

Resource Development International - Cambodia

## Ceramic Water Filter Handbook

***DRAFT DOCUMENT***



March 2008

Developed in Partnership Between:



Engineers without Borders provides voluntary assistance to  
RDIC on an ongoing basis.

Copyright: Resource Development International - Cambodia, Engineers  
Without Borders Australia 2008

Written By: Judy Hagan, Nick Harley, David Pointing, Mickey Sampson, and  
Vanna SOAM.

Reference: Hagan. J.M., Harley, N., Pointing, D., Sampson, M. Soam, V. 2008,  
*Resource Development International - Cambodia Ceramic Water Filter  
Handbook*, Phnom Penh, Cambodia.

Contact: RDIC@...EWB@...

Acknowledgements: ....

- For their assistance in development and review: Hannah Chiew, Sophie Bloem, Heather Murphy, [Om Mon], [Kiln Guys], [Samrach]
- For their commitment and drive in producing high quality filters every day:  
Manager : Mon, [WHOLE TEAM]
- [Funders of EWB position]
- Any RDIC funders?]

What comes next?

This is a first publication of RDIC's ceramic water filter production techniques, ideas and visions. We are already planning additions for the next version as RDIC and EWB Australia will continue working together in a productive relationship. So stay tuned and keep in touch as we continue to refine and provide further information to assist you with your factory projects. Information on updates can be found at [www.rdic.org/FilterFactoryManual](http://www.rdic.org/FilterFactoryManual).

## Contents

|   |  |    |
|---|--|----|
| Chapter 1   | Overview .....   | 5  |
| 1.1.  | Introduction .....   | 5  |
| 1.2.  | Why Ceramic Filters? .....   | 7  |
| 1.3.  | How the Ceramic Filter Works .....                                 | 8  |
| Chapter 2   | Quality Control Considerations.....                                | 11 |
| 2.1.  | RDIC's Commitment to Quality .....                                 | 11 |
| 2.2.  | Quality Assurance Considerations .....                             | 11 |
| Chapter 3   | Initial Considerations - Setting up a Ceramic Filter Factory.....  | 13 |
| 3.1.  | Are ceramic water filters right for you?.....                      | 13 |
| 3.2.  | Where to set up the factory? .....                                 | 13 |
| 3.3.  | Sourcing Inputs .....  | 14 |
| 3.4.  | Machinery .....  | 18 |
| 3.5.  | Staffing .....   | 20 |
| 3.6.  | Establishing your manufacturing process – some considerations..... | 21 |
| Chapter 4   | The Production Process .....                                       | 23 |
| Overview of material Inputs and Outputs for the factory ..... |  | 23 |
| Summary of the RDIC '10 Step' Production Process .....        |  | 24 |
| 4.1.  | Preparation of Raw Materials .....                                 | 25 |
| 4.2.  | Mixing of the Clay Components.....                                 | 30 |
| 4.3.  | Forming Clay Cubes for Filter Element Pressing .....               | 33 |
| 4.4.  | Pressing, finishing, and labelling the filter elements .....       | 34 |
| 4.5.  | Drying and Firing of Filter Elements.....                          | 38 |
| 4.6.  | Flow Rate Testing .....  | 45 |
| 4.7.  | Quality Check and Silver Painting .....                            | 49 |
| 4.8.  | Packaging of Filter System and Replacement Parts.....              | 52 |
| Chapter 5   | Occupational Health and Safety and Environmental Management .....  | 57 |
| 5.1.  | Occupational Health and Safety .....                               | 57 |
| 5.2.  | Environmental Management .....                                     | 59 |
| Chapter 6   | Distribution and Education .....                                   | 60 |
| 6.1.  | Introduction .....   | 60 |

|   |    |
|---|----|
| 6.2. Education Materials .....  | 61 |
| 6.3. RDIC's Distribution and Education Program .....                        | 63 |
| Chapter 7 References and Further Information .....                          | 65 |
| Appendix A Filter Efficacy Tests.....                                       | 67 |
| 'Detection of Waterborne Coliforms and E. coli with Coliscan Easygel' ..... | 69 |
| Appendix B RDIC Automated Water Spray System - for Clay Mixing.....         | 72 |
| Appendix C Example RDIC Filter Price List - November 2007 .....             | 73 |
| Appendix D RDIC Ceramic Water Filter .....                                  | 74 |
| Education and Maintenance Key Messages .....                                | 74 |
| Drinking Dirty Water Can Make You Sick.....                                 | 74 |
| Appendix E RDIC Ceramic Water Filter .....                                  | 80 |
| Instructional Brochures.....  | 80 |
| Appendix F RDIC Ceramic Water Filter .....                                  | 81 |
| Education Poster and Flip Chart.....  | 81 |
| Water Filter Education Flip Chart .....                                     | 82 |
| Water Filter Education Flip Chart (continued).....                          | 83 |
| Water Filter Education Flip Chart (continued).....                          | 84 |
| Appendix G How to build a kiln .....  | 85 |
| Appendix H Machine Diagrams .....   | 86 |
| Appendix I Factory Layout.....  | 87 |
| Appendix J Instructional Videos .....                                       | 88 |

# Chapter 1 Overview

*Ceramic water filters provide affordable high quality drinking water, at a household or classroom level, for communities who are otherwise without access to safe drinking water.*

## 1.1. Introduction



**Figure 1.1 Ceramic Filter System**

Resource Development International – Cambodia (RDIC) has been making ceramic water filters in Cambodia since 2003. RDIC's operation started at a small scale as it developed its manufacturing techniques and clay mix compositions. By September 2007 RDIC had distributed approximately 60,000 filters throughout Cambodia, and internationally, with 24,000 produced in 2007.

Ceramic water filters have proven to be tremendously effective in reducing the exposure of users to contaminated water, and the incidence diarrhoea over an extended period of time (Brown and Sobsey, 2006).

RDIC continues to invest significant time and energy into developing its processes and would like to share its knowledge and best practice approaches with organisations who wish to have a similarly positive impact on communities in developing countries.

Whilst the technology is simple, adherence and commitment to best practice manufacture, training and education is essential to ensuring the ceramic water filters provide the high quality, safe drinking water that its users require for good health.

The five key features of the *RDIC Ceramic Water Filter Programme* that have led to its success are:

1. the appropriate, simple, yet highly effective design of ceramic water filters,
2. a manufacturing and quality assurance process that ensures only high quality filters are distributed,
3. a manufacturing process that is inexpensive, using locally available and sustainable materials,
4. an education programme that informs people about the value of clean water, how filters work and how to take care of their filters and use them effectively, and
5. a distribution network through schools, communities, local business and other non government organisations (NGOs), that provides an ongoing contact point for filter replacements, purchases and queries.

RDIC would like to see the number of communities with affordable and sustainable access to safe drinking water and also provide skills improvement and employment opportunities.

This information package aims to provide information on all elements of the manufacture, education and distribution of water filters to facilitate the introduction of factories to new communities with maximum success.

Chapter One provides an overview of ceramic filters, how they work.

Chapter Two discusses the importance of quality assurance to the development of RDIC's processes.

Chapter Three highlights some early considerations for establishing a filter factory and setting up a manufacturing process. This Chapter draws on the experience RDIC has had to ensure key issues are considered early on.

Chapter Four importantly describes the complete manufacturing process of RDIC's filter manufacture and can form a key resource for training staff. This Chapter discusses different options for manufacturing and discusses some of the benefits and costs of different options.

Chapter Five identifies a range of environmental and health and safety issues that will improve the sustainability of production, protect staff from accident and injury, and minimise costs to the local community.

Chapter Six outlines RDIC's approach to education and distribution - an essential component of sustainability of use and efficacy of ceramic water filters.

*Although the handbook aims to provide as much detail as possible on the process and design of the filters, if you decide to set up a factory, RDIC would also recommend that the technical person/engineer in charge of its implementation spend time at RDIC's factory, learning the details of the process.*

## 1.2. Why Ceramic Filters?

Field trials of the effectiveness of ceramic water filters in Cambodia over time showed a 46% reduction in diarrheal disease between filter users and non-users, a 95.1% average (and up to 99.99%) reduction of *E.coli* in drinking water (Brown and Sobsey, 2006). Laboratory testing has shown a 90-99% reduction in viruses (Brown, 2007). These results support other trials of ceramic water filters (Lantagne, 2001) as a highly successful means of empowering households to manage their own safe water supply.



**Figure 1.2 RDIC Ceramic Water Filter**

Although statistics vary, the World Health Organisation (WHO) reports that in 2004 approximately 36% of urban and 65% of rural Cambodian's were without access to safe drinking water (WHO, 2007). Traditional water sources in Cambodia include rivers, ponds, lakes, open wells, and rainwater stored in open containers, which are all susceptible to contamination from disease causing organisms and other contaminants.

Lack of access to safe drinking water is one of the main causes of disease in Cambodia. Cambodia has a high under-five mortality rate (143 per 1000 live births in 2005 - compared with 6 per 1000 in Australia (WHO, 2007<sup>2</sup>)) with 16.6% of child deaths in 2000 attributed to diarrheal disease (WHO, 2007<sup>2</sup>).

- Drinking contaminated water can cause diarrhoea, cholera, dysentery, and various other diseases. Contamination can be caused by a number of different types of pathogens (disease causing organisms). Major pathogens causing water borne disease are:
- bacteria (eg salmonella, shigella – causing bacillary dysentery, cholera);
  - viruses (Hepatitis A, Hepatitis E, rotavirus); and
  - other parasites including protozoa (cryptosporidium, giardia, toxoplasma) and helminths (WHO, 2004).

Unclean drinking water poses a special threat to vulnerable new born infants in Cambodia, where low rates of exclusive breast feeding of infants, less than 7% of babies of up to five months of age, are practiced (National Institute of Statistics, 2000), leading to high risk of exposure of newborns to water borne diseases from water and bottles.

Water-borne illnesses also reduce household income by preventing family members from attending work for short periods, and reduce school attendance by children.

A key strategy for improving access to clean water is to enable rural households to purify water in their homes using an appropriate water treatment technology. One such technology is a ceramic water filter, a porous ceramic filter treated with silver to act as a disinfectant. Ceramic filters effectively reduce the number of bacteria, viruses, protozoa and helminths, making water safe for human consumption. (Brown and Sobsey, 2006)



Ceramic water filters offer a number of advantages over other techniques, such as boiling, including:

- on-demand availability of clean water in a clean storage container,
- physical filtering of the water to reduce contaminants such as silt and organic matter, and
- significant fuel savings - saving time in collection, cost, and pollution.

### *1.3. How the Ceramic Filter Works*

RDIC's Ceramic Water Filter elements are made from a mixture of clay powder, organic 'burn-out' material, and water. After firing, filter elements are painted with a silver solution.

The actions of the RDIC Ceramic Water Filters are:

1. Physical 'straining' of dirt and bacteria out of the water as it passes through the ceramic substrate.
2. Chemical action of silver as a biocide to kill microbes.

RDIC now adds laterite to its clay mix. Laterite, a material high in Fe oxides, has demonstrated a strong virus removal action in tests at RDIC.

**Clay** forms the base material of the water filter element. Clay can be readily accessed in most locations worldwide, it can be moulded easily, and when fired in the kiln it changes chemically to become a strong slightly porous container that does not deteriorate in water.

A normal clay pot allows an extremely slow movement of water through naturally occurring pores that exist between the platelets of fired clay. The size of these pores have been measured (by an electron microscope) to be in the range of 0.6 to 3.0 microns ( $\mu\text{m}$ ) which are capable of straining out most bacteria, protozoa, and helminths (Latagne, 2001a), as well as dust, and organic matter.

Organic '**burn-out**' **material**, such as ground rice husks, is added to the clay mix for ceramic water filters. When exposed to the high temperatures of the kiln, the burn-out material combusts, leaving behind a large number of cavities in the fired clay. Water moves easily in the cavities compared with the pores in the clay. Therefore the presence of the cavities decreases distance water needs to travel through the filtering pores between the platelets, and therefore increases the overall flow rate of the filter. If the burn-out cavities were actually joined up creating passageways through the filter, the flow rate would be well above the established tolerance zone (Lantagne, 2001a) and would be rejected during the manufacture process.

The ratio of clay to burn-out material in the clay is important in establishing the flow rate and therefore effectiveness of the filters.

Metal oxides (such as **laterite** and goethite) can also be added to the clay mix. Laterite and goethite are high in iron (Fe) and provide positively charged sites which attract and bind viruses – removing them from the final water output.

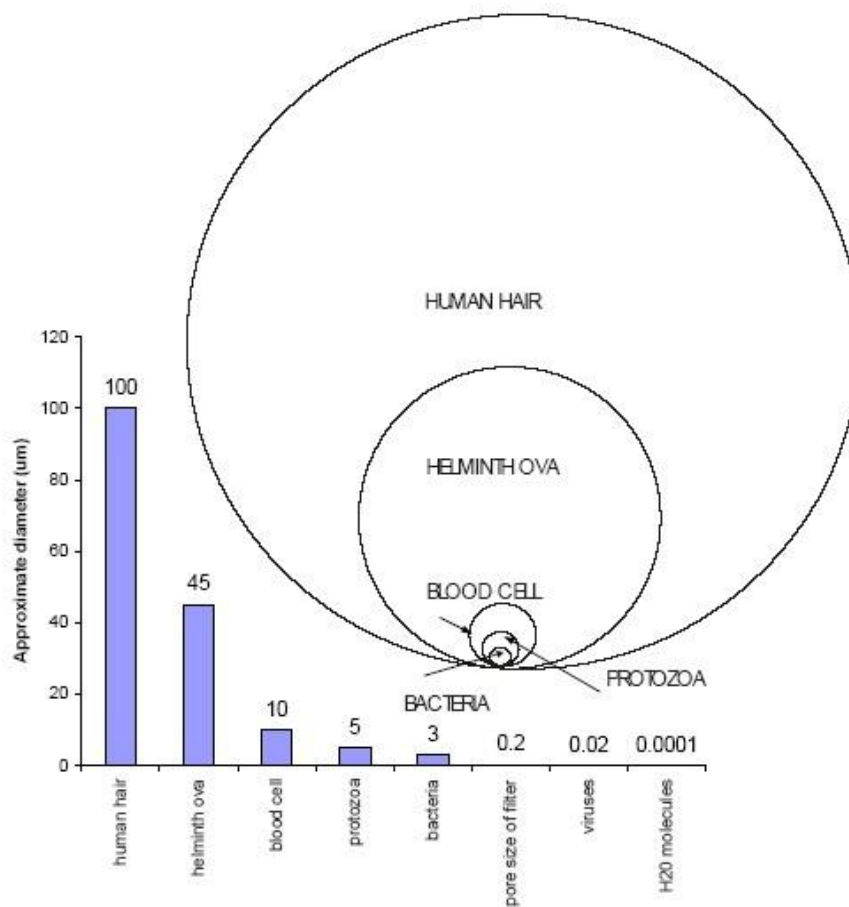
The **silver solution** is applied to the inside and outside of the filter element and is absorbed into the clay pores. The silver ions ( $\text{Ag}^{+1}$ ) are reduced to elemental silver and form colloids within the body of the filter. This silver acts as a biocide, killing bacteria and viruses. As long as there is sufficient contact time (i.e. the flow rate of the filter is not too large) pathogens that come into contact with the



silver will be killed. The silver also prevents bacteria from building up on the surface of the filter and within the ceramic material itself.

Following some minor leaching, silver is not removed or consumed during the process (bacteria and viruses can be killed on contact without the need for metal release - Heinig, 1993, in Lantagne, 2001). Silver action is therefore not reduced during the life of the filter.

Figure 1.3 shows the relative sizes of cells and organisms and how they compare with pore sizes of ceramic filters. The filtering pores of RDIC ceramic water filters have been measured as 0.2 - 3  $\mu\text{m}$  in diameter. This shows that filtering pores of ceramic water filters can remove helminth ova, protozoa, and most bacteria.



**Figure 1.3 Relative sizes of cells and microorganisms - Source Unknown**



**Figure 1.4 Ceramic water filter with additional 20L storage tank attached on top (see also Figure 4.44)**

The filter element is set in a plastic receptacle tank with a plastic lid and a spigot (or faucet). The filter element is manually filled with 10 litres of source water. The water is purified as it seeps through the clay at a rate of approximately 2 litres per hour.

