK), identified a pottery group named Bar chando Women's Group to make the modified clay pots. The CARE/Kenya team trained this group and ultimately distributed the pots to the support groups working under the umbrella of SWAK. The Bar chando Women's Group has made pots that are sold 100 km away in Kisumu City (Figure 1-4).

Beginning in February 2005, CARE/Kenya's SWS intervention began to expand to fifty schools in three districts of Nyanza Province: Homa Bay, Suba, and Rachuonyo (Figure 1-4). In each school, the SWS team earmarked a minimum of five modified clay pots for the storage of treated drinking water. In addition, the team is making available hand-washing facilities such as plastic vessels with taps in these schools. In March 2005, the team expanded the SWS intervention to the Siaya District (Figure 1-4) through the training of all health workers in the health facilities that provide Prevention of Mother to Child Transmission (PMTCT) of HIV services. SWS has also been integrated into the existing Water Sanitation and Education for Health (WASEH) project that is currently implementing activities in two districts as of April 2004. CARE/Kenya has high hopes that the SWS intervention will be further scaled up to include all of Kenya's Ministry of Health facilities.

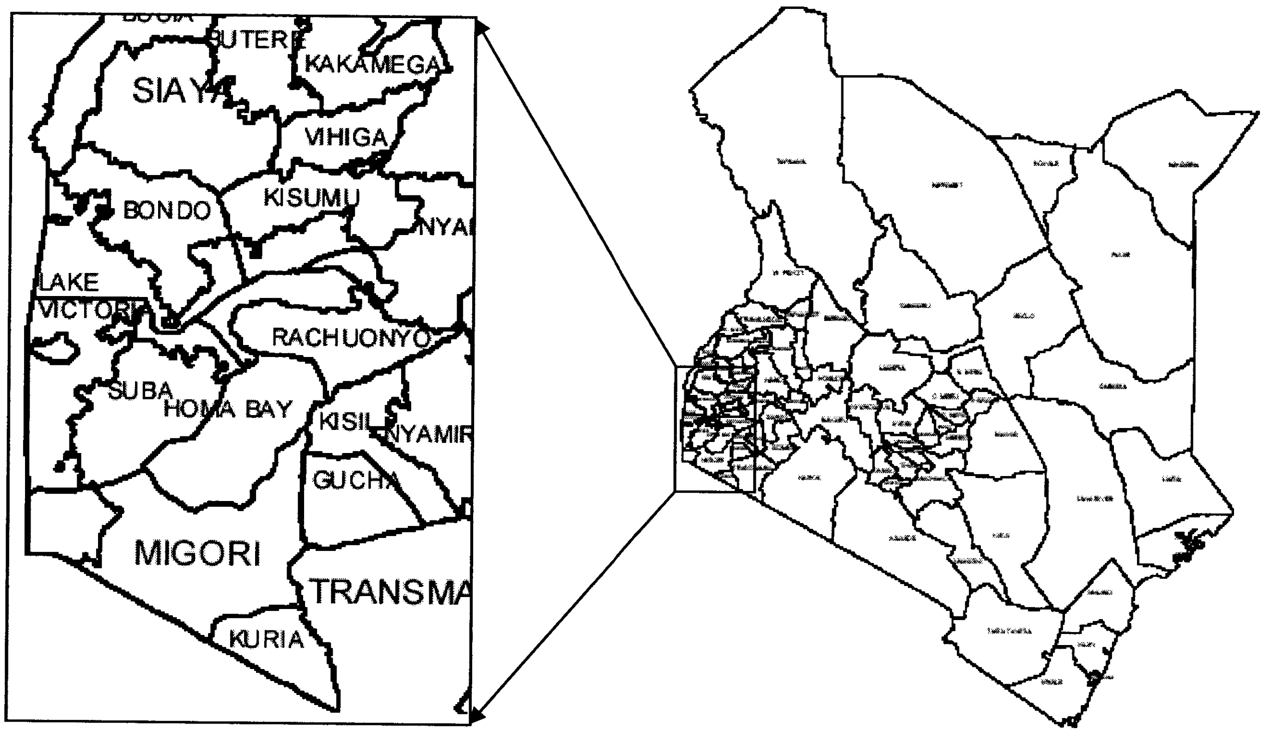


Figure 1-4. Map of Kenya showing administrative boundaries.
(Source: FAO, 2005)

Chapter 2

Research Objectives

2.1 Research objectives

The goals of this thesis are to document, analyze and suggest improvements for the design and cost of modified clay pots in Kenya's Nyanza Province, specifically with regards to the standardization of the pots, design of a new tap and cost recovery.

In parallel with the work of this thesis, in the Master of Engineering thesis of teammate Michael Pihulic, the entire production and manufacture process of modified clay pots, from start to finish, was documented using a combination of photography, videotape, and interviews conducted with the potters (Pihulic, 2005a).

2.1.1 Standardization

The first goal of this thesis is to address standardization of the modified clay pot. In order to implement a disinfection protocol that is simple and easy to use, either a versatile dosing system based on volume of household water storage container is required (which is complicated for users to implement) or much preferably, a standardized container should be utilized or introduced. Given the variation in the size of non-jerry can household water storage containers, it is not always feasible to design a simple disinfection dosing procedure for different volumes. The current method used in Kenya is to use a pre-measured dose of a 1% sodium hypochlorite solution for a known volume of water. The typical jerry can used to collect water in Kenya is a 20 liter volume; thus, a standard size of the pot, either 20 L or 40 L, is critical to ensure that people do not fill the pots with e.g. 1 ½ jerry cans. A 20 L or 40 L standard size means the chlorine dosing remains effective. A standard pot size also eases transport of the pots to local markets and to homes. Various methods for standardizing the size of the clay pot during production have been investigated and field tested in this thesis.

2.1.2 Tap design and attachment

A second goal of this thesis is to suggest an alternative to the modified clay pot's current metal tap design and attachment. The tap usually costs more than all the other materials required to make the modified clay pot (e.g. the tap costs 200 KSH out of a total material cost of 370 KSH at one pottery production site). In addition, however, the technique for attaching the tap also has not been perfected and often creates leaks that reduce the effectiveness of the containers. The goal is to design a replacement tap using locally available resources that will significantly reduce the cost of the safe water storage container and at the same time reduce leaks.

Several alternatives to the current tap design were developed and evaluated using the following criteria: cost, leakiness, local availability of materials and potential for distribution in the Lake Victoria region, ease-of-use for young children, ease of construction, social acceptability, likelihood of contamination, and maintenance. Each design alternative was evaluated against the current design using a tool called a Pugh chart.

Ensuring that the local populace is comfortable with any new tap design and attachment technique used is also a high priority.

2.1.3 Cost recovery analysis

Cost recovery of all of the materials used to make the modified clay pot is a key component, because one of the goals of designing a new tap is to address affordability. Cost data at Amilo was obtained via interviews and later updated with numbers provided via email correspondence with CARE/Kenya staff Alex Mwaki (2005), while cost data at Kinda E Teko was obtained by Gibney (2005) via interview. Cost data for Oriang was incomplete at the time of field work; however, unknown data was estimated using the Amilo data. The goal of the cost recovery analysis is to create the best product at the cheapest price, which is integral to creating a financially viable enterprise.

Chapter 3

Literature Review

The modified clay pot has been produced for only five years. Except for the work documenting the production process of the modified clay pot by teammate Michael Pihulic (2005a), the *Best Practices* publication from Nuffic and UNESCO/MOST (2002), *A Manual on the Safe Water System* from CARE Kenya (2003) and an unpublished presentation entitled "Safe Water System as a Home Care Intervention for People Living with HIV/AIDS" given by Alie Eleveld at the 2004 International Symposium "Household Technologies for Safe Water" in Nairobi, Kenya, it has never been studied before. Therefore, this literature review examines the work of previous Master of Engineering (M.Eng) students in the MIT Department of Civil and Environmental Engineering (CEE) and others on the related topics of ceramic water filter manufacture and performance and safe water storage.

3.1 Master of Engineering theses

Three students in the CEE M.Eng program at MIT have previously completed theses relevant to this study. Their work is summarized below, along with brief explanations as to how it relates to this study.

Chian Siong Low's (2002) thesis documents the production process of the terra cotta disk filter in Thimi's Potter Square. Low references the Potter's For Peace (PFP, 2001) web site, which encourages the use of a press mould for consistency in pot size and shape. Like Nepal, Kenya also has a long and established tradition in ceramic pottery making. It is therefore ideal for the SWS intervention to build on this tradition. Low also touches upon the issue of standardizing pot size and shape by use of a press mold.

Rob Dies (2003) documents in detail the ceramic water filter production process of Madhyapur Clay Crafts in Thimi, Nepal, which includes material selection, processing, shaping and pressing the filter element into a mold, firing, drying and quality control. He found that materials include clay, water, combustible material (used to increase the porosity of the material since combustible material will burn off during the firing, leaving behind pores or voids through which the water will travel, e.g. sawdust, flour), temper, known colloquially as “grog” (non-plastic material used to reduce shrinking/warping and to control porosity to some extent, e.g. ground bricks), and colloidal silver (used to reduce microbial contamination). Dies also notes that equipment is a major capital investment for the potter, and sources of energy in developing countries are usually unreliable or expensive, if at all available. Therefore, Dies found it preferable to use non-electricity powered equipment. When mixing clay, Dies reports the goal is to find the optimal combination of clay, water, combustibles and/or grog, which depends on the properties of materials, the equipment used, and methods of production. He discovered these optimal clay recipes depend on both experience and trial and error, and that mixing by hand, which is common in developing countries, is very labor intensive. This detailed documentation of ceramic water filter production was valuable for teammate Michael Pihulic’s M.Eng thesis (2005a), which focused solely on the production and manufacture of the modified clay pot. In addition, Kenyan potters experience similar bottlenecks to production, including limited equipment due to high capital costs and time- and labor-intensive steps such as mixing clay by hand.

Rebecca Hwang (2003) performed extensive field monitoring of the Potter's for Peace (PFP) ceramic water filter in Nicaragua. Hwang points out several of the manufacturing and transporting difficulties related to ceramics, which include inconsistent product standardization and quality control due to variability in the composition of clay in different geographic locations, and fragility of the ceramics, which causes easy breakage during transport and inhibits efficient shipping and delivery to distant rural areas. Hwang suggested improving the filter design to include increasing durability to reduce breakage by changing materials or adding steps to the manufacturing process, and standardizing the quality of raw materials to guarantee consistency of quality in the production. The modified clay pot has similar impediments to those of the PFP ceramic water filter, including lack of standardization and quality control, and breakage during transport.

3.2 Organization-based reports

Best practices using indigenous knowledge - Africa, a joint publication from Nuffic and UNESCO/MOST co-edited by Bovin and Morohashi (2002), contains a report entitled, "The use of locally produced clay pots modified for safe storage of drinking water in the home—a component of CARE Kenya's Nyanza Health Water Project." This is one of the only reports exclusively on the Kenyan modified clay pot. Nuffic and UNESCO/MOST indicate that the purpose of the modified clay pot is to reduce both the recontamination of treated water during storage and the incidence of water borne disease transmission. These two organizations state that the modified clay pots serve this purpose in addition to retaining an aspect of traditional culture, i.e. storing water in clay pots. Moreover, because the practice of making modified clay pots is based on indigenous knowledge, Nuffic and UNESCO/MOST consider the modified clay pot cost-effective. For these reasons, Nuffic and UNESCO/MOST deem the modified clay pot a "Best Practice". This report is valuable because it is the first written work documenting the modified clay pot. It introduces the practice, defines its purpose, details the role of indigenous knowledge, and describes the achievements, results and concerns to date.

A Manual on the Safe Water System Based on CARE Kenya's Experience in Rural Western Kenya by CARE Kenya (2003) is a case study based on CARE Kenya's experiences while conducting a scientific study and implementing SWS in areas where diarrhea prevalence is high, due to inaccessibility of safe water. CARE completed an entire study on home-based water chlorination in the Lake Victoria region. SWS intervention is a household-based point-of-use water treatment system whose component includes three strategies: 1) Water treatment using a 1% sodium hypochlorite solution branded Klorin (renamed Water Guard); 2) Safe water storage vessels; and 3) Behavior change. CARE Kenya describes the features of the modified clay pot, as well as its advantages and disadvantages. This report is relevant because modified clay pots are a specific example of a local adaptation of the SWS intervention.

Safe Water Systems for the Developing World: A Handbook for Implementing Household-Based Water Treatment and Safe Storage Projects by The Centers for Disease Control and Prevention (CDC, 2005) is a detailed and comprehensive reference guide for implementing household-based water treatment and safe storage projects. It serves to better clarify the definition of SWS and gives many examples of safe storage containers.

3.3 Other works

Daniele Lantagne (2001a, 2001b) reiterates the PFP mission statement, which includes the "stability and improvement of ceramic production" and the "preservation of cultural inheritance." Lantagne was contacted to provide an assessment of the Potter's for Peace filter to USAID/Nicaragua, including information on the intrinsic effectiveness in the laboratory and field performance in rural communities. Lantagne produced two reports, one on the intrinsic effectiveness of the filter (including studies on colloidal silver, flow rates, sliver concentration in water, and the health effects of ingesting silver), and the other on the performance of the PFP filter under field conditions in six rural communities. Lantagne's survey of 24 families indicated that the most common problems were the breakage of the filter and recontamination of the stored water after filtration, and that there currently exists a lack of education about safe water sources and correct filter cleaning and maintenance in the families using the filter. Lantagne's recommendations include dedicating a PFP staff member or a local community leader to the role of following up on filter use in the families, educating families about proper filter use and maintenance, and developing and selling a cleaning kit with the filters. This study is useful because it gives an example of the methodology, results, and recommendations of field-testing a ceramic product. The recommendations may also be relevant to the modified clay pot, i.e. following up on modified clay pot use in households, educating families about proper chlorine dosing, and developing and selling cleaning kits with the pots.

Stuart Cheeseman (2003) documented Reid Harvey's methods for producing ceramic candle filters and ceramic disk filters. Cheeseman catalogs the requisite tools and techniques for producing these filters. He includes schematics of the presses and molds used to create the filters, as well as the methods used to produce them. Cheeseman examines the variables inherent in each stage of the production process and how the local manufacturer, Hari Govinda, has altered and adapted the production process to produce ceramic filters according to the Reid Harvey method. These variables include production difficulties found at each stage and how they influence the final product. Cheeseman identified six design issues that were not addressed in the design specifications provided by Harvey. Cheeseman noted a smearing effect during extrusion that reduces filter porosity, the necessity of oil or paper to aid in mold extraction, the importance of obtaining a reliable silver source, the importance of drying following colloidal silver application, the parameters necessary for achieving good seals, and problems associated with carbon trapping when firing the ceramics. This study, in common with the theses of Low (2002) and Dies (2003), provides valuable information on ceramic water filter production methods and tools.

Alie Eleveld, a representative of the CDC/Kenya's Global AIDS Program, presented "Safe Water Systems as a Home Care Intervention for People Living with HIV/AIDS" at the 2004 International Symposium "Household Technologies for Safe Water," hosted by the Kenya Ministry of Health, Nursing Council of Kenya, Emory University, Population Services International (PSI), the Centers for Disease Control and Prevention (CDC) and CARE/Kenya in Nairobi, Kenya on June 16-17, 2004. Eleveld, working with the Society of Women and AIDS in Kenya (SWAK) helped to identify local potters in two areas in Asembo to be trained on manufacturing modified clay pots for safe water storage. Eleveld reported that the first modified clay pots from the Asembo pottery sites would be available in June 2003.

Teresa Yamana (2004) performed a paper survey of safe storage vessel types in the Dominican Republic. She found the most likely reason for contamination of stored water is contact with contaminated human hands or utensils used to scoop water from the storage vessel. As mentioned previously, contaminated hands are also the main reason for contamination of water stored in wide-mouth clay pots.

Significant research has been completed by MIT CEE M.Eng students, organizations, and others that is relevant to this thesis. A number of these authors identify some of the same issues with ceramics as they relate to "safe water" and as seen in Kenya, such as bottlenecks to production, the role of indigenous knowledge, standardization, breakage, and lack of quality control. The background literature also places the modified clay pot into the larger context of the household drinking water treatment and safe storage[1] intervention. This review of literature informed the development of the thesis plan and was valuable in fitting this one thesis into a larger picture.

---

[1] http://www.who.int/household_water

Chapter 4

Methodology

Each of the following organizations (with extent of visit in parentheses) was visited by the author Suzanne Young and teammate Michael Pihulic, with assistance also provided by Centers for Disease Control and Prevention (CDC) staff and former MIT Master of Engineering student ('01) Daniele Lantagne: Oriang Women's Pottery Group in Oriang (5 days); Amilo Community Based Organization (CBO) Pottery Group in Rangwe (5 days); and Kinda E Teko Pottery Group in Asembo (1 day). These locations are shown on Figure 4-1. While both the Oriang Women's Pottery Group and the Amilo CBO Pottery Group are supported by CARE/Kenya, the Kinda E Teko group is supported by the Society of Women and AIDS in Kenya (SWAK).

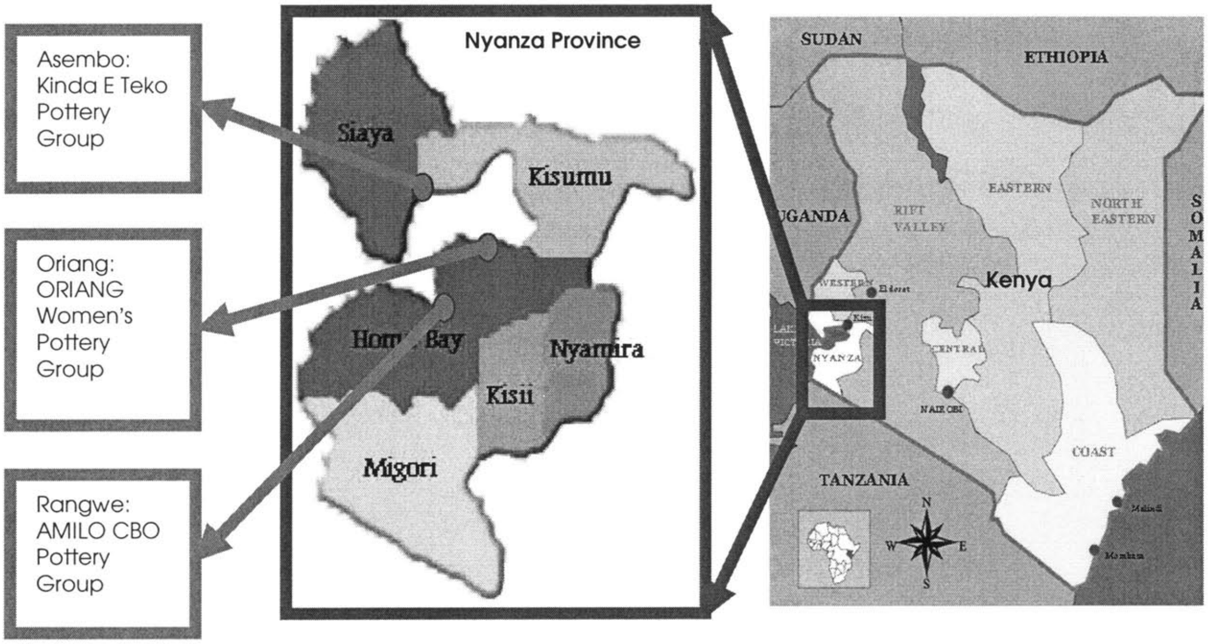


Figure 4-1. Map of Kenya's Nyanza Province and field site locations.
(Source: Kenya Web, 2001; United Nations Development Programme-Kenya/ GEF-SGP, 2004)

Methodology in the field during January 2005 included observing potters at work, interviewing potters and project partners, trial-and-error problem-solving with the women potters, and conducting focus groups. These methods are described in detail in sections 4.1-4.4. An essential part of the field methodology was working with the women potters to try new techniques and designs and to think outside of the box.

4.1 Observation

The first day at each site was spent jointly with teammate Michael Pihulic observing potters at work and visually documenting the current production and manufacturing processes. Since little was known about the exact processes, it was important to fully understand how the pots are made, step by step, and to begin to identify potential areas for improvement. This time was also spent becoming familiar with the potters' skill levels and willingness to try out new ideas. Observation and visual documentation continued during the remainder of the days spent at each site. (See Pihulic, 2005a for this complete process documentation.)

4.2 Interviews

The author carried a field notebook and pen at all times in order to record answers to any questions that came to mind as she observed the potters working. Because the potters only speak the local dialect of Luo, it was necessary to interview and ask them questions via a hired translator. (See sections in the next chapter, 5.3 and 5.4, for more detailed information regarding the translators.) Information on the subject of cost recovery was obtained by interviewing not only the potters, but CARE/Kenya staff and members of the Amilo Community Based Organization (CBO) as well. Answers to questions were carefully recorded in field notebooks and reviewed daily to ensure complete understanding of the responses. Any vagueness was clarified the next day with follow-up questions.

Here is a sampling of some of the questions asked and answers gathered during interviews of the potters (via a translator) and other members at the Amilo CBO:

Q: How long have the potters been making pottery, and specifically, modified clay pots?

A: The potters have each been making pottery for about ten years; they have made modified clay pots since 2003.

Q: How did the potters learn how to make pottery, and specifically, modified clay pots?

A: Each potter learned how to make pottery from her mother or mother-in-law. Two Amilo potters were sent to Oriang to learn how to make the modified clay pots and subsequently passed on this knowledge to other Amilo potters.

Q: What is the production rate of modified clay pots?

A: The average potter can make up to three pots per day; however, production rates are limited by potters having to share equipment and tools.

Q: What techniques have the potters tried to standardize the modified clay pot?

A: Potters rely on the length of their arms and the width of their hands as well as experience to shape modified clay pots into 20 L and 40 L sizes.

Q: For what price are the modified clay pots sold at the market?

A: 20 L modified clay pots are sold for 380 KSH; 40 L modified clay pots are sold for 500 KSH.

Q: Do the potters test the pots for leakage before selling them?

A: No, no attempt is made to test the pots before selling them.

4.3 Trial-and-error problem solving

After observing and interviewing potters at the field sites, and identifying potential areas of improvement to the modified clay pot production process, the author engaged daily in brainstorming sessions with teammate Michael Pihulic to formulate new ideas and decide which of these ideas to test in the field with the potters. Brainstorming sessions were conducted by discussing ideas aloud, posing possible solutions to problems identified, and evaluating each idea in terms of available time, access to materials, feasibility, and potters' willingness to participate in trying any new ideas developed. Reference books on ceramics properties and fabrication processes were also consulted to flesh out ideas in Kenya. If necessary, calculations were worked out and tools were constructed in preparation for the next day in the field. This approach of trial-and-error problem solving proved very effective and was used to address both the issue of standardizing the pots and designing a new tap.

4.4 Focus groups

In order to garner the local women potters' thoughts about the origins of the shape of the modified clay pot, and to have them develop ideas for pot shapes that would better ease the insertion of a tap, i.e. a pot that has at least one flat area large enough to accommodate a tap will create a fit between tap and pot that is less prone to leaking, focus groups were conducted at both Amilo and Oriang.

4.4.1 Definition and motivation

Focus groups consist of about 6 to 10 people that are part of a relevant target market or political entity gathered in the same room and guided through a moderator-led discussion that investigates attitudes about a specific client's services, products, or political persuasions. While often used in market research or political analysis, focus groups can also simply be a small group representative of a wider population and guided though open discussion for its members' opinions about or emotional response to a specific area or subject.

