Pure Home Water
Ceramic Filter Manufacturing Manual

T^2 LLC
Travis Reed Miller
Travis Russell Watters
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Massachusetts Institute of Technology
Department of Civil and Environmental Engineering
77 Massachusetts Ave, 1-143
Cambridge, Massachusetts

This is a first publication of the methods of production recommended by T^2 LLC for Pure Home Water, Ghana. It is by no means a fixed document, and should be amended with the best wisdom available from the experiences of manufacturing at the Pure Home Water factory in Tamale, Ghana.

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1 Introduction

To combat the lack of safe drinking water in Northern Ghana, Susan Murcott, Senior Lecturer at the Massachusetts Institute of Technology (MIT) founded the non-profit organization Pure Home Water (PHW) in cooperation with local Ghanaian partners in 2005.

PHW has two stated goals:

1. Provide safe water via household drinking water treatment and safe storage products to Ghanaians in need of safe drinking water, with special emphasis on the region of Northern Ghana.
2. Become locally self-sufficient and financially self-supporting.

(Pure Home Water, 2009)

During its first five years, PHW focused on distribution, training, and monitoring of Ceramic Pot Filters (CPFs) – a demonstrably effective method of home water treatment and safe storage (Johnson, 2004, p. 3; Oyanedel-Craver and Smith quoted in Kallman, 2009, p. 21; UNICEF, 2007, p. 4). . In order to more efficiently meet its stated goals, PHW has decided to pursue the local manufacture of CPFs as well.

The purpose of this manual is to document a manufacturing process that will produce filters of sufficient durability, flow rate, and removal efficiency to suit PHW's customers' need for safe drinking water.

PHW Staff, Local Potters of Gbalhai and MIT Team Members in January 2010

2 Method of Material Preparation

The first step in the manufacture of CPFs is the acquisition and preparation of the raw materials. One of the advantages of CPFs is the local availability of the raw materials necessary for their manufacture.

The four major raw materials required are:

- Clay, which shall be obtained from the pit in the village of Gbalhai to which PHW has obtained access via the sanction village Chiefs of Gbhalhai, Taha, and Nanton.

PHW Employee Digging Clay in Gbalhai

- Rice husk, which shall be obtained from local farmers (sawdust may be used as a substitute if rice husk is unavailable. However, the recommended recipe involves rice husk).

Rice Husk, Stored in Grain Sacks

- Water, which shall be obtained from a local source, such as the nearby Taha "dugout"[1]
- Fired ceramic materials for grog, i.e., either pre-fired pots or pre-fired bricks (optional).

2.1 Clay Preparation

After drying and breaking the clay clods dug from the ground, there are two possible methods of clay preparation; one, which involves pounding the clay using mortar and pestle, has been successfully demonstrated at the PHW factory. The other, which involves milling the clay through a hammermill, will need to be tested in order to determine if the existing PHW hammermill is capable of adequately crushing the clay or whether it can be adapted for this purpose.

Clay Dug from the Ground

PHW Employees Breaking Clay into Smaller Pieces and Laying it on Tarps

[1] A "dugout" is a source of untreated surface water, such as a man-made pond, used for water supply, including drinking water.

2.1.1 Drying and Breaking Clay

Equipment List:

- Tarp
- Bricks (or other weights)

Procedure:

1. Weigh down the edges of a tarp with brick or other sufficient weight. The tarp should be placed in a sunny area and should be of sufficient area to contain the clay once it has been broken into fist-sized pieces and laid out, unstacked.
2. Break the clay into smaller pieces, either by hand or by hand tools.
    a. If grinding the clay using mortar and pestle, the clay can be broken into fist-sized pieces.
    b. If grinding the clay by hammermill, the clay must be broken into 1/2” pieces because the smallest dimension of the hammermill feed chute which directs material into the grinding area is 5/8”.

Hammermill Components

3. Leave the clay to dry in the sun. Samples are sufficiently dry when, if broken apart, they show no color change in their centers due to remaining moisture. During Northern Ghana’s dry season, a period of 1-2 days is usually sufficient.

2.1.2 Grinding Clay Using Mortar and Pestle

Equipment List:

- 100-liter plastic bucket
  - If desired, plastic buckets of different volume and dimensions may be used; the goal is to line a receptacle with a grain sack that can store the desired amount of clay during clay processing.
- Bricks (or other weights)
- Clay
- Facemasks
- Grain sacks and ties
- Mortar and pestle
- Sieve box with 18x14 aluminum mesh (1.12 mm opening)
- Tarp
- Work gloves

Procedure:

1. Once the clay has dried, pound it into a powder using mortar and pestle. If desired, wear work gloves to protect against blistering. Wear a facemask to protect from dust inhalation. The particle size of the majority of the powder should be less than the sieve opening, i.e., less than 1.12 mm in diameter.

PHW Employees Grinding Dry Clay with Wooden Mortar and Pestles

2. In a wind-protected area, place a section of tarp with an area greater than the sieve box beneath the plastic bucket. Use bricks to pin down the edges of the tarp; the bricks will also be used to support the corners of the sieve box. Place the grain sack, open-mouthed, inside the plastic bucket, much like putting a trash bag into a trash can. If necessary, the sides of the sack may be split and rolled over the edges of the plastic bucket.