The plastic receptacle and filter element combined can store up to 35L. By cutting a hole in the lid of the plastic receptacle, a 20L plastic tank can be added, increasing the volume of the total system to 55L. The tank can slowly feed water into the filter as it drips through to the plastic receptacle below, and the increased head of this water source can give the filter a more constant flow rate. Such a modification can allow large quantities of water to be filtered with a filling single step which reduces the number of times families need to fill up the filter, and can be useful for large groups such as school classrooms.

Note: Ceramic water filters in their current form are not designed to remove chemical contaminants such as arsenic, heavy metals, nitrate and fluoride from the water.

## Chapter 2      Quality Control Considerations

---

### *2.1. RDIC's Commitment to Quality*

RDIC places great emphasis on producing high quality filters. RDIC developed its initial product requirements, manufacturing process, and maintenance instructions over a 12 month period prior to the release of its first filter. Through use of its own water quality testing laboratory RDIC has tested the performance of its water filters made using different techniques and with different qualities to allow an optimum formula and process to be determined. For example, during this development process the quality of discharge from filters with different ratios of clay to burn-out material were compared and assessed.

RDIC is the largest water quality tester in Cambodia. It provides water quality testing services for many non-government organisations and companies, and provides laboratory facilities and trained staff for partnership research with international institutions such as the University of North Carolina, Stanford University, and Buffalo State University (New York). This experience and background increases RDIC's ability to test, research and continue to develop ceramic water filter technologies.

The effectiveness of filters produced under the RDIC Water Filter Programme has been verified by: Brown, J. and Sobsey, M, 2006, *Independent Appraisal of Ceramic Water Filtration Interventions in Cambodia: Final Report* – Submitted to UNICEF 5 May 2006.

All steps in RDIC's manufacturing process are designed to reduce the chance of imperfections in the filters. RDIC has designed its system to aim for an optimal flow rate of 1.8-2.5 L per hour, with a overall tolerance range of 1.5-3.0 L. Flow rate tests are carried out to ensure the porosity of the filter is within the tolerance range of 1.5 to 3.0 L per hour. This ensures sufficient straining, and exposure of the water to silver, yet remains functional for users. The filter elements are examined for cracks and other defects at every production step, and removed from the process if they do not meet requirements.

The RDIC Ceramic Water Filter Manufacturing and Education Method (the RDIC Method) has been developed over 3 years and is continually reviewed and improved. Currently RDIC is reviewing its fuel source for the kilns and piloting the use of compressed rice husks as a more sustainable fuel. Additionally, RDIC has recently added laterite to its clay material because of its virus binding properties.

### *2.2. Quality Assurance Considerations*

Poor standards have the potential of placing communities at greater risk of ill health by giving them false comfort in the system. Communities who choose not to boil their water, in return for using ceramic water filters need to be ensured at least the same level of protection that traditional practices offer. Placing low quality ceramic water filters with communities can also unnecessarily degrade the reputation of ceramic filters worldwide leading to less implementation of an otherwise effective water filtration method.

Note that quality of filters may be dependent on the materials and processes available to you in your region. Thus, it is important to test filters thoroughly and monitor the effectiveness of at least the first batches in the field for several years.

Education on use and maintenance practices is just as important to the ability of ceramic water filters to make a sustainable difference to the lives of community members. RDIC has an extensive education programme outlined later in this Manual.

Further, this manual provides more detailed information about quality testing procedures that should be applied when first setting up a factory.

## Chapter 3 Initial Considerations - Setting up a Ceramic Filter Factory

---

When making a decision set up a ceramic filter factory and establishing your manufacturing processes, there are a number of questions which if considered early will assist you in being successful in your project. Some of these questions are outlined below:

### *3.1. Are ceramic water filters right for you?*

Before setting up a ceramic water filter factory you should consider if, as a technology, they will meet the needs of community members.

Ceramic water filters are an affordable, accessible, and appropriate technology for empowering households, school class rooms, and work places to manage their own drinking water quality. Ceramic water filters are suitable for treating the most common risk to drinking water quality – contamination with biological pathogens – as well as for removing general macro contaminants such as dirt and plant matter.

Ceramic water filters can be used in conjunction with:

- a piped water system – eg in urban or semi urban areas – where the quality of that water cannot be assured,
- rainwater, river, stream, pond water - where biological contamination and turbidity may be the highest risk to safe drinking water, and
- groundwater.

The biggest physical constraints to using ceramic water filters are:

- the volume of water production – which can be limiting for very large organisations where there are not discreet management or operational units to manage the individual filters, and
- where the primary health risk associated with the source water is chemical such as arsenic, manganese etc.

Human resources and organisational structure to ensure a quality education and distribution programme is also essential to a ceramic water filter facility. Consideration of the market, the users, the community, the ability to establish an ongoing and informed market presence will improve long term sustainability of the technology within the community.

### *3.2. Where to set up the factory?*

In choosing the location of a ceramic water filter factory, there are a number of factors you could consider:

1. Transport accessibility: in developing countries access to good roads can greatly constrain the ability to access materials and deliver products. Poor roads lead to greater delivery time, and higher costs.

2. Materials accessibility: locating the factory near clay sources/clay brick factories and near sources of fuel, such as timber mills where off-cuts can be purchased, can increase efficiency of production.
3. Locating your factory near major distribution centres will help facilitate a steady base market for filters.
4. Location near major transport routes/intersections of major transport routes will facilitate easy distribution to more distant regions.
5. Consider other suppliers of household water treatment options. You may choose to target an area of the country that has the least access to drinking water.
6. In establishing a filter factory, water quality testing is required to test the efficacy of filters as the process is established. Whilst some of this can be conducted with onsite tests access to a high quality water laboratory to undertake batch testing, problem testing, etc should occur.
7. Consider the fumes and smoke that will be generated by your kilns and how they may impact the surrounding community, Placement of factories away from dense community populations is recommended.

### *3.3. Sourcing Inputs*

Early on you should be deciding the key materials you will utilise to manufacture the filters including the:

- clay,
- organic burn-out material,
- laterite (if you decide to use it)
- kiln fuel
- energy – to power mixer, press, hammer mill
- water
- plastic, moulds and manufacturer for receptacle.

These inputs are each discussed further below.

#### *3.3.1. Sourcing the Clay*

In practice, any clay that is suitable for other pottery processes should be suitable for water filter production. However high sand content in clay can cause filters to break. Additionally, naturally high levels of organic matter in the clay can affect the strength and filtering capacity of ceramic filters, as this material can burn out during firing, leaving behind large and unregulated additional cavities.

Clay may be used directly from the pit, or as unfired bricks from a factory, as long as they are completely dried so they can easily broken down into a powder for easy and even mixing with other filter components.

RDIC is situated near a brick factory. Clay is mined locally and extruded into bricks before drying. RDIC uses unfired extruded bricks for convenience. They are easy to transport, cheap and the extrusion process enhances the plasticity of the clay material.

### 3.3.2. Sourcing the burn-out material

RDIC uses ground rice husks as the organic „burn-out’ material in their ceramic filters. Rice husks are a waste product from rice production in Cambodia and are easily available. The rice husks are bought from a local supplier and are provided in rice bags pre ground, but a hammer mill may also be used to grind the husks if sourced “raw”. The size of the rice husk grounds will affect the flow rate, and possibly filter element strength and should be monitored. RDIC seeks rice husks to be less than 1mm in size, and alters the quantity of rice husks added to the mix based on the size of the grounds (see the Production Process for more information).

Other materials that may be suitable include: saw dust, recycled paper, and coffee grounds. It is important to use materials that are most appropriate for the region – for example, RDIC prefers not to use saw dust as a burn-out material since it may contribute to deforestation.



**Figure 3.1 Laterite is crushed and added to RDIC's clay mix**

Filter effectiveness testing is essential when choosing or changing the burn out material for the filters.

### 3.3.3. Sourcing Laterite (optional)

Laterite has recently been added to RDIC's clay mix to provide viral binding sites. Other minerals that are high in Fe (iron) are also suitable such as Goethite.

RDIC sources laterite from local sources in Cambodia, where it is used as a surface material on rural roads. Goethite is used as a red pigment and may be able to be sourced through local suppliers or shipped (eg from India).

Any laterite, or other metal oxide, used in the process also needs to be dry and able to be powdered for even mixing.

### 3.3.4. Sourcing kiln fuel

RDIC uses off-cuts of rubber trees to fuel the kilns. It burns approximate 1.5 m<sup>3</sup> of wood for each batch of filter elements (96). The fire is lit and continually fuelled by the kiln operator. Wood is added gradually in order to increase the temperature gradually.

RDIC is planning to change its fuel source from wood off-cuts to compressed rice husks as an alternative fuel source. The rice husks are a by-product of rice production and their use will further reduce solid waste and the risk of plantations or forests being accessed to provide fuel for the kilns.

There are many other possible fuels that may be used, the best choice being determined by cost ease of access, and environmental and occupational health and safety considerations.

In choosing an appropriate fuel for your region it is important to minimise the risk of deforestation of native vegetation, or of other negative environmental effects to maximise the sustainability of the technology. Use of by-products from other processes is recommended where possible.



RDIC has previously trialled some alternative kiln fuels, including:

- rice husk injections. In this process, the fire was preheated with wood to about 250°C. Then rice husks and air were blown into the fire box using a paddle blower (electric powered). The existing high heat, high oxygen environment and small particles of the rice husks meant the fuel burnt quickly and completely. Around 1 tonne of rice husks were required to fire each kiln. The high cost of electricity to fuel the blower, and the large requirement for rice husks meant this fuel source was too expensive for RDIC's operations, but may be an option in the future.
- Another trial was conducted at RDIC using liquid fuel (crude palm oil or waste motor oil). A set of steel 'steps' were placed inside the kiln fire box, and were heated with an initial wood fire. Metal pipes with drip points were inserted laterally into the fire box. Once the steps were hot, liquid fuel was dripped onto the steel plates in the fire box, causing it to vaporise and burn instantaneously. If the fuel at the top did not vaporise, it will instantly flow to the next step to be heated further. The high cost of palm oil, and the risk of contaminating the filters with the gases and by-products of oil combustion, meant this fuel source was not appropriate for RDIC.

### 3.3.5. Sourcing energy

In setting up a filter factory, consideration needs to be given to the power sources for the factory machinery – such as electricity grid, generators, diesel motors.

RDIC primarily uses diesel generators to meet its electricity requirements in the factory. Whilst a grid electricity supply is available on site, this power source can be unreliable which would impact on the reliability of the factory.

Electricity is also very expensive in Cambodia, particularly when compared with neighbouring countries, so it needs to be considered when making all decisions about the factory operations.

### 3.3.6. Sourcing water

A reliable and reasonably clean source of water is required as a component for the clay filter elements, and for flow rate testing.

### 3.3.7. Sourcing Plastic Components

Plastic parts for the ceramic water filter systems include:

- The plastic receptacle (which receives water from the filter element and stores it for use)
- Fitting ring - which sits between the filter element and the plastic receptacle to protect the filter.
- Faucet and pipe - which discharges the water from the plastic receptacle.
- Scrubbing brush (sourced locally) - for cleaning.

RDIC sources the faucets in bulk from a supplier in China. The faucet is ceramic inside and was tested for durability. It is guaranteed for 100,000 openings and closings.

The plastic pipes and scrubbing brushes are accessed from local suppliers. RDIC has the plastic receptacle and fitting rings manufactured according to specific requirements.

### Sourcing and Characteristics of Plastic Receptacles

Sourcing of plastic receptacles you need to consider:

- Manufacture appropriate moulds;
- Have a reliable source of food grade PET plastic;
- Have a reliable receptacle manufacturer.

Alternatively, plastic receptacles could be manufactured on site, or existing plastic containers could be purchased from the market.

RDIC uses a blown mould for the manufacture of its plastic receptacles. Blown moulds were selected, rather than pressed moulds, because they are cheaper and allow logos to be impressed on the plastic. Additionally, press moulds generally require a tapered container which makes it less stable (as the filter system is top heavy with the filter element and water at the top).

Due to limitations for Cambodian manufacturing, RDIC's moulds were manufactured in Vietnam. The mould is used by a local Cambodian plastic manufacturer to produce the receptacles as required. Figures 2.2 to 2.4 show the manufacture of RDIC's plastic receptacles using a blow mould.



**Figure 3.2 Blow mould for RDIC plastic receptacle**



**Figure 3.3 Heat-softened plastic 'poured' down into mould cavity - two mould halves come together and hot air blows the plastic against the sides of the mould to set.**



**Figure 3.4 Removing moulded receptacle from mould**

Food grade PET plastic is the raw material and is sourced from Taiwan where government regulations require high standards for plastic manufacture.

Plastic receptacles should be of sufficient thickness and flexibility to withstand shock from dropping as well as wear and tear from being lifted and supporting the significant weight of the ceramic filter element with water inside (approximately 16kg). A crack in a plastic receptacle can allow bugs, animals, bacteria, and dirt to get into the filtered water and contaminate it.

RDIC's plastic receptacle has a number of specific characteristics:

- Food grade PET plastic is the raw material to prevent leaching of plasticisers into the water as may occur from inferior plastic products;
- Slightly translucent plastic makes the water level visible, yet prevents most light from entering and facilitating algal growth. Pigment is not added to the plastic due to the risk of leaching and the additional cost;
- The receptacles are quite thick (making the plastic receptacles a large proportion of the cost of the filter system ~50%) and flexible, to reduce breakage from dropping, weight bearing, and carrying - and therefore extend lifespan;
- The lip of the plastic receptacle slopes away from the container, so any water splashed on it does not flow into and contaminate the filtered water;
- The plastic around faucet hole is thicker to prevent cracking
- Built-in handles allow for easy carrying

### Sourcing and Characteristics of Plastic fitting Rings

A plastic fitting ring is inserted under the rim of the ceramic filter element before it is placed into the plastic receptacle. The fitting ring protects the rim of the filter element by evenly distributing the force on the rim when it is carried. The ring is raised, sloping towards the outside to ensure any water that collects on it flows away from, not into the filtered water supply.

RDIC's plastic fitting ring is sourced from the same supplier as its plastic receptacle. It is made in two sizes to allow for some variation in final filter shape.



**Figure 3.5 Fitting rings from supplier**

### 3.4. Machinery

RDIC has mechanised a number of steps in the manufacture process to increased product consistency and quality, and to reduce hard labour requirements of staff. A summary of machinery used by RDIC, and its source is identified below. Note, the prices identified are highly dependent on materials and labour costs and can fluctuate greatly with market demand. Cambodia has faced significant increases in the costs of materials in recent years.