Focus groups typically have six features, according to Focus Groups: A Practical Guide for Applied Research by Richard A. Krueger (1994): "(1) people, (2) assembled in a series of groups, (3) possess certain characteristics, and (4) provide data (5) of a qualitative nature (6) in a focused discussion." Krueger (1994) further elaborates on each of these six features:

> (1) Focus groups are typically composed of 6 to 10 people, but the size can range from as few as 4 to as many as 12. The size is conditioned by two factors: It must be small enough for everyone to have opportunity to share insights and yet large enough to provide diversity of perceptions.
>
> (2) The focus group interview is conducted in a series. Multiple groups with similar participants are needed to detect patterns and trends across groups.
>
> (3) Focus groups are composed of people who are similar to each other [and] who do not know each other...More recently, however, researchers are questioning the necessity and practicality of this [latter] guideline, especially in community-based studies.
>
> (4) Focus groups produce data of interest to researchers. In this respect the purpose differs from other group interactions in which the goal is to reach consensus, provide recommendations, or make decisions among alternatives.
>
> (5) Focus groups produce qualitative data that provide insights into the attitudes, perceptions, and opinions of participants. These results are solicited through open-ended questions and a procedure in which respondents are able to choose the manner in which they respond and also from observations of those respondents in a group discussion. The researcher serves several functions in the focus group: listening, observing, and eventually analyzing, using an inductive process.
>
> (6) The topics of discussion in a focus group are carefully predetermined and sequenced.

Focus groups were included in the methodology because it was ideal to ask questions and encourage discussion in a group setting. Focus groups provided a dynamic atmosphere for participants to share ideas. Because the potters have the first-hand experience in producing and manufacturing the modified clay pots, it is their attitudes, beliefs and perceptions that are of interest. Discussions in a group setting were also more time efficient than one-on-one interviews.

4.4.2 Format of discussions

The author's objectives of the focus group discussions at each site included the following:

- Discover the potters' thoughts on the origins of the rounded shape typical of the wide-mouthed and modified clay pots;
- Obtain the potters' opinions about a cylindrical shaped pot (an example of which was made the previous day according to the author's specifications at the Amilo CBO);
- Have the potters each come up with her own drawings of pot shapes after being told that the goal is to ease insertion of the tap (i.e. because the tap is currently inserted on the rounded surfaces of the pots, the "fit" is not very good—a flat surface is ideal); and,
- Determine preferences of several different sketches of pot shapes drawn by the author, also keeping with the condition that the aim is to ease insertion of the tap.

The only deviation from the objectives sought during the Amilo focus group versus those sought during the Oriang focus group is that the researchers did not ask the Oriang potters to make a cylindrical shaped pot at all, so the question of whether they preferred the rounded shaped pot or the cylindrical pot (i.e. their opinions about a cylindrical shaped pot) was not asked.

The results of observation, interviews and trial-and-error problem solving are found throughout Chapters 6, 7, and 8, while the results of the focus group discussions are found in Chapter 5.

Chapter 5

Focus Group Results

Before the results of the focus groups conducted at Amilo and Oriang are discussed, it is important to understand the variations in the shapes of clay pots in traditional Kenyan pottery and how the skills and knowledge of pottery making are passed down.

5.1 Background on shapes of clay pots

In western Kenya, pottery has almost exclusively been in the woman's domain (Mutagaywa, 1995). However, only a small proportion of the women in any potting community are involved in the trade, and those women who do make pottery usually undertake this craft part-time in combination or alternating with other household tasks (Wandibba 2003).

Women produce various types of clay pots and pans mainly for household use in food processing, preparation, and storage and for water carriage and storage. Mutagaywa (1995) classifies traditional Kenyan pottery into three forms (with Luo terminology in parentheses):

1) Simple open form: Smaller sizes for processing and serving meat and vegetables, or larger sizes for brewing and serving beer or fermenting and serving porridge of millet/maize (*nyalora*);
2) Simple restricted form: For cooking and preparing fish (*haiga*), or for cooking and storing grains and starchy foods (*kabange* or *dakuon*);
3) Forms with a neck: For brewing and storing beer (*mbiru*), for carrying and storing water (*dapi*), or for odd jobs (*agulu*).

Figure 5-1 shows examples of some of these different traditional forms of pottery. Those in the foreground (*haiga*) are for cooking fish, while those with a neck (*dapi*) are for carrying and storing water. Examination of different pottery forms produced suggests that variation in size within form classes relates to differential function, such that potters distinguish these differences with terminological distinctions (Wandibba 2003). However, sometimes distinct forms have the same terminology. One specific example of this is described by Wandibba (2003):

> The Okiek [tribe of west central Kenya] traditionally made three different forms of the honey pot, depending on whether the honey pot was to be stored in the forest or at home. Although the three forms were ingrained in the potter's mental template, she had no separate names for them and simply referred to all three as "honey pots." Although all three forms had necks, the pots varied in size and body form. The vessel for storing the honey in the forest was elongated in form and had a narrow mouth to accommodate a stopper to facilitate sealing before the pot was buried in the ground for safekeeping. The shape designed for storage in a cave was much bigger and had a rounded body to enable it to stand unsupported on a shelf or the floor. Finally, the house honey pot (the only one of the honey pots still being made today) has a rounded body and a short cylindrical neck, with a tight-fitting leather cover and leather carrying handle. It would thus appear that unique functions produce subtle differences in vessel forms.

This example explains that one function of the rounded body is to enable a pot to stand unsupported on a shelf or floor, and that rounded bodies can be much bigger than elongated forms. This suggests why pots used for water transport and storage traditionally have rounded bodies, i.e. rounded pots are bigger and can hold more water.

Figure 5-1. Examples of different traditional forms of Kenyan pottery with different uses; those in the foreground (*haiga*) are for cooking fish, while those with a neck (*dapi*) are for carrying and storing water.
(Source: Mutagaywa, 1995)

The wide-mouth clay pot (Figure 5-2a), the traditional shape of pots used to store water in the Nyanza Province, has a rounded body, a wide mouth, and a rounded base. The method for drawing water from such shaped pots typically involves dipping in cups or calabashes with one's hands. The modified clay pot (Figure 5-2b), a variation of the traditional shape, has a more prominent base so that sediment can settle below the tap, a rounded body, a narrow neck opening to a narrow mouth, and a lid, also made of clay. This shape, which is a designated safe water storage container, was developed by CARE-Kenya's SWS team in 2000. Water is dispensed by turning the tap handle. An alternate pot shape, the cylindrical pot (Figure 5-2c), was suggested by the author and built by one of the potters at the Amilo Community Based Organization (CBO). The idea behind this shape is that a flat, not round, surface would ease insertion of the tap and reduce leakiness around the tap caused by an imperfect fit between the clay pot and tap.

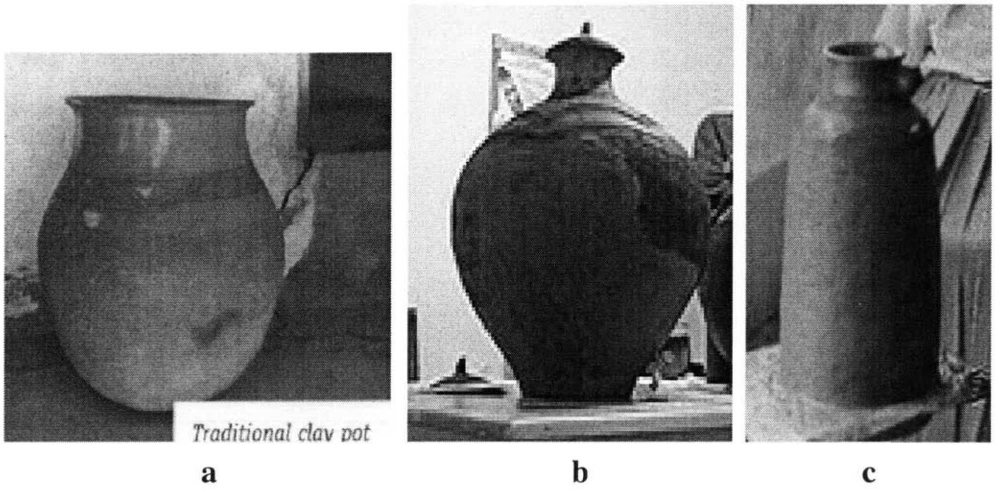


Figure 5-2. Various shapes of clay pots: wide-mouth clay pot (a), modified clay pot (b), and cylindrical pot (c).
(Source: CARE Kenya, 2003; Murcott, 2004; Pihulic, 2005b)

Skills and knowledge of pottery making are passed through generations (mother to daughter, mother-in-law to daughter-in-law, aunt to niece, and so on) as well as between the different regions and tribes via intermarriage, through informal channels of communication such as observation, imitation and working together (Wandibba, 2003; Mutagaywa,1995).

5.2 Preparation for focus groups

In preparation for the focus group discussions, during a brainstorming session, the author drew several additional pot shapes (Figure 5-3), keeping in mind that having at least one flat surface on the pot would aid in tap attachment and reduce leakiness. One of the drawings is a modified clay pot with an even more prominent cylindrical base (Figure 5-3a), such that the tap could be attached to this cylindrical portion while still leaving room below the tap for sediment to settle out. The other drawings included a cylindrical shape with a wider base (Figure 5-3b), making the height shorter than the cylindrical pot shown in Figure 5-2c; a cylindrical pot with a base that flares out like a salt-shaker (Figure 5-3c); an asymmetrical pot with one rounded side and one flat side (Figure 5-3d); and a hexagonal pot (Figure 5-3e). Once the author was prepared for the focus groups with the necessary background research and materials, focus groups were conducted at Amilo and Oriang.

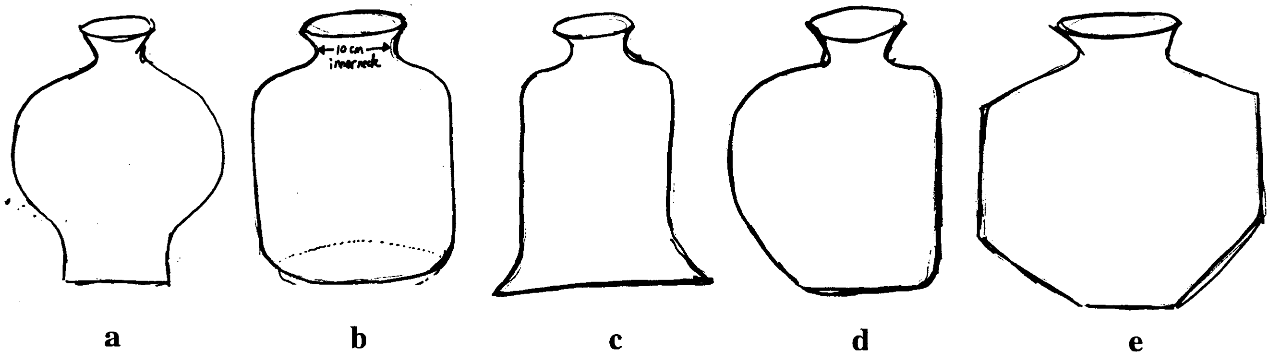


Figure 5-3. The author's drawings of pot shapes: rounded pot with extended cylindrical base (a), cylindrical pot (b), cylindrical pot with flared base (c), asymmetrical pot with one rounded side and one flat side (d), and hexagonal pot (e).

5.3 Amilo focus group

The first of two focus group meetings was conducted on the third day of field research, January 8, 2005, at the Amilo CBO. Members of the group included four local women potters (Amilo Potter #1-4), a translator, a listener from the Centers for Disease Control (CDC), and the author, who served as the moderator for the discussion. All of the women are of Luo ethnicity and are mothers. Most of the women learned how to make clay pots from their mothers or their husband's mothers after they were married, and have roughly ten years experience each (the range of experience is unknown, as each woman stated they had ten years experience making pots). However, only two of the women potters traveled to Oriang to receive training in making the modified clay pots. They subsequently taught the other potters at the Amilo CBO the new design and techniques they learned. It is noteworthy that the translator is an elderly man who is the General Chairman of the Amilo Community Learning Resources Centre (CLRC), one component of the Amilo CBO. This position is the most senior position of the Amilo CBO's Executive Committee. It was originally suggested by the CARE/Kenya representatives upon the initial meeting between the Amilo group and the researchers that perhaps a young local woman would be most appropriate to serve as translator. The listener from the CDC, Ms. Daniele Lantagne, served as an advisor and friend to the research project.

The potters could not say much about the origins of the rounded shape typical of both the wide-mouth and modified clay pots. (Studies have suggested that shapes are dictated by function, and that rounded pots used for water transport and storage are shaped so they can hold more water. See Section 5.1.) The shape is just the way that they were taught to make clay pots by their mothers or other relatives when they first started. As for whether they preferred the rounded shape or a cylindrical shape, the women collectively agreed (as summarized by the translator) that they prefer the cylindrical shape because it is more easily carried, it uses less clay, and attaching the tap is easier. While the potters themselves support the cylindrical shape, since the idea is new and people are free to make their own choices, they do not know if the local population will as readily welcome the differently shaped pot. Therefore, they said they will make both the modified clay pot and the cylindrical pot and see which one sells better in the market.

Examples of the potters' individual drawings of clay pots are shown in Figure 5-4. All of the women's drawings included at least one clearly cylindrical shaped pot (Figures 5-4a, g, h, l, n), and one or more rounded shaped pots. The women at first were hesitant to start drawing and needed encouragement from the author and translator. However, it was later evident by their facial expressions and comments after completing the exercise that they found it enjoyable.

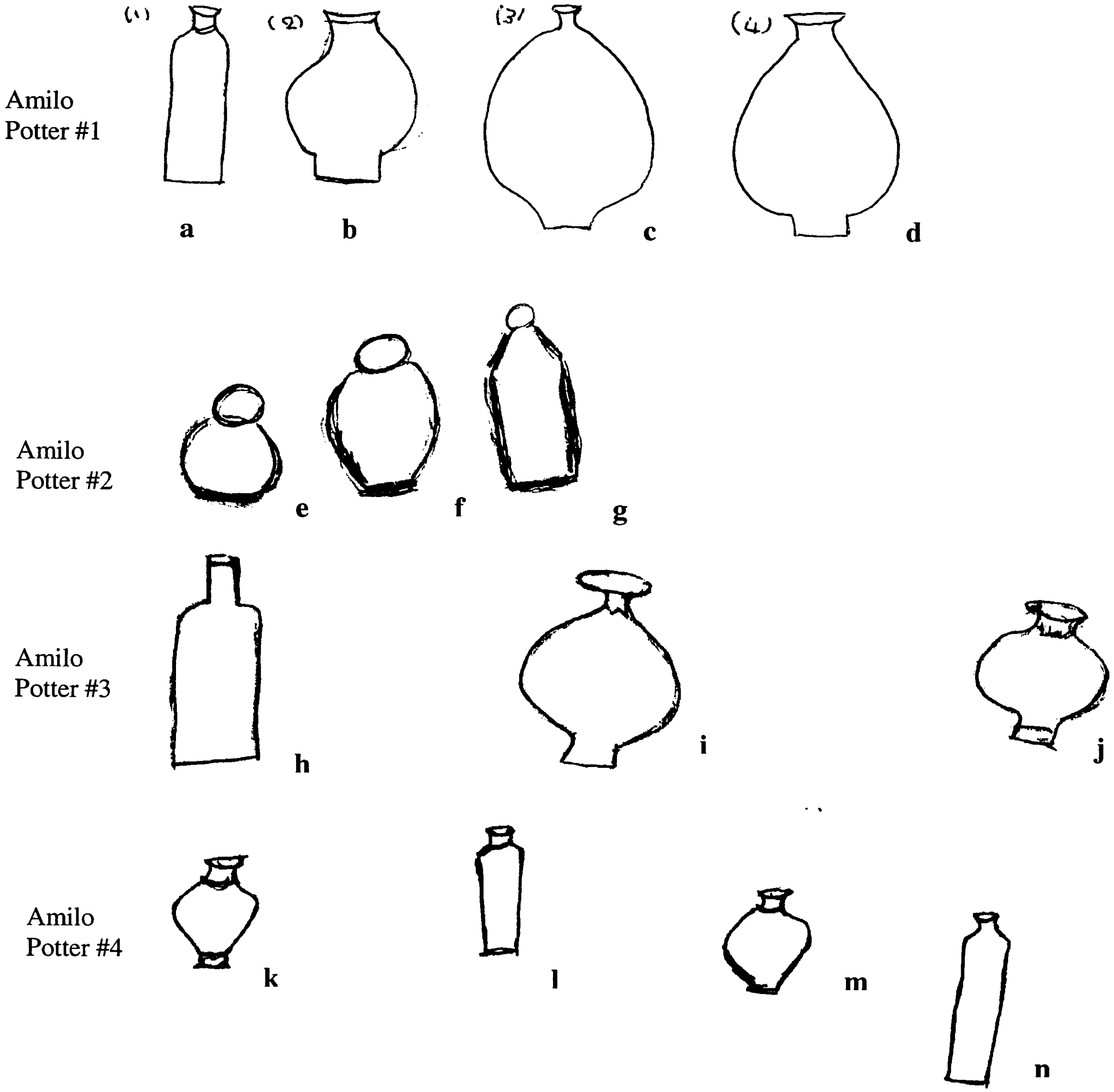


Figure 5-4. Examples of Amilo Potters' individual drawings of clay pots.

When next asked which of the author's drawings (Figure 5-3) they liked the best, keeping in mind that they should choose the drawing that would best ease insertion of the tap, two of the potters, Amilo Potter #1 and Amilo Potter #4, chose the rounded pot with the extended cylindrical base (Figure 5-3a) because it is easy to attach a tap and particles in the water can settle out and be retained in the base, below the tap. Amilo Potter #2 originally picked the cylindrical pot with the flared base (Figure 5-3c) but seemed to be convinced by the group and translator otherwise. She eventually also chose the rounded pot with the extended base (Figure 5-3a). Amilo Potter #3 chose the cylindrical pot (Figure 5-3b) because she said making that shape is easier and that it uses less clay.

After voting on which of the researcher's drawings they preferred most, Amilo Potter #1 proceeded to make the rounded pot with the extended cylindrical base and Amilo Potter #3 a cylindrical pot with a wider base than was made the previous day. Amilo Potter #1 did not make the extended base envisioned by the researcher; instead, she just made it less slanted and more gradual than the base of the modified clay pot (similar to the shape of a clay flower pot). Both a lack of sufficient communication and translation and the potter's misunderstanding contributed to this outcome.

There were several limitations of the January 8, 2005 Amilo focus group. One important thing to note is that a cylindrical shaped pot was made the day before the focus group took place, as per request by the author. The timing may have been poor because it may have influenced the potters' preference for the cylindrical shaped pot over the rounded shaped pot. The potters may also have chosen it because they thought it was the author's own preference. In addition, one of the reasons they preferred the cylindrical pot is because it uses less clay; however, the amount of clay was never formally quantified, so whether or not this assumption is true is unknown. Also, whether the women carry through with actually making both the modified clay pot and the cylindrical pot and selling them at the market remains to be seen. Furthermore, it is believed that the male translator added bias to the all women's group's responses because he seemed to dominate their discussion and not merely translate but add his own ideas and convince the women of certain responses. To what extent this bias contributed is unknown.

5.4 Oriang focus group

A second focus group was conducted at the Oriang Women's Pottery Group on the fourth day of field research at that site, January 12, 2005. Members of the group included seven local women potters (Oriang Potter #1-7), a translator, the author (who served as the moderator for the discussion) and teammate Michael Pihulic. All of the women potters in this group are of Luo ethnicity and are mothers, each with more than ten years of experience doing pottery work. The translator was a 25-year old woman who works at a local elementary school teaching kindergarten-aged children. She was asked to serve as the translator because of her fluency in both Luo and English, and because she lives nearby and is acquainted with one of the woman potters.

When asked why pots that store water are molded into the traditional rounded shapes, the potters said the rounded pots are so shaped in order to better fetch water, i.e. pots with rounded bodies can hold more water. Historically, rounded ceramic pots were used to both fetch and store water. They also said that different pot shapes serve different purposes, which is consistent with background research. Each potter drew shapes of pots, taking into account that a flat spot is needed to better accommodate tap attachment. Examples of the potters' individual drawings are shown in Figure 5-5.

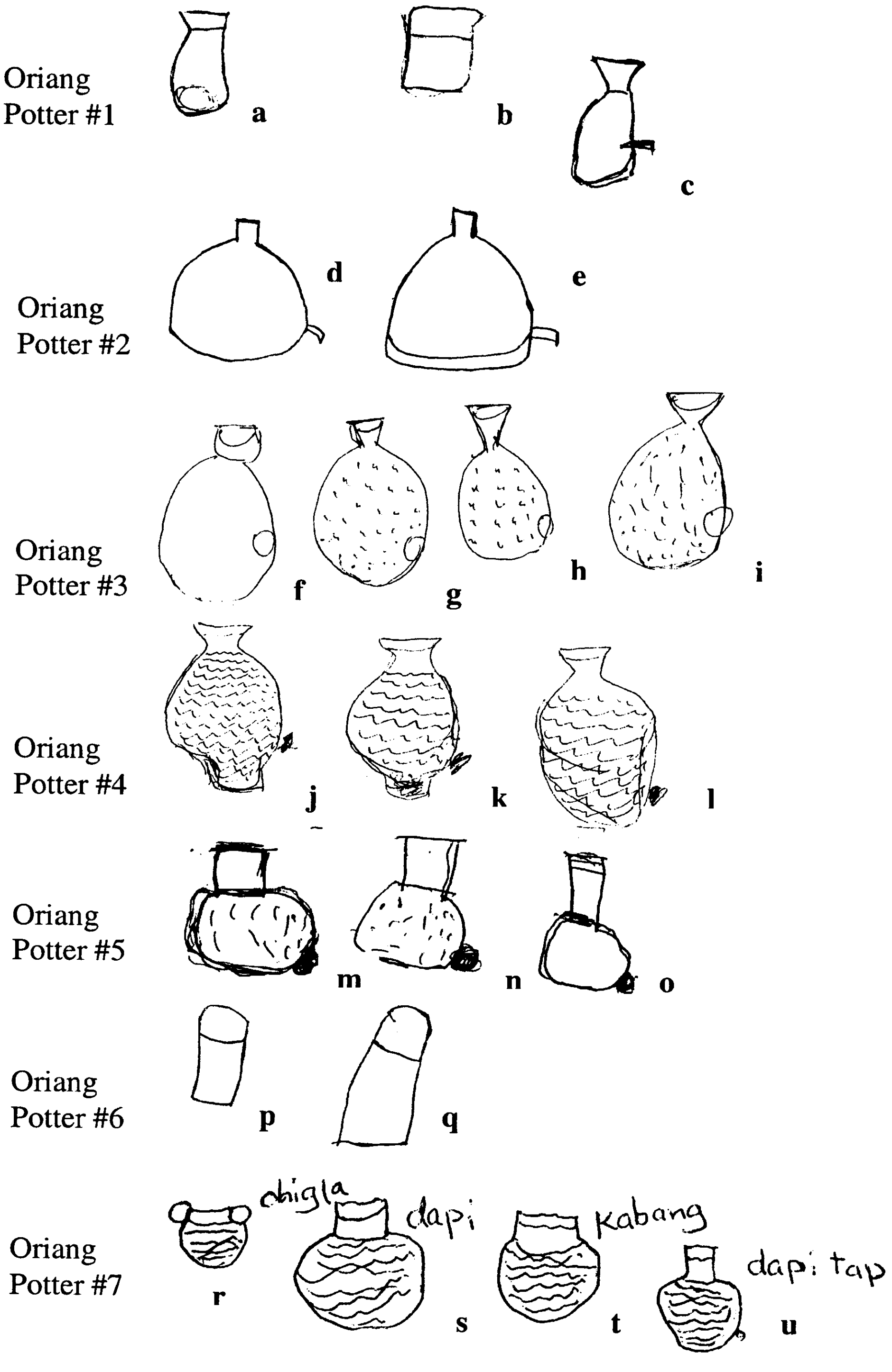


Figure 5-5. Examples of Oriang Potters' individual drawings of clay pots.