3. Place the sieve box on the plastic bucket such that its screen overlays the open grain sack.

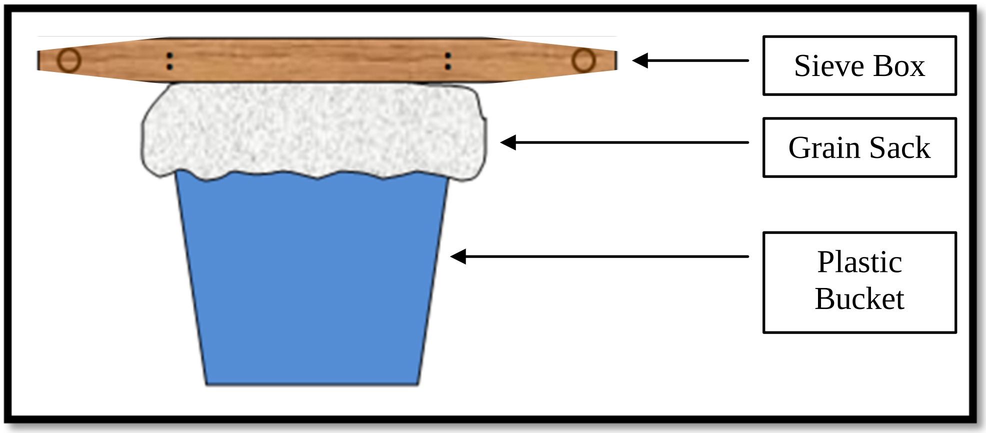


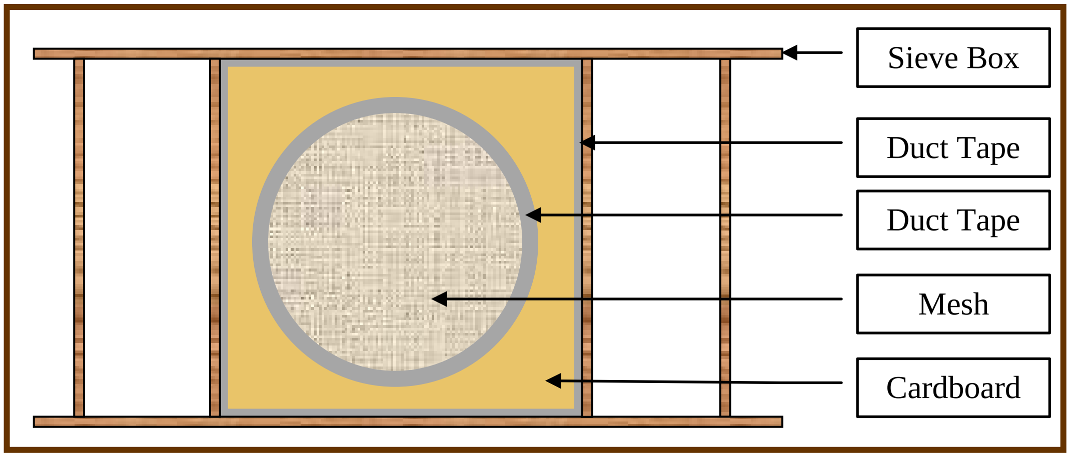
Diagram of Plastic Bucket, Grain Sack, and Sieve Set-up (Side View)

This method is an improvement on the method used in January 2010, shown in the image below. The January 2010 method involved making four short walls out of bricks, and placing a tarp into the middle of the walls to catch the sieved clay. It is cumbersome to collect the sieved clay from the tarp into a grain sack this way.

Sieve Box Set on top of Brick Walls and a Tarp

4. Pour the clay powder through the sieve such that it empties into the grain sack below. The purpose of this step is the removal of any non-clay particles (e.g., pebbles) that may collect in the powder. If such particles are allowed to remain in the powder and are incorporated into the filters, they may "pop" when firing and crack the filters.
5. It may be necessary to shake the sieve or gently move the clay around on top of the sieve to help it pass through. It is important to keep in mind that handling the mesh roughly will create larger openings, allowing larger pebbles to fall through.

6. If the diameter of the bucket is much smaller than the sieve area, it may be useful to cut a piece of cardboard to the dimensions of the inside of the sieve box, then cut a hole the size of the bucket in the middle of the cardboard, and secure the cardboard to the sieve box with duct tape, as diagrammed below in top-view.



Sieve Box (from Above) with Cardboard to Direct Clay into Mesh over Bucket

7. When necessary, collect any clay that missed the bucket and fell onto the tarp, and pour it through the sieve into the bucket.
8. When the grain sack is sufficiently full of clay, remove the sieve box and tie the grain sack closed. Store the grain sack in a shady area if possible.
9. The pebbles collecting on top of the sieve should be stored separately, for use as construction fill material if needed for another project.

2.1.3 Grinding Clay Using Hammermill

Note: This procedure should only be undertaken if it is found that the hammermill can sufficiently crush the clay without damaging it.

Equipment List:

- Brick (or other weight)
- Chair or bench
- Clay (dried, broken into small pieces)
- Duct tape
- Cardboard (roughly 6" x 12")
- Electrical generator (single phase, with diesel fuel, properly-rated oil, extension cords, and plug)
- Grain sacks and ties
- Hammermill (with single phase motor)
- Plastic Bucket
- Watch (or other timing device)

Procedure:

1. Place a plastic bucket under the waste chute of the hammermill.
2. Roll the cardboard around the radial chute of the hammermill, and use duct tape to hold its place, as diagrammed below. This is done because it is easier to attach the grain sack to the cardboard than to the radial chute itself.

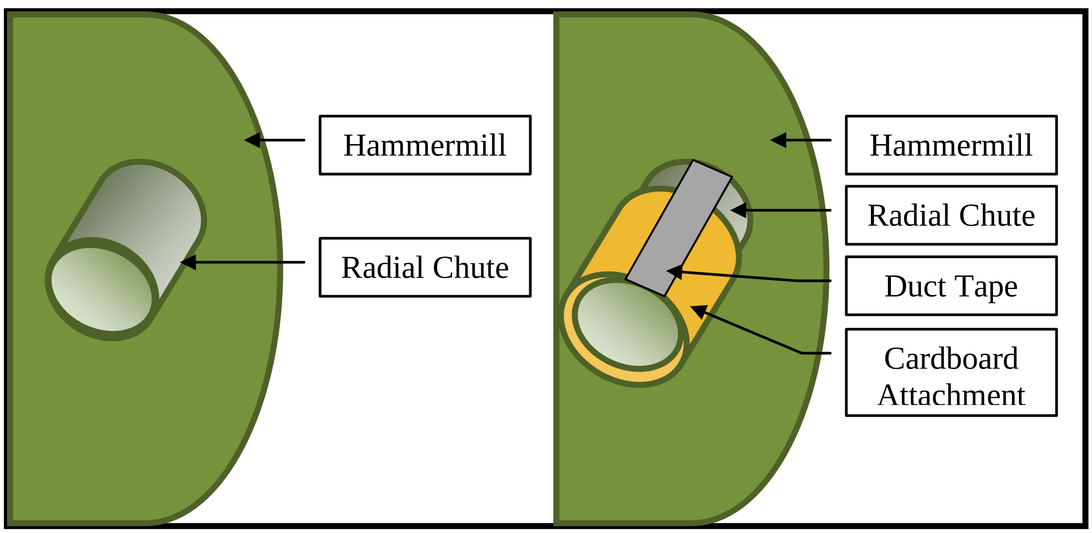
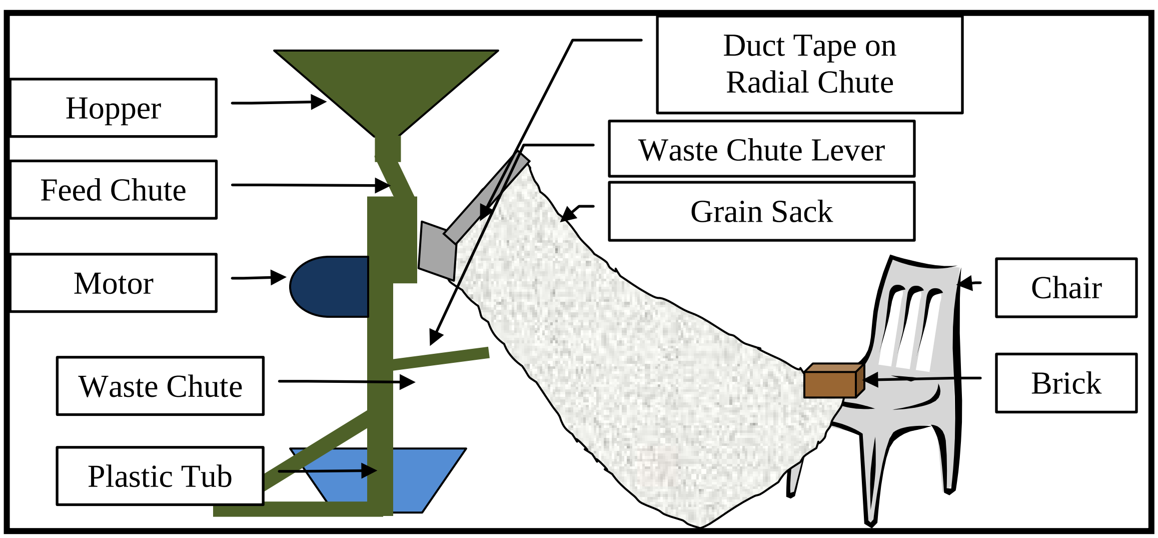