## Machinery Needed

|                  |  |
|------------------|--|
| Elephant's Foot  | <p>Long bamboo pole fixed to heavy steel plate. Used to break clay bricks and laterite into small pieces prior to placement in the hammer mill to reduce wear on the hammer mill.</p> <p>Constructed: on-site.<br/>Approximate cost: \$10.<br/>Weight: 5.7 kg.<br/>Number required: RDIC uses 3.</p> |
| Hammer Mill      | <p>Reduces clay brick and laterite pieces to fine powder. Fineness determined by screen size.</p> <p>Purchased commercially.<br/>Approximate cost: ??.<br/>Powered: diesel fuel.<br/>Number required: RDIC uses 1.<br/>Specifications: see Table 4.1 and XX.</p>                                     |
| Diesel Generator | <p>Produce electricity for clay mixers, pumps, timers and lights.</p> <p>Purchased commercially.<br/>Approximate cost: ??.<br/>Specifications: ??.<br/>Number required: 1 plus back up.</p>  |

|   |   |
|---|---|
| Clay Mixer                              | <p>Mixes dry and wet clay mixture. Designed by RDIC based on commercial cement mixer.</p> <p>Constructed on site (available for sale from RDIC).<br/>Approximate Cost:.<br/>Powered: by electricity via diesel generator.<br/>Number required: RDIC uses 2.<br/>Specifications at XX.</p>   |
| Automated Water Spray System (optional) | <p>Tube measuring tank, water storage tank, 2 pumps, switches, timer - that form the automated spray system to add water to the clay mix process.</p> <p>Constructed on site from market supplies.<br/>Approximate cost: US\$50 where recycled tanks are used.</p>  |
| Filter Press                            | <p>Hydraulic press fitted with male and female moulds to manufacture consistent filter elements.</p> <p>Constructed on site with customised moulds (available for sale from RDIC).<br/>Approximate cost: \$2300 excluding shipping and handling [from Mickey]<br/>Powered: by electricity via diesel generator.<br/>Number required: RDIC uses 2.<br/>Specifications at XX.</p> |
| Drying Racks                            | <p>Steel racks designed by RDIC hold 24 filters (6 on each of 4 shelves). They include a framework for supporting tarpaulins for rain protection.</p> <p>Constructed on site using L-shaped steel, welded and painted.<br/>Approximate cost: ??.<br/>Number required: RDIC uses 90.<br/>Specifications at: XX.</p>  |
| Manual pallet                           | <p>Trolley used to shift drying racks for stacking, drying, and emptying.</p>   |

|                         |   |
|-------------------------|---|
| trolley                 | Purchased commercially.<br>Approximate cost US\$300-500.<br>Number required: RDIC uses 1.   |
| Kilns                   | Brick kilns designed by RDIC. Uses to fire chambers under the kiln chamber floor for burning wood, which is circulates hot air and smoke up into kiln chamber.<br><br>Constructed on site using bricks and mortar.<br>Construction Photo Journal at <a href="#">XX</a> .<br>Specifications at <a href="#">XX</a> .<br>Number required: RDIC uses 5. |
| Flow rate testing bath  | Brick and concreted bath connected to water pumps sufficient to fully submerge 96 filter elements. .<br><br>Constructed on site using bricks, and concrete rendered<br>Approximate cost: <a href="#">??</a> .<br>Number required: RDIC uses 1.<br>Internal Dimensions: 83 x 179 x 304cm.  |
| Flow rate testing racks | Metal racks to hold ceramic filter elements (10 on each of 3 shelves) with centre drain to take water away from filters and recycle into flow rate testing bath.<br><br>Constructed on site.<br>Approximate cost: <a href="#">??</a> .<br>Number required: RDIC uses 4.<br>Specifications: <a href="#">?</a>  |
| Stationary Disc Grinder | The grinder is used to refine rims of filter elements so that they fit under plastic receptacle lids.<br><br>Purchased commercially.<br>Approximate Cost: <a href="#">??</a> .<br>Number required: RDIC uses 1.   |
| Hand drill              | To drill a hole in the plastic receptacle for the faucet.<br><br>Purchased commercially at local supplier.<br>Approximate cost: US\$20.<br>Number required: 1.  |
| Wagon                   | Used to transport raw materials, an buckets of materials and items around the site safely.<br><br>Purchased locally.<br>Approximate cost ??.<br>Number required: RDIC uses 2.   |

### 3.5. Factory Layout

Maximum efficiency in your production process will be dependent on maximising outputs from the time, labour, and energy resources invested into it. You will need want to:

- Minimise the distance overwhich materials and products need to be transports between production steps;
- Minimise vertical lifting and setting down both to reduce energy (fuel and labour) and to reduce risk of injury to staff;
- Set up an easy flow of activity reducing awkward movements to get around machines, materials and buildings; and

- Set up walkways and surfaces that allow trolleys and wagons to be used to minimise carrying.

Appendix I shows the existing layout of RDIC's ceramic filter factory and the movement of materials and products around it. Developing such a map allows analysis for efficiency to be conducted.

### *3.6. Staffing*

Who will you seek to staff your factory?

Who will manage and oversee production? Who will be responsible for quality assurance, establish the manufacturing process for local conditions and solving technical problems?

Who will be responsible for establishing a market? Who will be responsible for setting up and for implementing educational programs?

Existing factories in Cambodian provide labouring work for 10-15 staff.

What will your employment policies be to ensure incentives for staff to encourage high quality and reliable outputs?

### *3.7. Establishing your manufacturing process – some considerations*

There are two key components of manufacturing that need to be established for each individual factory based on local materials: the acceptable flow rate for the filter, and the kiln firing temperature.

These two factors vary depending on the materials used, and should be developed and tested before filters are released for use by the community.

#### *3.7.1. Flow Rates*

The flow rate of ceramic water filters (measured in litres that pass through the filter per hour) is determined by the thickness of the clay, the composition of the local clay used, the proportion of burn out material used in the clay mix (and therefore the quantity of open spaces created by the burn out material).

Previous testing by RDIC determined that the size of burn out material, if ground generally and evenly distributed through the clay, did not have a significant impact on the flow rate, rather the proportion of burn-out material to clay was the major contributing factor to determining the appropriate mix for given source materials. Whilst the proportions for burn out material to clay provided in this manual can be used as a basis for a new factory, testing of flow rates and filter effectiveness needs to occur at each factory.

*Flow rate tests* can be carried out as described in Appendix as part of the quality assurance process

*Testing Microbiological Effectiveness* can be carried out in accordance with suggested guidelines at Appendix A.

### 3.7.2. Filter Firing Regime

When establishing your process you should consider the firing temperatures, the time periods of firing used. The shape of the kiln, the stacking pattern of filter elements within kiln as well as the air inlets and outlets will all affect how hot air will circulate within the kiln. Sufficient firing temperatures, time periods of firing, and even distribution of heat will ensure all filter elements are exposed to sufficient heat to go through the stages of dehydration and vitrification throughout the thickness of the clay.

The two firing temperatures used in this manual allow:

- 1) the complete dehydration of the clay and
- 2) the vitrification (chemical modification) of the clay to form the finished filter element.

The first temperature allowing complete dehydration of 100°C is generic and can likely be used for other factories.

The second temperature point is more specific to the make-up of your clay. To save energy and cost over the long term, this should be the minimal temperature that still allows full vitrification. RDIC fires at a maximum temperature of 866°C. Note higher temperatures have additional chemical affects on the clay (see The American Ceramic Society, 2005).

In examining experimental fired filter elements consider:

- Has all burn-out material been burnt out across the thickness of the filter?
  - Filters that are not fired for long enough may retain specks of black carbon. This carbon indicates that the burn out material did not burn long enough to vaporise and be removed from the filter. Carbon remaining in the filter can block pores, and create sites for bacterial growth.
  - Note: rice husks are high in silica and will leave some silica residue in the cavities
- Has the filter been vitrified across the whole thickness. RDIC's fired filter elements are a deeper red after they are vitrified. Note that natural variation in clay colour across the thickness even after full vitrification can occur.
- A fully fired filter element has a bell like ring when struck, compared with a thud if not fully vitrified.



## Chapter 4      The Production Process

---

### *Overview of material Inputs and Outputs for the factory*

The production process developed by RDIC consumes the following resources (inputs), and results in the following products and waste sources (outputs).

#### **Inputs:**

1. Clay material feedstock – unfired (currently from locally produced sun-dried bricks)
2. *Laterite/goethite (from naturally occurring sources or supplier) (optional)*
3. Ground rice husks - added to clay material to produce air spaces when burned in kiln)
4. Water for mixing with the clay, and burn out material for pot manufacture
5. Water for testing of fired pots (mostly internally recycled)
6. Plastic bags for the mechanical pressing process (2/pot)
7. Fuel for kiln furnace (eg timber, compressed rice husks)
8. Mortar clay (to seal kiln doors) and pyrometric cones for furnace operation
9. Silver solution as natural disinfectant in the finished pots
10. Plastic receptacle, tap (faucet), and scrubbing brush for use of filter
11. Diesel fuel (for hammer mill, and generator)
12. Physical labour
13. Packing tape to seal the completed filter system.

#### **Outputs:**

1. Ceramic water filter systems with 2 year life (greater for plastic container)
2. Employment/wages for local community workforce
3. Clay powder from brick crushing and grinding
4. Smoke from furnace operation
5. Charcoal/ash from furnace operation
6. Exhaust emissions from electricity generator operation
7. Plastic bags from mechanical pressing process
8. Packaging from filter product faulty filters that fail quality control steps (turned into road fill etc)

### *Summary of the RDIC '10 Step' Production Process*

RDIC has developed a simple '10 step' production process for fabrication of the ceramic water filters. Each of the production steps is examined in greater detail in this report, and in the associated training videos at Appendix J.

1. Preparation of raw materials: clay powder, ground rice husks; water and laterite powder (optional)

2. Mixing clay mix components - clay powder, laterite (optional), ground rice husks and water to form a mouldable paste

3. Forming clay cubes for pressing

4. Pressing of clay cubes into ceramic filter form

5. Surface finishing and labelling of pressed filter elements

6. Drying of pressed filter elements – to remove initial excess water

7. Firing of filter elements in kiln – to finish dehydration and vitrification

8. Flow-rate testing of fired filter elements

9. Painting of silver biocide solution on surfaces of filter elements and „shape' quality check

10. Packaging of ceramic water filter system (plastic holder etc)

## 4.1. Preparation of Raw Materials

The RDIC ceramic filter mixture contains:

- clay powder from crushed, dried, unfired clay bricks,
- laterite powder (optional)
- ground rice husks and
- water

RDIC has included laterite into its clay mix, because of the benefit of additional viral binding sites, however the clay filters are effective without this additional measure.

These instructions are supported by *Instructional Video 1 - Raw Materials*.

| PREPARATION OF RAW MATERIALS |
|------------------------------|
| MIXING OF CLAY COMPONENTS    |
| FORMING CLAY CUBES           |
| PRESSING FILTERS             |
| FINISHING FILTER SURFACES    |
| DRYING FILTERS               |
| FIRING FILTERS               |
| FLOW-RATE TESTING            |
| SILVER PAINTING              |
| PACKAGING                    |

### Preparing Clay and Laterite

You will need...

| Item  | Use   |
|---|---|
| Unfired clay bricks or other dry clay source      | Provides base material for clay mix   |
| Laterite bricks (optional)                        | Optional part of the clay material with viral binding properties  |
| Elephants Foot                                    | Breaks the bricks into small pieces   |
| Hammer Mill (or other fine crushing device)       | To create clay powder.  |
| Shovel  | For loading the hammer mill with crushed bricks   |
| Rice or cement bags                               | Captures the clay powder produced by the hammer mill. The holes in the bag let air escape while retaining the powder. |
| Rubber strap                                      | To connect the rice bag to hammer mill outlet   |
| Buckets/old plastic receptacles (of known weight) | To hold and shift crushed brick and clay powder during production.  |
| Scales  | To weigh the buckets of clay/laterite powder and rice husks, and the clay cubes                                       |

### Occupational Health & Safety Considerations

|              |   |
|--------------|---|
| Fan          | To blow clay dust away from the working environment of staff. |
| Face masks   | For protection against dust inhalation                        |
| Goggles      | For protection against dust.                                  |
| Gloves       | To prevent wearing of hands during manual crushing activities |
| Closed shoes | To protect feet when using elephant's foot.                   |

## RDIC's Method



**Figure 4.1 Unfired clay bricks**



**Figure 4.2 Crushing brick with elephant's foot**

Clay brick crushing should be conducted in an open, well ventilated space, to reduce the risk of breathing in the fine dust. RDIC uses a fan to blow dust generated by the hammer mill away from the working space of staff members.

1. Throw the unfired clay bricks down onto a hard and clean concrete floor to break them up initially, and then crush them into smaller pieces using an 'elephant's foot'. See Figure 4.2.

The elephant's feet are heavy bamboo poles attached to heavy metal plates. They are free standing and are raised vertically by the pole and brought down onto the bricks.

2. Shovel crushed brick into plastic buckets (eg old cut down plastic receptacles) of known weight - RDIC's buckets weigh 1 kg.
3. Attach a rice sack to the outlet of the hammer mill using a rubber strap. See Figure 4.4.
4. Pour the crushed brick into the top of the hammer mill.

The hammer mill pounds the clay brick pieces with turning metal 'hammers', and when clay particles are small enough, they pass through the hammer mill screen and discharge as fine powder. The clay powder will pass through the outlet into the rice sack. The rice sacks allow air to escape yet still trap the clay powder. Particle size is not critical, however a powder, rather than granules are required.

5. As each rice-sack fills with clay powder discharged from the hammer mill, remove and replace it quickly with a second sack (preferably using 2 staff members) so that minimal dust escapes. Interchange the use of multiple bags for this purpose.

The details of the hammer mill are seen in Table 4.1.

**Table 4.1 Specifications of the Hammer Mill Motor**

|                                  |                   |
|----------------------------------|-------------------|
| Motor Type                       | 3 Phase Induction |
| Motor Power                      | 3.7 kW            |
| Motor Voltage                    | 220 V             |
| Motor Amp                        | 12.6 A            |
| Motor RPM                        | 2880 RPM          |
| Gear Reduction to Crusher Rotors | 5:9               |



**Figure 4.3 Hammer mill**



**Figure 4.4 Hammer mill discharge with rice sack attached**

6. Pour 15 kg of the clay powder from the rice sacks into plastic buckets. As RDIC's buckets weight 1kg, the total mass of the bucket with clay is 16 kg. Each sack fills about 2 to 3 buckets. See Figure 4.5.

***If laterite or other iron oxide is to be used:***

7. Prepare a store of laterite powder in the same way, by crushing dried laterite with the Elephant's Foot and forming a powder using the Hammer Mill.
8. Add 1kg of laterite powder to each bucket of clay powder.



**Figure 4.5 Scales for weighing out clay powder from the hammer mill.**

## Other Methods

- Whilst it may be possible to source clay directly from its source, it is still necessary for it to be completely sun dried to allow it to be crushed to a powder for even mixing with other filter element components.
- Alternative, less labour intensive, methods for undertaking the initial crushing of brick could be considered – for example using a heavy roller.
- The powder may also be produced manually by crushing the bricks by hand. This is very labour intensive and time consuming.
- Consideration could also be given to different methods of dust suppression.

## Preparing rice husk 'burn-out' material

You will need...

| Item   | Use   |
|--|---|
| Rice husks (milled)                                  | Create porosity in the mixed clay by combusting during the firing process |
| Silo or other dispensing method                      | For easy storage and dispensing   |
| Buckets (of known weight)                            | To carry ground rice husks  |
| Scales   | To weigh rice husks   |
| <b>Occupational Health and Safety Considerations</b> |   |
| Face masks   | For protection against dust   |
| Goggles  | For protection against dust   |

## RDIC's Method

1. Load the milled rice husks into a silo for efficient distribution in the factory.

Dispense the milled rice husks into buckets of known weight. The amount added is dependant on rice husk size and whether or not laterite is to be added. See **Error! Reference source not found.** for reference RDIC's reference based on its regular source of rice husks of approximately 1mm.

Note the weight of the bucket needs to be added to these figures when providing instructions to staff.

*Eg When adding 1mm rice husks in a mix that includes laterite, 7.5 kg of rice husk is added. If the weight of the bucket is 1kg, staff are asked to weigh the rice husk until the bucket weighs 8.5 kg.*

RDIC sources ground rice husks from three different suppliers. The size of the rice husk particles can vary between suppliers. Larger particles create larger pores in the clay decreasing the thickness of the walls between pores, which results in an overall increased flow rate through the filter when compared to the same mass of small rice husk particles. Therefore when particles are larger, less mass of rice husks is added to the clay mix.

| With Laterite        | Without Laterite     |
|----------------------|----------------------|
| 7.5 kg of rice husks | 8.9 kg of rice husks |

***If laterite or other iron oxide is to be added:***

When laterite is added to the mixture, the amount of rice husk is reduced depending on successful flow rate and microbiological efficacy testing. Laterite particles increase the porosity of the fired filter as they do not form the same vitrified bonds as the clay between particles, so less rice husks are needed to achieve the required flow rate.

## Other Methods

Rice husks may be purchased whole, and milled in the hammer mill to create the powder required for mixing into the clay. Purchased ground husks need to be monitored for consistency of size.

## Clean Water

It is important that clean water is used in the production of the ceramic filters. Water contaminated by some chemicals may leave toxic residues in the filter elements that may be passed onto the filtered water.



## 4.2.

## Mixing of the Clay Components

The raw materials of crushed/ground clay, ground rice husks and water are combined to produce a homogenous working material. Laterite may also be added. RDIC uses an electrically powered mixing machine – powered by a diesel generator - to combine the dry ingredients and then automatically adds the required water.

Raw ingredients of the clay are combined according to the following formulas:

|                              |
|------------------------------|
| PREPARATION OF RAW MATERIALS |
| MIXING OF CLAY COMPONENTS    |
| FORMING CLAY CUBES           |
| PRESSING FILTERS             |
| FINISHING FILTER SURFACES    |
| DRYING FILTERS               |
| FIRING FILTERS               |
| FLOW-RATE TESTING            |
| SILVER PAINTING              |
| PACKAGING                    |

### Clay Mix

30 kg clay powder + 8.9 -10 kg rice husks + 12.5 L water

### Clay Mix (when laterite is added)

30 kg clay powder + 7.5 - 8.8 kg rice husks + 12.5 L water + 2 kg laterite

These instructions are supported by *Instructional Video 2 - Mixing the Clay*.