All of the drawings were of rounded pots, except for two single sketches of pots with flatter surfaces, one drawn by Oriang Potter #1 (Figure 5-5b) and the other by Oriang Pottery #6 (Figure 5-5p). The lack of cylindrical shaped pots is perhaps expected. Recall that at Amilo, the idea of a cylindrical pot was introduced by the author prior to the focus group discussion; however, this was not the case at Oriang. It is noteworthy that Oriang Potter #7 labeled her pot drawings (Figures 5-5r, s, t, u) with their Luo names. Figure 5-5r is a drawing of an *ohigla*, which by its shape may be another name for a *haiga*, a pot used for cooking and preparing fish. Figure 5-5s is a drawing of a *dapi*, historically used for water carriage and storage, while Figure 5-5u is a drawing of a *dapi tap*, which is the name given for a water storage container with a tap, i.e. the modified clay pot. Figure 5-5t is a drawing of a *kabange*, used for cooking and storing grains and starchy foods.

Finally, potters were shown the researcher's drawings of various pot shapes (Figure 5-3) and asked to choose which they liked best by raising their hands. Six potters chose the rounded pot with the extended cylindrical base (Figure 5-3a), while two voted for the asymmetrical pot with one rounded side and one flat side (Figure 5-3d). (Note that an eighth potter joined the group late and participated in this activity). The potters who chose the rounded pot with the extended cylindrical base (Figure 5-3a) said they liked it because they have tried that idea before, and that they liked the rounded, symmetrical shape because it is aesthetically pleasing. The two potters that chose the asymmetrical pot (Figure 5-3d) said they liked it because they think they are capable of making it. Furthermore, the potters all said that the shape of the pot does not matter so much as the cooling effect the clay has on the water and the taste of the water from the pot.

One limitation of this focus group discussion is that the moderator did not have the complete attention of the members because they were engaged in other activities (e.g. molding pots, mixing clay) while answering questions. However, unlike at Amilo, the translator at Oriang was a woman and a teacher (and not an "official"). It is believed that the translation at this site was more accurate and more effective than at Amilo, and that the translator added little if any bias to the potters' responses.

5.5 Summary of findings

While not only serving to achieve the objectives sought by the author, the focus groups at Amilo and Oriang also aimed to encourage the woman potters to try new things and think outside of the box by having them each participate in drawing pots, hopefully encouraging them to take ownership of their ideas. A summary of the findings of the focus groups is found below.

- While the Amilo potters do not know the origin of the rounded shape typical of both the wide-mouth and modified clay pot, the Oriang potters say that rounded shapes have historically been used to fetch and store water because they can hold more water than other shapes. The author's own research into the history of traditional Kenyan clay pots revealed that rounded bodies enable a pot to stand unsupported on a shelf or floor and can be much bigger (i.e. can hold more water) than elongated forms (Wandibba, 2003).

- The Amilo potters collectively preferred the cylindrical pot because they say it is more easily carried, uses less clay than the rounded pots, and eases tap attachment. The Oriang potters were not asked to compare the rounded and cylindrical pots.
- The Amilo potters drew a mix of both cylindrical and rounded pots, while the Oriang potters drew mostly rounded pots.
- At Amilo, three potters voted for the modified clay pot with a prominent cylindrical base, and one voted for the cylindrical pot. At Oriang, six potters voted for the modified clay pot with a prominent cylindrical base, and two voted for the asymmetrical pot with one rounded side and one flat side. Overall, the potters seemed to want to retain the rounded shape of the pots.

Furthermore, the translator plays a key role in the accuracy and effectiveness of the focus group discussions. While the "ideal" focus group encourages the free flow of ideas, the translator may inhibit this flow by imposing his or her own views onto the members of the focus group, thereby preventing the emergence of unbiased responses. It is therefore critical to consider what type of translator (gender, age, position, etc.) is most appropriate for the focus group members. Also, the variety of drawings made by women at Amilo differed from those at Oriang, largely because the idea of a cylindrical pot was introduced at Amilo a day prior to the focus group, while it was not introduced at Oriang. Lastly, because only two focus groups were conducted, the discussions and conclusions for this research paper cannot necessarily and should not be applied to the country of Kenya, or even the Lake Victoria region, as a whole. Patterns and trends across groups should only be detected after conducting multiple focus groups with similar participants (Krueger, 1994).

Chapter 6

Standardization

In this chapter, the background and motivation for addressing the issue of standardizing the size and shape of modified clay pots are given. It is essential to understand how pots are constructed before describing any pre-existing techniques used by potters to address standardization. In addition, any techniques used for standardization should account for shrinkage that occurs during drying. The author documents the variability in pot dimensions and volumes of completed 20 L and 40 L modified clay pots at all three pottery sites and introduces a reference rope tool to aid potters in standardizing certain dimensions of the modified clay pot.

6.1 Background and motivation

The size and shape of the modified clay pot are currently non-standard, as each potter makes her own pots following only the rough design. Standardization of the size of the pots is essential for proper chlorine dosing, while standardization of the shape of the pots is ideal for prevention of leaking from the tap attachment and prevention of breaking during transportation.

Potters currently produce two different sizes of modified clay pots: roughly 20 liters and roughly 40 liters. Plastic 20 liter jerry cans are used to collect and transport water from the source to the household storage container. Thus, from a chlorine dosing perspective, it is important that modified clay pots are either 20 liters or 40 liters so that people do not fill the pots with, for example, 1 ½ jerry cans of water, since chlorine dosing is prescribed for 20 liter volume multiples. From a practicality standpoint, it is ideal to restrict pot size to hold a maximum of 40 liters. Any size larger than this will increase difficulty in transportation. Additionally, because the pots will need to be cleaned periodically by the user, the inner mouth diameter and height of the pot need to be appropriate to enable proper washing, even by school children. However, the mouth size should not be so big as to encourage hand and cup dipping.

The rounded shape of the pot is such that the modified clay pot is wide on the sides, and short in height. If the pot is too short, the structure will be too weak and the pot will collapse downward and cave in, or "buckle down". Some members of the CARE/Kenya staff say that because pots are hand-molded, the shape largely depends on a potter's ability to control the dimensions of the modified clay pot (Figure 6-1), which include the following:

— Inner Mouth Diameter

— Mouth Circumference

— Middle Circumference (i.e. the pot's widest circumference)

— Base Circumference

— Mouth Inflection Point

— Height

— Height to Middle Circumference

The height of the Mouth Inflection Point marks the volume of water, either 20 liters or 40 liters, which a pot can hold. Sometimes, due to poor technique, pots are asymmetrical. The CARE/Kenya staff also like to joke that potters may have a tendency to make pots like their own body shapes, e.g. shorter and wider, or taller and narrower; similarly, those purchasing pots may have a psychological attachment to certain pots, i.e. they prefer to buy pots that are similar to their own body shapes.

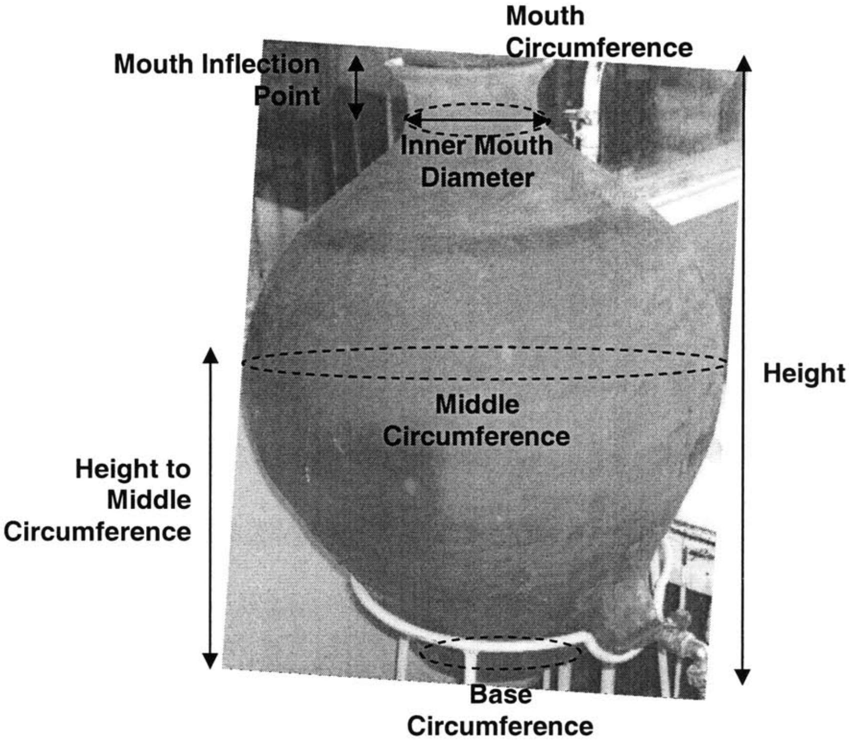


Figure 6-1. Dimensions of the modified clay pot.

Before making any recommendations to help standardize both the size and shape of the modified clay pots, it was first necessary to learn how pots are constructed and to determine techniques already utilized by the potters to address standardization.

6.2 Construction of modified clay pots

Modified clay pots are constructed using a handbuilding technique known as segmental coiling, which is a shaping process suited for producing large storage vessels. Handbuilding means constructing pottery from pre-made parts that are molded, coiled, or fashioned by hand. Segmental coiling consists of building each layer of the outer wall of the vessel from several small ropes, or coils. Individual coils are formed by hand squeezing and rolling the clay into long ropes. The diameters of the coils should be 2-3 times the desired thickness of the vessel to provide sufficient material to extend the vessel upward while merging with the previous layer. The coils are then joined to the vessel by pinching, which allows a larger binding area than simply stacking them and creates a stronger bond. The junctures and seams that are created between successive coils are then removed by smoothing the surface (Rice, 1987).

Pihulic (2005a) details the process of shaping modified clay pots using the segmental coiling technique:

> The potter begins by taking a fistful of clay and pounding it flat with the palm of her hand (Figure 6-2). Once the clay has spread out to a certain size the potter then pinches the edges, forming the beginning of the vessel wall. Once the base has been formed, the potters begin to form coils of clay by squeezing the clay into a cylinder shape, and then rolling it to smooth the edges (Figure 6-3). The coil is then applied to the exposed edge of the vessel, and then pressed on, forming a join. The material is then pinched and extended upward, and the process is repeated (Figure 6-4). Once the vessel is roughly half finished in height, the potter smoothes the interior and exterior by wetting the surfaces and scraping with [a smoothing tool called] an *ombasa*. Figure 6-5 [shows] the surface before and after smoothing. Once the surface has been treated, the potter continues building up the vessel wall, varying the coil size to control the circumference. The size of the opening of the neck [is] dictated by the necessary size to give the potter access to the inside. Because there are no set references or specifications for the dimensions of the pot they tend to be left to the discretion of the potter.

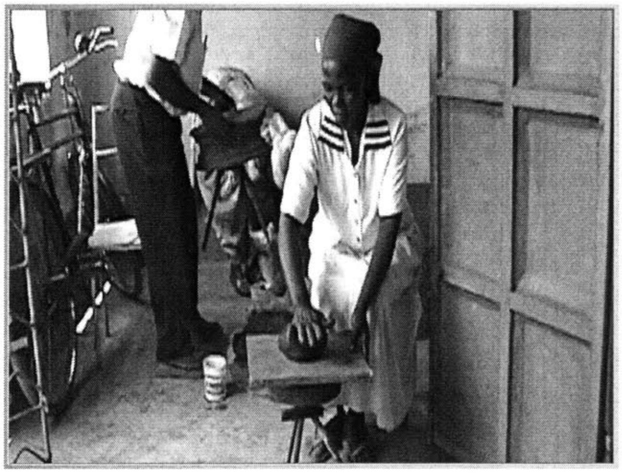


Figure 6-2. Potter, front, begins forming base by pounding clay into a flat disk. (Source: Pihulic, 2005a)

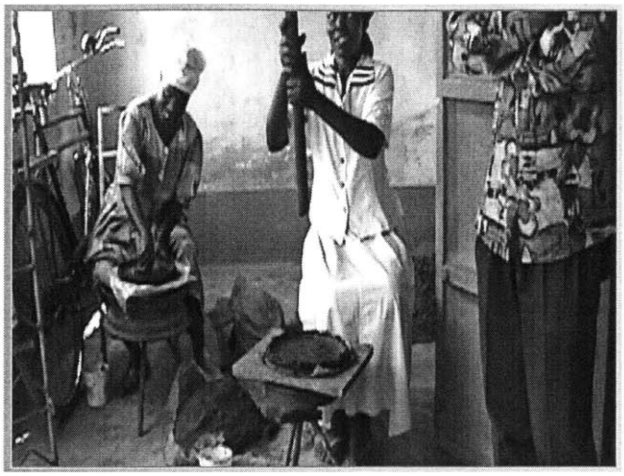


Figure 6-3. Potter, front, begins extending vessel walls.
Source: (Pihulic, 2005a)

Figure 6-4. Continued vessel wall extension. Coiling process is repeated.
(Source: Pihulic, 2005a)

Figure 6-5. Before and after smoothing. Top photo shows discrete layering from coils, while bottom photo shows the obliteration of distinct layers.
(Source: Pihulic, 2005a)

6.3 Pre-existing techniques

Most of the techniques used to make clay pots, whether wide-mouth or modified, are passed-down knowledge inherited from foremothers. The potters learn to use their arm length to judge how tall to make a 20 liter or 40 liter pot, while they use their arm circumference or hand width to judge how wide to make the mouth diameter. These "standard arm lengths" differ from potter to potter and are thus relative measurements. The only example of a potter using an absolute measurement scale was found at the Oriang Women's Pottery Group. One of the potters there uses a measuring tape while molding her pots. She hung it around her neck and used it a couple of times to measure the pot height and mouth diameter. She claims that in order to make a 20 liter pot, she makes the height 19 inches (48.26 cm), which shrinks to 18 inches (45.72 cm) after drying, and the mouth diameter 6.5 inches (16.51 cm), which shrinks to 6 inches (15.24 cm) after drying. Shrinkage is discussed further in the next section.

6.4 Shrinkage

The drying process is an important step in the manufacture of clay articles. Because shrinkage occurs during drying, any techniques used to standardize the modified clay pots must take into account this reduction in size.

The CARE/Kenya team says that during drying the height of the modified clay pot will come down 2-3 cm, and that the outer circumference of the belly also shrinks. In order to better understand the extent of shrinkage, a line test was performed at Oriang, and measurements of freshly made pots after several days of drying were taken at Oriang. Line tests are commonly used to determine the shrinkage of clay bodies (Kaplan, 2003).

To perform a simple line test, a 9-inch (22.86 cm) long line was drawn on a thin, rectangular slab of wet clay using a sharp edge. Exactly one day later, the length of the line reduced to 8-7/8 inches (22.54 cm) long. After the ninth day of drying, the line on the clay slab measured 8-7/16 inches (21.43 cm) long (~6% linear shrinkage from when molded to when completely dry). Another line test was performed on a second rectangular slab of wet clay. Only two measurements were taken: when the line was drawn, it measured 10-2/16 inches (25.72 cm) long; after the eighth day of drying, the line measured 9-9/16 inches (24.29 cm) long (~6% linear shrinkage from when molded to when completely dry). These results are summarized in Table 6-1. It is unknown how this linear shrinkage corresponds to volume shrinkage. Norton (1974) notes that it is often desirable to convert linear shrinkage to volume shrinkage or vice versa. According to Norton (1974), the ratio is 1 to 3 when changes are quite small; however, as they get larger, there is substantial departure from this simple ratio.

Table 6-1. Shrinkage line tests performed at Oriang.

	Length of line in inches (length of line in cm in parentheses)			
	Start = Day 0	Day 1	Day 8	Day 9
Clay slab #1	9.0000 (22.86)	8.8750 (22.54)		8.4375 (21.43)
Clay slab #2	10.1250 (25.72)		9.5625 (24.29)	

Freshly made pots were also measured after several days of drying to record reduction in the following pot dimensions: Inner Mouth Diameter, Mouth Circumference, Middle Circumference (i.e. circumference of the widest part of the belly), Base Circumference, Mouth Inflection Point, Height, and Height to Middle Circumference. The data for pot measurements at Oriang on the day that the pots were made as well as seven days later are summarized in Table 6-2.

Table 6-2. Dimensions of modified clay pots made at Oriang on Day 1 (freshly made) and Day 8 (after several days of drying).

	Measurements (cm)						
	Day 1						
Pot I.D.	Inner Mouth Diameter	Mouth Circumf.	Middle Circumf.	Base Circumf.	Mouth Inflection Point	Height	Height to Middle Circumf.
R1	10	36	113	78	5.5	41.5	19
R2	10	36	108	77	5.5	41.5	20
R3	10.5	39	110.5	77	5.5	42	19
R4	12	44.5	114.5	88	4.5	40.5	23.5
R5	12	42.5	121	74.5	6.5	42.5	22
R6	10	39.5	117	86	7.5	45.5	22
	Day 8						
Pot I.D.	Inner Mouth Diameter	Mouth Circumf.	Middle Circumf.	Base Circumf.	Mouth Inflection Point	Height	Height to Middle Circumf.
R1	9.5	37.5	106.5	65	5	36	20.5
R2	10	38.5	113	65	5.5	39	17.5
R3	9	35	107.5	66.5	5	38.5	22
R4	10.5	40	106	65.5	5	38	16
R5	10	39	101	68	5	36	16
R6	10	38.5	105	68	4	37	22

Table 6-3, based on the data in Table 6-2, shows the percent shrinkage of the modified clay pots made at Oriang after several days of drying. The values were calculated by first subtracting the measurements of Day 8 from the measurements of Day 1, then dividing by the measurements of Day 1, and finally multiplying by 100. Positive values indicate shrinkage (white); values equal to 0 indicate no change (light gray); and negative values indicate expansion (dark gray). While nearly all (75%) of the measurements in Table 6-2 show that the dimensions of the pots experienced shrinkage during the drying process over several days, some measurements (14%) increased and others (10%) remained the same. Error in measurement is the most likely explanation for why some of the measurements appeared to increase or stay the same. Measurements were taken using a seamstress measuring tape, and it was sometimes difficult to estimate where to take the measurement for the Middle Circumference, Height to Middle

Circumference, Mouth Inflection Point, and Mouth Circumference. Measuring the Height and the Base Circumference were more straightforward. Overall, while the pots shrunk, they do not shrink significantly, with an overall average shrinkage of just under 10% (standard deviation is 6%). The 6% linear shrinkage resulting from the two line tests at Oriang seems to agree with this finding. From what was gathered from interviews, both the potters and CARE/Kenya underestimate the shrinkage. Both groups mentioned that the height of the modified clay pot reduces about 2-3 cm after drying; however, according to data in Table 6-2, the height reduces an average of about 5 cm.

Table 6-3. Percent (%) shrinkage of modified clay pots made at Oriang after several days of drying. Positive values indicate shrinkage (white); values equal to 0 indicate no change (light gray); negative values indicate expansion (dark gray).

	Percent (%) shrinkage in dimensions						
Pot I.D.	Inner Mouth Diameter	Mouth Circumference	Middle Circumference	Base Circumference	Mouth Inflection Point	Height	Height to Middle Circumference
R1	5	-4	6	17	9	13	-8
R2	0	-7	-5	16	0	6	13
R3	14	10	3	14	9	8	-16
R4	13	10	7	26	-11	6	32
R5	17	8	17	9	23	15	27
R6	0	3	10	21	47	19	0
Avg	8	3	6	17	13	11	8
Stdev	7	7	7	6	20	5	19

According to Norton (1974), moving air serves a dual role in the drying process, i.e. "it supplies heat to the ware as compensation for the evaporative cooling, and it carries away the water vapor formed. Water evaporated from a piece of ware by drying must come mainly from the interior of the piece through the fine interconnecting channels." Furthermore, the rate of evaporation from the surface of drying clay depends on the rate of evaporation from a free water surface (which is dependent on air temperature, air velocity, and water content of the air) and drying rates of ceramic bodies, which are explained in detail in Norton (1974):

> Should the weight of a drying ceramic piece be plotted against time, the result would be a smooth curve without any great significance. However, if the rate of drying, or the slope of the weight-loss curve, is plotted against the water content of the piece, a curve like that in (Figure 6-6) results. As first pointed out by Sherwood (1929) [under laboratory conditions], the wet clay starting at point A dries at a constant rate until B is reached. This constant drying rate is about half that for a free water surface. At point B the rate starts to decrease rapidly and finally reaches the origin. It is significant that point B is that at which the mass changes from a dark to a light color. In other words, down to point B there is over the surface a continuous water film which acts as free water, but below this point the water retreats further and further into the pores so that the drying rate becomes less and less. These steps in the clay structure are shown by (Figure 6-7).

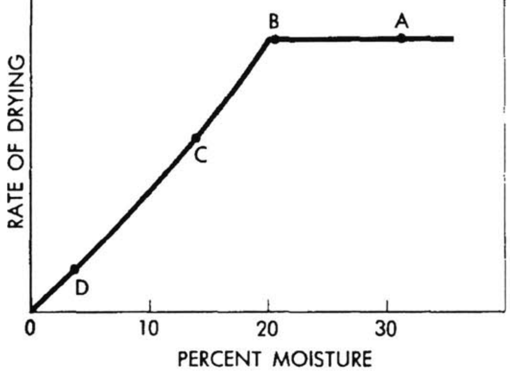


Figure 6-6. Rate of water loss in drying moist clay.
(Source: Norton, 1974)

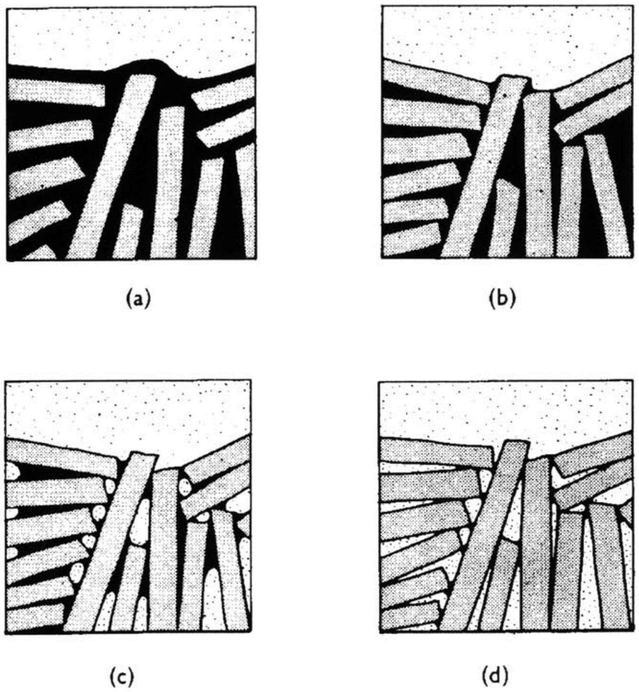


Figure 6-7. Stages in drying moist clay. A cross section at the surface. The letters correspond to those on the curve of Figure 6-6.
(Source: Norton, 1974)

Too much shrinkage may lead to cracking and distortion of a clay piece. The most common way to reduce drying shrinkage is to add non-plastics such as grog, which is a gritty material such as ground clay that has already been fired, such that they "reduce the number of water films per unit distance by displacing a group of clay particles and their associated films by an equal volume of stable particles" (Norton, 1974). Non-plastics that are relatively coarse materials will reduce more water films per unit distance; similarly, coarse-grained clays shrink less than fine-grained clays.

Shrinkage may also occur during the firing process. However, no attempt was made to calculate percent shrinkage after firing during field work in Kenya since both the potters and CARE/Kenya stated that the pots only shrink during drying. According to Kingery (1960), before clay is fired, it is composed of individual grains separated by between 25 and 60 volume per cent porosity, depending on the particular material and processing method used. During the firing process this porosity is removed, such that the volume firing shrinkage is equal to the pore volume eliminated. Adding non-shrinking material, such as grog (pre-fired clay), to the clay before firing can reduce shrinkage (Kingery, 1960).