Diagram of Radial Chute and Cardboard Attachment

3. Wrap the mouth of a grain sack around the cardboard on the radial chute of the hammermill, and use duct tape to hold it in place. It should be a tight fit so that no material blows out of the grain sack. Use duct tape to close any grain sack opening.

Attaching the Grain Sack to the Radial Chute

4. Place the chair several feet away from the hammermill, and use the brick to weigh down one end of grain sack on the chair. This is to ensure that air can flow into the grain sack. The grain sack may rise, and it may be necessary to reposition the brick.



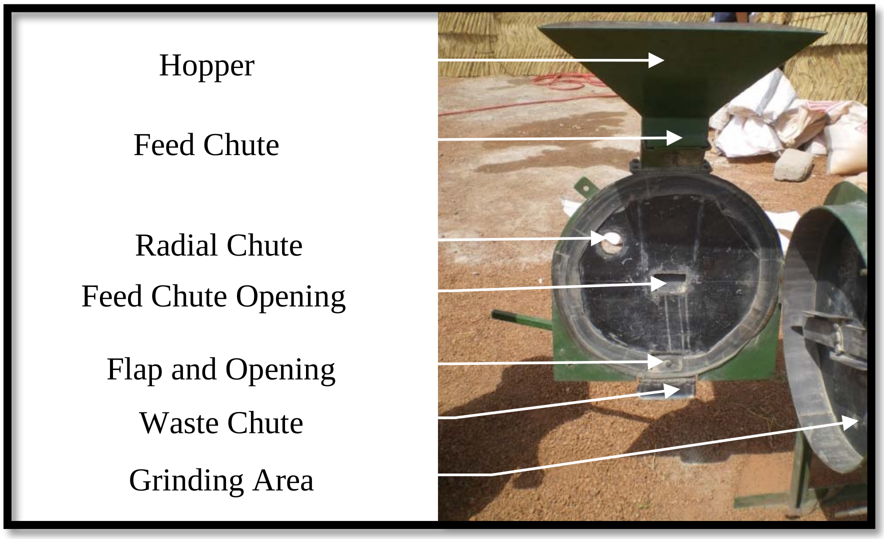
Hammermill Set-up, Plastic Tub, Grain Sack and Chair for Clay and Grog Preparation

5. Plug the generator into the hammermill and start the generator.
6. Wear a face mask to protect against dust inhalation.
7. Place approximately 1 L of dried clay in the hopper of the hammermill. Note that this volume is very approximate; in the field, a bowl with a volume of approximately 1 L was used. The goal is to avoid loading too much material into the chute; if too much material is added at once, either the feed chute will clog or the motor will stall.

8. Open the gate to the feeding chute located below the hopper to allow the clay to enter the hammermill.
9. Allow the material to mill for a period of approximately one minute.

Adding Material to Hammermill and Timing

10. Open the waste chute of the hammermill using the lever at knee-height to allow the waste to empty into the plastic tub below. If the waste material appears to contain useful clay material, this bucket may be re-emptied into the feeding chamber of the hammermill.
    a. There is a spring-loaded flap that prevents material from leaving the grinding area until the waste lever is used to open the flap. This flap, originally made from rubber, was not large enough to cover the entire opening. The flap was removed and a larger piece of cardboard was secured to it with duct tape, and replaced. If the duct tape becomes excessively covered in dusty materials, it made need to be replaced. In lieu of this, a proper rubber flap should be fitted to the hammermill.



Inside Door of Hammermill

11. Continue milling clay until the grain sack attached to the radial chute has collected the desired amount of milled clay.
12. Turn off the generator, detach the grain sack from the cardboard roll, and tie it shut.
13. Store the grain sack in the shade.
14. Store the material from the waste chute for use as construction fill in another project.
15. Periodically, the grinding area of the hammermill needs to be cleared, especially if switching materials from combustible to clay and vice-versa.
    a. Unplug the hammermill from the generator.
    b. Use wrenches to remove the nuts from the bolts holding the hammermill together.
    c. Open the grinding area and remove any remaining material.
    d. Replace the nuts on the bolts, and tighten very tightly with wrenches.
        i. If the nuts are on the bolts loosely, the seal on the sides will not be tight enough to prevent fine material from bypassing the radial chute and blowing out of the sides.

2.2 Grog Preparation

Grog is ground, pre-fired ceramic, either bricks or pottery, including broken filters. The process for grog preparation is identical to the process for clay preparation using a mortar and pestle in Section 2.1.1, with the following exceptions:

- The grog does not need to be dried as it is already dry
- It may be useful to break up larger bricks or pottery before grinding in a mortar and pestle. The hammermill should not be used for grinding grog; it is expected that the hammermill blade will readily dull if used for this purpose.
    - Pots can be broken by throwing them down on a solid surface.