You will need...

| Item   | Use   |
|--|---|
| Clay mixer   | To form a uniform mixture   |
| Buckets of clay powder                               | Part of clay mixture  |
| Buckets of ground rice husks                         | Part of clay mixture  |
| Water  | Part of clay mixture  |
| Small hand trowel                                    | To scrape clay from edges of mixing tub                                     |
| <b>Occupational Health and Safety Considerations</b> |   |
| Face masks   | For protection against dust when pouring into the mixer, and during dry mix |
| Goggles  |   |
| Risk of crush when emptying clay from mixer          | Consider turning off blades during clay removal                             |

## RDIC's Method

1. Turn on the clay mixer. See Figure 4.7.
2. Empty 1 bucket of clay and laterite mix (15kg clay powder *optional addition of 1 kg of laterite*) into the mixer.
3. Add 1 bucket of rice husks (7.5 - 10 kg depending on rice husk source and use of laterite see).
4. Then add a second bucket of clay powder and laterite mix (15 kg clay powder *optional addition of 1 kg of laterite*).
5. Mix it dry for 10 minutes with mixer lid closed - to minimise dust emissions.
6. Evenly spray approximately 12.5 litres of water into the mixture. This addition of water needs to ensure even wetting of all the dry components, relatively quickly to create a smooth paste. RDIC does this via an automatic process which utilises a sprinkler system within the mixer to evenly distribute the water. If the machine is hot a small amount of additional water may be needed to get the right consistency.



**Figure 4.6 RDIC Automatic Water Spray System - measuring and storage tanks**

### *RDIC's Automatic Water Spray System*

RDIC uses an automated system to supply water to each of its mechanical mixers. This is an easily operated system that evenly distributes a set amount of water through the clay mix. The operator also has the ability to adjust the volume should additional water be required during hot conditions.

The system sets 10 minutes of dry mixing, before 12.5 L of water is sprayed into the mix. A further 10 minutes of wet mix occurs before mixing is stopped and the mixer emptied. Details of RDIC's Automated Water Spray System are at Attachment X.

7. Continue mixing for another 10 minutes after the water has been added.  
  
10 minutes is a minimum time. The mixture may be mixed for longer or left for a while without any significant change in properties.
8. Occasionally turn the mixing machine off, and using a small hand trowel, scrape the blades and surface of the mixing tub to bring any partially mixed clay into the middle of the mixture to ensure a uniform mix.

9. At the end of the day, the clay mixer is left closed with a load of wet mixed clay. This improves the start up time for the following day, and prevents pieces of dry clay being mixed into the next day's batch.



**Figure 4.7 Clay Mixer - during operation**



**Figure 4.8 Clay Mixer - open for emptying**

## Other Methods

1. An alternative spray water system can use an elevated water tank (bucket) with an adjustable overflow outlet at 12.5L. See Figure 4.9

Water is pumped up to the bucket (e.g. using a rope pump from a ground water well). A simple timer set for 10 minutes at the beginning of the dry mix will sound an alarm indicating time to open the valve to the tank to allow water to flow in through the spray pipe.

Water will stop being sent to the mixer once the tank is empty. Once the valve to the mixer is closed again, the tank is refilled.

The height of the tank will affect the pressure of the water flow into the tank. Higher pressure will increase the penetration of the water into the clay mix.

2. At a minimum, adding water by hand should ensure an even distribution of water to maximise the consistency of the clay mix. A watering can could be used for this purpose.
3. It is possible to manually mix the clay powder, ground rice husks, and water by kneading (as used commonly by potters). RDIC recommends mechanising this process though, due to hard work and therefore low efficiency of hand kneading.
4. Fuel motors can be used to replace electrical motors if electricity is not available; alternatively water can be added manually. Any process should ensure even wetting of dry components.



**Figure 4.9 Alternative Spray Water System - Raised bucket with adjustable overflow at between 12 and 15L gravity feeds into clay mixer through spray pipe**

### 4.3. *Forming Clay Cubes for Filter Element Pressing*

Wet clay mix is formed into cubes for pressing. The cubes are turned and thrust against the tarpaulin to remove air bubbles in the mix prior to pressing - and therefore to reduce imperfections in the clay.

|                              |
|------------------------------|
| PREPARATION OF RAW MATERIALS |
| MIXING OF CLAY COMPONENTS    |
| <b>FORMING CLAY CUBES</b>    |
| PRESSING FILTERS             |
| FINISHING FILTER SURFACES    |
| DRYING FILTERS               |
| FIRING FILTERS               |
| FLOW-RATE TESTING            |
| SILVER PAINTING              |
| PACKAGING                    |

You will need...

| Item            | Use                                 |
|-----------------|-------------------------------------|
| Clean tarpaulin | As surface to form clay cubes on    |
| Scales          | To weigh 8.0 – 8.2 kg cubes of clay |

#### RDIC'S Method

1. Release the lock on the mixer and tip the mixer tub forward. See Figure 4.8
2. Empty the clay from the mixer onto a clean tarpaulin. It is recommended to turn the mixer off after initial clay has been emptied out to allow the sides and blades to be scraped safely.
3. The clay is then formed into cubes of 8.0 - 8.2 kg each (weighed on scales). It is better to have excess weight in these blocks due to slight losses in the moulding process as clay is squeezed out the top. Excess material ensures that air bubbles will be pressed out of the walls of the filter in the moulding press. See Section 4.4.

#### 4.4. *Pressing, finishing, and labelling the filter elements*

The moulding of ceramic water filter elements is mechanised at RDIC. Use of a hydraulic press greatly decreases labour requirements of the process, and greatly increases efficiency and consistency of product. The filters are pressed between a male and female mould which are covered with plastic bags to prevent sticking. The hydraulic press incorporates a fixed plate in the bottom mould which pushes the pressed mould out as the mould opens up.

Minimal surface finishing is required following moulding but is conducted to ensure the rim is strong, and that the surface is even.

Filters are labelled to indicate the date of pressing, the batch and the filter number.

|                              |
|------------------------------|
| PREPARATION OF RAW MATERIALS |
| MIXING OF CLAY COMPONENTS    |
| FORMING CLAY CUBES           |
| PRESSING FILTERS             |
| FINISHING FILTER SURFACES    |
| DRYING FILTERS               |
| FIRING FILTERS               |
| FLOW-RATE TESTING            |
| SILVER PAINTING              |
| PACKAGING                    |

You will need...

| Item   | Use  |
|--|--|
| Moulding Press (including top and bottom moulds) | To form the filter shape.  |
| Clean tarpaulin and undercover space             | For initial drying of moulds.  |
| Drying racks                                     | To store moulded filters.  |
| Paint brush + water                              | Wets the rim of the filter immediately after being removed from the press.   |
| Metal plate                                      | Used to move the un-hardened filter to the drying area.  |
| Lid / bowl                                       | Stops the rim from becoming out of shape when moving the un-hardened filter to drying area.                                |
| Plastic scrapper / spatula with a smooth edge    | Smooth the inside of the filters after moulding.   |
| Metal stamps                                     | To imprint date, filter number and manufacturer into the rim of the filter.  |
| Rag and water                                    | To wipe the rim of the filter after the inside has been smoothed.  |
| Plastic bags 2 per filter element                | Stops the clay from sticking to the mould these should be as thin as possible to reduce wrinkles being formed in the clay. |

#### **Occupational Health and Safety Considerations**

|                                    |  |
|------------------------------------|--|
| Face masks                         | For protection against dust when pouring into the mixer, and during dry mix. |
| Goggles                            | For protection against dust when pouring into the mixer, and during dry mix. |
| Risk of crush injury when removing | Turn off mixer when removing clay.   |

clay from mixer

## Pressing

### RDIC's Method

These steps are aligned with *Instructional Video 3 - Moulding*.

1. Place the round metal plate on the press and the cover this plate and the bottom die with a plastic bag. These plastic bags are reused as many times as possible (until they tear) however they usually rip first time.
2. Place the 8.0 - 8.2 kg cube of clay mixture on the plate of the hydraulic press and then cover again with a plastic bag. This ensures the filter is lined with plastic on the inside and outside during the moulding process. See Figure 4.10.
3. Pull the lever to activate the hydraulic press and ensure that the male and female moulds (top and bottom die) fully press together. When the moulds are almost fully together, excess clay should squeeze out of the run-off holes. Remove this excess then reverse the press to release to moulded filter. See Figure 4.11.



**Figure 4.10** RDIC's hydraulic press



**Figure 4.11** Hydraulic press in operation

## Surface Finishing and Labelling

Once each filter element has been pressed, all the surfaces need to be manually finished to meet quality standards and to minimise the potential for failure (cracking) in the future.

The clay must have a high water content to be formed into the filter shape. This high water content means the newly pressed filter element is very soft and must be treated carefully to prevent deformation. Each filter element is also individually stamped with identification marks.



## RDIC's Method

1. Remove the filters from the press using the circular metal plate from the press as a support surface. Remove the inside bag and wet the filter rim with water using a brush. Using small amounts of wet clay fill in any gaps or cavities and smooth out any defects around the rim. Using a plastic scraper smooth all edges of the rim. See Figure 4.12.



**Figure 4.12 Smoothing the edges of newly formed filter element**



**Figure 4.13 Freshly pressed filter element with plastic bowl to hold the shape**

2. Place a correctly sized and shaped plastic bowl inside the filter element and spin around slowly to even out the inside edges. See Figure 4.13.
3. Carefully carry the filter element to the drying area - with the plastic bowl in place and using the metal plate as support. Slide the filter element off the metal plate onto the drying tarpaulin and remove the plastic bowl.



### Quality Check Point

If the filter element deforms out of shape, return it to be reformed into a new cube and repressed.

4. Leave the freshly pressed filter elements under a shelter for 3 – 4 hours (or overnight) to harden. It is important they are left in the shade and not the sun to ensure a more uniform drying process. See Figure 4.14.
5. After this time, hand refine the filter elements using a piece of plastic with a soft edge to remove irregularities on the inside surface and to scrape the surface to open up clay pores. Shine a light into each filter element to ensure all irregularities are visible, and use a wet cloth to wipe the rim of all the filters to reduce the likelihood of cracks. See Figure 4.15.





**Figure 4.14 Initial drying of filter elements**



**Figure 4.15 Plastic scraper for smoothing filter elements**

6. Mark each filter element with a date, serial number and manufacturer's name using a metal "stamp". A database may then be used to track the filters. See Figure 4.16 and Figure 4.17.
7. Leave the filter elements in the shade to harden further until the following day.



**Figure 4.16 Stamps for filter element identification**



**Figure 4.17 Stamped filter element**

### Other Methods

- RDIC previously used a hand press to mould the filters but this was found to be labour intensive and slow.
- RDIC has also tested alternative methods of stopping the clay from sticking that doesn't involve using plastic bags (such as a light oil coating); however alternative methods did not work effectively.

#### 4.5.

#### *Drying and Firing of Filter Elements*

Drying of filter elements removes the excess water in preparation for firing in the kiln. It is necessary to remove the water from the clay slowly so that it does not expand too quickly and crack the clay.

Dehydration: initial drying of filter elements is on drying racks in the air. It removes much of the excess water required for moulding the clay to the desired shape. After this initial drying period the filters are able to hold their shape but are not strong, not water tight, and if water is added to them, they would deteriorate.

The firing process, with initially a low heat of around 100°C removes the remaining excess water. Further heating then removes water chemically bonded to the clay's alumina and silica molecules.

Vitrification: finally at high temperatures (over 600°C) vitrification of the clay occurs where the silica and alumina molecules melt and bond into a new mineral with fibrous needle like structures. Vitrified clay is hard, resistant to stress, and will not change shape when water is added.

After vitrification the clay has a new chemical structure and cannot be reduced to powder and reused as clay dust.

When heated to high temperatures the ground rice husks leave behind air pockets in the clay. These air pockets thin the walls of clay through which the source water moves through the filter increasing the rate of flow, while still requiring the water to pass through the closely packed vitrified clay which removes the dirt and pathogens.

|                              |
|------------------------------|
| PREPARATION OF RAW MATERIALS |
| MIXING OF CLAY COMPONENTS    |
| FORMING CLAY CUBES           |
| PRESSING FILTERS             |
| FINISHING FILTER SURFACES    |
| DRYING FILTERS               |
| FIRING FILTERS               |
| FLOW-RATE TESTING            |
| SILVER PAINTING              |
| PACKAGING                    |

#### Air Drying of Pressed Pots

#### You will need...

| Item                  | Use  |
|-----------------------|--|
| Drying racks          | To support and spread out the filter elements for drying.                                |
| Large tarpaulins      | To completely cover the drying racks to prevent filter elements getting wet in the rain. |
| Manual pallet trolley | To move drying racks into the sun and to the kiln as needed.                             |
| Drying area           | Large concrete slab to easily move drying racks onto and off.                            |

#### Occupational Health and Safety Considerations

Use of the manual pallet trolley reduces strain from carrying and shifting filter elements by

hand.

## Drying Racks

RDIC's drying racks are manufactured from flat and angle steel sections, designed to provide sun exposure and air flow around the pots. The top shelf includes a frame to support the tarpaulins used to protect the pots from rain. Each rack holds 24 pots, 6 on each of 4 shelves. The racks are moved using a standard wheeled pallet lifting jack.

## RDIC's Method

1. The next day, move the pots to drying racks and to the drying area. RDIC uses colour coded racks to track each batch of filters through the multi staged process.
2. Filter elements require 7-15 days drying time in the Cambodian dry season, and 15-18 days to dry during the wet season, prior to firing.
3. In the event of rain, cover the racks with tarpaulins and tie off to minimise delay in drying.

Tarpaulins are used at RDIC to cover the pots when it is likely to rain. Direct sunlight and wind quickens the drying process; hence the tarpaulins are removed in these weather conditions.

As pots on the bottom shelf are likely to dry slower than those on the top shelf, the readiness of the pots for firing in the kiln is judged by the bottom pots. When the filter elements are ready for firing they should make a leathery sound when flicked with a finger.



**Figure 4.18 Drying racks**



**Figure 4.19 Manual pallet trolley used to shift drying racks**

## Firing the Ceramic Filter Elements

### The Kilns

The kilns are simple in design and operation. Filter element 'firing' within the kiln is conducted in batches where the kilns are loaded with filters, slowly heated to the firing temperature, retained at high temperatures, then cooled and emptied. The kilns operate with two 'fire boxes' where timber fuel is combusted beneath the kiln chamber where the filters are located. The exhaust gases, smoke, and heat from the two fires rise into the oven chamber through internal chimneys and pass around the filters, to exit through a central exhaust slot in the floor before rising out a chimney in the rear of the kiln.

The RDIC kiln design includes an arch roof to facilitate circulation of hot air within the kiln and even distribution of heat, as well as to extend the life of the roof structure.

Further information about RDIC's kiln design and construction techniques is located at Appendix G.

### Temperature Monitoring

The temperature within the kiln chambers (not the fire chambers) are monitored by use of standard industrial:

- 1) thermocouples, and
- 2) pyrometric cones.

Thermocouples are simple electric devices that utilise the temperature relationship created in voltage created between two different metals when they are heated.

Pyrometric cones are small ceramic cones designed to melt at a certain temperature under a certain rate of heating (a large range of temperatures are available). They are placed at a point visible from outside the kiln to indicate to the kiln operators, the temperature of the kiln chamber. (See Orton Ceramic Foundation, 2008 for more information).

RDIC has a heating rate of approximately 100 °C per hour. To monitor kiln temperatures RDIC uses an Orton small cone size 014 as the vitrification temperature (approximately 866°C when heated at 100 °C per hour), and 012 as an indicator cone the temperature is close to being reached (approximately 830°C).