6.5 Variability in pot dimensions and volumes

Measurements of completed 20 L and 40 L modified clay pots that were for sale at the collectives were taken using a seamstress measuring tape (Figure 6-8) at all three field site locations. The following dimensions were measured for each pot: Height, Base Circumference, Middle Circumference, Height to Middle Circumference, Mouth Circumference, Inner Mouth Diameter, and Mouth Inflection Point. Table 6-4 displays the dimensions of 20 L modified clay pots, and Table 6-5 displays the dimensions of 40 L modified clay pots.

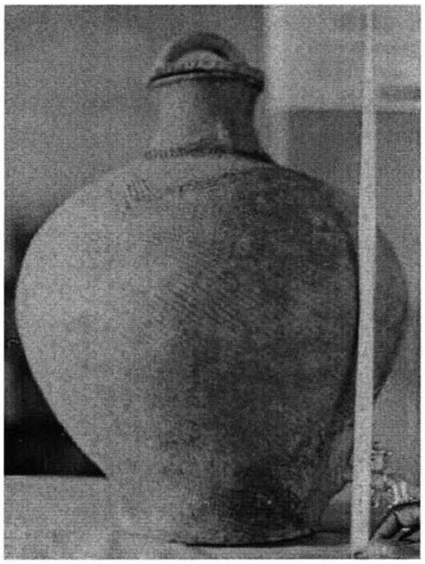


Figure 6-8. Measuring pots with a seamstress tape at Amilo.
(Source: Pihulic, 2005b)

Table 6-4. Dimensions (cm) of 20 L modified clay pots.

Pot number	Height	Base Circumf.	Middle Circumf.	Height Middle Circumf.	Mouth Circumf.	Inner Mouth Diameter	Mouth Inflection Point	Pot I.D.	Location
1	38.0	62	114.5	21	37.5	10	6.5		Amilo
2	43	61	118	22	38	10	7.5		Amilo
3	42	58.5	111.5	20	34.5	9	11		Amilo
4	39	60	111.5	18	37.5	9	9		Amilo
5	41.5	66	110.5	18	33.5	9	10		Amilo
6	38	66	106.5	17	35	9.5	8		Amilo
7	37	74	110.5	18	40	10	6.5		Amilo
8	41.5	60	118.5	19	41	11.5	9		Amilo
9	43	64	116	19	34	8.5	9.5		Amilo
10	44	60	112	20	32	8	11.5		Amilo
11	39	71	114	17	34.5	9	8		Amilo
12	45.5	66.5	118.5	23	40.5	11	10		Amilo
13	42	72	119	20.5	38	10	10		Amilo
14	38.5	65	111	19.5	35.5	8.5	9	7	Amilo
15	37	65	110	19	33.5	8.5	6.5	7	Amilo
16	35.5	61	110.5	18	33	8.5	8.5	7	Amilo
17	39	77	114	20	32.5	8	5	2	Amilo
18	41.5	69	118	23	29.5	7.5	5	2	Amilo
19	41	64	113	20	37	10	7		Amilo
20	40	88	115.5	19.5	42	10	12		Amilo
21	36	56.5	109	17.5	34	8.5	8	7	Amilo
22	40	80	114	20	41.5	11.5	5		Oriang
23	42	85	114	19	43.5	11.5	5.5		Oriang
24	43	81	123	19.5	42	12.5	5		Oriang
25	39	83	107	17	42.5	11.5	5.5		Oriang
26	42	81	115	22	38	10.5	6		Oriang
27	41	83.5	114	21.5	41.5	11	4.5		Oriang
28	40.5	87	124	18	60.5	17	9.5		Oriang
29	44.5	75	121	28	35	9	5		Oriang
30	42.5	80.5	115	22.5	39	10	5.5		Oriang
31	42.5	53.5	113	24	36	9.5	6		Oriang
32	41.5	78	113	19	36	10	5.5	R1	Oriang
33	41.5	77	108	20	36	10	5.5	R2	Oriang
34	42	77	110.5	19	39	10.5	5.5	R3	Oriang
35	40.5	88	114.5	23.5	44.5	12	4.5	R4	Oriang
36	42.5	74.5	121	22	42.5	12	6.5	R5	Oriang
37	45.5	86	117	22	39.5	10	7.5	R6	Oriang
38	38	82	104	17.5	37.5	10	7.5	F25	Amilo
39	37	71	107	18.5	37	10	4.5	M	Amilo
40	38.5	54.5	112.5	21	34.5	8.5	6		Asembo
41	47	56	108	30	33.5	7.5	7.5		Asembo
Average	40.8	71.2	113.6	20.3	37.9	10.0	7.2		
Stdev	2.7	10.4	4.6	2.7	5.1	1.7	2.1		
Variability	7%	15%	4%	14%	13%	17%	29%		

Table 6-5. Dimensions (cm) of 40 L modified clay pots.

Pot number	Height	Base Circumf.	Middle Circumf.	Height Middle Circumf.	Mouth Circumf.	Inner Mouth Diameter	Mouth Inflection Point	Pot I.D.	Location
42	50	74	137.5	24	34.5	9	8.5		Amilo
43	49.5	71	135.5	26	34.5	8.5	9.5		Amilo
44	51	76	152	27.5	37	8	6		Amilo
45	53.5	81	153	25	14	10	9.5		Amilo
46	48	79	145	22	32.5	8	6.5	2	Amilo
47	44	75.5	127	22.5	33	8.5	6.5	2	Amilo
48	46	77.5	131	25.5	33	9	7.5	2	Amilo
49	45.5	72	126	23	34	8.5	7		Amilo
50	56	87	138	33	42.5	12	6		Oriang
51	51.5	74.5	141.5	28	38	9.5	7.5		Oriang
52	55	77.5	148.5	28	39	10	7.5		Oriang
53	54	72.5	144	33	38.5	10	7.5		Oriang
54	55	82	154.5	32	37	9.5	6		Oriang
55	55.5	83	142	31	43	10.5	5.5		Oriang
56	54	86	139	29	40.5	10.5	5.25		Oriang
57	53	78.5	139	31	37.5	10	5		Oriang
58	51	82	135	28	38	10	5.5		Oriang
59	54.5	79	141.5	28.5	36	10	7		Oriang
60	57	60	147.5	30	39	9.5	7.5		Oriang
61	58.5	82	145	32	44.5	11	7		Oriang
62	53.5	85	142	28.5	42.5	10.5	6		Oriang
63	50	83	139	29	37	10	5		Oriang
64	51.5	73	140	29.5	40.5	10.5	6		Oriang
65	51.5	66	136	34.5	43	11.5	6		Oriang
66	58.5	82	148	39	40.5	11	6.5		Oriang
67	50	70	138	30	37.5	10.5	5		Oriang
68	51.5	79	140	26	38	10.5	6		Oriang
69	50	71	138	26	36.5	9.5	6.5		Amilo
70	49.5	60	134	29	36	8.5	7.5		Asembo
71	49.5	48	135	30	35.5		7.5		Asembo
Average	51.9	75.6	140.4	28.7	37.1	9.8	6.7		
Stdev	3.6	8.6	6.9	3.7	5.4	1.0	1.2		
Variability	7%	11%	5%	13%	15%	10%	18%		

From Table 6-4 and Table 6-5, it is evident that the pot dimensions do not vary much. For the 20 L modified clay pots, the variability in dimensions is within 17% (average dimensional variability is 12%), with the exception of the Mouth Inflection Point. The variability in the Mouth Inflection Point is irrelevant, since the pot is filled with water up to this point; the height above this point does not matter. For the 40 L modified clay pot, discounting the Mouth Inflection Point dimension since it does not play a role in volume variability, the variability in dimensions is within 15% (average dimensional variability is 10%). Figures 6-9 and 6-10 are graphical representations of Tables 6-4 and 6-5, respectively. When comparing pots made within locations (Table 6-6), average variability in the 20 L and 40 L modified clay pot dimensions are less than or equal 12% (average dimensional variability is 10%). This suggests that potters within locations generally shape pots in the same way. However, when comparing pots made between locations, variability appears much greater. When comparing just the Base Circumference of 20 L pots between locations, the range is from 55.3 cm (Asembo) to 79.4 cm (Oriang). This suggests that potters between locations do not generally shape pots in the same way.

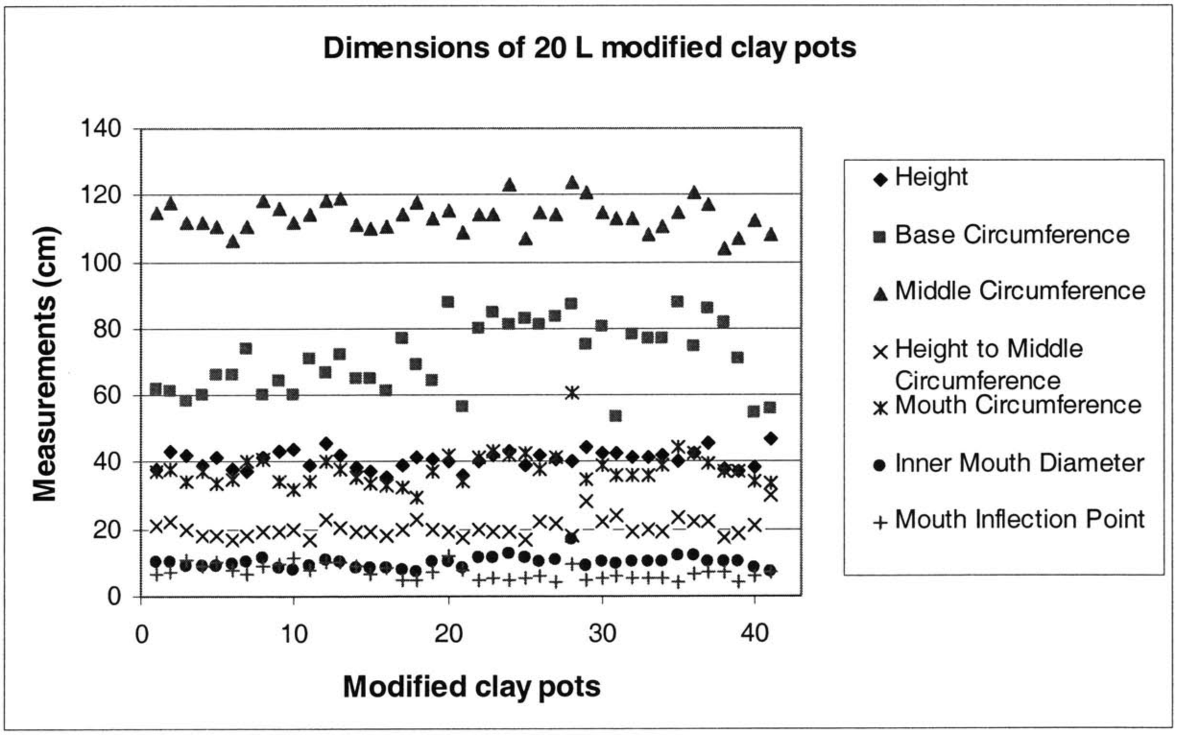


Figure 6-9. Graphical representation of the dimensions of 20 L modified clay pots.

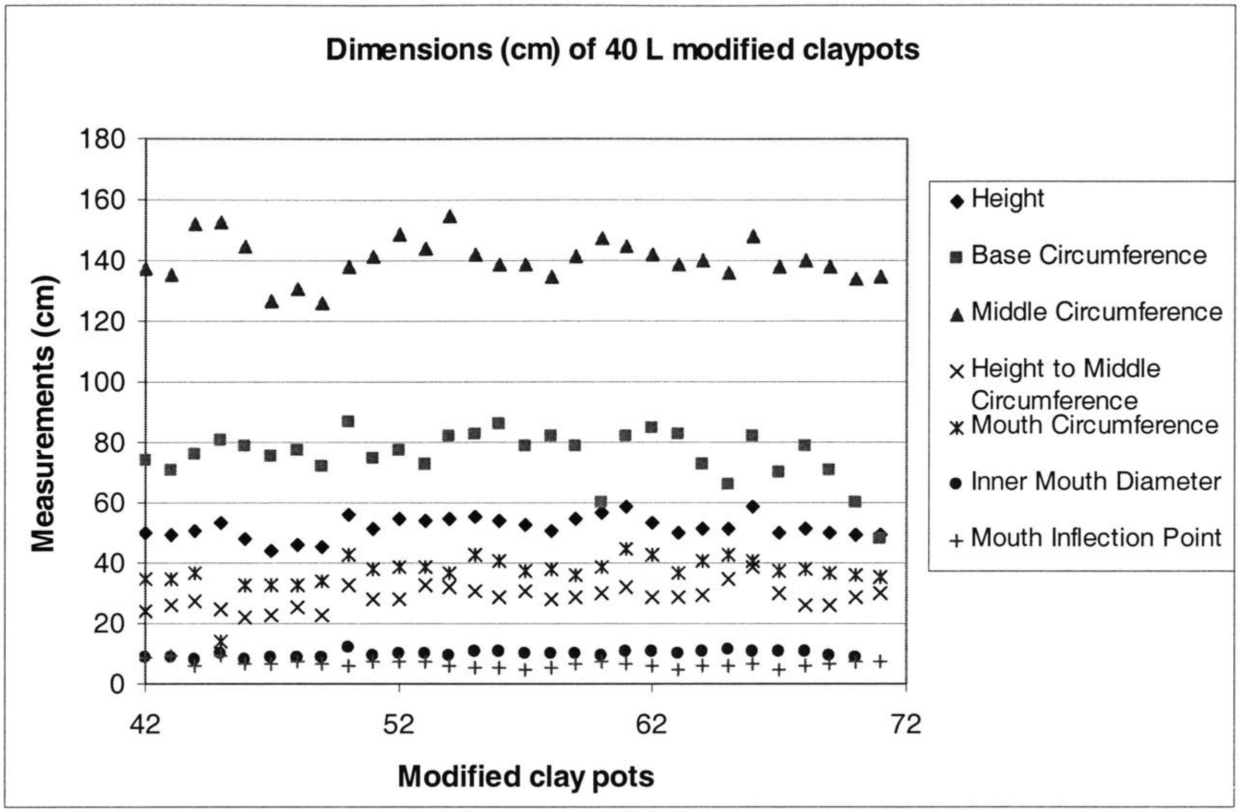


Figure 6-10. Graphical representation of the dimensions of 40 L modified clay pots.

Table 6-6. Variability in 20 L and 40 L modified clay pot dimensions by location.

Location and Pot size		Height	Base Circ.	Middle Circ.	Height to Middle Circ.	Mouth Circ.	Inner Mouth Diam.	Mouth Inflection Point	Overall Average
Amilo 20 L	Average	39.9	66.9	112.7	19.3	36.0	9.3	8.2	
	Stdev	2.7	7.8	4.1	1.7	3.2	1.0	2.0	
	Variability	7%	12%	4%	9%	9%	11%	25%	11%
Amilo 40 L	Average	48.6	75.2	138.3	24.6	32.1	8.8	7.5	
	Stdev	3.0	3.6	9.9	1.9	7.0	0.7	1.3	
	Variability	6%	5%	7%	8%	22%	8%	18%	10%
Oriang 20 L	Average	41.9	79.4	115.3	21.1	41.1	11.2	5.8	
	Stdev	1.6	8.0	4.9	2.7	6.0	1.9	1.2	
	Variability	4%	10%	4%	13%	15%	17%	21%	12%
Oriang 40 L	Average	53.8	78.0	142.0	30.5	39.6	10.4	6.2	
	Stdev	2.6	7.1	4.9	3.0	2.5	0.7	0.9	
	Variability	5%	9%	3%	10%	6%	6%	15%	8%
Asembo 20 L	Average	42.8	55.3	110.3	25.5	34.0	8.0	6.8	
	Stdev	6.0	1.1	3.2	6.4	0.7	0.7	1.1	
	Variability	14%	2%	3%	25%	2%	9%	16%	10%
Asembo 40 L	Average	49.5	54.0	134.5	29.5	35.8	8.5	7.5	
	Stdev	0.0	8.5	0.7	0.7	0.4		0.0	
	Variability	0%	16%	1%	2%	1%		0%	3%

The potters at Amilo are each assigned a number so that they can sign the pots that they make. In this way it is possible to know which pots are made by each potter; however, not all of the pots are signed. Nonetheless, there is some data available in order to indicate the variability in pots made by the same potter. Figure 6-11 shows the variability in 20 L modified clay pots made by Amilo Potter No. 7, while Figure 6-12 shows the variability in 40 L modified clay pots made by Amilo Potter No. 2. The graphs show that the potters are both very consistent in making pots.

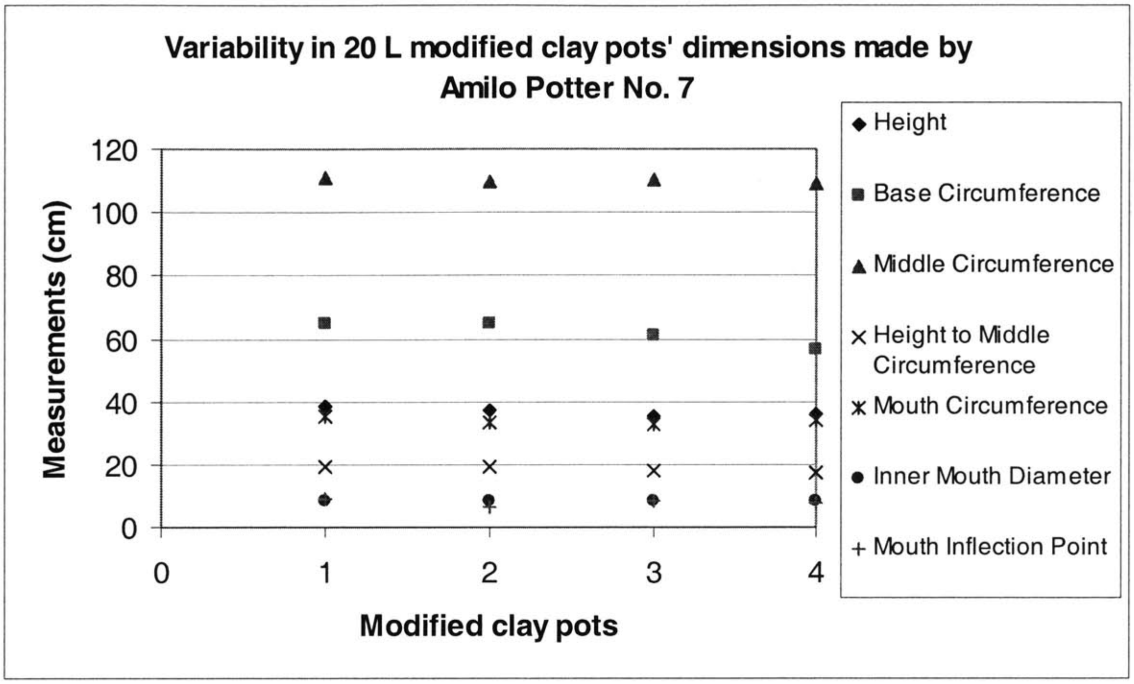


Figure 6-11. Variability in 20 L modified clay pots made by Amilo Potter No. 7.

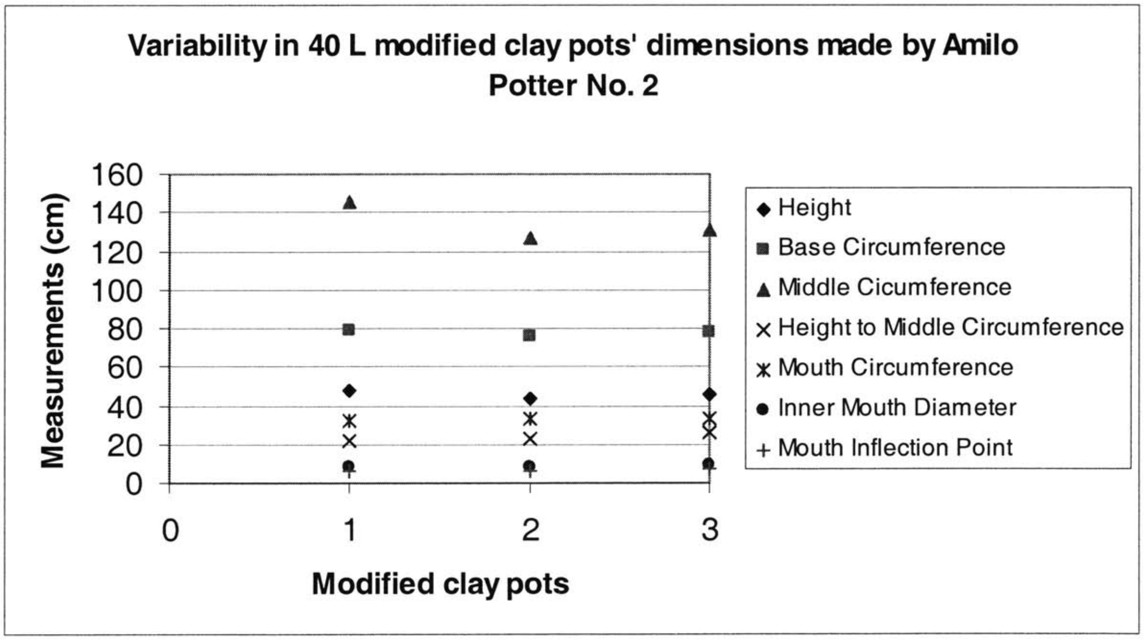


Figure 6-12 Variability in 40 L modified clay pots made by Amilo Potter No. 2.

To get a preliminary understanding of volume variability, four 20 L modified clay pots at Amilo were filled with water to the Mouth Inflection Point to determine the exact volume of water each pot could hold. The volumes were the following: 19 L, 19.3 L, 22 L, and 20 L. The average of these volumes is 20.1 L with a standard deviation of 1.4 liters, giving a variability of 7%. The dimensions of these four 20 L modified clay pots at Amilo were also measured. These data are summarized in Table 6-7.

Table 6-7. Measured volumes (L) and dimensions (cm) of four 20 L pots.

Pot number	Measured Volume (Liters)	Height	Base Circ.	Middle Circ.	Height to Middle Circ.	Mouth Circ.	Inner Mouth Diameter	Mouth Inflection Point	Location
A1	19	39	62.5	114	21	37.5	10	8	Amilo
A2	19.3	41	58	110.5	23	34.5	9.5	10.5	Amilo
A3	22	41	62.5	119	21	38	10	7.5	Amilo
A4	20	38	70	115	17	34.5	9	7.5	Amilo
Average	20.1	39.8	63.3	114.6	20.5	36.1	9.6	8.4	
Stdev	1.4	1.5	5.0	3.5	2.5	1.9	0.5	1.4	
Variability	7%	4%	8%	3%	12%	5%	5%	17%	

In an attempt to relate dimensional variability to volume variability, a method was developed to convert known pot dimensions to volumes. The following symbols (Figure 6-13) were used, with units in brackets:

V_{TOT} = Total Volume [cm^3]

V_b = Volume of the bottom [cm^3]

V_t = Volume of the top [cm^3]

r = radius [cm]

z = height [cm]

r_b = radius of the bottom (i.e. Base Circumference / 2π) [cm]

r_m = maximum radius (i.e. Middle Circumference / 2π) [cm]

r_t = radius of the top (i.e. Mouth Circumference / 2π) [cm]

h = height from r_b to r_m (i.e. Height to Middle Circumference) [cm]

h' = height from r_m to rt (i.e. Height – h – Mouth Inflection Point) [cm]

α = value relating r to z

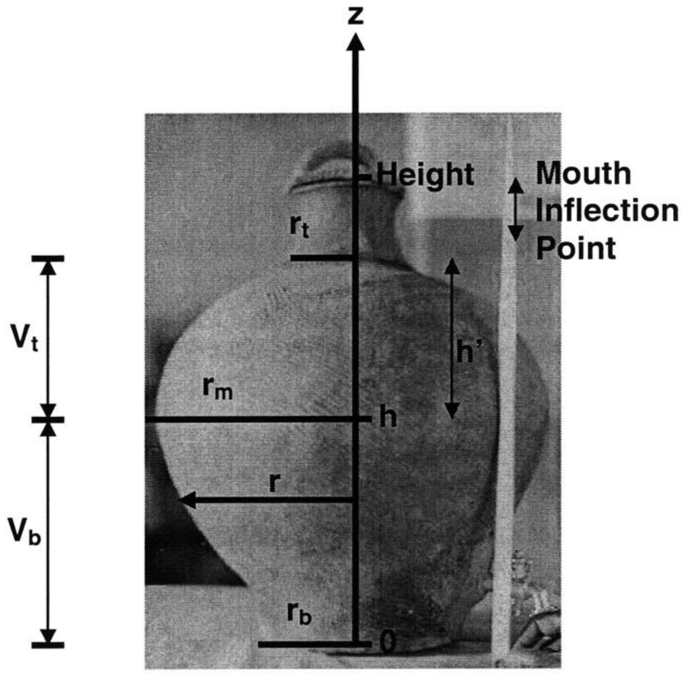


Figure 6-13. Symbols used in equations to convert dimensions to volumes.