Breaking Large Pots by Throwing on Solid Surface

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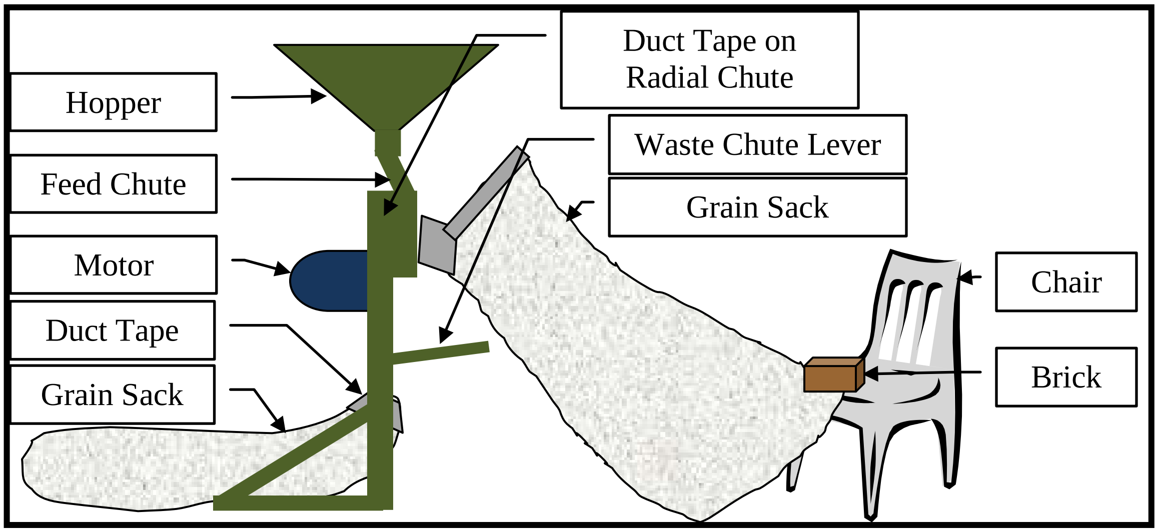
    - Bricks can be broken by using a long pole with a steel plate fixed to the bottom, often called an “elephant’s foot” or “tamper”. The bricks should be set on a tarp on top of a very hard surface, such as a concrete slab.

2.3 Rice Husk Preparation

The process for rice husk preparation, or for the preparation of any other combustible that PHW might use to make ceramic filters, is identical to the process described in Section 2.1.3 for grinding clay using the hammermill, with the exception that a grain sack should be taped to the hammermill’s waste chute to capture all of the rice husk processed through this chute. Material from this chute will be referred to as “waste,” though it *is* included in the final mix. Material from the radial chute will be referred to as “fine,” and is also incorporated into the final mix.



Hammermill Set-Up, Grain Sacks, and Chair for Combustible Preparation

3 Method of Mixing Materials

Once the clay, grog, and rice husk have been prepared, they must be mixed to create a uniform composition. Based on the recommendations of Miller (2010) and Watters (2010), the following recipe shall be used:

Table 3-1: Recipe for Manufacture of Ceramic Pot Filter on the PFP Press

Quantity of Filters	Dry Clay Powder Mass (kg)	Dry Fine Rice Husk Mass (kg)	Dry Waste Rice Husk Mass (kg)	Total Mix Mass (kg)
1	5.50	1.00	1.00	7.50

If one desires to add grog, 0.50 kg of grog may be added to the mix. Local potters prefer to add grog to the clay mix, in part to reduce shrinkage when the pottery is drying.

This recipe is designed to produce a single filter using the nylon mold produced for PHW by Alex Bernabo, with allowance for excess. The absolute amounts of materials used may be increased so as to create a batch that will produce more than one filter, provided that the relative masses of the components do not change. Achieving a consistent mix when mixing by hand will become difficult, however, if the recipe is increased to produce more than three filters.

Equipment:

- Clay (pounded and sieved or hammermilled)
- Plastic bucket
- Rice husk (hammermilled)
- Scale (Camry dial spring scale, capacity: 20 kg) – purchased at Hatoum, Tamale, Ghana.
- Tarp
- Water

Procedure for the manufacture of a single filter:

1. Place a tarp in a mixing area protected from extraneous contaminants or excessive wind.
2. Fill the plastic bucket with the required volume of water and place it in the mixing area.
3. Place an empty container on top of the scale, or use the scale's metal pan as the weighing container.
4. Turn the knob on the scale to set the mass to 0 kg.

Adding Rice Husk to Pan on Scale (It is also possible to add material to a container)

5. Mass the required materials
    a. 5.5 kg dry clay powder
    b. 1 kg dry fine rice husk
    c. 1 kg waste dry rice husk
    d. 0.50 kg grog (if desired)
6. Combine the dry materials on the tarp. Dry-mix the materials by hand. Mix for several minutes until the entire mix appears and feels homogenous.

Dry-Mixing the Clay, Grog and Rice Husk Mixture on a Tarp

7. Add water from the plastic bucket and continue to mix by hand. Stop adding water to the mix once it becomes cohesive enough to be wedged.
    a. The only reason for the addition of water is to create a malleable mix; the water will be removed during the drying and firing process. Therefore, the exact amount of water can be left up to the discretion of those who wedge the clay, but approximately 0.50 L per filter is a reasonable amount.

b. Adding too much water will make it difficult to remove the filter from the mold. Furthermore, adding too much water will make it difficult for the filter, once pressed, to maintain its shape while drying.

Wet-Mixing the Clay, Rice Husk and Water Mixture

8. Wedge the clay mixture by kneading it aggressively in a rocking motion. Continue until the mix appears uniform. This step is also important to remove any air pockets within the clay. Wedging is a technique that requires an experienced potter to perform properly.

Wedging the Wet Clay, Rice Husk and Water Mixture

9. Add wedged clay mixture to the scale to achieve a mass of 8.5 kg for flower pot-shaped nylon mold filters or 7.5 kg for paraboloid filters. If the wedged clay does not mass at the appropriate value, add or remove mix until the appropriate mass is achieved.

10. Form the clay into an approximate cube. Slap the top, sides, and bottom with a flat hand to create smooth surfaces. With experience, the size of 8.5 kg or 7.5 kg clay can be estimated, and the cube formed before being added to the scale for checking.

Forming 8.5 kg of Clay into Roughly a Cube

4 Method of Pressing

PHW has two different presses in its possession: the portable Potters for Peace press (hereafter referred to as the PFP press), and the permanent press designed and built by Emmanuel Hernandez (hereafter referred to as the Mani press). Separate methods will be described for the PFP press and the Mani press.