**Figure 4.20 Kiln showing doors to fire chamber bottom left, filter element chamber right**



**Figure 4.21 Kiln from back - with chimney**

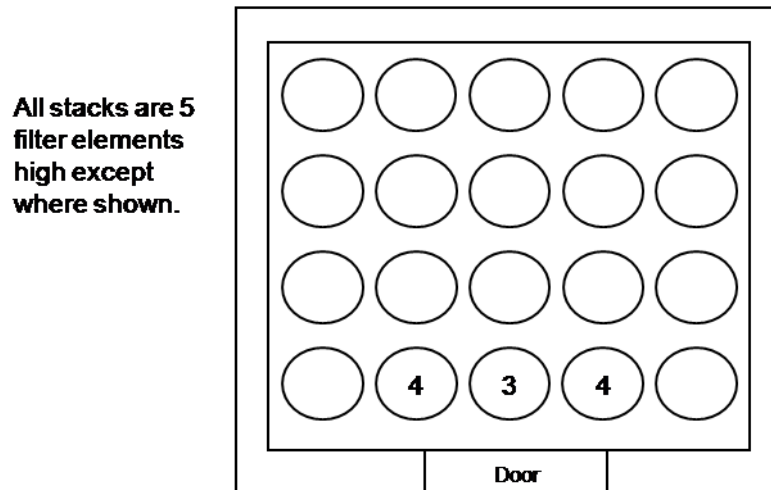
You will need...

| Item   | Use   |
|--|---|
| Kiln   | Chamber to provide high heat to pots to dehydrate and vitrify the clay          |
| Fuel (consumable)  | To heat the kiln.   |
| Completely dry filters   | 96 per kiln   |
| Spare bricks   | To cover kiln door.   |
| Mud mixture (consumable)   | To cover bricks in kiln door.   |
| 2 x pyrometric cones (consumable) <ul style="list-style-type: none"> <li>One cone with a melting point at the temperature of vitrification (RDIC uses Orton small cone 014)</li> <li>One cone with a melting point a little before the temperature of vitrification (RDIC uses Orton small cone 012).</li> </ul> | Accurately tells the operator the temperature of the kiln at high temperatures. |
| Thermocouple and voltmeter (pyrometer)   | Measures temperature of kiln at low temperatures ( $T < 200^{\circ}\text{C}$ ). |
| Shovel   | For stoking fire.   |
| <b>Occupational Health and Safety Considerations</b>   |   |
| Face masks and Goggles   | For protection against smoke and ash  |
| Gloves and closed shoes  | For protection against hot ash and pots   |

## RDIC's Method

These steps are written in conjunction with *Instructional Video 4 - Kilning*.

The dried ceramic filters are carefully loaded into the kilns and stacked in a formation in order to maintain uniform heat distribution. See Figure 4.22.



**Figure 4.22 Pattern for Stacking Filter Elements in Kiln**

1. Once all filters are stacked in the kiln (96 fit in RDIC's kilns), the open doorway is packed with bricks as tightly as possible. See Figure 4.23.
2. Cover any remaining cracks with a mud mixture order to keep as much heat in as possible. See Figure 4.24.
3. Add the two pyrometric cones to the kiln through a small window in the kiln chamber which can be opened and viewed by removing a single brick. See Figure 4.25 and Figure 4.26.





**Figure 4.23 Worker closing kiln opening tightly with bricks**



**Figure 4.24 Kiln opening bricked and cracks sealed with mud**



**Figure 4.25. Pyrometric Cones inside kiln, viewed through viewing window (not yet melted)**



**Figure 4.26 Pyrometric cone window viewed from the outside**

4. Place wood, or other solid fuel, in the fire chambers below the kiln. Light the fuel and increase the heat until the kiln temperature reaches 100°C – as measured by the pyrometer.
5. Keep the damper doors (corrugated iron panels) open during this process to ensure sufficient oxygen for a complete burn. Maintain the kiln temperature at 100°C for 2 hours to dry off any excess water within the pots – dehydration. Temperatures above this may cause excess water to expand quickly and crack the filters.
6. After 2 hours, gradually increase the kiln temperature by adding more fuel. When the first pyrometric cone melts, the operator knows the required temperature has almost



been reached. Once the second cone has melted, the required temperature has been reached. It usually takes between 8 and 10 hours to reach the maximum temperature. [The pyrometer is not used to measure these temperatures since it is not accurate at these levels.]

The correct temperature for firing your filter elements will vary depending on the nature of your clay. A minimum temperature that will achieve a complete vitrification process should be set as the firing temperature in order to minimise fuel use. Vitrification temperature for RDI's filter elements is 866°C.

7. Once the required temperature for vitrification has been reached, remove the fuel and cover with the damper doors. Leave for 9 hours.
8. After this main firing time, remove the damper doors and let the kiln cool over 24 hours.

These times may be varied according to weather conditions and the design of the kiln.

9. After 24 hours remove the pots from the kiln and place back on racks. Let them cool further in the open air.

Note: faster cooling times are not thought to have a deleterious effect on filter structure, yet if achievable can speed up production time (Gelders, T., 2007).

## 4.6.

*Flow Rate Testing*

Flow rate testing is an important quality assurance step which indicates the rate at which water passes through the filter element. Once a clay formula and production process has been established, flow rate testing is conducted on EVERY filter element that is produced to ensure its viability.

A high flow rate is an indicator of cracks or imperfections in the filter element that could reduce the effectiveness of filtration and may not remove the required bacteria, parasites and other impurities. Additionally a high flow rate reduces the exposure time of the filtered water to the silver solution thereby reducing the ability to kill bacteria in the water.

A flow rate that is too low may prove impractical for use by households who may choose to stop using the filter and thereby waste their investment and put their health at risk.

You will need...

| Item  | Use   |
|---|---|
| Large water tight tank  | To hold water for soaking pots  |
| Clean water supply – including piping to tank                             | To supply and top up the water tank   |
| Filter element racks with water tight drainage                            | To hold the filter elements during flow rate test, with the ability to drain water as it passes through pots without leaking into pots below. |
| Timer with alarm  | To accurately measure 1 hr  |
| A t-piece with markings to measure change in volume in the filter element | To measure the flow of water from filter elements in one hour.  |



**Figure 4.27** Soak bath for flow rate test process

|                              |
|------------------------------|
| PREPARATION OF RAW MATERIALS |
| MIXING OF CLAY COMPONENTS    |
| FORMING CLAY CUBES           |
| PRESSING FILTERS             |
| FINISHING FILTER SURFACES    |
| DRYING FILTERS               |
| FIRING FILTERS               |
| <b>FLOW-RATE TESTING</b>     |
| SILVER PAINTING              |
| PACKAGING                    |

## RDIC's Method

These steps are written in conjunction with *Instructional Video 4 - Flow Rate Testing*.

1. Fully immerse the pots in water and soak overnight (or a minimum of 5 hours) to ensure full saturation of filters at the beginning of the test and to therefore achieve standardised results. RDIC does this in a large concrete tank that holds up to 120 filters in three stacked rows.
2. Once soaked, the filters are transferred onto a flow testing rack. These are designed to drain the water away (pipes in figure below, right) and most importantly, to stop water from dripping into the filters below and thus altering the flow rate readings. See Figure 4.28 and Figure 4.29.



### Quality Check Point

When transferring the soaked filters to the racks check for two things:

- i. Check for cracks in the filters. Remove any pots if the cracks are large and threaten its durability or flow rate. These pots are destroyed or used as flower pots. They CANNOT be re-crushed and re-mixed as the material clay has fundamentally changed.
- ii. Check that the pots are fired properly. If they are not completely fired, the clay will easily rub off and / or crumble in your fingers. The pots will also have a bell sound when struck if properly fired. Filter elements that are not completely fired can be refired using a specific firing regime, but are generally destroyed as faulty pots. A common application for the smashed pots is as a road base around the factory.

3. Fill each of the filters to the brim with water, then top up all the filters to ensure they all start full at the same time. Once all filters are filled to the brim, start a timer for 1 hour. See Figure 4.30.
4. After an hour, test the flow rate of each filter element with a T-piece that measures the water level drop. The optimum flow rate RDIC designs its filter elements to meet is 1.8 – 2.5 litres. Filters of flow rate 1.5-3.0L are within the accepted flow rate range. See Figure 4.31.

The T-piece in Figure 4.32 indicates litres and half litre reductions in water level in the filter.



**Figure 4.28** Filter rack for flow rate test



**Figure 4.29** Drainage for filter racks



**Figure 4.30** Flow rate testing



**Figure 4.31 T-piece measuring flow rate**



**Figure 4.32 T-piece with pre-measured markings**

5. All filter elements within this tolerance are emptied, tipped on their side and left to dry on the drying racks. The filter elements that did not pass the flow rate test are stacked together and destroyed or holes are drilled in their bases for use as plant pots.

It usually takes 5-8 days in the dry season, and 7-10 days in the wet season, to dry the pots.

Tarpaulins are used at RDIC to cover the pots when it is likely to rain. Direct sunlight and wind speeds up the drying process hence the tarpaulins are removed in these weather conditions.

All water used in the flow rate testing process, particularly that which drains through the pots, is collected in an underground tank beneath the flow rate testing racks. This water is then pumped back into the soaking batch and into the pots as required during testing.

## 4.7. *Quality Check and Silver Painting*

Silver is recognised for its strong microbiocidal properties. Colloidal silver has been used in hospital and clinical settings as an antimicrobial agent for cuts, burns, and in preventing eye infections in newborns (Lantagne, 2001) and for disinfecting drinking water and swimming pools (Russell, 1994, in Lantagne, 2001). Silver is used by NASA for purifying water for space flights (NASA CASI, 2007) and by airlines for in-flight water purification.

The use of silver in ceramic water filters has been conducted by a number of organisations with very positive results (Lantagne, 2001).

RDIC uses silver nitrate solution ( $\text{AgNO}_3$ ) for its silver solution.

You will need...

|                                     |
|-------------------------------------|
| <b>PREPARATION OF RAW MATERIALS</b> |
| <b>MIXING OF CLAY COMPONENTS</b>    |
| <b>FORMING CLAY CUBES</b>           |
| <b>PRESSING FILTERS</b>             |
| <b>FINISHING FILTER SURFACES</b>    |
| <b>DRYING FILTERS</b>               |
| <b>FIRING FILTERS</b>               |
| <b>FLOW-RATE TESTING</b>            |
| <b>SILVER PAINTING</b>              |
| <b>PACKAGING</b>                    |

| Item   | Use  |
|--|--|
| <b>For Shape Testing:</b>                                  |  |
| Plastic lid from the plastic receptacle                    | To test that the shape and size of the filter element rim will fit into its plastic receptacle.  |
| Grinder  | To grind the rim of filters that don't fit the lid.  |
| <b>For Silver Painting:</b>                                |  |
| $\text{AgNO}_3$ crystals 100g                              | To make silver solution  |
| Deionised water - 1.5L to make silver solution concentrate | Used to dissolve $\text{AgNO}_3$ for silver solution concentrate   |
| Filtered water - 18L makes enough for 60 pots              | Used to dilute concentrate to make silver solution   |
| Paint brushes  | To apply the silver solution   |
| Plastic cups marked at 300ml and 100ml                     | To hold the silver solution while it is being applied to the filter, markings indicate the quantity of solution to go on the inside and the outside of the filter element. |
| Large plastic container (20L)                              | To store silver solution longer term. It should be a plastic light-proof container to stop the mixture reacting. It should be well sealed to minimise oxidation.           |
| <b>Occupational Health and Safety Considerations</b>       |  |
| Gloves, goggles  | To protect eyes and hands during grinding of the filter elements   |

## RDIC's Method



### Quality Check Point

Before painting with silver, inspect each filter element. Look for large cracks and imperfections that may reduce filtration capacity, or reduce consumer acceptance. Dispose of any unacceptable pots.

## Filter Rim Size Testing

1. Place a plastic lid from the receptacle onto each filter element and spin it around to ensure the filter element is the right shape still and has not warped during the firing process.

If the lid does not fit easily, grind the filter element rim back on the grinder. This is done at RDIC using a stationary disc grinder.

## Preparation of Silver Solution

1. Add 100g of  $\text{AgNO}_3$  crystals (RDIC purchases crystalline  $\text{AgNO}_3$  of around 99.8% purity) to 500 ml of deionised water and mix well.
2. Add a further 1000 ml of deionised to the solution and mix for 1 minute.
3. Store this silver solution concentrate in a light proof plastic container.
4. To make up silver solution, take 100 ml of the silver solution concentrate and place it in a light proof container. Add 18 L of distilled water and mix. 18.1 L makes enough solution for approximately 60 filter elements.

Note: Containers should be kept closed as the silver in the solution oxidises upon exposure to air.

## Application of Silver Solution:

These steps are to read in conjunction with *Instructional Video 6 - Silver Coating*.

1. RDIC paints the silver nitrate on manually.
  - 47 mg or approximately 200 ml of mixture are applied to the inside of the pot using a paint brush
  - 23 mg or 100 ml of mixture are applied to the outside of the pot.





**Figure 4.33 Cup for measuring silver nitrate solution (note 2 levels marked)**

A higher volume of solution is applied to the inside because there is more water in contact with this surface. Additionally, as water passes through, it will impregnate the silver deeper into the ceramic wall. The application on the outside of the pot also helps to prevent pathogens growing on the outside of the filter wall.

These amounts are measured out into a cup with two markings. The silver nitrate is filled to the top marker and then painted on the inside until the level drops to the second marker. The rest of the solution is painted on the outside. See Figure 4.33.

Approximately 30% of the silver is leached out when first used. While not dangerous, RDIC recommends that the 33 L of water filtered (3 pots full) are disposed of.

6. Once the filters have been painted, leave them to dry for a short time.

## Other Methods

**Colloidal silver** is an alternative and commonly used silver source in ceramic filters. It has been used in the production of a number of ceramic filters. The formula of this compound is unknown. RDIC uses silver nitrate ( $\text{AgNO}_3$ ) instead of colloidal silver due to its known formulation (sources of colloidal silver do not always have a defined formula or concentration), effectiveness, availability, and affordability.

**Dipping** of pots into silver nitrate solutions is possibly a quicker process than painting however there are several reasons why RDIC does not do this:

- oxidation may occur in the dipping tank causing effective silver loss;
- different application levels are required on the inside and outside and since the higher level is required on the inside, silver nitrate would be wasted (because of higher application on the outside);
- drying time may increase due to fast absorption rates of  $\text{AgNO}_3$  into the ceramic wall.

**Spraying** is also possibly a faster application method and although it is easier than dipping to control the application rate, it is not used by RDIC due to wastage via droplets in the air. Spray droplets in the air also increase health risks to workers; hence better personal protection equipment is required which can be relatively expensive.

## 4.8. *Packaging of Filter System and Replacement Parts*

RDIC filters are packaged with a number of items to ensure best use and maximum life. The filter package includes:

### 1. Ceramic Filter Element

Manufacture of the ceramic filter element is described fully in this manual.

### 2. Plastic receptacle with lid

The plastic receptacle supports and protects the clay filter element, receives the water as it drips through the filter element, and is fitted with a plastic faucet for dispensing the filtered water. The inside of the plastic receptacle needs to be kept sterile as it stores the treated filtered water before distribution and no further treatment occurs after this storage point. The receptacle needs to have a certain level of flexibility and strength to hold the filter full of water, and to withstand cleaning and occasional moving. See Figure 4.34.

RDIC's receptacle is made from food grade quality PET (polyethylene-terephthalate) plastic and is produced using a blow mould process.

RDIC had the mould manufactured in Vietnam and brought to Cambodia. Following a small amount of training - a local firm manufactures the plastic receptacles with PET imported from Taiwan.

### 3. Fitting ring

The fitting ring is designed to help protect the receptacle from damage within the plastic receptacle and to help lift the filter element to reduce damage to the clay rim. It is made from plastic. RDIC has two slightly different sizes to accommodate slight variations in final filter element size. See Figure 4.35.

### 4. Plastic faucet

A small plastic faucet with durable ceramic interior is included in the package with a small length of plastic pipe. See Figure 4.36.

### 5. Cleaning brush

A plastic bristle brush (nail brush sized) is provided for scrubbing the clay filter element and loosening the filtered dirt, and dead bacteria and viruses. These can be purchased locally. See Figure 4.37.

### 6. RDIC Ceramic Filter Maintenance and Use Brochure

RDIC had designed an instruction brochure which is printed locally in colour.

|                              |
|------------------------------|
| PREPARATION OF RAW MATERIALS |
| MIXING OF CLAY COMPONENTS    |
| FORMING CLAY CUBES           |
| PRESSING FILTERS             |
| FINISHING FILTER SURFACES    |
| DRYING FILTERS               |
| FIRING FILTERS               |
| FLOW-RATE TESTING            |
| SILVER PAINTING              |
| PACKAGING                    |



**Figure 4.34 Plastic Receptacle**



**Figure 4.35 Fitting ring**



**Figure 4.36 Plastic Faucet (tap)**



**Figure 4.37 Cleaning brush**

### Assembly of Filter Package

1. Drill a hole in the plastic receptacle to insert the faucet pipe.
2. Place the faucet, brush and pamphlet in a plastic bag and staple it closed. Place the bag at the bottom of the receptacle. Then place the plastic ring on the rim of the receptacle. RDIC has two ring sizes to accommodate slight variations in filter size as they come out of the kiln, and to ensure a tight fit. Try each ring size to determine which fits the filter best. See Figure 4.38.
3. Place the filter element into the receptacle tank. See Figure 4.39.
4. Now place the lid on top and tape down with sticky-tape. See Figure 4.40 and Figure 4.41.