The following equations were used to approximate the radius, r, and the Total Volume, V_{TOT}:

1) $V_{TOT} = V_b + V_t$

2) $V_b = \int \pi r^2\, dz$ (integrating from 0 to h)

3) $r = r_b + r_m - r_b(z/h)^{\alpha} = r_b + ((r_m - r_b)/h^{\alpha})z^{\alpha}$ (substitute r into Equation 2)

4) $V_b = \pi\, [r_b^2 h + (2r_b((r_m - r_b)/h^{\alpha})h^{\alpha+1})/(\alpha+1) + (((r_m - r_b)/h^{\alpha})^2 h^{2\alpha+1})/(2\alpha+1)]$

5) $V_t = \pi\, [r_t^2 h' + (2r_t((r_m - r_t)/h'^{\alpha})h'^{\alpha+1})/(\alpha+1) + (((r_m - r_t)/h'^{\alpha})^2 h'^{2\alpha+1})/(2\alpha+1)]$

Equation 1 gives V_{TOT} in cubic centimeters; therefore, to covert V_{TOT} to liters, it is necessary to divide by 1000 (since 1000 cm^3 = 1 L). The value that relates r to z, α, was calibrated using the known volumes and dimensions of the four 20 L modified clay pots found in Table 6-7. The α values ranged from 0.64 to 0.89, with an average $\alpha = 0.79$. This average value of α was used to back-calculate the volumes of the four 20 L modified clay pots found in Table 6-7. Table 6-8 compares the measured volumes with the calculated volumes. While the average of the calculated volumes is equal to the average of the measured volumes, the variability in the calculated volumes (9%) is slightly greater than the variability in the measured volumes (7%).

Table 6-8. Comparison of measured volumes to calculated volumes of four Amilo 20 L modified clay pots.

Pot number	Measured Volume (Liters)	Calculated Volume (Liters)
A1	19	19.7
A2	19.3	18.1
A3	22	22.6
A4	20	19.8
Average	20.1	20.1
Stdev	1.4	1.9
Variability	7%	9%

The key assumptions made in developing this method (Equations 1-5) for converting pot dimensions to volumes are that the shapes of the modified clay pots are all uniform and that the α for V_t is the same as the α for V_b. However, as can be seen from Figure 6-14, the shapes of modified clay pots are not uniform, and the way that the radius relates to the height (i.e. the curvature of the pot, or α) differs for the tops and bottoms of the pots. It was hypothesized that α would differ between locations and between differently sized pots (20 L vs. 40 L). Thus, this method, which should be taken as an approximate method to convert pot dimensions to pot volumes, was applied to calculate volumes from the dimensions of additional 20 L modified clay pots from only the Amilo location (Pot numbers 1-21, 38, and 39 found in Tables 6-4), since a 20 L Amilo modified clay pot was used to calibrate α. These calculated volumes are found in Table 6-9. For the 20 L Amilo modified clay pots, the average volume is 20.0 L with a variability of 13%. These data agree with the data in Table 6-8. When this method was used to calculate the average volumes from the dimensions of all other modified clay pots found in Tables 6-4 and 6-5 (Pot numbers 22-37 and 40-71), the results (Table 6-10) varied widely, suggesting that α is indeed both location-specific and size-specific. Thus, in order to apply this method to a wider range of modified clay pots, further research is required so that the α value can be calibrated separately with both measured dimensions and measured volumes for each size and for each location.

The volumes of modified clay pots are important since chlorine dosing is prescribed for 20 L volume multiples. The CDC determined that a roughly 10% volume variability is acceptable to dose the volume of water with the prescribed amount of chlorine (CDC, 2004). However, since people who own modified clay pots generally use 20 L plastic jerry cans, buckets or some other standardized container to transport water from sources to fill the modified clay pots, generally do not fill the modified clay pots completely (i.e. to the Mouth Inflection Point), and generally dose the water with chlorine in the containers used to transport the water before filling the modified clay pots, the issue of volume variability does not play such an essential role in chlorine dosing as previously thought (Lantagne, 2005). However, little variability in volume is still a valid goal, and this thesis showed that the volume variability in 20 L Amilo modified clay pots is under 10%, when averaging the measured volume variability of Pot numbers A1-A4 (Table 6-8), the calculated volume variability of Pot numbers A1-A4 (Table 6-8), and the calculated volume variability of Pot numbers 1-21, 38, and 39 (Table 6-9).

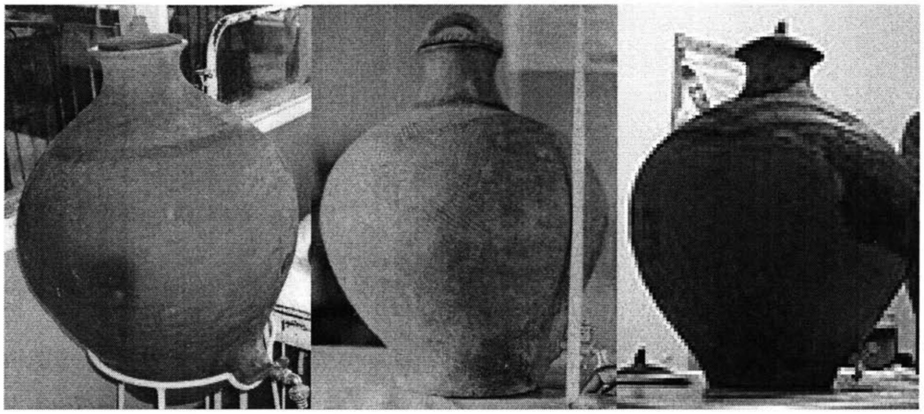


Figure 6-14. Varying shapes of modified clay pots.
(Source: Murcott, 2004; Pihulic, 2005b; Murcott, 2004)

Table 6-9. Calculated volumes (V_{TOT} in L) of Amilo 20 L modified clay pots.

Pot number	r_t	r_m	r_b	h	h'	α	Location	V_{TOT}
1	6	18.2	9.9	21	10.5	0.79	Amilo	20.1
2	6	18.8	9.7	22	13.5	0.79	Amilo	23.4
3	5.5	17.7	9.3	20	11	0.79	Amilo	18.3
4	6	17.7	9.5	18	12	0.79	Amilo	17.9
5	5.3	17.6	10.5	18	13.5	0.79	Amilo	18.8
6	5.6	17	10.5	17	13	0.79	Amilo	17
7	6.4	17.6	11.8	18	12.5	0.79	Amilo	19.5
8	6.5	18.9	9.5	19	13.5	0.79	Amilo	21.5
9	5.4	18.5	10.2	19	14.5	0.79	Amilo	21.3
10	5.1	17.8	9.5	20	12.5	0.79	Amilo	19.3
11	5.5	18.1	11.3	17	14	0.79	Amilo	19.9
12	6.4	18.9	10.6	23	12.5	0.79	Amilo	24.6
13	6	18.9	11.5	20.5	11.5	0.79	Amilo	22.8
14	5.7	17.7	10.3	19.5	10	0.79	Amilo	18.2
15	5.3	17.5	10.3	19	11.5	0.79	Amilo	18.2
16	5.3	17.6	9.7	18	9	0.79	Amilo	16
17	5.2	18.1	12.3	20	14	0.79	Amilo	22.7
18	4.7	18.8	11	23	13.5	0.79	Amilo	24.7
19	5.9	18	10.2	20	14	0.79	Amilo	21.1
20	6.7	18.4	14	19.5	8.5	0.79	Amilo	21.6
21	5.4	17.3	9	17.5	10.5	0.79	Amilo	15.7
38	6	16.6	13.1	17.5	13	0.79	Amilo	18.5
39	5.9	17	11.3	18.5	14	0.79	Amilo	19.2
Average								20.0
Stdev								2.5
Variability								13%

Table 6-10. Calculated volumes (V_{TOT} in L) of modified clay pots by location and size.

Location and size of pot	Calculated volumes (L) using method	
Amilo 20 L	Average	20.0
	Stdev	2.5
	Variability	12.5%
Amilo 40 L	Average	36.9
	Stdev	6.4
	Variability	17.2%
Oriang 20 L	Average	25.4
	Stdev	2.6
	Variability	10.2%
Oriang 40 L	Average	46.1
	Stdev	4.8
	Variability	10.4%
Asembo 20 L	Average	20.7
	Stdev	2.3
	Variability	11.3%
Asembo 40 L	Average	33.1
	Stdev	1.2
	Variability	3.5%

6.6 Techniques and tools to standardize pottery

There are several techniques and tools available to standardize handbuilding, which is constructing pottery from pre-made parts that are molded, coiled, or fashioned by hand. As mentioned in section 6.2, the modified clay pot is constructed from coils that are placed one on top of the other. The most common tools used to standardize pottery making are in general molds, calipers, and measuring tapes. With the exception of one potter from the Oriang Women's Pottery Group, none of the potters used any of these tools.

A mold is a plaster shape designed to pour slip cast into and let dry so the shape comes out as an exact replica of the mold (Stoke-on-Trent, 2005). Slip refers to clay mixed with water to make it fluid-like, and cast means to produce shapes by pouring this fluid clay into molds. Molds are usually made from plaster of Paris, otherwise known as gypsum or calcium sulphate (Pottery Studio, 2001). In more general terms, a mold is a hollow form or matrix for shaping a fluid or a plastic, or a frame or model around or on which something is formed or shaped[2]. It may be possible to produce a mold for the modified clay pot; however, due to the large size of the pot (20 L or 40 L) and the limited resources for materials, this technique is not the most ideal method for standardization.

Calipers are used to make pots similar in size because they measure inside and outside dimensions, or, more specifically, the diameter of round forms. For example, calipers are used to get lids to fit just right (Stoke-on-Trent, 2005). Figure 6-15 shows examples of both hardwood and aluminum calipers.

---

[2] http://dictionary.com

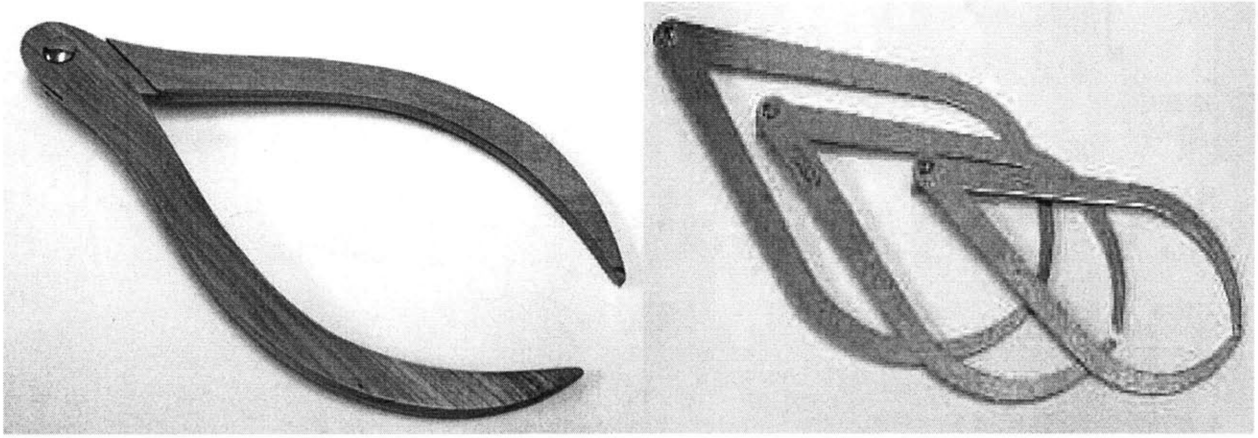


Figure 6-15. Hardwood calipers (left) and aluminum calipers (right) used to standardize pottery. (Source: BigCeramicStore.com, 2005)

Measuring tapes can also be used to control size, although they are a rather simple and unsophisticated tool. However, their ease of use is ideal for low-technology areas such as rural districts of developing countries. When making modified clay pots, potters would have to use the measuring tape frequently in order to control the size and ensure proper dimensions. The tool actually tested during field work in Kenya is an even simpler version of a measuring tape: a piece of rope with 3-4 knots marking off certain dimensions of the modified clay pot. These ropes are termed "reference ropes".

6.7 Reference Ropes

Reference ropes were developed to help standardize the dimensions of the modified clay pot. This simple tool consists of a length of rope with knots tied to indicate measurements that correspond to dimensions of the modified clay pot. It was thought that a minimum of three dimensions (i.e. Height to Middle Circumference, Middle Circumference, and Inner Mouth Diameter) would be necessary to make the desired modified clay pot, and that the other correct dimensions would naturally be achieved by the potter's experience and skill. A reference rope for a 20 L modified clay pot was made based on the following calculations, taking into account 10% shrinkage in volume during the drying process:

Volume of 20 L modified clay pot approximated as sphere =

$V = 4/3\ \pi r^3 = 20\ \text{L} = 20000\ \text{cm}^3$

Radius = $r = 16.8$ cm

Circumference = $C = 2\pi r = 105.8$ cm

10% of volume = $V_{10} = 0.1\ (4/3\ \pi\ (16.8\ \text{cm})^3) = 1986.17\ \text{cm}^3$

Volume taking into account 10% shrinkage = $V_{new} = 20000\ \text{cm}^3 + 1986.17\ \text{cm}^3$

$V_{new} = 21986.17\ \text{cm}^3 = 4/3\ \pi r^3$

$R_{new} = 17.38\ \text{cm} \approx 18\ \text{cm}$ =Height to Middle Circumference

$C_{new} = 109.20\ \text{cm} \approx 110\ \text{cm}$ = Middle Circumference

It was assumed an Inner Mouth Diameter equal to 10 cm would be both narrow enough to discourage hand and cup dipping and wide enough to allow attaching of the tap and cleaning of the pot. Table 6-11 summarizes the three dimensions calculated for the 20 L modified clay pot reference rope. Figure 6-16 shows a pictorial drawing of this reference rope and Figure 6-17 shows a photograph of the actual reference rope.

Table 6-11. Dimensions calculated for the 20 L modified clay pot reference rope.

	Height to Middle Circumference	Middle Circumference	Inner Mouth Diameter
Measurement (cm)	18	110	10

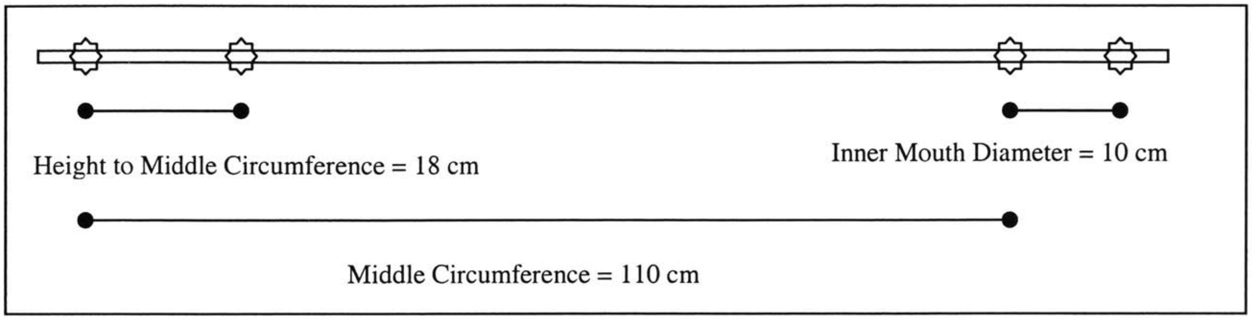


Figure 6-16. Pictorial drawing of 20 L modified clay pot reference rope.

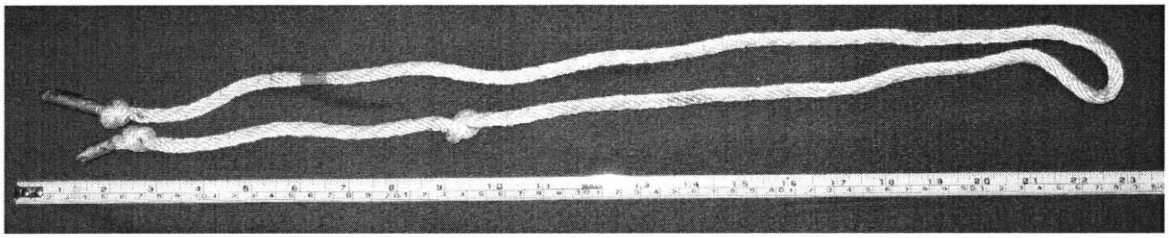


Figure 6-17. Photograph of 20 L modified clay pot reference rope.

A potter at Amilo was the first one to try using the 20 L modified clay pot reference rope (Figure 6-18). Halfway through making the pot, it was obvious that the pot was too small and it was impossible to make the Middle Circumference wide enough to match the reference rope's specifications. It was thought that the potter started with too small of a base. This perhaps is reason to also mark off a desired Base Circumference on the reference rope in addition to the other three dimensions. She destroyed the unfinished pot and started over. The second time around she was encouraged to use the reference rope more frequently to check that the dimensions would be accurate. With coaching from the researchers (Figure 6-19) and reminders to keep using the reference rope, the potter succeeded the second time in making a beautiful 20 L modified clay pot in exact accordance with the dimensions designated on the reference rope. The potters reported that the ropes were easy to understand and easy to use, two factors essential to developing a successful standardization tool in this context. The exact shrinkage of the modified clay pot during the drying process will need to be determined to make more accurate reference ropes, since 10% shrinkage was assumed based on measurements in Section 6.4 and the results in Table 6-3. A method of trial-and-error problem solving in conjunction with good record keeping is necessary to improve the reference rope tool and to make a similar reference rope for the 40 L modified clay pot.

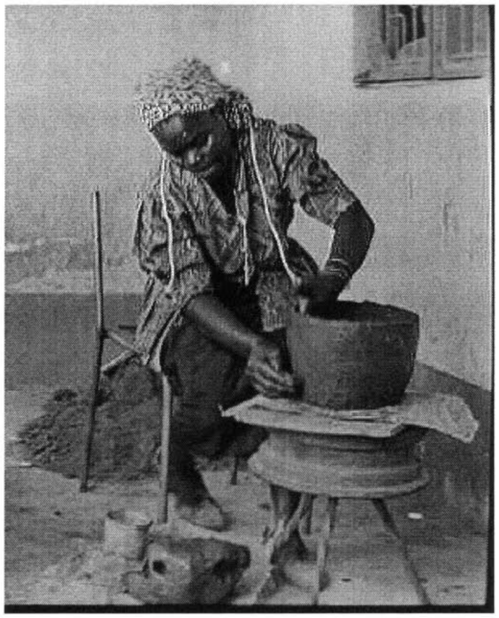


Figure 6-18. A potter using the 20 L modified clay pot reference rope at Amilo. (Source: Pihulic, 2005b)

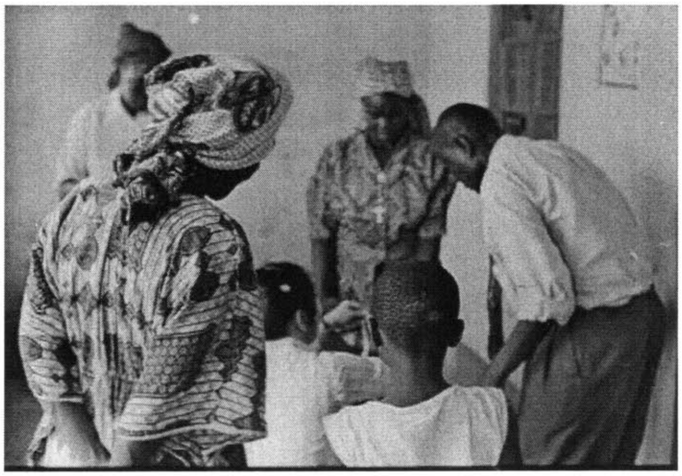


Figure 6-19. Teaching the potters how to use the reference rope tool. (Source: Pihulic, 2005b)

6.8 Summary of results

The potters learn to make 20 L and 40 L pots from knowledge passed down and from experience. They frequently use their own arm lengths or hand widths to know how wide or long to make certain pot dimensions. Line tests performed at Oriang showed that linear shrinkage of the clay is about 6% during the drying process. Modified clay pot dimensions measured over several days showed that freshly made pots at Oriang shrunk an average of 10% during the drying period.

20 L and 40 L modified clay pots were measured at all three field sites (Amilo, Oriang, and Asembo) to determine variability in pot dimensions. The average dimensional variability of the 20 L pots is 12%, while the average dimensional variability of the 40 L pots is 10%. When comparing pots made within each location, the average dimensional variability is 10%, suggesting that potters within locations generally shape pots in the same way. However, when comparing pots made between each location, the variability appears much greater, suggesting that potters between locations do not generally shape pots in the same way. Data also showed that potters are individually very consistent at making similarly sized clay pots. After measuring the volumes of 20 L modified clay pots at Amilo and calculating their volumes using a method to convert pot dimensions into volumes, it was found that the volume variability is within 10%. This is acceptable to dose the volume of water with the prescribed amount of chlorine (CDC, 2004). Further research is required to convert pot dimensions into volumes for a wider range of modified clay pots by location and size.

Molds, calipers, and measuring tapes are common techniques and tools used to standardize pottery. For this thesis, a reference rope tool was developed to help control the dimensions of the 20 L modified clay pot. Specifically, the rope was marked off to specify

Height to Middle Circumference, Middle Circumference, and Inner Mouth Diameter. The use of tools such as reference ropes can be encouraged as a tool for training new potters to make the modified clay pots; however, given the little variability in pot dimensions and volumes, reference ropes are not necessary for potters already experienced in making modified clay pots. If the reference ropes are used, it is important to account for shrinkage that will occur during the approximately two-week drying period.

Chapter 7

Tap design and attachment

The current tap design, the metal tap, represents a significant investment, costing about the same as all other materials required to manufacture the modified clay pot combined. When also factoring in the materials required to attach the tap, i.e. sand, regular cement, waterproof cement, and the black PVC pipe, the cost is even higher, accounting for approximately 60-65% of the total cost of the finished pot. Also, because the preparation and attachment of the metal tap to the modified clay pot wall is one of the most complex stages of production, requiring the assembly of several individual components, the time to attach the tap is lengthy. In addition, the techniques for attaching the tap also have not been perfected and often create leaks that reduce the effectiveness of the pots' ability to store water. Finally, the method of attaching the metal tap to the pot using cement is such that it is difficult to replace the tap if it breaks.

Because of these cost concerns and leakage problems, one goal of this thesis has been to design a replacement tap that will accomplish, as a minimum, two things: 1) reduce the cost of the modified clay pot; and, 2) eliminate or reduce the leakage from the tap attachment area. This chapter describes the current design and attachment process, characterizes the leakiness of this current design, and discusses alternative designs. Then it describes the recommended new design, the plastic tap, and finally summarizes the findings.