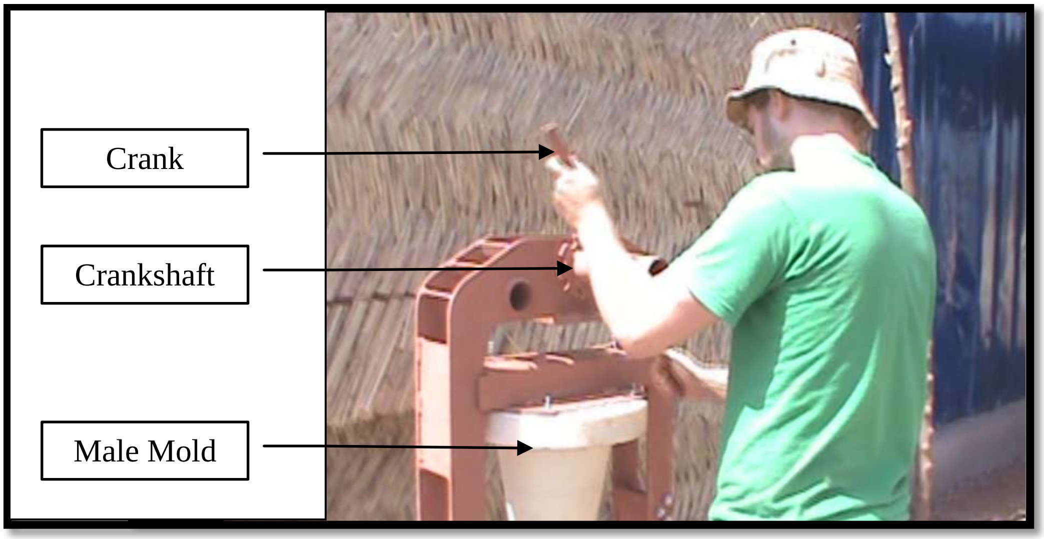
4.1 Method of Pressing for PFP Press

Equipment:

- 8.5 kg cube of clay mixture
- Cutting tool
- Female mold (removable)
- Hydraulic jack (20-ton)
- Male mold (attached to the PFP press)
- Metal or rubber number stamp
- PFP press
- PFP crank
- Plastic bags (preferably without creases, similar to dry cleaner's bags)
    - One large enough to cover the outside of the male mold
    - One large enough to cover the inside of the female mold
- Plastic bucket (unspecified volume)
- Plywood bats (wooden, 16" x 16" rounded rectangles, to fit over the mold and inside the press)
- Rubber mallet
- Water

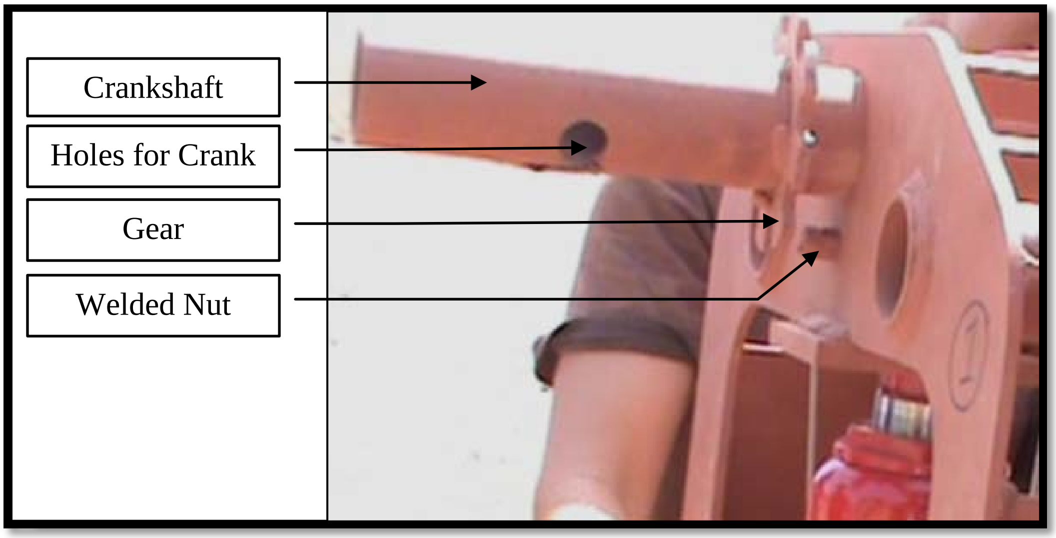
Procedure:

1. When the process begins, the empty male mold is resting inside the female mold. Slide the PFP crank through the holes in the crankshaft and raise the male mold out of the female mold.



Raising the Male Mold to the Maximum Height Using the Crank

2. Once the male mold is raised to its maximum height, lock it in place by pushing the crank against the crankshaft until the welded nut on the press fits into the gear of the crankshaft.



Crankshaft, Gear and Welded Nut

3. Remove the female mold from the press.
4. Fill the plastic bucket with water. Dunk the plastic bags into the water-filled plastic bucket. Remove the plastic bags and shake them out – they should be moist, but should not contain pools of water[2].
5. Fit a wetted plastic bag over the outside of the male mold. Fit a wetted plastic bag over the inside of the female mold.
6. Place the 8.5 kg cube of clay mixture into the female mold.

[2] It would be useful to test pressing filters with bags wetted on both sides, only on the outside, only on the inside, and not at all to see which method is best at releasing the filter from the mold.

Placing 8.5 kg Cube of Clay Mixture into Female Mold with Wetted Bag Inside

7. Using a fist, create an even depression several inches deep in the clay wedge. This is necessary to allow the male mold to fit in the female mold with enough clearance to allow the hydraulic jack to fit into the press.

"Punching" the Clay with a Fist to Create an Even Depression

8. Return the female mold to its place in the portable press. Check to make sure that it is centered and level.

Returning the Female Mold to the Press

9. Put the crank back through the slots in the crankshaft and pull the gear free of the welded nut on the press. Turn the crank to lower the male mold into the female mold.

Left: Adjusting the Wetted Bags on the Molds, Right: Lowering the Male Mold

10. Position the 20-ton hydraulic jack in the press, above the male mold.

Positioning the 20-Ton Hydraulic Jack into its Groove in the Center of the Press

11. NOTE! Be sure that the gear is no longer fixed on the nut; if the nut is not clear of the gear, pumping the hydraulic jack will not move the molds but *will snap the suspension cables.*
12. Use the notch cut out of the end of the crank to turn the valve at the base of the hydraulic jack so that it is ready to pump.

Turning the Valve at the Base of the Hydraulic Jack using the End of the Crank

13. Pump the hydraulic jack until excess clay emerges from all sides, and until the male and female molds are nearly touching on all sides. Use judgment when deciding how close the molds should be together, as this determines the thickness of the filter walls. Usually, approximately 200 pumps are required.

Pumping the Hydraulic Jack to Push the Male Mold into the Female Mold

Clay Emerging from All Sides of the Molds

14. Release the hydraulic jack by using the notched end of the crank to turn the valve at the base in the opposite direction.

15. Remove the hydraulic jack from the press.

Removing 20-Ton Hydraulic Jack from the Press Just After the Valve is Opened

16. Press down the piston by standing on it with one foot, if it does not go down easily.
17. Reinsert the crank in the crankshaft and rotate it to raise the male mold out of the female mold. Push the crank until the welded nut locks back into the gear.
18. If the male and female molds do not separate easily, use the rubber mallet to strike the female molds on all sides until it falls.