**Figure 4.38** Receptacle, faucet, instructions, brush and fitting ring



**Figure 4.39** Filter element added to Filter Package



**Figure 4.40** Filter Package with lid



**Figure 4.41** Filter Package taped for distribution

## Replacement Ceramic Filter System Parts

RDIC generally recommends that the **filter element be replaced every 2 years**. Recent studies have indicated no reduction in effectiveness for up to four years as long as the filter element is not broken or cracked (Brown and Sobsey, 2006).

To assist with supporting continued use of filters by community members, it is important to make sure replacement parts are easily available.

RDIC provides the following parts in a Replacement Ceramic Filter Pack:

- filter element,
- fitting ring,
- plastic faucet,
- brush for cleaning filter, and
- instruction brochure.

NOTE – in the standard replacement pack, the plastic receptacle is not provided due to its robustness.

In assembling the Replacement Ceramic Filter Pack, RDIC puts a piece of polystyrene at the bottom of a cardboard box and then places the ceramic filter, brush and tap in the box. Another piece of polystyrene is placed on top of the pot with an instruction pamphlet. The box is then taped closed.

RDIC also uses woven baskets to prevent breakage during transportation. See Figure 4.42 and Figure 4.43.



**Figure 4.42 Replacement Filter Kit in box**



**Figure 4.43 Replacement Filter Package in basket**



## Modification for High Volume Use



**Figure 4.44 Ceramic Water Filter System with modifications to allow 20L container to be inverted to provide additional storage for pre-filtered water (see also Figure 1.4).**

RDIC supports modification of its ceramic water filter through the addition of a 20L plastic tank, where high volumes of use require constant refilling of the water filter. RDIC does not make this modification themselves, but provides advice to others on how to do so.

1. Locate a 20L plastic water tank for use with the filter – such as those used with water cooler systems. The tanks should be laterally symmetrical so that it can balance steadily upside down when attached to the filter. Clean the tank/bottle.
2. Cut a hole in the centre of the lid of the plastic receptacle that is the same size as the nozzle of the tank/bottle. Place the lid back onto the plastic receptacle.
3. Fill the tank/bottle with water and turn upside. The filter element can be filled with water initially to maximise the amount of water filtered with this process.
4. The water pressure of the filter will stop the tank from emptying out immediately. As the water filters through, the tank will slowly empty, filling the filter element with water to filter.

## Chapter 5 Occupational Health and Safety and Environmental Management

RDIC has identified health, safety and environmental issues associated with filter production and continues to take steps to address them. Some health, safety and environmental issues that should be taken into consideration when preparing a production facility include:

### 5.1. Occupational Health and Safety

As with any manufacturing process, there are a number of potential hazards to workers.

The primary areas of risk to workers and possible precaution actions are listed in the table below.

*Many types of clay contain crystalline silica, a suspected carcinogen. It is the fine particles (the respirable fraction) of crystalline silica that can penetrate the gas exchange region of the lungs, and cause silicosis and lung cancer. Management of clay dust in the work environment is a key worker safety issue for this manufacturing process.*

**Table 5.1 Occupational Health and Safety Considerations of Filter Manufacture**

| Plant           | Hazard and Source  | Actions - Precautions  |
|-----------------|--|--|
| Elephant's foot | Crush to foot if elephant's foot not controlled properly, or is becomes 'heavier' due to fatigued muscles from constant use.   | Wearing covered shoes (preferably steeled capped), being systematic in movement through the brick pile, keeping feet out of line of movement.  |
| Hammer Mill     | Crush to hand when shifting/freeing brick in input chute at the top of the hammer mill.<br><br>Inhalation of dust escaping from the hammer mill input chute, and from the output chute when changing rice bags over.<br><br>Dust in the eyes causing irritation and infection. | Identify and mark a safe level on the chute above which the operator may safely shift crushed brick into the hammer mill. Turn off the mill when freeing brick in the input chute.<br><br>Wear appropriate mask and goggles<br><br>Use a fan to blow dust directly away from operators.<br><br>Wear safety goggles. Use two operators to change over bag to minimise the time dust emitted into the air from bottom of the mill. |



|                        |   |  |
|------------------------|---|--|
| Clay Mixer             | <p>Inhalation of dust during dry mixing process.</p> <p>Crush to hand when extracting clay from sides of mixer when in the tipped position.</p> | <p>Keep lid to mixer closed throughout mixing process. Consider possibility of a smaller opening for pouring in clay and husk powders.</p> <p>Turn the blades off during this process.</p>   |
| Hydraulic Press        | <p>Crush to hand or arm during operation of the press.</p>  | <p>RDIC runs the press on a very low speed to minimise the chance of crush injury.</p> <p>The second plastic bag could be placed over the clay cube before operating the press.</p>  |
| Kiln                   | <p>Inhalation of smoke from fires.</p> <p>Burns to feet and hands when removing ashes from kiln, or if removing pots too early.</p>             | <p>Use high chimneys to disperse the smoke. Avoid greenwood (freshly cut down), and ensure fuel is fully dried before using in the kiln. Wear appropriate mask when removing ashes from kiln. Locate the kiln a suitable distance from other work areas.</p> <p>Wear gloves and covered shoes.</p> |
| Transport of materials | <p>Back and muscle strain and injury from transporting materials around the site.</p>   | <p>Locating materials and plant in appropriate locations to minimise physical labour. Use of trolley's or vehicles to move materials around the site. See Figure 4.19 and Figure 5.1</p>   |



**Figure 5.1 Trolley used to transport raw materials onsite**

## 5.2. *Environmental Management*

- Sourcing the clay – consideration should be given to the legality of the clay source, and the environmental impact of extraction processes – ie consideration should be given to illegal or unsustainable land clearing, safety and sustainability of the site and its management, and downstream water pollution effects from the clay pit.
- Sourcing of fuel – utilising wood to fuel the kiln may encourage deforestation or habitat destruction in the local environment, leading to an unsustainable production process. Consideration of alternative fuel sources – such as waste products is encouraged.
- Air pollution – the type of fuel, its condition, and the firing practice used has a major impact on the quantity of smoke pollution produced by the kiln fires and the efficiency of the fires. Greenwood (freshly cut down) produces high quantities of smoke.

It is recommended by some sources that wood should be at least 1 year old before burning. Additionally wet wood produces high quantities of smoke. Wood containing high volumes of water reduces the temperature of the fire – because much of the fire's heat is required to evaporate the water before burning can occur. When the temperature decreases, much of the organic matter of the wood is released as smoke particles rather than being fully burned and utilised.

Overloading the kiln fires with wood without sufficient oxygen to fully burn will greatly increase the production of smoke, decrease the efficiency of the fires and therefore increase fuel requirements.

The positioning of the kilns should be considered carefully in terms of impact of smoke on workers and the surrounding community.

Diesel generators – used to power machinery where reliable electricity grids are not available - also release particulate pollution. Diesel generators, if used, should be maintained to minimise pollution.

- Noise pollution – the primary sources of noise pollution from the manufacturing process are the diesel generator and the hammer mill. The timing of operation and location of the facility will affect whether the noise from generators or plant will have a negative impact on the surrounding community. Maintenance of machinery will also help to minimise noise and its effects on workers and the community.
- Dust pollution – the crushing of the bricks, and the pouring of clay powder and rice husks, create small dust particles in the air. This can cover vegetation, and affect air quality of surrounding area. Clay powder usually contains silica which is a known carcinogen. Measures to manage dust were dealt with in more detail in Section 5.1.
- Solid Waste – Plastic bags are currently a waste product from the RDIC manufacture process. Consideration is being given to opportunities to recycle these bags. Opportunities to re-use the ash in compost, or in other manufacturing processes could also be given.

## Chapter 6 Distribution and Education

### 6.1. Introduction

RDIC employs a number of different methods to ensure filters become accessible to community members following manufacture including through:

- schools;
- private distributors;
- non-government organisations (NGOs); and
- direct sales (from RDIC straight to end user) – most minimal form.

Whichever method of distribution is employed, education of distributors and users is integral to the success and sustainability of ceramic water filter technology.

Key issues to consider in distribution strategies are:

- ensure appropriate training and education material is provided to the distributor in the short and long term so that they are capable of explaining the operation and maintenance requirements, and answering questions about the filter;
- the distributor needs access to educational and instructional material to provide to the end user to ensure correct maintenance is conducted in the long term;
- an ongoing connection between the distributor and the community is important – such a role would provide an ongoing access point for questions and replacement supplies. Additionally, a long term presence of the filters in a community would continue to reinforce the value of filters and remind people about the opportunity to access replacement parts or a later opportunity to buy a filter.

Ceramic water filters are not a passive resource, they require ongoing management and maintenance by users. Therefore, like computers, „after sales support’ is essential for ongoing and appropriate use of ceramic water filters.

For the ongoing sustainability and viability of water filtration programs, RDIC considers it essential that water filters are sold to users for a sustainable price. This means the cost of production (plus any required supplier’s profit). This position is supported by research on sustainability by Brown and Sobsey (2006).

RDIC’s own experience indicates that villages where filters were provided at no cost, or at a significantly subsidised rate initially, may have a slower uptake of technology into the future, as villagers seem to be less willing to pay themselves to replace the filters when it is necessary, instead perhaps waiting for when they may be provided for free in the future.

It is therefore highly recommended that filters be provided under a sustainable cost structure, and use of local entrepreneurs to distribute, and potentially manufacture, is likely to contribute to the sustainability of the uptake and use of the technology in the long term. RDIC’s Price List is included at Appendix C as an example.

## 6.2. Education Materials

One of the most important aspects of an effective water filter implementation program is education. RDIC has developed an extensive education program that links with the distribution of filters as well as other programs (such as school rainwater tanks and hand-washing bays).

RDIC has also developed some key media that it uses in a range of educational settings, and that reinforce the requirements for filter care and maintenance including:

- Instruction Brochure provided with the filter;
- Colour posters;
- Flip chart;
- Educational Video.

These are described in more detail below.

It is essential that all elements of the RDIC Water Filter Education Program reinforce the same messages to villagers, community members, and distributors to ensure correct use and maintenance practices are retained and implemented. For this reason the **'RDIC Ceramic Water Filter Education and Maintenance – Key Messages'** has been produced and is updated as needed. The January 2008 version of this document is at Appendix D.

Note: RDIC has the facilities to produce all education material (print, audio, video) and can work in conjunction with the partner so that all material is produced in the appropriate language with cultural sensitivity. RDIC charges a fee for this service.

### Ceramic Water Filter Instructional Brochure

The instructional brochure provides diagrams and text to explain to customers the key requirements for using and maintaining the water filters safely. It is available in English and Khmer for use by Cambodians and for the use of NGOs and their employees. A copy of the ceramic water filter instructional brochure is at Appendix E.

### Water Filter Education Poster and Flip Chart

The Water Filter Education Poster is given to schools, or communities (e.g. coffee shops) to post with the filters for message reinforcement. They can also be provided to individual families who purchase the filter.

The water filter education flip chart is used when it is not possible to use the video or for a small family group. The flip charts describe the ceramic filters and provide the prompt for instructing on filter maintenance. A copy of the poster and flip chart is at Appendix F.

### Community Water Filter and Hygiene Education Video

The purpose of the video is to teach students and community members the need for a water filter, by explaining about the bacteria that is present in source waters, how filters work, and how to maintain them.

The video shows:

- the manufacturing process for the filters in brief;
- how the filter is assembled;

- how to set up the filter in the home (including that it is in the shade and on a stand off the ground);
- using puppets, that the filter strains dirt and bacteria from the water, as well as the role of the silver nitrate in killing bacteria in the water
- the different steps for cleaning the filter element, as well as the receptacle
- shows not to touch the faucet, the outside of the filter element, nor to put your hands in the receptacle.

The educational video is available in Khmer, and also with English subtitles. The video is available on DVD at cost price.

### *6.3. RDIC's Distribution and Education Program*

RDIC uses a number of techniques for distributing ceramic water filters. These methods of distribution are integral to designing and implementing the RDIC Ceramic Water Filter Education Program.

#### 1. Education and Promotion through Schools

RDIC targets schools for education and promotion of ceramic water filters to improve the understanding of Cambodia's future generations on hygiene and health issues, and to provide a safe and healthy school environment to maximise educational opportunities for Cambodia's children. The schools program is generally sponsored by RDIC donors, and there is no charge for the school systems that are implemented. Teachers are also given the opportunity to be filter distributors within the community.

#### **Teacher Training**

RDIC offers opportunities to local school teachers to distribute filters within the community. Teachers are also responsible for maintaining water filters provided to each classroom. To perform these functions teachers are given training about clean drinking water and ceramic filters including ceramic filter manufacturing, use and maintenance. RDIC demonstrates the filter in action as well as the correct cleaning techniques.

RDIC provides each teacher with a filter for use in their home, and provides a follow-up home visit to provide individual training in filter use and maintenance. Teachers in schools close to RDIC are also invited to come to RDIC for a factory tour and training on the manufacturing process and our agricultural projects.

There are a number of benefits of having teachers as distributors of ceramic water filters:

- Teachers are often respected members of the community with recognised education and knowledge that give the filters credibility
- Being responsible for distribution not only increases the respect for teachers in the community, but provides an opportunity for teachers to supplement their incomes and therefore decreases their need to seek additional fees from students (a practice that is understood to be common in Cambodia to supplement low teaching wages).

RDIC establishes letters of agreement with the schools to ensure there is clear understanding of the roles of the school in maintaining equipment – ceramic water filters, rainwater tanks, toilets, hand-washing stations.

#### **Student Education**

Using a puppet show, RDIC's educational team teaches up to 50 students at a time about health, hygiene and safe drinking water. RDIC discusses contamination of groundwater by arsenic (in regions where appropriate) and pollution, and encourages treatment of water against pathogens by boiling, chemical treatments, or water filters. Students are quizzed on key messages at the end and provided with free drink bottles to encourage the use of clean drinking water and re-hydration.

#### **Provision of Filters**

Two water filters are provided for each classroom in the school at no cost.

## 2. Education and Distribution through Village Group Leaders – Cluster Training

RDIC also meets with and utilises Group Leaders within the villages to promote and distribute filters to households. It is very important for successful filter uptake within a village that village leaders support and encourage the use of ceramic water filters.

To engage with Village groups, RDIC meets with a Group Leader (who is generally responsible for about 15 families) and teaches them about the importance of safe drinking water, the risk of high arsenic in groundwater, and the use of ceramic water filters to treat drinking water.

RDIC provides the Group Leader with a ceramic water filters to sell onto community members (\$8) who may on sell for \$8.50 or \$9.

The Group Leaders will normally have access to a filter prior to a community meeting being held. This gives them an opportunity to try the filter, ask questions, understand how it works and increases their support of the filter.

RDIC often runs cluster training for a group of community members once support is shown by the Group Leader. Training in a cluster increase uptake as individuals buying the filter, or asking questions influences those around them, people learn more and are more likely to support a technology being taken up by neighbours.

The Group Leader has about 10 filters to sell, and does not need to pay any money to RDI up front, just pass on \$8 to RDI for each filter sold.

## 3. Distribution through private distributors

RDIC has a large network of distributors that is now starting to grow more in the provinces. Distributors may have a stall at the market, a shop front on the road, be a pharmacy, or a government building or health centre. Distributors are trained on production methods and shown an information video. The filter is demonstrated and its output is compared with boiled water (which retains sediment).

Distributors have access to RDIC filters for \$8 and can then onsell for a profit.

RDI encourages distributors by providing a free filter if they sell 15 or more in a month.

RDI is working towards a private distribution network where distributors can then onsell to a number of distributors in the provinces.

## 4. Direct sales to households

RDIC undertakes limited direct sales to households – but those in the local areas may come to get one. Limited training is provided but the brochure is provided.