7.1 Current design and attachment

The current design used to dispense water from the modified clay pot is the metal tap. It consists of a threaded shaft on one end, an outlet through which water flows downward on the other end, and a handle that must be turned on a horizontal plane to control the flow of water. The taps used by the three different pottery groups cost between 100-200 KSH (US$1.30-US$2.70[3]). Both ½ and ¾ in. diameter taps are used, where the diameter refers to the diameter of the outlet of the tap through which the water flows downward. Locals prefer the ¾ in. diameter taps because the flow rate of water is increased. The outer diameter of the threaded shaft is typically ¾ in., onto which a PVC pipe with 7/8 in. inner diameter and 1 in. outer diameter is attached to extend its length before attaching it to the pot. Figure 7-1 shows an example of a metal tap.

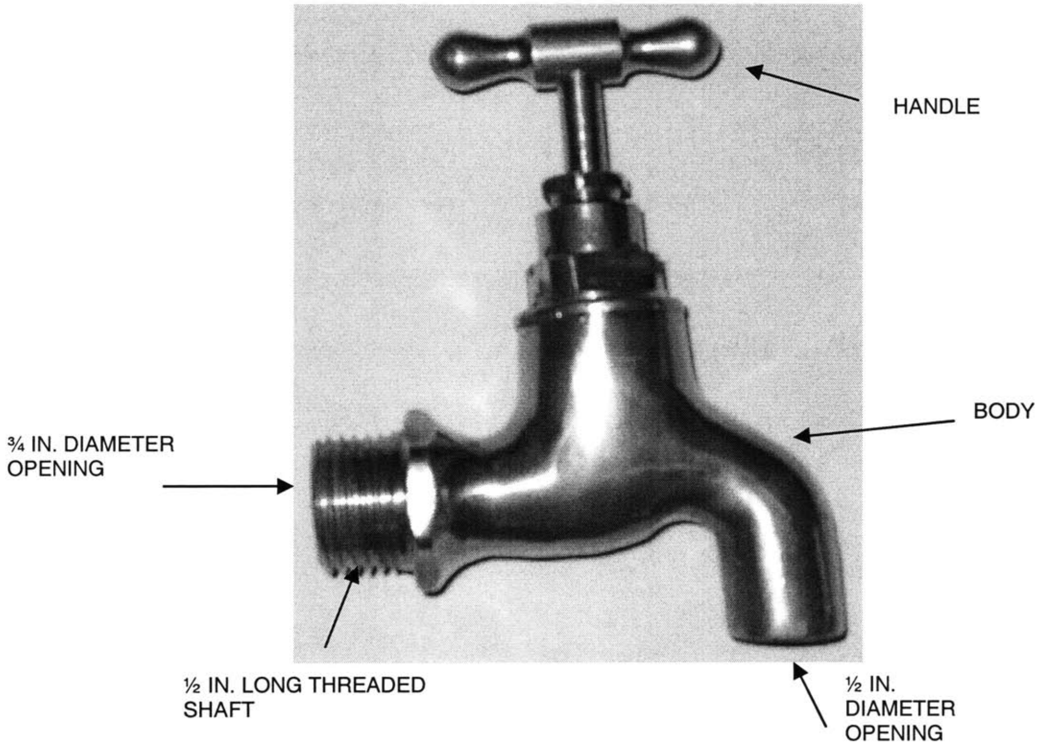


Figure 7-1. Example of a metal tap attached to modified clay pots and used to safely dispense water.

---

[3] Exchange rate is 75 KSH = US$1.00

Before the metal tap is attached to the modified clay pot, it must be prepared. This tap preparation process is described in detail in Pihulic, 2005a:

> A tap must first be modified lightly by extending the length of its body before it can be attached to the vessel. Currently all three groups use a variable length of PVC tubing with 7/8 in. inner diameter and 1 in. outer diameter. Extension of the tap length is required to accommodate the physical space needed to interact with and operate the tap and to secure a sufficiently strong join between the tap and the vessel. The tap is attached near the base of the vessel to maximize the amount of the water that is accessible. Curvature near the base of the vessel combined with the vessel's thickness, approximately 1 cm to 1.5 cm, require the tap's threaded end to be longer in order to install the tap level to the ground. Additionally, taps with levers for handles cannot function if they are installed too close to the vessel surface. Strength requirements are also an issue. Because the tap extends beyond the surface of the vessel it is prone to be jostled, bumped or even used as a grip. A minimal amount of extension beyond the vessel interior and exterior [is] required in order to properly cement the fixture in place. The size of the PVC [pipe] extension is variable, usually ranging from 6 cm to 10 cm...The pipe is then cut using a hacksaw blade (Figure 7-2)...Once the tubing has been cut to the proper length it must be fitted to the tap joint...The Oriang and Amilo groups use a crude form of press fitting to attach the tubing to the tap, [i.e.] a small fire is used to heat the end of the pipe (Figure 7-3). The pipe is then pressed over the threading of the tap joint. This process is repeated until the pipe fits snugly over the threads (Figure 7-4). On the final pass the Oriang potters coat the threads in a rubber cement compound to ensure a good seal is formed. In contrast, the Kinda E Teko group cuts a ½ cm vertical notch in the end of the pipe and press fits it to the tap joint (Figure 7-5). The notch relieves tension allowing the pipe to spread to accommodate the threading...Once the tube is attached, the tap is ready to be joined to the vessel.

Figure 7-2. Oriang potter cutting PVC pipe to proper length with a hacksaw blade. (Source: Pihulic, 2005a)

Figure 7-3. Oriang potter heating PVC pipe to thermally press fit it to the metal tap threads. (Source: Pihulic, 2005a)

Figure 7-4. The PVC pipe fits snugly over the metal tap threads after thermal press fitting. (Source: Pihulic, 2005a)

Figure 7-5. Close-up of split PVC pipe used by Kinda E Teko potters to fit tap to PVC pipe. (Source: Pihulic, 2005a)

The method of using cement to attach the prepared metal tap to the modified clay pot is similar among the three pottery groups. Because the Oriang group attaches the tap in the most time-efficient manner, their technique is described below (as found in Pihulic, 2005a):

> A single potter works on several vessels in parallel (Figure 7-6). To prevent cement from clogging the tap during fixing, the end of the PVC tube is stuffed with plastic or cardboard. The vessels are placed on a bench, and the [prepared] tap is inserted into the opening. The taps are then wedged into the openings, using [fired pottery] shards and vessels to prop up the tap. Because the opening is made near the base where the surface is tilted, wedging the tap in the opening only produces a minor tilt, allowing it to remain roughly parallel with the ground (Figure 7-7). Several vessels are secured in succession. A 1-to-1 mixture of cement and sand referred to as "*nill*", a local term for the substance, is mixed with some water and used to fix the tap in place. Attachment of the tap occurs in two stages over the course of two days. In stage 1 only the opening and a small region around it in the exterior and interior are covered in *nill*. This initial deposit of *nill* serves to stabilize the tap and fix it in place (Figure 7-8). Once it has been allowed to dry for a day, and has been checked for cracks, a covering layer of *nill* is applied to the base (Figure 7-9) and the lower surface of the vessel, extending up to the tap (Figure 7-10). The vessel is placed upside down. The additional covering layer serves two purposes. First it serves to strengthen the base and the tap attachment. Second it serves to cover up cracks that may have formed in the base or initial layer of *nill*. Overall the potter may spend two hours working on three pots over the course of two days.

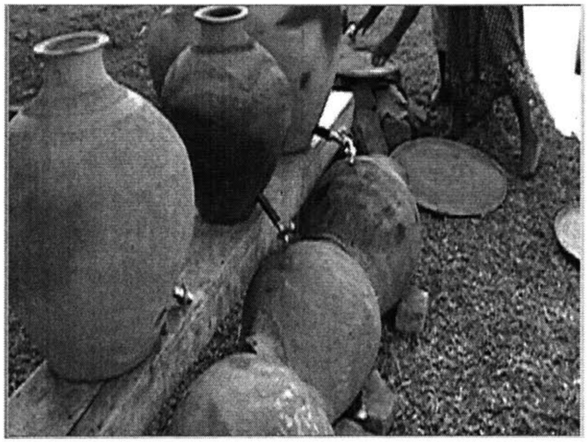


Figure 7-6. Tap attachment in parallel at Oriang.
(Source: Pihulic, 2005a)

Figure 7-7. Tap wedged in vessel using another clay vessel and shards for stabilization and support.
(Source: Pihulic, 2005a)

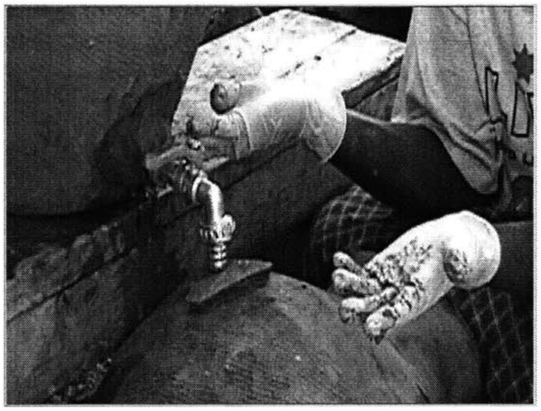


Figure 7-8. Tap is fixed in place using *nill* on inside of outside of vessel.
(Source: Pihulic 2005a)

Figure 7-9. *Nill* is applied to the base, forming an outer layer.
(Source: Pihulic, 2005a)

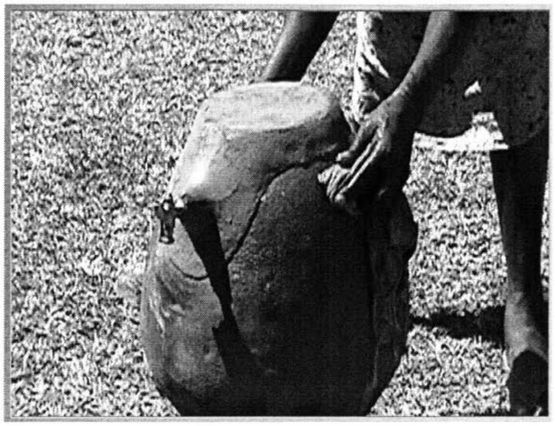


Figure 7-10. ***Nill*** **is extended up to the tap and around the base of the vessel.**
(Source: Pihulic, 2005a)

One difference to note with regards to the attachment of the tap at the Amilo CBO pottery group is that rocks and pottery shards are used to stabilize the tap in the opening and wedge it into place (Figure 7-11). Cement is then used to fill in the cracks. It is thought that this method contributes to the likelihood that the area around the tap will leak.

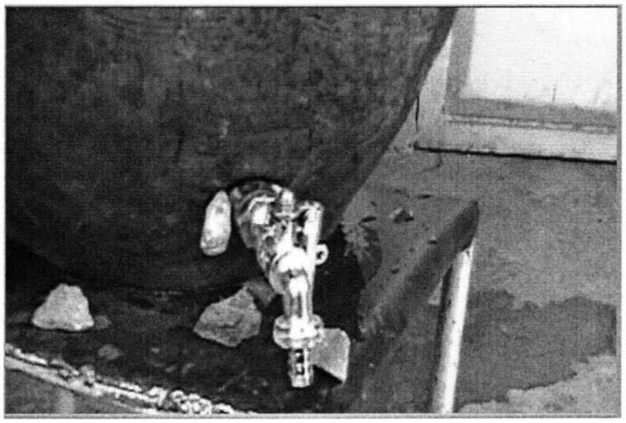


Figure 7-11. Using rocks and pottery shards to stabilize tap and wedge it into vessel at Amilo.
(Source: Pihulic, 2005a)

7.2 Leakiness from current tap

Leaking in the modified clay pot is caused by high porosity levels in the clay material, the formation of cracks in the pot wall, and poor attachment of the metal tap to the pot (Pihulic, 2005a). The porosity of the clay allows for the flow of water through the pot wall and its evaporation from the exterior surface, leading to an evaporative cooling effect (Schiffer, 1990). This evaporative cooling effect is one reason locals like the modified clay pots. Cracks in the pot wall caused by the stresses of drying, firing, or poor shaping can also contribute to leaking. Frequent opening and closing of the metal tap by turning its handle can generate stresses that many loosen the tap if it is not properly secured during the attachment process. These stresses may create cracks and cause leaking (Pihulic, 2005a). Based on interviews with the potters, an excessively leaky pot is defined by a more than one third (33%) volume loss of water over 24 hours. Similarly, an excessively leaky tap is one that contributes to a water volume loss of greater than one third (33%) over 24 hours.

In order to test leakiness from the modified clay pots, both from the pot as a whole and from the area around the metal taps, experiments were conducted at Oriang and Amilo. At Oriang, three 40 L modified clay pots were filled with exactly 40 L of water using a 1 L plastic measuring cup. The volume of water was then measured the following day, about 24 hours after the pots were first filled, by emptying out water from the tap one liter at a time. Because one of the pots had a substantial crack around the tap, water leaked out at the rate of about 150 ml per minute (9 liters per hour). At this rate the pot would be empty in less than 5 hours. When it became clear that the leaking would continue at this rate, the pot was emptied. This is an example of an excessively leaky tap. Table 7-1 shows the results of the leakiness experiment for the other two pots filled at Oriang. One pot lost 7% of its volume, while the other pot lost 17% of its volume. This loss of water was due to a combination of the pot's porosity and leakage around the tap. Thus, these two Oriang pots are not excessively leaky.

A second leakiness experiment was conducted at Amilo by filling four 20 L modified clay pots up to their respective Mouth Inflection Point. The results of this experiment are summarized in Table 7-2. The volume of water lost over 24 hours ranges from 6% to 32%. The average water loss for all the pots filled, including those from both Oriang and Amilo, is 15%. Thus, besides the one Oriang pot that leaked excessively from the tap area, none of the pots studied leaked excessively. Despite this finding, the potential for leaking from the metal tap area is high because of the way the metal tap is attached using cement and because of the stresses caused by frequent turning of the tap handle to dispense water.

Table 7-1. Leakiness experiment at Oriang.

Pot number	Volume water (Liters) Day 1	Day 2	Water loss
O1	40	37.3	7%
O2	40	33.2	17%

Table 7-2. Leakiness experiment at Amilo.

Pot number	Volume water (Liters) Day 1	Day 2	Water loss
A1	19	17.9	6%
A2	19.3	15.2	21%
A3	22	15.8	32%
A4	20	18.5	9%

7.3 Alternative designs

Several ideas were generated as an alternative to the current metal tap design. They are described below:

(a) Attach calabash (ladle) to the inside of the pot by hooking it under the lid (Figure 7-12a);

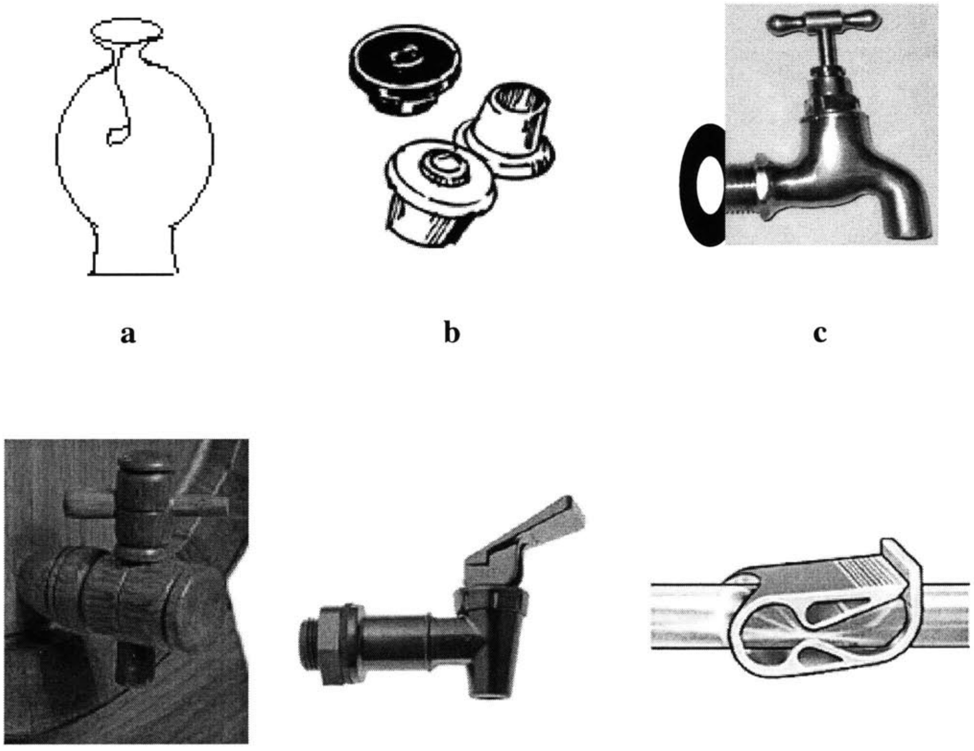
(b) Plug the hole with a rubber stopper, removing it to dispense water (Figure 7-12b);

(c) Place rubber washers on metal tap currently used instead of using cement (Figure 7-12c);

(d) Construct wooden tap similar to those found on European wooden beer casks (Figure 7-12d);

(e) Insert plastic tap with rubber washers, using jam nut to secure it to pot wall (Figure 7-12e);

(f) Insert a tube in the hole and regulate flow with a clamp (Figure 7-12f).



a b c

d e f

Figure 7-12. Alternative designs to current metal tap design: attached ladle (a); rubber stopper (b); rubber washers on metal tap (c); wooden tap (d); plastic tap (e); tube with clamp (f). (Source: American Science & Surplus, 2005 (b); African Trading Company, 2004 (d); Tomlinson Industries, 2001 (e); McMaster-Carr, 2005 (f))

A Pugh chart was used to compare each of these alternative designs to the current design. This tool helps to evaluate ideas by setting up a list of characteristics and judging each idea in terms of the design criteria. The current metal tap design was chosen as the datum, or the idea to which all others were compared. For each criterion, it was decided if the option being evaluated was the same (0), better (1), or worse (-1) than the datum. The results for each are totaled to determine which idea is the best. The criteria used to evaluate alternative tap designs were:

- Cost;
- Leakiness;
- Access to materials;
- Ease of use;
- Ease of construction or attachment;
- Social acceptability;
- Contamination likelihood; and
- Maintenance or fixability.

The Pugh chart is shown in Table 7-3. The plastic tap scored the highest, with a total of 4, while the rubber stopper scored the second highest, with a total of 2. The plastic tap was ultimately chosen to be tested in the field as an alternative to the metal tap.

Table 7-3. Pugh chart used to evaluate tap design alternatives.

Options	Evaluation criteria								TOTAL
	Cost	Leak-iness	Material access	Ease of use	Ease of construct	Social accept	Contam-ination	Maint. or fix	
Metal tap (datum)	0	0	0	0	0	0	0	0	0
Attached calabash	1	1	0	-1	0	0	-1	1	1
Rubber stopper	1	1	-1	0	1	0	-1	1	2
Rubber washers + metal tap	-1	1	-1	0	0	0	0	1	0
Wooden tap	1	0	0	0	-1	0	0	1	1
Plastic tap	1	1	-1	1	1	0	0	1	4
Tube with clamp	1	0	-1	-1	0	-1	-1	1	-2

7.4 Plastic tap

The plastic taps tested in the field were purchased from a water cooler store in the United States. The manufacturer of these plastic taps (HFSA series, Model #1000019) is Tomlinson® Industries, which is located in Cleveland, Ohio. The plastic taps are similar to the ones used in the Potters for Peace Filtrón System (Figure 7-13). Ron Rivera of Potters for Peace has experimented with an assortment of spigots in the field and has found that the spring-operated plastic spigot "shows [more] promise for overall acceptance and practical usability" than alternate designs (PFP 2001). Field experience in Nicaragua showed Rivera that target households consistently preferred manufactured taps over taps "hand fashioned from readily available materials such as bamboo, flexible hoses, and PVC tubing" because of their perceived inferior quality, no matter their actual durability (PFP 2001).

The Tomlinson® plastic taps tested in the field consist of a threaded shaft onto which two rubber washers and a jam nut are secured. The water is dispensed by pushing down a spring-loaded lever that opens the tap. The threaded shaft is 1 in. long, has a 9/16 in. inner diameter and an 11/16 in. outer diameter. However, the diameter including the threads is ¾ in. The outlet through which the water flows has a 3/8 in. inner diameter. The rubber washers have ¾ in. inner diameters and 1-1/4 in. outer diameters. They are flat on one side and slanted on the other side. Figure 7-14 shows a schematic drawing of the plastic tap.

The cost of each Tomlinson® Industries plastic tap is US$4.68 (350 KSH) when purchased from the manufacturer. If the plastic faucet, washers and jam nut are each bought separately in bulk, then the prices of each are US$1.35 (101 KSH), US$0.19 (14 KSH) and US$0.26 (20 KSH), respectively. Thus, the total cost of the plastic tap (including two washers) is US$1.99 (150 KSH). Incidentally, Lantagne (2005) has a special deal with Tomlinson® Industries in which the plastic taps only cost US$0.75 (56 KSH) each. She purchases these taps for the Jolivert Safe Water for Families Project in Haiti.

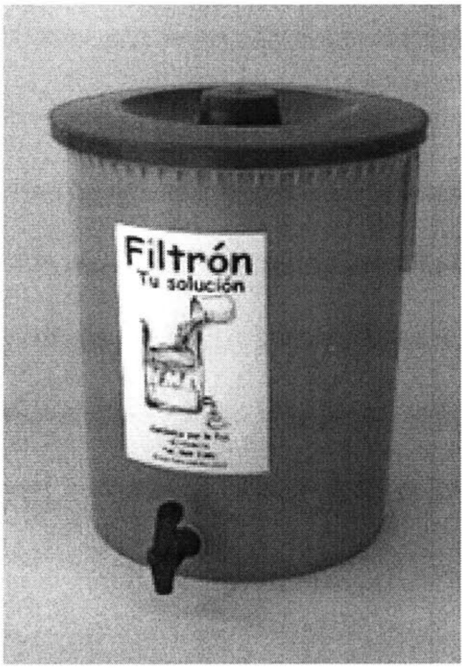


Figure 7-13. Potters for Peace Filtrón System, with a spring-operated plastic tap. (Source: PFP, 2001)

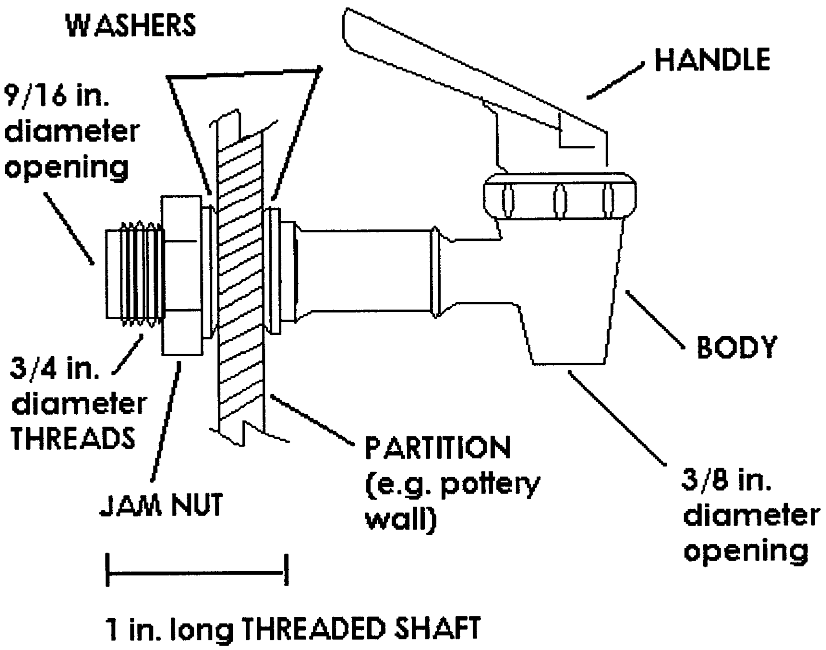


Figure 7-14. Schematic drawing of the spring-operated plastic tap.