Striking the Female Mold to Encourage the Molds to Separate

19. Place the plywood bat on top of the newly formed filter. Remove the female mold from the press.

20. Two people are required for this step: place one hand on the bottom of the female mold and one on the plywood bat. Invert the mold and bat and place the combination on the ground.

Inverting the Female Mold with the Plywood Bat on Top

21. Lift the female mold off the filter. If the bag is attached to the filter, remove the bag.

Lifting the Female Mold off the Newest Filter

22. Use the cutting tool to trim the edges of the filter.
23. Using a wet finger, smooth the edges of the filter lip and sides if needed.
24. Stamp an identifying mark on the filter lip.

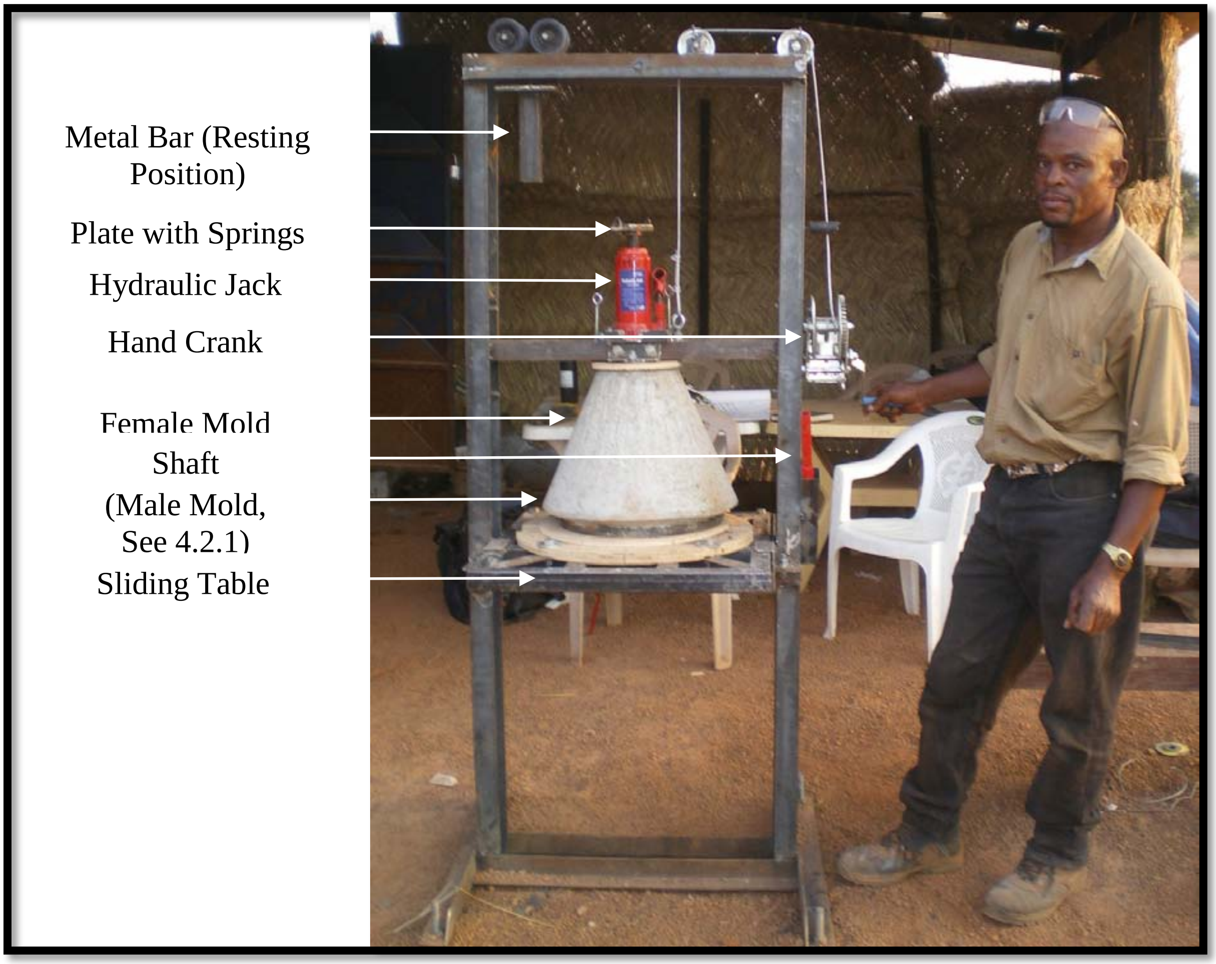
4.2 Method of Pressing for Mani Press

Equipment:

- 7.5 kg cube of clay mixture
- Cutting tool
- Donut-shaped plywood bats (cut with a jigsaw to fit over male mold)
- Female mold (attached to the Mani press)
- Hydraulic jack (8-ton)
- Male mold (attached to the Mani press)
- Mani press
- Metal or rubber number stamp
- Plastic bags (large enough to cover each mold)
- Plastic bucket (unspecified volume)
- Water

Procedure:

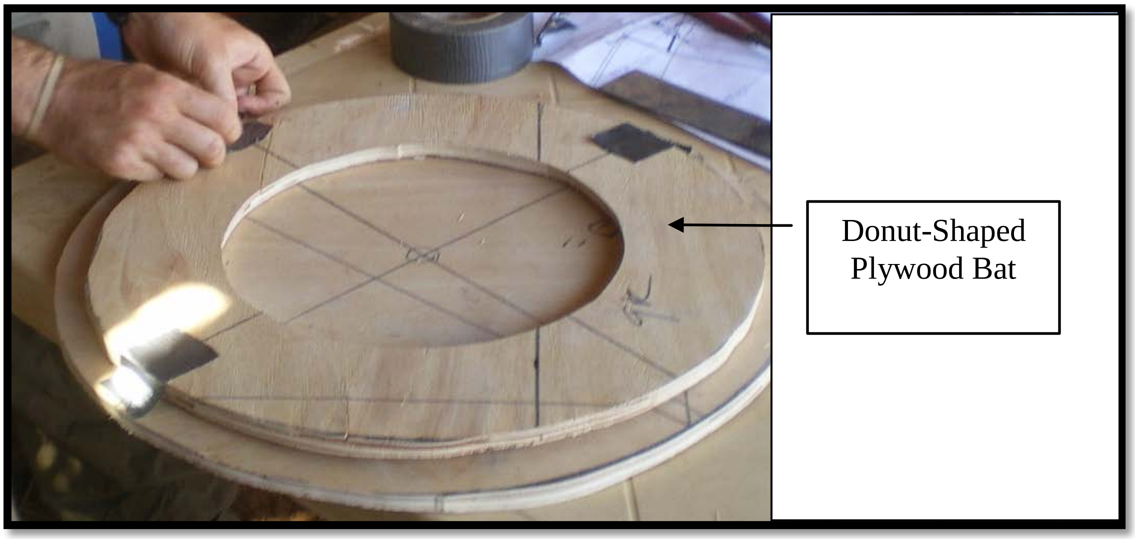
1. Slide the table to which the male mold is affixed out from under the female mold.