## 5. Distribution by third party NGOs

Major distributors of RDIC's ceramic water filters are 3<sup>rd</sup> party NGOs, who see the filters as integral to implementation of their programmes and successful completion of their developmental goals. RDIC takes major orders from 3<sup>rd</sup> party NGOs



## Chapter 7      References and Further Information

---

1. Brown, J. and Sobsey, M, 2006, *Independent Appraisal of Ceramic Water Filtration Interventions in Cambodia: Final Report* – Submitted to UNICEF 5 May 2006.
2. IDE, 2003, *Ceramic Water Purifier Cambodia Field Trials: IDE Working Paper Number 1*.
3. Brown, J. and Sobsey, M, 2006, *Independent Appraisal of Ceramic Water Filtration Interventions in Cambodia: Final Report* – Submitted to UNICEF 5 May 2006.\*
4. Brown, J.M, 2007. *Effectiveness of Ceramic Filtration for Drinking Water Treatment in Cambodia*. Dissertation, (PhD.) University of North Carolina - Chapel Hill.\*
5. Gelders, Thijs. 2007. *Cambodia - December 2007 Proposal to increase the final quality and improve the working conditions for the production of ceramic water filter pots*. Unpublished report provided to RDIC.\*
6. Lantagne, D.S. 2001 (a). *Investigation of the Potters for Peace Colloidal Silver Impregnated Ceramic Filter - Report 1: Intrinsic Effectiveness*. Submitted to Jubilee House Community. <http://www.edc-cu.org/pdf/report1-final.pdf> \*
7. Lantagne, D.S. 2001 (b). *Investigation of the Potters for Peace Colloidal Silver Impregnated Ceramic Filter - Report 2: Field Investigations*. Submitted to Jubilee House Community. <http://pottersforpeace.org/wp-content/uploads/alethia-report-2.pdf>
8. NASA CASI (National American Space Authority – Centre for Aerospace Information), 2007, *Water Treatment Makes a Big Splash*, Spinoff  
[http://www.sti.nasa.gov/tto/Spinoff2004/er\\_1.html](http://www.sti.nasa.gov/tto/Spinoff2004/er_1.html)
9. National Institute of Statistics (Cambodia), 2000, *Cambodia Demographic and Health Survey, 2000; Preliminary Report*.  
<http://www.childinfo.org/MICS2/nat/MICSrepz/Cambodia/PRELIMrj.pdf>
10. Orton Ceramic Foundation, 2008, *Cone Equivalent Temperatures*,  
<http://www.ortonceramic.com/resources/reference/cone.chart.C.html>.
11. The American Ceramic Society, 2005, 'Kiln Firing Chart', *Pottery Making Illustrated*.  
<http://www.pottery-making.org/KilnFiringLayout.pdf>
12. WHO, 2004, *Guidelines for Drinking-water Quality: Third Edition, Volume 1 Recommendations*.
13. WHO, 2007, *World Health Statistics 2007: Risk Factors*  
[http://www.who.int/whosis/whostat2007\\_4riskfactors.pdf](http://www.who.int/whosis/whostat2007_4riskfactors.pdf)
14. WHO, 2007, *World Health Statistics 2007: Mortality*  
[http://www.who.int/whosis/whostat2007\\_1mortality.pdf](http://www.who.int/whosis/whostat2007_1mortality.pdf).
15. Vu, K.B., Kaminiski, D., and Nune, L., „Review of Arsenic Removal Technologies for Contaminated Groundwaters’ Argonne National Laboratory, Argonne, Illinois, operated by

the University of Chicago for the United States Department of Energy under Contract W-31-109-Eng-38. <http://www.ipd.anl.gov/anlpubs/2003/05/46522.pdf> .

Further information can be provided upon request. Please contact RDIC via its website [www.rdic.org](http://www.rdic.org).

## Appendix A Filter Efficacy Tests

When initially developing manufacturing processes for ceramic water filters it is necessary to test the appropriateness of components, mixing techniques, firing temperatures and methods, by testing the efficacy of ceramic filters produced.

This efficacy testing is also employed when changing, or reviewing production methods, and as part of overall quality assurance.

The overall objective of a ceramic water filter is to produce water that is of drinking water quality. The primary international reference for drinking water is the World Health Organisation's Guidelines for Drinking Water Quality ([http://www.who.int/water\\_sanitation\\_health/dwg/guidelines/en/](http://www.who.int/water_sanitation_health/dwg/guidelines/en/)). These guidelines do not dictate the requirements for drinking water quality, instead individual nations are able to implement them in a way the best suits their needs including through national guidelines.

Testing of the effectiveness of ceramic water filters should give consideration to these guidelines and any national guidelines operating in the country of interest. Note, the WHO is currently finalising guidelines for point of use water treatment for drinking which will provide additional guidance.

As the key objectives of ceramic water filters are to remove diarrhoea causing bacteria, viruses, some core quality assurance tests that can be used for establishing a manufacturing process, and for ongoing quality assurance testing are identified here

Additionally, filters provide a very sound way to reduce turbidity in drinking water. Testing of turbidity not only indicates the ability of a filter to achieve this, but where a turbidity test comes back high, it indicates the likelihood of cracks within the filter.

### **IMPORTANT**

Care needs to be taken in testing the microbiological removal efficacy of the filters. Silver is initially leached out of the filters as water is added. Even very small amounts of silver leached into a sample will have a very strong biocidal impact on any bacteria in the filtered water. Therefore microbiological testing can provide a false negative by showing no live microbes, when they have only been killed by the leached silver rather than by action of the filter - straining or contact with silver fixed in the filter itself.

Any microbiological testing needs to occur after significant flushing of the filters with water - perhaps up to 3 months of constant use.

The longer samples are left aside prior to microbiological testing, the greater the contact time of any leached silver with the sample and therefore the poorer the result of the microbiological testing.

Therefore samples (particularly for filters less than 12 months old) should be tested immediately after they are filtered to reduce the contact time of any leached silver.

NOTE: Other tests may be needed based on individual risks from specific regions.

**Table 1 Key Tests for Ceramic Water Filter Efficacy**

| <b>Pathogen/<br/>Contaminant</b> | <b>Indicator/Units</b>              | <b>Test</b>   |
|----------------------------------|-------------------------------------|---|
| Pathogenic bacteria              | Escherichia coli                    | Membrane filtration method - USEPA Method 1604<br><br>United States Environment Protection Authority, 2002, Method 1604: Total coliforms and Escherichia coli in water by membrane filtration using a simultaneous detection technique (MI Medium). Publication EPA-821-R-02-024. USEPA Office of Water (4303T), Washington, D.C.   |
|                                  | Escherichia coli                    | Coliscan Easygel which allows remote testing outside of a laboratory.<br>*provided in full here   |
|                                  | Coliforms                           | Microbiology Laboratories, 2008,<br><a href="http://www.microbiologylabs.com/Home/Our_Meth ods/Coliscan_Easygel/Coliscan_Easygel_Instru ctions">http://www.microbiologylabs.com/Home/Our_Meth ods/Coliscan_Easygel/Coliscan_Easygel_Instru ctions</a>   |
| Enteric Viruses                  | MS2 bacteriophage                   | USEPA - Method 1602<br><br>United States Environment Protection Authority, 2001, Method 1602: Male-specific (F+) and somatic coliphages in water by single agar layer (SAL) procedure. Washington DC: USEPA Office of Water, Publication EPA 821 - R-01-029   |
| Turbidity                        | NTU (Nephelometric Turbidity Units) | 1) APHA, 1998 - Method 2130 - Turbidity<br><br>APHA (American Public Health Association), 1998 - „Standard Methods for the Examination of Water and Wastewater’ 20th Edition, Washington DC - Method 2130 - Turbidity.<br><br>2) Secchi Disks or Transparency Tubes<br><br>Waterwatch Australia Steering Committee, 2002, Waterwatch Australia national technical manual- Module 4 physical and chemical parameters.<br><a href="http://www.waterwatch.org.au/publications/module4/turbidity.html">http://www.waterwatch.org.au/publications/module4/turbidity.html</a> |

*'Detection of Waterborne Coliforms and E. coli with Coliscan Easygel'*

Directly Sourced Microbiology Laboratories, 2008:

[http://www.micrologylabs.com/Home/Our\\_Methods/Coliscan\\_Easygel/Coliscan\\_Easygel\\_Instructions](http://www.micrologylabs.com/Home/Our_Methods/Coliscan_Easygel/Coliscan_Easygel_Instructions)

„Introduction:

The Coliscan Easygel medium is a patented formulation for water testing. It contains a sugar linked to a dye which, when acted on by the enzyme  $\beta$ -galactosidase (produced by coliforms including E. coli), turns the colony a pink color. Similarly, there is a second sugar linked to a different dye which produces a blue-green color when acted on by the enzyme  $\beta$ -glucuronidase. Because E. coli produces both  $\beta$ -galactosidase and  $\beta$ -glucuronidase, E. coli colonies grow with a purple color (pink + blue). The combination of these two dyes makes possible the unique ability to use one test to differentiate and quantify coliforms and E. coli. (Because E. coli is a member of the coliform group, add the number of purple colonies to the number of pink colonies when counting total coliforms.)

Instructions:

Either collect your water sample in a sterile container and transport the water back to the test site, or take a measured water sample directly from the source and place directly into the bottle of Coliscan Easygel. Water samples kept longer than one (1) hour prior to plating, or any Coliscan Easygel bottle that has had a sample placed into it for transport longer than ten (10) minutes, should be kept on ice or in a refrigerator until plated.

Label the petri dishes with the appropriate sample information. A permanent marker or wax pencil will work.

Sterilely transfer water from the sample containers into the bottles of Coliscan Easygel (Consult the following table for rough guidelines for inoculum amount). Swirl the bottles to distribute the inoculum and then pour the medium/inoculum mixtures into the correctly labeled petri dishes. Place the lids back on to the petri dishes. Gently swirl the poured dish until the entire dish is covered with liquid (but be careful not to splash over the side or on the lid).

| Inoculation of Coliscan Easygel                       |                 |
|---|-----------------|
| Water Sources   | Inoculum Amount |
| Environmental:<br>river, lake, pond, stream,<br>ditch | 1.0 to 5.0 mL   |
| Drinking water:<br>well, municipal, bottled           | 5.0 ml          |

The dishes may be placed right-side-up directly into a level incubator or warm level spot in the room while still liquid. Solidification will occur in approximately 40 minutes.

Incubate at 35° C (95° F) for 24 hours, or at room temperature for 48 hours. (See comments on incubation)

### Inspect the dishes

Count all the purple colonies on the Coliscan dish (disregard any light blue, blue-green or white colonies) , and report the results in terms of E. coli per ml of water. NOTE: To report in terms of E. coli per 100 ml of water, first find the number to multiply by. To do this: first, divide 100 by the number of ml that you used for your sample. Then, multiply the count in your plate by the result obtained from #1. For example, a 3 ml sample,  $100 / 3 = 33.3$ . So, 4 E. coli colonies multiplied by 33.3 will equal 133.2 E. coli per 100 ml of water.

Count all the pink and purple colonies on the Coliscan dish (disregard any light blue, blue-green or white colonies) and report the results in terms of coliforms per ml of water.

Do one of the following prior to disposal in normal trash:

Place dishes and Coliscan bottles in a pressure cooker and cook at 15 lbs. for 15 minutes. This is the best method.

Place dishes and Coliscan bottles in an ovenproof bag, seal it, and heat in an oven at 300° F for 45 minutes.

Place dishes and Coliscan bottles in a large pan, cover with water and boil for 45 minutes.

Place 5 ml (about 1 teaspoon) of straight bleach onto the surface of the medium of each plate. Allow to sit at least 5 minutes. Place in a watertight bag and discard in trash.

### Comments on Incubation:

Micrology Laboratories, LLC in-house studies indicate that Coliscan can effectively differentiate general coliforms from E. coli when incubated at either room temperatures or at elevated temperatures (such as 90-98° F). However, some further explanation may be helpful.

There is no one standard to define room temperature. Most would consider normal room temperature to vary from 68-74° F, but even within this range the growth of bacteria will be varied. Members of the bacterial family Enterobacteriaceae (which includes coliforms and E. coli\*) are generally hardy growers that prefer higher than room temperatures, but which will grow at those temperatures. They tend to grow at a faster rate than most other bacterial types when conditions are favorable. It is therefore logical to try to place inoculated dishes in a "warm" place in a room for incubation if a controlled temperature incubator is not available. It is a very easy task to make an adequate incubator from a box with a 40-60 watt bulb in it to provide heat at an even rate. One can also use a heat tape such as it is used to prevent the freezing of pipes in the winter as your heat source.

Our general instructions indicate that incubation times for coliforms (including E. coli) are generally 24-48 hours at elevated temperatures (90-98° F) and 48 or more hours at room temperatures. At elevated temperatures, no counts should be made after 48 hours as any coliforms present will be quite evident by that time and if new colonies form after 48 hours as any coliforms present will be quite evident by that time and if new colonies form after 48 hours they are most likely not coliforms, but some other type of slow growing organisms that should not be included in your data.

At room temperatures, the best procedure is to watch the plates by checking them at 10-12



hour intervals until you observe some pink or purple colonies starting to form and then allowing another 24-30 hours for the maturation of those colonies. Since the coliforms (including *E. coli*) are generally the faster growing organisms, these will be the first to grow and be counted. Colonies that may show up at a later time are likely to not be coliforms. As you can see, there are advantages to incubating your dishes at elevated temperatures. First, you can count the results earlier. At 95° F, it is often possible to do accurate counts at 18-20 hours of incubation. There is also less probability of variation from batch to batch when the incubation temperatures are kept at one uniform level. And a higher incubation temperature will tend to inhibit the growth of non-coliforms that may prefer lower temperatures.

\**E. coli* is the primary fecal coliform, however, *Klebsiella* is sometimes of fecal origin. Other general coliform genera include *Enterobacter* and *Citrobacter*.

#### Interpretation of Results

This test method utilizes well established, widely accepted criteria for the recognition of coliforms and *E. coli* and proper application of the method will result in accurate results. Therefore, if you suspect that your water is dangerously contaminated based on the results you get using Coliscan Easygel, you should contact your local health department and ask for their help in performing an official assessment of water.

Non-fecal coliforms are widely distributed in nature, being found both as naturally occurring soil organisms, and in the intestines of warm-blooded animals and humans. Fecal coliforms are coliforms found naturally only in the intestines of warm-blooded animals and humans. Fecal coliform contamination is therefore the result of some form of fecal contamination. Sources may be either animal or human.

#### General Notes on Differentiating Coliforms and *E. coli*

Generally, water containing *E. coli* (the fecal contamination indicator organism) should not be used for drinking water unless it is sanitized in some manner. Contact your local health department for guidelines regarding *E. coli* and coliforms in recreational waters. Inform them if you suspect that contamination may be occurring from a specific source.

Colonies which have the blue-green color are not exhibited any  $\beta$ -galactosidase activity (which is evidenced by the pink color). Because of this, they are not considered to be either coliforms or *E. coli* and therefore should be ignored when counting your coliform or *E. coli* colonies. Similarly, colonies which are white are exhibiting neither color-causing enzyme, and should also be ignored.

Colonies on the surface of the plate are exposed to the medium on only the underside of the colony. This causes these colonies to appear with much less of the indicator color. *E. coli* colonies may only have a slight purple tinge to them, and it may appear only in the center of the colony with the remainder of the colony being white. Similarly, coliforms on the surface may be light pink or white with a pink center'.