No preparation is needed before attaching the plastic tap to the modified clay pot wall. However, the hole must be small enough so that the rubber washers fit snugly and create a water-tight seal with the pot wall. In addition, the pot wall cannot be too thick; otherwise, the jam nut cannot be screwed on and secured tightly. The pot wall is typically 1-1.5 cm (0.4-0.5 in.) thick, while the shaft length is 1 in. long. The following steps are required to attach the plastic tap: first, the jam nut and one of the washers is removed; then, the plastic tap is placed into the hole from the outside of the pot; and finally, the rubber washer and jam nut are replaced from the inside of the pot. There is one rubber washer on either side of the pot wall (Figure 7-14).

The first attempt to attach the plastic tap to a pot occurred at Oriang. All of the finished modified clay pots could not accommodate the plastic tap because the holes were too large. Potters typically make the holes larger than the diameter of the PVC pipe attached to the metal tap since the current attachment process involves using cement to fill in the extra space between the pipe and pot wall. Several pots with holes the right sizes were still drying and would be fired in a few days. Therefore, other options were considered for the first trial test. A small flower pot was found to have a hole nearly the right size for the tap to fit through, i.e. slightly bigger than the threaded diameter of the plastic tap. Since the hole was still a bit too large, an additional large rubber washer (1/8 in. thick, 2-1/4 in. outer diameter, inner diameter cut to fit the threaded diameter) was placed on the inside of the pot. Unfortunately, the rubber washer was unable to fit snugly to the pot wall because there was a slight lip (raised edge) around the hole on the inside of the pot. When filled with water, the area around the tap leaked a lot. When the large rubber washer was moved to the outside of the pot (Figure 7-15), which had a flat surface around the hole and no lip, there was no leakage because the seal was good. Figure 7-16 shows a close-up of the jam nut used to secure the tap on the inside of the small flower pot at Oriang.

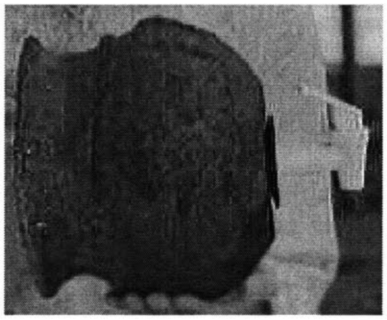


Figure 7-15. The plastic tap attached to a small flower pot at Oriang. An additional large rubber washer was placed on the outside of the pot to create a better seal, since the hole was slightly too large for the plastic tap. (Source: Pihulic, 2005b)

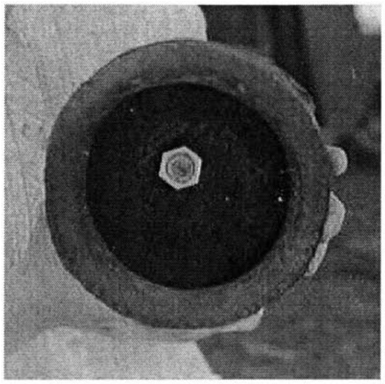


Figure 7-16. Close-up of the jam nut used to secure the plastic tap on the inside of the small flower pot at Oriang.
(Source: Pihulic, 2005b)

The second attempt to attach the plastic tap occurred at Amilo. A few 20 L modified clay pots with holes that were only slightly bigger than the plastic tap's threaded diameter were chosen to test the plastic tap. The additional large rubber washer was again used to since the holes were still too large. Overall, the roundedness of the pots did not allow for good seals. However, on the third pot tried, there was no leakage.

The third and final attempt to attach the plastic tap occurred at Oriang and involved using the recently fired 20 L modified clay pots with holes that were made with the plastic tap itself, to ensure the correct size. It is important to note that each of these modified clay pots had a unique improvement, i.e. a flat area around the holes to create a better fit with the tap. Though shrinkage was considered, the holes shrank more than hypothesized. The edge of a pair of heavy duty scissors was used to widen the holes by scraping away some of the fired clay around the hole. The plastic tap was then attached to one of these 20 L modified clay pots, filled with water, and observed for leakage (Figure 7-17). There was no leakage evident.

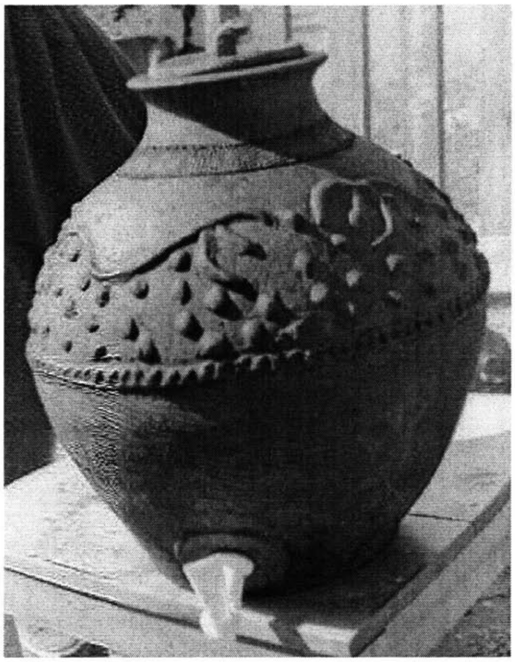


Figure 7-17. A 20 L modified clay pot at Oriang with the plastic tap attached. No leakage was observed from the tap area.
(Source: Pihulic, 2005b)

One advantage of the plastic tap over the metal tap is that the spring-operated tap automatically shuts the tap after each use, thereby making it more user friendly, especially for children. In addition, the spring-loaded handle on the plastic tap creates less stress on the pot than the metal tap, which has a metal lever that must be turned 90° counter-clockwise on a horizontal plane by using a good amount of force and sometimes requiring a free hand to steady the pot. Since the rubber washers and jam nut are sold together with the plastic tap, no additional materials, e.g. cement or PVC pipe, are required for attachment. Another huge advantage is that the plastic taps can be removed and replaced safely without destroying the pots. Since the threaded shaft of the metal tap is only ½ in. long, compared to the 1 in. long threaded shaft of the plastic tap, washers and a metal jam nut cannot feasibly be added to the metal tap. Finally, the cost of the plastic tap is US$0.75 (56 KSH), which is less than the cost for a metal tap (100-200 KSH). This price, however, is a lower bound estimate.

It is unknown whether the spring-operated plastic tap is available in local Kenyan markets. An initial search located one on a water purifying unit sold in the capital city of Nairobi; however, none were found to be sold separately. CARE/Kenya suggested that perhaps Kentainers, a local plastic manufacturer well-known for making large plastic water storage containers, could be contacted to determine their interest and the feasibility in producing plastic taps. Lantagne (2005) has visited all the plastic manufacturers in Kenya and discovered none are currently capable of making the plastic taps. However, Lantagne (2005) learned similar spring-operated plastic taps (Indian-manufactured) are imported from India to Nigeria, where they retail for approximately US$1.00 (75 KSH). Since Kenya has as good, if not better, contacts with India than Nigeria, and all the plastic manufacturers in Kenya are Indian owned and operated (and it costs less to transport taps from India to Kenya than from India to Nigeria), perhaps the best estimate on a price for spring-operated plastic taps in Kenya is equal to or less than US$1.00 (75 KSH). On a related note, Murcott (2005) learned that spring-operated plastic taps are being imported from China to Ghana by a ceramic water filter manufacturer, on the advice of Ron Rivera of Potters for Peace. These plastic taps, which are Chinese-manufactured and imported to Ghana, sell for US$2.25 (169 KSH) each in Ghana. This compares with the metal taps in Ghana, which were US$4.00 (300 KSH) in the remote market in the north (3/4 in. size), and were US$2.00 (150 KSH) in the capital, bought in bulk (½ in. size). It may be possible, then, for Kenya to import plastic taps from India or China and that the costs would be similar to those in Nigeria and Ghana, respectively.

The following improvements could be made in the design of the spring-operated plastic tap:

(1) a longer threaded shaft to better account for the thickness and roundedness of the pot;

(2) a larger jam nut to distribute force over a greater area of the pot wall and be easier to grasp; and,

(3) the diameter of the outlet through which water flows can be made larger so that flow rates are increased.

One improvement that can be made in the manufacture of the modified clay pot is to mold a flat area around the tap hole to create a better fit with the tap.

7.5 Summary of results

The current metal tap design requires substantial preparation before attachment, and the tap attachment process itself is lengthy and tedious. There is high interest to replace the metal tap with a cheaper design that can be removed and replaced if necessary.

Leakiness experiments conducted at Oriang and Amilo showed that pots on average lost about 15% of their volume of water over 24 hours. This loss of water is due to a combination of factors, including water escaping through the pores (the evaporative cooling effect of the clay), leakage from cracks in the pot, and leakage from the tap area. According to potters, excessively leaking pots are characterized by a greater than one third volume loss over 24 hours. The potential for leaking from the tap area is high because of the way the metal tap is attached using cement and because of the stresses caused by frequent turning of the tap handle to dispense water.

A Pugh chart was used to evaluate several alternative designs to the metal tap. Based on cost, leakiness, material access, ease of use, ease of construction, social acceptability, contamination, and maintenance or fixability, the plastic tap was found to be the most promising design to replace the metal tap. However, the plastic tap itself may need some modifications, including a longer threaded shaft, a larger jam nut, and a larger outlet for which water to flow through.

The plastic tap is spring-operated and similar to the ones found on the Potters for Peace Filtrón System. The attachment process is simple and does not require any preparation. A plastic tap attached to a 20 L modified clay pot at Oriang did not leak, showing must promise. The plastic tap has several advantages over the metal tap, including its lower cost, elimination of leakage, ease of use, ease of attachment, and its capacity to be removed and replaced without ruining the entire pot. Thus, it satisfies the two minimum requirements outlined in the beginning of this chapter. Further research is required to determine its local availability in Kenyan markets and the possibility of importing it from elsewhere.

Chapter 8

Cost Recovery Analysis

Because one of the goals of the program in Kenya is to reach those most in need, and the more affordable the pot the more people can be reached, cost recovery of all the materials, labor and transportation used to manufacture the modified clay pot is a key component. The Bovin and Morohashi (2002) *Best Practices* study reports that the metal tap used to dispense water in the modified clay pot is very expensive, costing nearly the same amount as all of the other materials combined. There are some variations in the material inputs necessary to manufacture the modified clay pots at each field site. For example, potters at Kinda E Teko do not mix sand into the clay because the clay is of a better quality than that found at Amilo and Oriang; therefore, sand does not factor into the cost breakdown of the modified clay pots made at Kinda E Teko in Asembo. Below is a list of all of the material inputs and their purposes:

- Clay: Molded to form pots;
- Sand: Mixed in with the clay before molding pots, and also mixed with regular and waterproof cements and used to cover bottom of pot and attach tap;
- Pala: Decorative clay used on the outside of pots;
- Red oxide: Decorative red coloring used on the outside of pots;
- Dried grass: Used to cover pots and to start the fire during the firing process;
- Small wood: Used to cover pots and to fuel the fire during the firing process;
- Metal tap: Used to safely dispense water from modified clay pots;
- Black PVC pipe: Attached to the metal tap to make it longer and thus more easily fitted into the hole cut out specifically for the metal tap in the modified clay pot;

- Regular cement: Mixed with waterproof cement and sand and used to cover bottom of pots and to attach tap;
- Waterproof cement: Mixed with regular cement and sand and used to cover bottom of pots and to attach tap.

It is important to distinguish material costs from other costs, including labor costs (payment to the potters), transportation costs (costs of transporting pots to and from the market), and sale prices of the pots. In this thesis, material cost is taken to be the cost of each material item, including any labor and transportation costs required to obtain the item. It is assumed that the breakdown of costs at all three locations does not apply specifically to either 20 liter- or 40 liter-sized modified clay pots, but to an overall average of all the modified clay pots produced at that location.

8.1 Cost breakdown of Amilo modified clay pot

Data for the breakdown of material costs used to manufacture the modified clay pots produced at Amilo CBO in Rangwe were obtained by interviewing people at the Amilo CBO site (Figure 8-1) and are summarized in Table 8-1 and Figure 8-2. The situation quickly became somewhat chaotic because everyone wanted to contribute to calculating costs of each material input, i.e. ten people would discuss the bulk price of each component and give a rough estimate of the unit cost based on the number of pots each bulk quantity of materials could yield. According to their numbers, grass and small wood make up nearly three-quarters of the total material cost of the modified clay pot, which seems a large overestimation, considering these material inputs are used just to fire the pots. The total cost of one modified clay pot, based on this estimate, equals 1018 KSH (US$13.60), which is more than twice the sale price of a 40 L modified clay pot, which is 500 KSH (US$6.70). The sale price of a 20 L modified clay pot is only 380 KSH (US$5.10). Costs for transporting the pots to and from the market are unknown. According to Amilo CBO members, payment to potters is 150 KSH (US$2.00) for making a 40 L modified clay pot and 100 KSH (US$1.30) for making a 20 L modified clay pot. These data are questionable since the numbers clearly do not add up.

Figure 8-1. Interviewing Amilo CBO members for cost breakdown of a modified clay pot at Amilo. (Source: Pihulic, 2005b)

Table 8-1. Material cost breakdown of Amilo modified clay pot (reported by Amilo CBO).

Item	Cost per item (KSH)	Number of pots made per item	Cost per pot (KSH)	Notes
Clay	2000	50	40	Cost is for area of land that contains clay
Sand	3500	50	70	Includes driver fee and vehicle rental
Pala	2000	500	4	
Red oxide	250	20	13	
Grass	25800	50	516	86 bundles of grass
Small wood	10500	50	210	Includes labor and transportation
Metal tap	150	1	150	Larger tap costs 180 KSH
Black PVC pipe	200	61	3	Cost for 20 feet; 10 cm used per pot
Waterproof cement	250	20	13	
Total Material Cost			1018	

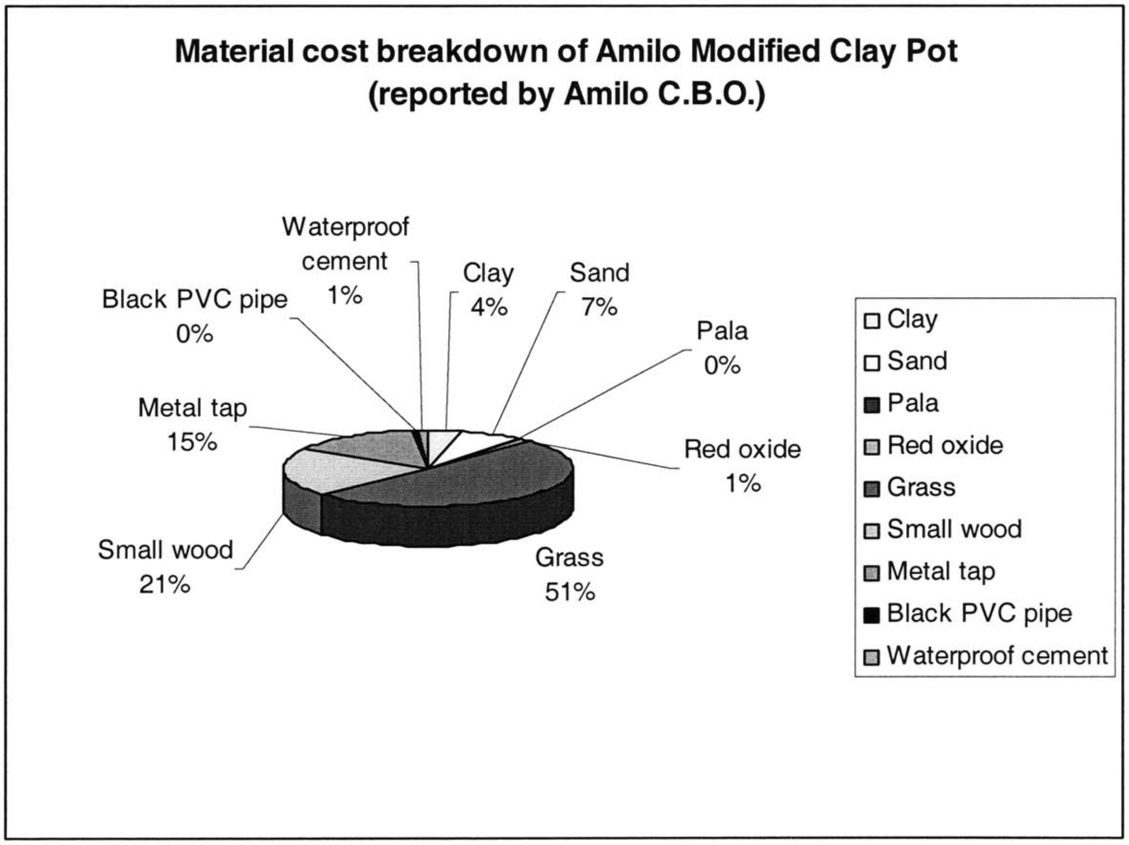


Figure 8-2. Pie chart showing material cost breakdown of Amilo modified clay pot, as reported by Amilo CBO members.

In order to double check these cost data, CARE/Kenya staff member Alex Mwaki was contacted to provide a more accurate breakdown of costs (Mwaki, 2005). These data, summarized in Table 8-2 and Figure 8-3, seem more reasonable, as they show that the metal tap comprises about half the total material cost of the modified clay pot, which is consistent with the researcher's understanding from the Bovin and Morohashi (2002) report. According to Mwaki's (2005) numbers, the total material cost of the Amilo modified clay pot is now approximately 370 KSH (US$4.90), which is almost identical with the sale price for the 20 L modified clay pot, which is 380 KSH (US$5.10). However, when adding in the labor cost for a 20 L modified clay pot, which is 100 KSH (US$1.30), the cost of the Amilo modified clay pot is 470 KSH (US$6.30). Thus, based just on Mwaki's (2005) material costs plus labor costs for a 20 L modified clay pot, cost recovery is not achieved. Similarly, when adding the labor cost for a 40 L modified clay pot, 150 KSH (US$2.00), to the material costs, the cost of the Amilo modified clay pot is 520 KSH (US$6.90). The sale price of the 40 L modified clay pot is 500 KSH (US$6.70). Thus, cost recovery is again not achieved. Table 8-3 summarizes the material costs, labor costs, transportation costs and sale prices for 20 L and 40 L modified clay pots at Amilo. Transportation costs are not included because they are unknown. It is also unknown whether or not CARE/Kenya subsidizes any of the material, labor or transportation costs. Furthermore, it is unknown who coordinates payment to the potters, and it may be possible that the women potters are subsidizing some of the costs of the modified clay pots through unpaid labor. Further research is required to identify unknown transportation costs and subsidies to determine whether cost recovery is indeed not achieved.

Table 8-2. Material cost breakdown of Amilo modified clay pot (reported by Mwaki, 2005).

Item	Cost per item (KSH)	Number of pots made per item	Cost per pot (KSH)	Notes
Clay	20	1	20	Estimate
Sand	800	181	4	Sold in tons, 5 kg/pot, 1 ton = 907 kg
Pala	10	1	10	
Red oxide	120	15	8	
Grass	90	1	90	
Small wood	20	1	20	
Metal tap	200	1	200	3/4 in. size
Black PVC pipe	120	60	2	
Regular cement	630	50	13	
Waterproof cement	120	50	2	
Total Material Cost			369	

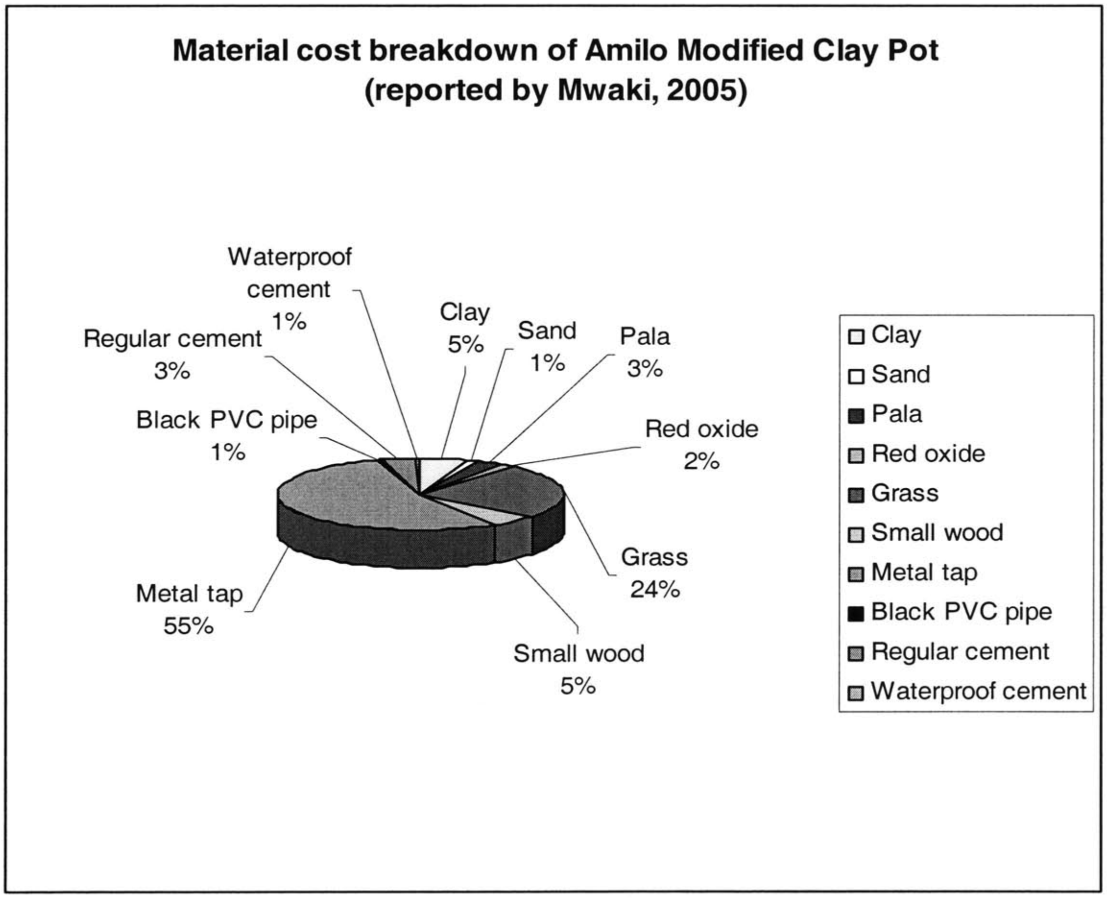


Figure 8-3. Pie chart showing material cost breakdown of Amilo modified clay pot, as reported by Mwaki, 2005.

Table 8-3. Summary of material costs, labor costs, transportation costs and sale prices for 20 L and 40 L modified clay pots at Amilo.