Mani Press with the Male Mold under the Female Mold, with its Welder, Red

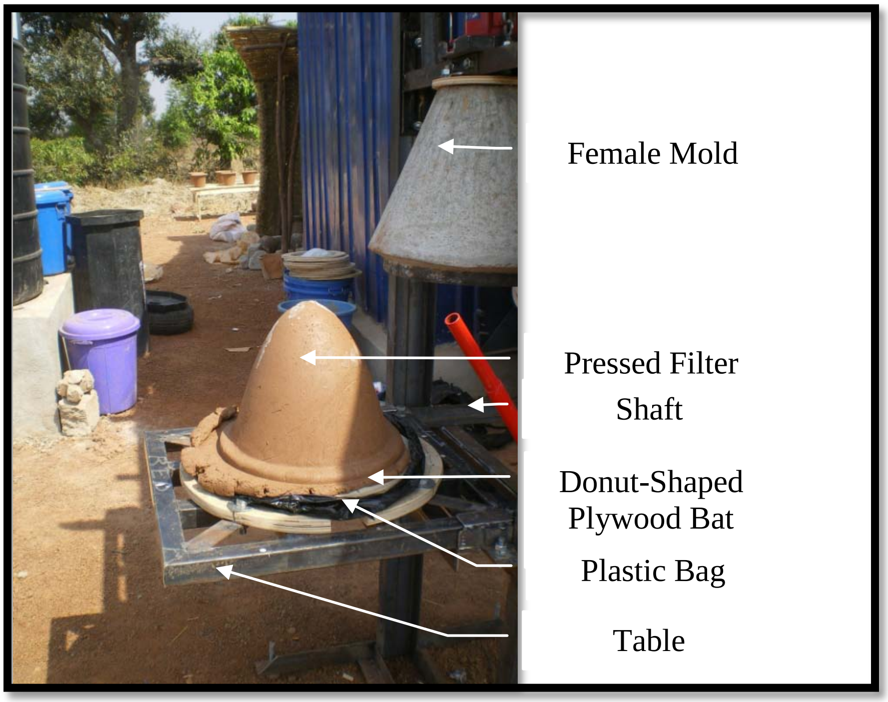
2. Fill the plastic bucket with water. Dunk the plastic bags into the water-filled plastic bucket. Remove the plastic bags and shake them out – they should be moist, but should not contain pools of water.
3. Fit plastic bags over the male and female molds.

4. Set a donut-shaped plywood bat over the plastic bag on the male mold.



5. Place a 7.5 kg wedge of clay mix on top of the male mold. Pat it down to roughly match the shape of the top portion of the male mold.
6. Slide the table back so that the male mold is under the female mold.
7. Use the hand crank to lower the female mold on top of the male mold.
8. Move the metal bar suspended from the top of the press from its resting position on the left side of the press to its active position in the middle of the press.
9. Use the notch in the end of the shaft to turn the valve at the base of the 8-ton hydraulic jack.
10. Pump the 8-ton hydraulic jack until the bottom edge of the female mold reaches the plywood bat around the male mold. Usually, approximately 40 pumps are required.
11. Release the 8-ton hydraulic jack by turning the valve in the opposite direction as before.
    a. Springs attached to a plate will press the piston back into its starting position.
12. Slide the metal bar back into its resting position.
13. Use the hand crank to lift the female mold off the male mold.

14. Slide the table with the male mold and filter out from under the female mold.



Mani Press With Table Extended

15. Lift the plywood bat with the pressed filter off the male mold. Place the filter lip-side-down on the plywood bat.
16. Use the cutting tool to trim the edges of the filter.
17. Using a wet finger, smooth the edges of the filter lip and sides if desired.

Smoothing the Edges of the Filter Lip

18. Remove the plastic bag from inside the filter.
19. Stamp an identifying mark on the filter lip.

4.2.1 Adjusting the Mani Press and Mold

The Mani press is designed so that the position of the male mold under the female mold can be adjusted. This is useful so that the filter walls have an even thickness on all sides. The male mold is secured to the table by four bolts and washers, which can be loosened, shifted and retightened so that the male mold can move slightly around the table.

To test if the male mold is centered under the female mold, follow this procedure:

1. Press a filter in the current configuration
2. Slice the pressed filter in half with a sharp object while still on the mold for support
3. Measure the thickness of the filter walls on all sides.
4. Continue to adjust the male mold following steps 1-3 until the thickness of the filter walls are even.
    a. The same clay can be used repeatedly to press the test filters.

Left: Male Mold on Table , Right: Male Mold, Plastic Bag and Test Filter, Cut in Half

4.2.2 Comments on Relative Ease of Use of Mani Press vs. PFP Press

The Mani press holds several advantages over the PFP press in terms of ease-of-use.

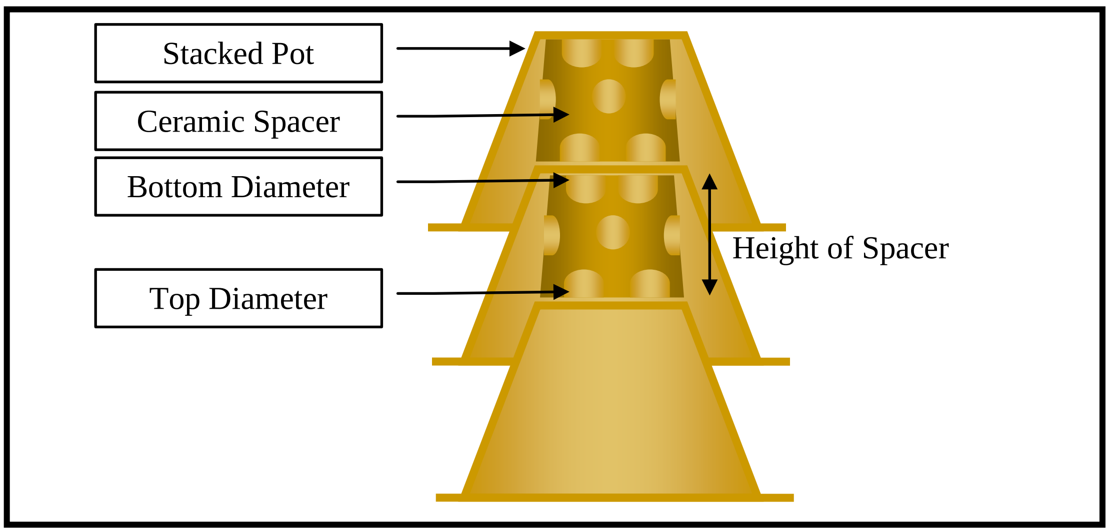
1. The male mold is the removable portion of the Mani press, and can be easily positioned on its table when the table is slid out from under the female mold. The table can then be used to center the male mold beneath its female counterpart. By contrast, the female mold is the removable portion of the PFP press; the nylon mold currently in use at the PHW factory is heavy and must be positioned in the press by hand. It is difficult to level and center this mold.
2. The 8-ton hydraulic jack used in the Mani press is easily positioned, unlike the 20-ton jack of the PFP press, which must be forcibly wedged into place and can only be positioned after a sufficient depression is made in the wedged clay mixture placed in the female mold.