## **Appendix B RDIC Automated Water Spray System - for Clay Mixing**

## Appendix C Example RDIC Filter Price List - November 2007

| Item   | Price \$US<br>(\$US is a commonly used currency in Cambodia)  |
|--|---|
| Complete Filter Package (wholesale)  | \$8.00  |
| Complete Filter Package (to user)  | ~\$10.00 (though varies depending on the mark up required by distributors to cover costs and make a profit eg for transport in the provinces) |
| Replacement Filter Element (also called insert)  | \$3.00  |
| Replacement Plastic Receptacle (including lid)   | \$4.00  |
| Replacement Plastic Lid only   | \$0.50  |
| Replacement Faucet   | \$1.25 (or available in the markets)  |
| Blue Pipe (for the faucet)   | \$0.20  |
| Filter stand (cane)  | \$5.00  |
| Replacement Brochure   | Free  |
| Fancy Filter Package (this uses a more designer jar instead of the plastic receptacle) | \$10.00 (wholesale)   |
| Replacement designer jar   | \$5.00  |
| Supplier Educational materials   |   |
| Community Water Filter and Hygiene Education Video                                     | \$1.00/\$3.00   |
| Education Flip Chat – printed  | \$8.00  |

## Appendix D RDIC Ceramic Water Filter Education and Maintenance Key Messages

### *Drinking Dirty Water Can Make You Sick*

- Many drinking water sources in Cambodia have the potential to cause sickness.
- Sicknesses such as: diarrhoea, cholera, typhoid, hepatitis A and B can be caused by drinking polluted water.
- Surface water – lakes, ponds, rivers, streams – may carry pollutants from animal and human faeces, from dead animals, from rubbish and industrial waste, from fuel and oil washed off the road, from motos and cars washed in the lakes and ponds, or from pesticides that wash off agricultural fields.
- Groundwater may carry pollutants washed down through the soil from surface water sources, or may carry certain chemicals in high quantities that are bad for human health – such as arsenic, manganese and iron.
- Rainwater is usually of high quality. However, rainwater may carry contaminants from the roof such as and bacterial contamination from bird faeces. So it is best to divert the first water that comes off the roof in a storm (first flush) away from a rainwater storage tank.
- Storage of water is very important to keep it safe. Even if water is very pure at the beginning, poor storage can re-contaminate the water and make you sick. Water containers need to be:
  - out of reach of floodwaters,
  - in the shade (or covered) to prevent algal growth,
  - dispensed using a clean dipper, or tap and not through human contact, and
  - cleaned with a sterile cloth or brush.
- Next time you or someone you know is sick from diarrhoea, check where you got your drinking water from and how you treated and stored it. It may be contaminated.
- Drinking contaminated water is not the only way you can get sick. Cleaning your teeth or preparing fresh vegetables with contaminated water can also make you sick
- Additionally if you bathe or swim in VERY contaminated water, and splash water into your mouth, you may also get sick. So be careful what water gets into your mouth and your children's mouths. Teach your children not to drink water when bathing, or swimming.
- Wet does not mean clean. If you wash your plates, food containers and cutlery in untreated water, YOU NEED TO dry them completely in the sun. Complete drying will bacteria and organisms that live in the water and can make you sick. If your containers are clean **and dry** – water borne diseases cannot survive.

### How to Get Safe Drinking Water

- Whilst there are many ways your water can become polluted, the biggest risks for Cambodian drinking water at home is: contamination of the water by bacteria (from human or animal waste), and from high arsenic or manganese contamination in the groundwater.

- Ceramic water filters provide an effective and affordable means to treat surface water and shallow well water by removing turbidity (dirt suspended in the water), bacteria, and many viruses.
- Other ways to get safe drinking water is by:
  - rapid boiling for 15 minutes,
  - adding chlorine to the water (chlorine tablets can be purchased from pharmacies, markets – 12 tablets (25L) for 1200 riel), or
  - using biosand filters.

These are all safe ways to get safe drinking water.

- DO NOT USE A CERAMIC WATER FILTER, BOILING TREATMENT or a BIOSAND FILTER to treat arsenic laden water.
- Treated drinking water should be used for
  - drinking;
  - washing vegetables and cooking where boiling is not involved; and
  - cleaning your teeth.
- Items that will touch food – such as plates, cups, cutlery, pots – should be washed well with detergent and water then dried completely in the sun to kill any bacteria in the water.
- There is currently no really affordable or effective way to remove arsenic available in Cambodia from contaminated groundwater – though some measures may reduce the quantity a little - so where groundwater is contaminated with high levels of arsenic, you need to identify and use a new source of drinking water.
- Wells that are painted red have been tested and found to be unsafe to drink due to high levels of chemical contamination. Wells painted green have been tested and been found to have safe levels of chemicals. Wells not painted have not been tested.
- If you use well water and you live in areas known to have arsenic in the groundwater, you should get your well tested. Note that the concentration of arsenic in groundwater can change over time.

## How Ceramic Water Filters Work

Ceramic water filters;

- „strain’ the dirt and bacteria out of the water as it passes between the particles the ceramic filter element; and
- kill bacteria as it comes into contact with the silver solution

RDIC’s filters also contain laterite which helps bind viruses, removing them from the water.

The RDIC ceramic filter mixture contains clay and laterite and ground rice husks mixed with water.

- When clay is baked in the kiln it makes a strong container that can hold water. Water can pass between the particles of the clay, but dirt, bacteria, and other parasites cannot, they are kept behind in the filter. A normal clay pot only lets water seep through very very slowly
- In ceramic water filters, ground rice husks (or other organic material) are added to the clay mixture. The rice husks burn out in the high temperatures of the kiln, creating

thin clay walls with cavities in between. These thinner clay walls increase the speed that the water moves through the filter, whilst still requiring water to pass between clay particles and therefore still removing dirt and pathogens.

- Laterite added to the clay has a high amount of iron (Fe) in it. The iron has a positive charge when in the filter and seems to hold onto viruses which have a negative charge (like a magnet that holds onto metal – daek chhork). This can help remove viruses from the water.
- Silver also kills bacteria. It is used on airplanes, by NASA in space, and in hospitals as a disinfectant. The silver solution in ceramic water filters is very important in killing bacteria and inactivating viruses.

The filter element is set in a plastic receptacle tank with a plastic lid and a faucet (or tap).

The filter element is manually filled with 10 litres of source water. The water is purified as it seeps through the filter element at a rate of approximately 2 litres per hour. The plastic receptacle combined with filter element can store up to 35 L of water. For high volume needs, the filter system can be modified by cutting a hole in the lid and placing a 20 L water tank on top.

Whilst the filters do not remove chemical contaminants, having access to water filters enables communities currently dependant on chemical affected waters to access and treat alternative water sources, such as surface water, that filters would be unsafe to drink.

## Treating Water is a Big Responsibility

Treating drinking water is a big responsibility for parents and family members, and for teachers and students in schools.

- Filters are fragile. If you drop them and crack them, they may no longer function properly and should be replaced.
- Washing filters incorrectly can contaminate them. It is particularly important that the plastic receptacle is free from contamination, as only treated water should be in this container before it is used. If the water in the plastic receptacle becomes contaminated the filter may no longer be safe – this may cause you, your family, or your friends to get sick.
- Keys to successful treatment
  - Make sure you understand the rules very well. Ask questions if you don't understand. Go home and try it. Come back and ask your distributor or your teacher any more questions you have.
  - Get someone who understands the rules to take responsibility for cleaning the water filter at home, or in the school. Other people can help, but a single person should be aware of all water going into the filter, and how it is being looked after.
  - Implement the rules you have been taught.

## Using a Ceramic Water Filter Safely

- Select the cleanest source water you have – eg from a well that has safe levels of arsenic, from a rainwater tank, from a fast flowing stream or river, from a clean looking lake away from dead animals, or other peoples faeces or rubbish dumps.



- Do not drink, arsenic laden water (greater than 50 ppb).
- Identify who is responsible for filling up, cleaning and managing the water filter.
- Find a clean and safe place to store the filter – away from animals (eg dogs licking the faucet can contaminate it), floodwaters, toilets.
- The filter should be stored in the shade to prevent algal growth, and to protect the plastic which may break down in the sun. If the filter is placed in the sun algae may make the water taste unpleasant, and possibly contaminate it, and prevent proper treatment of the water.
- Cover the filter with a lid to prevent dust and insects which will clog the filter.
- Use a cloth over the top of the filter - tied on - to strain water if it is very dirty or has material in it.
- Fill up your filter regularly - eg 2-3 times per day if there are many people using the filter - so that you always have a supply of safe water for drinking.

#### Before using for the first time

- When you take a new filter home, fill and empty the clay filter element 3 times and dispose of this water (33L total). This will flush out any silver taste, tiny amounts of arsenic in the clay, and to remove the taste of the clay.
- Wash out the receptacle.

#### Cleaning the Water Filter

Cleaning of the clay filter element is DIFFERENT to cleaning the plastic receptacle. This is because the inside of the filter is where unclean water is placed, whereas the outside of the filter and the inside of the plastic receptacle should only ever be exposed to clean and treated water.

The clay filter element should not be exposed to soapy water because it is hard to rinse off and will make the water taste bad. Soap may also decrease the activity of the silver solution as a biocide.

General instructions for cleaning the filter system are provided here. A brochure has also been prepared that gives detailed procedures and should be followed.

#### ***Scrubbing the Clay Filter Element***

- Scrubbing the clay filter element is important to release the dirt, dust, and dead bacteria and organisms trapped on the inside of the filter, and to remove any build up of biofilm (slime) on the outside of the filter element.
- You should scrub the inside of the filter element **when the flow rate drops a lot, or every 2-4 weeks.**
- The outside of the clay filter element only comes into contact with the very clean filtered water. This surface should only be **scrubbed with filtered or boiled water**. The scrubbing brush should be clean – eg boiled in a pot of water, or cleaned with detergent and rinsed thoroughly.  
DO NOT TOUCH THE OUTSIDE OF THE FILTER ELEMENT WITH YOUR HANDS.
- The inside of the clay filter element is where the bacteria, dirt, and other impurities become trapped. As they build up, they slow down the flow of water. Sites for

collecting viruses also become clogged and the ability of the filter to deliver clean water is reduced.

- This surface needs to be **scrubbed with filtered, or boiled, water and a brush** to release the dirt and dead bacteria from the clay, it should then be rinsed out.
- Some clay may come away with the scrubbing, but it is minimal and will not affect the filter's effectiveness. The silver solution soaks right into the clay and **will not** be removed too much from scrubbing.

### ***Cleaning the Plastic Receptacle***

- It is most important that the plastic receptacle is ***cleaned properly***. The water is not cleaned within or after the plastic receptacle so if it gets contaminated here, it will be contaminated when you use it.
- If any bacteria or algae gets into the plastic receptacle it can become very contaminated – it is warm and wet inside, which creates an environment that grows lots of bacteria and algae.
- The inside of the plastic receptacle, and the plastic faucet should be cleaned with a ***firm clean cloth and soapy filtered (or boiled) water every 2-4 weeks***.
- Once cleaned, the plastic receptacle should be rinsed with fresh filtered or boiled water to remove the soap.
- After cleaning, the plastic receptacle should be air dried. When it is completely dry, any remaining water borne bacteria and pathogens will die.

### Life of a Water Filter – maintenance and replacements

- RDIC recommends you replace your filter element every 2 years.
- The filter element should be replaced sooner if:
  - It has been dropped (dropping may produce small cracks that you cannot see that may stop the filter working properly)
  - It is visibly cracked; or
  - After cleaning the flow rate is too slow.
- The plastic receptacle should be replaced if it is cracked, or broken
- The faucet should be replaced if it is broken.

Whilst RDIC recommends filter elements are replaced every 2 years, recent studies have indicated no reduction in effectiveness for up to four years as long as the filter element is not broken or cracked (Brown and Sobsey, 2006).

### **Frequently Asked Questions**

**Question 1: When I scrub the filter with the brush, clay comes off. Does this mean my filter will stop working? Does it mean the silver is coming off?**

**Answer 1:** No. The silver soaks into the pores deep within the clay so cannot be scrubbed off. Scrubbing that removes some clay may actually improve the

performance of the filter by opening up more sites for virus binding and silver action.

**Question 2 : The filter is too slow, and I can't get the water I need fast enough. What can I do?**

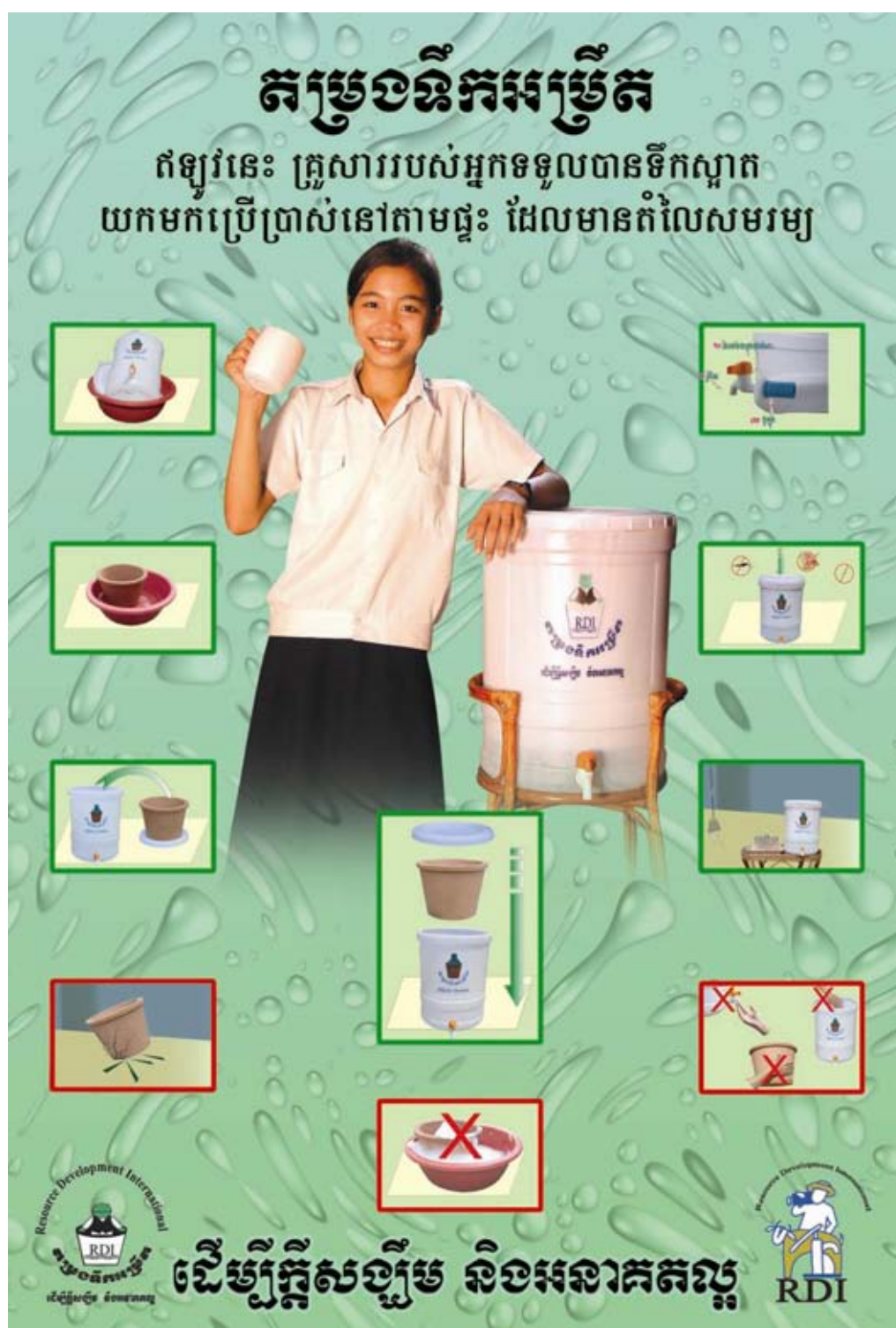
Answer 2: Scrub the inside of the filter and rinse out the material that is produced. If after scrubbing it is still too slow, replace the filter for a new one.

**Question 3: The outside of my filter element feels like jelly/slimy? Does that mean I need to clean it? Will it make me sick if I don't?**

Answer 3: Clean both the inside and the outside of the filter. The jelly substance is called biofilm. Often it is harmless and will not cause bad health, but sometimes it may have a negative effect.

## **Appendix E RDIC Ceramic Water Filter Instructional Brochures**

## Appendix F RDIC Ceramic Water Filter Education Poster and Flip Chart



## Water Filter Education Flip Chart

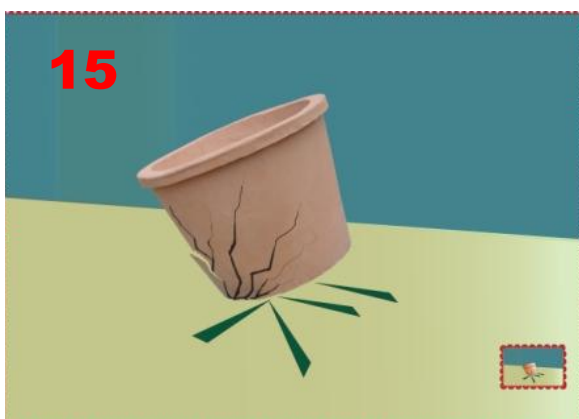




*Water Filter Education Flip Chart (continued)*



*Water Filter Education Flip Chart (continued)*



RDIC, 2007.

## **Appendix G      How to build a kiln**

## **Appendix H   Machine Diagrams**

Kiln

Drying Rack

Clay Mixer -

- Schematic Diagram
- Photos

Hydraulic Press

Alternative – Manual Press

Filter

## **Appendix I**

## **Factory Layout**

## **Appendix J      Instructional Videos**