	Amilo modified clay pots	
	20 L	40 L
Material cost	370	370
Labor cost	100	150
Transportation cost	?	?
Total cost	470	520
Sale price	380	500

8.2 Cost breakdown of Oriang modified clay pot

Data for the breakdown of material costs used to manufacture modified clay pots produced at the Oriang Women's Pottery Group in Oriang were obtained by interviewing members of the Oriang Women's Pottery Group and CARE/Kenya staff and are summarized in Table 8-4. However, this material cost breakdown is incomplete since Oriang members and CARE/Kenya staff could not recall the prices of all of the material items. When the potters at Oriang first started making modified clay pots in 2000 (see section 1.5 in Chapter 1), CARE/Kenya provided metal taps, black PVC pipe, waterproof cement and regular cement without charge since these items were the additional ones necessary to modify the clay pots to have taps. While the Oriang Women's Pottery Group now say it is financially independent, it is unclear who is responsible for buying certain components used to make the modified clay pots. However, if one uses the itemized costs of materials provided by Mwaki (2005) for Amilo (Table 8-2) for those items for which material costs were not available for Oriang (a fair assumption given the groups operate in the same general locale and purchase materials locally), the total material costs of the unknown materials would equal roughly 60 KSH (US$0.80). This brings the total material cost of the Oriang modified clay pot to about 270 KSH (US$3.60). This assumption gives a material cost that falls in the range of the sale price for the 20 L modified clay pot, which is between 250-280 KSH (US$3.30-$3.70), and for the 40 L modified clay pot, which is 350 KSH (US$4.70). However, the labor costs and transportation costs are unknown, so it is unclear whether cost recovery is actually achieved. Furthermore, the sale prices for 20 L and 40 L modified clay pots at Oriang differ enormously from those at Amilo. The Oriang potters reported that they originally sold the 40 L modified clay pot for 500 KSH (US$6.70) but that CARE/Kenya told them to reduce the price because it was too high. Further research is required to determine whether or not CARE/Kenya subsidizes some of the material, labor, and transportation costs at Oriang, causing the Oriang potters to not be commercially independent but still very much viable as a social enterprise. Figure 8-4 shows a graphical breakdown of material costs of the Oriang modified clay pot, assuming that the unknown material costs equal 60 KSH (US$0.80). Table 8-5 summarizes what is known of the material costs, labor costs, transportation costs and sale prices of 20 L and 40 L modified clay pots at Oriang.

Table 8-4. Material cost breakdown of Oriang modified clay pot (reported by Oriang potters and CARE/Kenya staff).

Item	Cost per item (KSH)	Number of pots made per item	Cost per pot (KSH)	Notes
Clay				
Sand				
Pala				
Red oxide				
Grass	200	10	20	
Small wood	400	10	40	
Metal tap	150	1	150	Taps range from 150-200 KSH
Black PVC pipe				
Regular cement				
Waterproof cement				
Total Material Cost			210+	

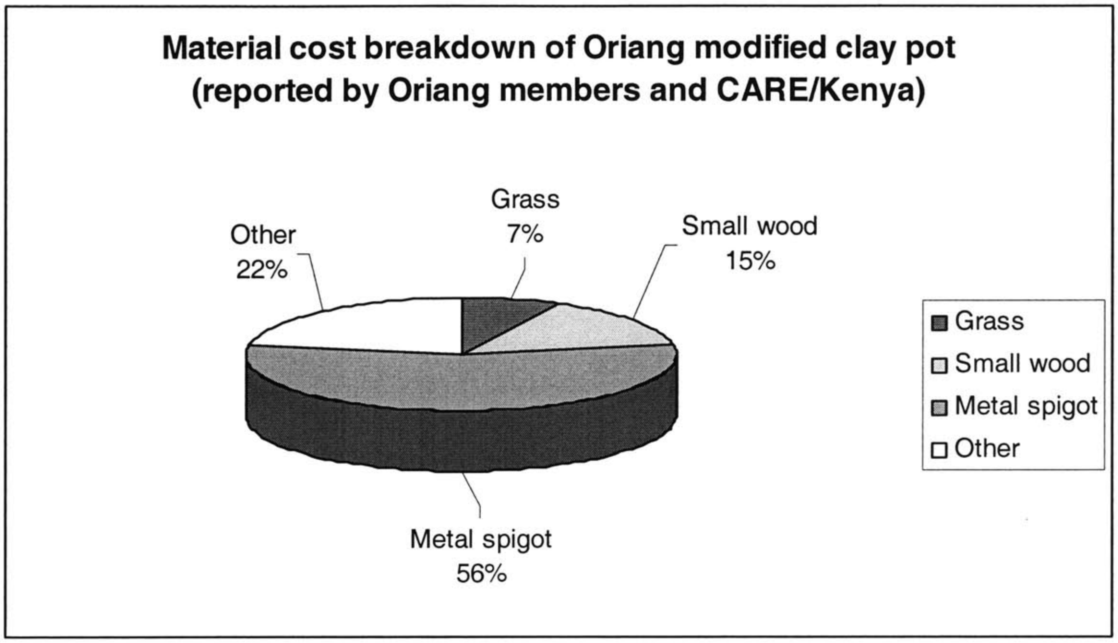


Figure 8-4. Pie chart showing material cost breakdown of an Oriang modified clay pot, as reported by the Oriang potters and CARE/Kenya staff. Note that an assumption for the unknown costs of some materials ("other") was made based on data from Table 8-2.

Table 8-5. Summary of material costs, labor costs, transportation costs and sale prices for 20 L and 40 L modified clay pots at Oriang.

	Oriang modified clay pots	
	20 L	40 L
Material cost	270	270
Labor cost	?	?
Transportation cost	?	?
Total cost	270	270
Sale price	250-280	350

8.3 Cost breakdown of Kinda E Teko (Asembo) modified clay pot

Data for the cost breakdown of materials used to manufacture modified clay pots produced at Kinda E Teko Pottery Group in Asembo were obtained by Gibney (2005) by interviewing people at the Kinda E Teko site and are summarized in Table 8-6 and Figure 8-5. The total cost of the Kinda E Teko modified clay pot is 202 KSH (US$2.70), and the sale price is 370 KSH (US$4.90). It appears that cost recovery is achieved; however, labor and transportation costs are unknown. Table 8-7 summarizes what is known of material costs, labor costs, transportation costs and sale prices of modified clay pots at Kinda E Teko.

Table 8-6. Material cost breakdown of Kinda E Teko modified clay pot (reported by Kinda E Teko potters to Gibney, 2005).

Item	Cost per item (KSH)	Number of pots made per item	Cost per pot (KSH)	Notes
Clay transport	100	4	25	Clay is free, cost is for donkey transport
Red oxide	80	80	1	Negligible amount used per pot
Small wood	450	10	45	
Metal tap	100	1	100	
Black PVC pipe	300	20	15	
Regular cement	600	50	12	
Waterproof cement	120	30	4	
Total Material Cost			202	

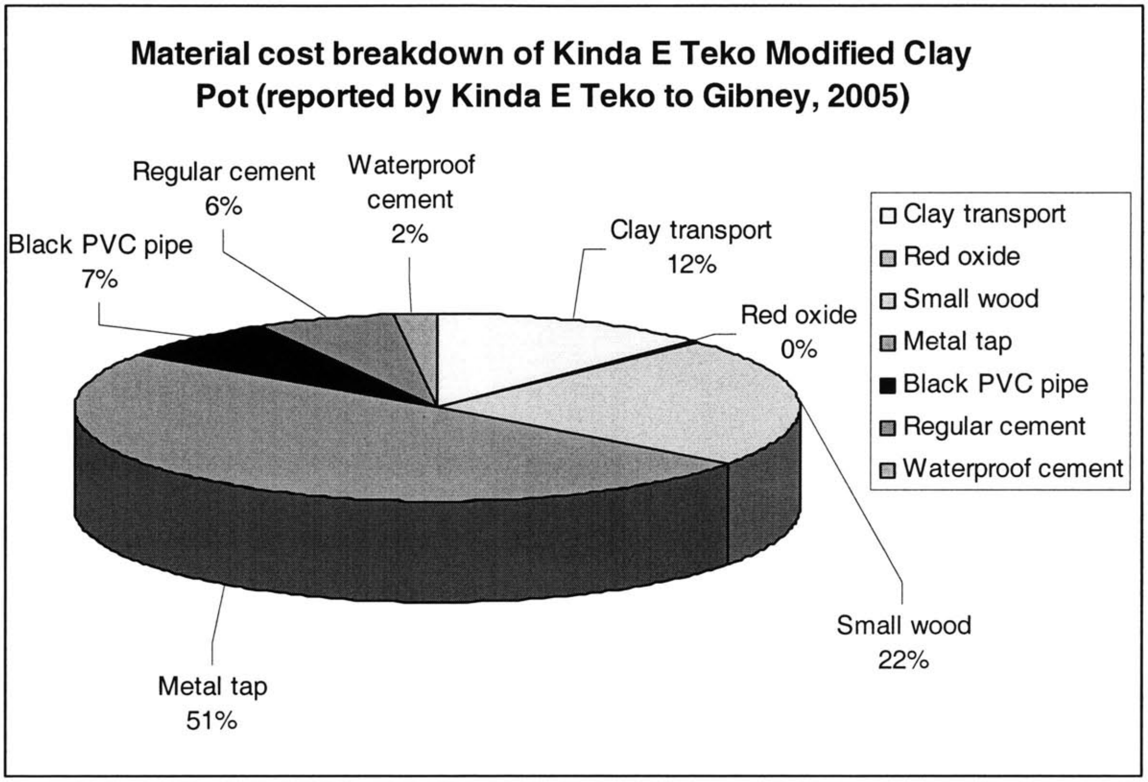


Figure 8-5. Pie chart showing material cost breakdown of a Kinda E Teko modified clay pot, as reported by the Kinda E Teko potters to Gibney (2005).

Table 8-7. Summary of material costs, labor costs, transportation costs and sale prices for modified clay pots at Kinda E Teko.

	Kinda E Teko modified clay pots
Material cost	202
Labor cost	?
Transportation cost	?
Total cost	202
Sale price	370

8.4 Limitations of analysis

There are several limitations to this cost recovery analysis, mainly due to a lack of complete financial information:

(1) In order for the cost recovery analysis to be complete, data on material costs, labor costs and transportation costs is necessary. Labor costs are only available for Amilo, and transportation costs are unknown for all three pottery sites.

(2) It is unknown whether or not CARE/Kenya subsidizes any of the material, labor and transportation costs at Amilo and Oriang and whether or not SWAK subsidizes any of the material, labor and transportation costs at Kinda E Teko. It is also unknown whether the women potters subsidize any of these costs through unpaid labor.

(3) It is unclear how each of the pottery groups sets the sale prices of its modified clay pots, i.e. whether or not sale prices are set at or near cost (including materials, labor and transportation) of the modified pots and whether or not there are mark-ups in sale prices to include a profit margin, and if so, who is collecting that profit.

(4) It is unknown how loss of pots due to breakage during transportation, cracking or other means factors into the cost recovery analysis.

(5) Due to the lack of complete data necessary to determine cost recovery, the financial viability and hence sustainability of the pottery groups' enterprises cannot be clearly ascertained.

8.5 Summary of results

It is unknown whether cost recovery is achieved at all three pottery locations, due to incomplete or unknown data on material, labor and transportation costs, subsidies, setting of sale prices and profit margins, and losses due to pot breakage, pot leakage, or other means. The understanding that the metal tap comprises about half of the total material cost of the modified clay pot is confirmed at all three locations (Table 8-8).

Table 8-8. Summary of the cost of the metal tap, total material cost of modified clay pot and the metal tap's percentage of the total material costs at Amilo, Oriang, and Kinda E Teko.

	(All prices in KSH)		
	Amilo	Oriang	Kinda E Teko
Cost of metal tap	200	150	100
Total material costs of modified clay pot	370	270	202
Metal tap cost % of total material costs	54%	56%	50%

Chapter 9

Conclusions

9.1 Standardization

Contrary to perceptions that the modified clay pot sizes and shapes are non-standard, this thesis shows that variability in both 20 L and 40 L pot dimensions and volumes is within an acceptable range, and that potters are both individually and collectively consistent in making similarly sized and shaped clay pots. One concern of the rounded shape of the pots is that it is difficult to transport. While no attempt was made to address this issue, findings from focus groups conducted at Amilo and Oriang showed that potters seem to want to retain the rounded shape of the pots. While it is possible that a cylindrical-shaped pot is more easily transported, further research is required to determine its feasibility and acceptability.

For this thesis, a reference rope tool was developed to help control the dimensions of the 20 L modified clay pot. The use of tools such as reference ropes can be encouraged as a tool for training new potters to make the modified clay pots. However, given the little variability in pot dimensions and volumes, reference ropes are not necessary for potters already experienced in making modified clay pots. The data suggests that the current method of passing down knowledge and learning by experience is sufficient. If the reference ropes are used, it is important to account for shrinkage that will occur during the approximately two-week drying period. More research is necessary to better quantify this shrinkage.

9.2 Tap design and attachment

The current metal tap design requires substantial preparation before attachment, and the tap attachment process itself is lengthy and tedious. The current design is also prone to leakage, is expensive, and cannot be removed and replaced if it becomes defective. The spring-operated plastic tap was found to be the most promising design to replace the metal tap for several reasons:

1) no preparation required before attachment;

2) simple attachment process;

3) lower cost;

4) the spring-operated tap automatically shuts the tap after each use, thereby making it more user friendly, especially for children;

5) no leakage;

6) can be removed and replaced without ruining the entire pot; and,

7) the spring-operated handle creates less stress on the pot.

Further research is required to determine if it works in households and whether or not it is locally available in Kenyan markets. If the plastic taps cannot be found locally, CARE/Kenya suggested that perhaps Kentainers, a local plastic manufacturer, could be contacted to determine their interest and the feasibility in producing plastic taps. Perhaps a more promising and immediate option is to determine how to import spring-operated plastic taps from India or China, similar to what is being done in Nigeria and Ghana, respectively.

Several improvements could be made in the design of the spring-operated plastic tap. First, a longer threaded shaft could better account for the thickness and roundedness of the pot. Second, a larger jam nut would distribute force over a greater area of the pot wall and be easier to grasp. Third, the diameter of the outlet through which water flows downward can be made larger so that flow rates are increased. One improvement that can be made in the manufacture of the modified clay pot is to mold a flat spot around the tap hole to create a better fit with the tap.

9.3 Cost recovery

Due to incomplete or unknown data on material, labor and transportation costs, subsidies, setting of sale prices and profit margins, and losses due to pot breakage, pot leakage, or other means, it is unknown whether cost recovery is achieved at all three pottery locations. Sufficient data was available to determine a complete breakdown of material costs at both Amilo and Kinda E Teko, but not at Oriang. The understanding that the metal tap comprises about half of the total material costs of the modified clay pot is confirmed at all three locations.

9.4 Overall conclusions

This thesis documented, analyzed, and suggested improvements for the design of the modified clay pots, specifically with regards to the standardization of the size and shape of the pots and the tap design and attachment. Further research is required to determine whether or not cost recovery of the modified clay pot is achieved at all three pottery sites visited in Kenya. It is hoped that this information will be useful to potters, NGOs, and others committed to making water safe through disinfection and safe storage at the point of use.

References

African Trading Company (2004). *Close-up of the wooden spigot.* http://www.sciplus.com/category.cfm?category=50 Accessed 25-6-2005.

American Science & Surplus (2005). *Lab supplies and equipment—corks, stoppers and lids.* http://www.sciplus.com/category.cfm?category=50 Accessed 25-6-2005.

BigCeramicStore.com (2005). *Kemper calipers.* http://www.bigceramicstore.com/Supplies/Kempertools/kemper_calipers.htm Accessed 6-6-2005.

Bovin K (Nuffic) and Morohashi J (UNESCO) (2002). Editors. *Best practices using indigenous knowledge - Africa.* "The use of locally produced clay pots modified for safe storage of drinking water in the home—a component of CARE Kenya's Nyanza Health Water Project." A joint publication of Nuffic, The Hague, The Netherlands, and UNESCO/MOST, Paris, France.

CARE Kenya (2003). *A manual on the Safe Water System based on CARE Kenya's experience in rural western Kenya. First Edition.* Nairobi, Kenya.

CDC (2004). *Chlorine dosing report: Maputo, Mozambique.* Centers for Disease Control and Prevention, Atlanta, GA. 13 pp. Available from: http://home.earthlink.net/~danielelantagne/Mozambique%20Stuff/Deliverables/Dosing%20Report.pdf Accessed 26-4-2005.

CDC (2005). *Safe Water Systems for the developing world: A handbook for implementing household-based water treatment and safe storage projects.* http://www.cdc.gov/safewater/ Accessed 25-5-2005.

Central Bureau of Statistics (2003). *Kenya's Central Bureau of Statistics: Ministry of planning and national development.* http://www.cbs.go.ke/ Accessed 28-6-2005.

Dictionary.com (2005). *Entries for "mold".* http://dictionary.reference.com/search?q=mold Accessed 6-6-2005.

Dies R (2003). *Development of a ceramic water filter for Nepal.* Available from: http://ceemeng.mit.edu/Water/public_html/Docs/Student%20Theses/Nepal/Dies2003.pdf Accessed 21-10-2004. Master of Engineering in Civil and Environmental Engineering Thesis, Massachusetts Institute of Technology, Cambridge, MA.

Eleveld A (2004). "Safe Water Systems as a home care intervention for people living with HIV/AIDS." Presented at the 2004 International Symposium "Household Technologies for Safe Water," hosted by the Kenya Ministry of Health, Nursing Council of Kenya, Emory University, Population Services International (PSI), the Centers for Disease Control and Prevention (CDC) and CARE/Kenya in Nairobi, Kenya on June 16-17, 2004.

FAO (2005). *Map of Kenya showing administrative boundaries.* Available from: http://www.fao.org/ag/agl/swlwpnr/reports/y_sf/z_ke/ke_map/kemp112.pdf Accessed 22-6-05.

Gibney J (2005). *Notes from field work in Kenya, January 2005.* Graduate student, Massachusetts Institute of Technology, Cambridge, MA. Email: jgibney@mit.edu

Gordon B, Mackay R, and Rehfuess E (2004). *Inheriting the world: The atlas of children's health and the environment.* World Health Organization (WHO). Available from: http://www.who.int/ceh/publications/en/atlas.pdf Accessed 25-5-2004.

Hwang R (2003). *2003 Six-month field monitoring of point-of-use ceramic water filter by using H2S paper strip most probable number method in San Francisco Libre, Nicaragua.* Available from: http://ceemeng.mit.edu/Water/public_html/Docs/Student%20Theses/Nicaragua/Hwang2003.pdf Accessed 21-10-2004. Master of Engineering in Civil and Environmental Engineering Thesis, Massachusetts Institute of Technology, Cambridge, MA.

Kaplan J (2003). *PPP: Testing for success.* Available from: http://www.ceramicindustry.com/CDA/ArticleInformation/features/BNP__Features__Item/0,2710,104732,00.html Accessed 24-6-2005.

Kenya Web (2001). *Nyanza Province map.* http://www.kenyaweb.com/regions/nyanza/nyanza.html Accessed 25-5-2005.

Krueger R (1994). *Focus groups: A practical guide for applied research. Second Edition.* Sage Publications, Inc. Thousand Oaks, California.

Kingery W (1960). *Introduction to ceramics.* John Wiley & Sons, Inc. New York.

Lantagne D (2001a). *Investigation of the Potters for Peace colloidal silver impregnated ceramic filter. Report 1: Intrinsic effectiveness.* Alethia Environmental. Allston, Massachusetts.

Lantagne D (2001b). *Investigation of the Potters for Peace colloidal silver impregnated ceramic filter. Report 2: Field investigations.* Alethia Environmental. Allston, Massachusetts.

Lantagne D (2005). *Personal communication with Young, S. on June 27, 2005 via email.* Daniele Lantagne, PE, Centers for Disease Control and Prevention, Foodborne and Diarrheal Diseases Branch. Email: dlantagne@cdc.gov

Low C (2002). *Appropriate microbial indicator tests for drinking water in developing countries and assessment of ceramic water filters.* Available from: http://ceemeng.mit.edu/Water/public_html/Docs/Student%20Theses/Nepal/Low2002.pdf

Accessed 21-10-2004. Master of Engineering in Civil and Environmental Engineering Thesis, Massachusetts Institute of Technology, Cambridge, MA.

McMaster-Carr (2005). *Plastic flow-control tube clamps.* http://www.mcmaster.com/ Accessed 25-6-2005.

Murcott S (2004). *Photographs from trip to Kenya, summer 2004.* Susan Murcott, Lecturer, Massachusetts Institute of Technology, Cambridge, MA. Email: murcott@mit.edu

Murcott S (2005). *Personal communication to Young, S. on June 24, 2005 via email.* Susan Murcott, Lecturer, Massachusetts Institute of Technology, Cambridge, MA. Email: murcott@mit.edu

Mutagaywa J (1995). "Pottery technology in Kenya." *Do it herself: Women and technical innovation.* Ed. Appleton H. Intermediate Technology Publications, London, UK. 162-166.

Mwaki A (2005). *Personal communication with Young, S. on May 5, 2005 via email.* Alex Mwaki, Staff, CARE/Kenya Homa Bay Office. Email: alex@ksm.care.or.ke

Norton F (1974). *Elements of ceramics: Second Edition.* Addison-Wesley Publishing Company. Reading, MA.

Pihulic M (2005a). *An analysis of the production and manufacture of the modified clay pot at the Oriang Women's Pottery Group, the Amilo-Rangwe Pottery Group, and the Kinda E Teko Pottery Group in Nyanza Province, Kenya.* Master of Engineering in Civil and Environmental Engineering Thesis, Massachusetts Institute of Technology, Cambridge, MA.

Pihulic M (2005b). *Photographs from Master of Engineering thesis field work in Kenya, January 2005.* Graduate student, Massachusetts Institute of Technology, Cambridge, MA. Email: pihulic@alum.mit.edu

PFP (2001). *Filters: technical data: spigots.* Potters for Peace. http://www.potpaz.org/pfptechdata.htm#spigots Accessed 14-6-2005.

Pottery Studio (2001). *The Pottery Studio glossary of terms and abbreviations.* http://www.studiopottery.com/news/glossary.html Accessed 6-6-2005.

Quick R, Kimura A, Thevos A, Tembo M, Shamputa I, Hutwagner L, and Mintz E (2002). *Diarrhea prevention through household-level water disinfection and safe storage in Zambia.* American Journal of Tropical Medicine and Hygiene. 66(5):584-589. Available from: http://www.cdc.gov/safewater/publications_pages/2002/quick_2002.pdf Accessed 25-5-2005.

Quick R (2004). *Personal communication with Young, S. on December 13, 2005 via telephone.* Robert Quick, MD, MPH, Foodborne and Diarrheal Diseases Branch, Centers for Disease Control and Prevention, Atlanta, Georgia. Email: rxq1@cdc.gov

Rice P (1987). *Pottery analysis: A sourcebook.* Chicago Press; Chicago, IL.

Schiffer M (1990). "Technological change in water-storage and cooking pots: Some predictions from experiment." *The changing roles of ceramics in society: 26,000 B.P. to the present.* Ed. Kingery W. Westerville, OH: American Ceramic Society, Inc. 119-136.

Semenza J, Roberts L, Henderson A, Bogan J, and Rubin C (1998). *Water distribution system and diarrheal disease transmission: a case study in Uzbekistan.* American Journal of Tropical Medicine and Hygiene. 59:941-6. Available from: http://www.cdc.gov/safewater/publications_pages/1998/semenza_1998.pdf Accessed 25-5-2005.

Sherwood T (1929). *The drying of solids.* Ind. Eng. Chem. 21(12).

Stoke-on-Trent (2005). *A-Z of ceramics.* http://www.thepotteries.org/types/az.htm Accessed 6-6-2005.

Tomlinson Industries (2001). *No-drop commercial faucets: For hot water, hot and cold beverages and bottled water coolers.* http://www.tomlinsonind.com/products/nodrip/index.asp Accessed 25-6-2005.

United Nations Development Programme-Kenya/GEF-SGP (2004). *Provincial map of Kenya.* http://www.ke.undp.org/GEF-SGP/Kenya%20project%20frame.htm Accessed 25-5-2005.

Wandibba S (2003). "Ceramic ethnoarchaeology: Some examples from Kenya." *East African archaeology: Foragers, potters, smiths, and traders.* Eds. Kusimba C and Kusimba S. University of Pennsylvania Museum of Archaeology and Anthropology, Philadelphia. 59-70.

Yamana T (2004). *Post-filtration: Safe water storage and chlorination.* Undergraduate Research Opportunities Program (UROP) Trip to Dominican Republic Report. Massachusetts Institute of Technology, Cambridge, MA. Email: tkcy@alum.mit.edu