3. There is no risk of snapping the suspension cables when pumping the hydraulic jack of the Mani press.
4. The Mani press requires approximately 40 pumps to properly press a mold, whereas the PFP press requires approximately 200. Consequently, filters can be pressed more quickly with the Mani press than with the PFP press.
5. Removing filters from the PFP press is difficult, especially if the molds do not separate after pressing. In this case, the rubber mallet must be used to loosen the adhesion between the molds. Even so, a great deal of force must often be applied to the female mold in order to pull it free from the male mold, which results in an impact when the female mold breaks free and crashes into the bottom of the press. By contrast, the female mold of the Mani press is easily removed by a hand crank.
6. Springs automatically return the 8-ton hydraulic jack of the Mani press to its starting position, whereas the 20-ton hydraulic jack of the PFP press must be removed and stepped on in order to return it to its starting position.

5 Creating Ceramic Spacers

Ceramic spacers are necessary to allow heat to flow more evenly between stacked filters in the kiln. The potters are very skilled at making small bowls, so the design of the spacer is a modified small bowl. The spacers can be made out of excess clay to the potters' liking, provided the following stipulations are observed.

The height of spacers should be the desired distance between the filters in the kiln. The current recommendation is 20cm. Pieces of wood can be measured using a ruler and cut to size to check the height of the spacers. The bottom of the diameter of the spacer should be smaller than the interior, bottom diameter of the filter. The top diameter of the spacer should be the same size as the exterior, bottom diameter of the filter. Also, the amount of shrinkage expected during drying of the spacers should be taken into account. Holes should be cut in the sides, top and bottom of the spacer to allow heat to flow to the bottoms of the stacked filters.



Stacked Filters and the Ceramic Spacers


Left: Potter Crafting the Ceramic Spacer, Right: Fired Ceramic Spacers (More Holes to be Added to the Top)

6 Method of Drying

Once the filters have been pressed, they must be dried before they can be fired. Without this step, the filters will undergo dramatic volume change in the kiln, which will cause cracking. Cracking is also a risk during drying; filters should be closely monitored during this step and removed from intense heat and sunlight if cracking is observed.

Equipment:

- Filters (pressed)
- Metal or rubber number stamp
- Plywood bats
- Shade
- Sunlight

Procedure:

1. Place the filters lip-side-down on the plywood bats in a shaded area to dry for the first 24 hours.

Filters Drying Lip-side-down on Plywood Bats in a Shaded Area

2. After the first 24 hours, turn the filters right-side-up so that the interior of the pot can dry in the shade. Filters from the Mani Press, which are paraboloid in shape, should be placed on their sides.

3. Once the interiors of the pots are dry to the touch, set the filters right-side-up on bats or tables in the sun. Paraboloid filters will not stand right-side up; place them on their sides.
    a. It is very important that the filters do not dry unevenly; the interior and exterior of the filter should be equally dry.

Filters Drying Right-side-up on Plywood Bats in the Sun

4. Once every 30 minutes, rotate the filters 90 degrees clockwise about a vertical axis.
5. After several hours, flip the filters so that they are lip-side-down, and continue to rotate them every hour.

Filters Drying Lip-side-down on a Table with Holes

6. If the filters develop cracks, wet the entire filter and patch the cracked areas with excess clay mix. Remove them from the sunlight to dry in a less intense heat.

7. Consult with local potters to determine when the filters are sufficiently dry to begin firing. Ordinarily, a period of two to three days of sun exposure during Northern Ghana's dry season is sufficient. If the weather is more humid, it will take longer to dry. Note: PHW does not yet have rainy season experience in drying the filters.
    a. If leaving the factory site before the sun goes down, it is best to place the filters in the shade overnight.

7 Method of Firing

With the drying process complete, the firing may begin. NOTE: Firing the kiln is an eight-hour process. One should begin firing first thing in the morning so as to complete the firing within a single work day.

Equipment:

- Brick
- Ceramic spacers
- Gloves (thick and sturdy)
- Iron rake
- Kiln
- Filters (dried)
- Firewood
- Mortar
- Large plastic bucket with water
- Pyrometer probe and temperature readout
- Wood saw
- Shimpo cone packs

Procedure:

1. Load the filters into the kiln, rim-side-down. The filters may be stacked on top of one another, provided they are separated by pre-fired ceramic spacers, which allow for heat flow through between the stacked filters. Though five sets of five-stacked flower pot filters can fit inside the small Mani kiln, stacking just four flower pot filters with taller ceramic spacers will result in better heat flow. The large kiln, which is currently under construction, will have an estimated capacity of 50 filters.
    a. If testing filters of various types, load them randomly so that differential heating does not factor into performance of one type over another.

Flower Pot Filters (Left) and Paraboloid Filters (Right) Stacked for Firing in Kiln

2. Prepare plenty of firewood, pre-cut with a wood saw to fit into the kiln's fireboxes.
3. Fix a series of Shimpo Ceramic Cones into a lump of clay. Each Shimpo cone pack contains cones 013, 012, and 011; these should be placed sequentially in the clay lump. Repeat this process until the desired number of cone packs have been prepared. At least two cone packs should be prepared; one for the kiln door and one for the spyhole.
4. Place the cone packs in locations in the kiln where it is desired to measure the kiln temperature. This should include, at a minimum, the spyhole and the platform on the door of the kiln, though the cone pack for the door cannot be placed until the door is sealed shut with brick and mortar. Additional possible locations are the four corners of the kiln and the center. The purpose of placing the cones in these locations is to determine if regions of the kiln are appreciably hotter or cooler than others, so as to inform later modifications to the kiln for the achievement of more uniform heating.
    a. Orient the cones so that when viewed later, it will be clear which is which.
5. Partially seal the kiln door with brick and mortar. Place a pyrometer probe in one of the mortared joints, so as to monitor the temperature inside the kiln.

Sealing the Kiln Door with Brick and Mortar, Except for Upper Row of Bricks

a. Rotate one of the bricks 90 degrees, so that it protrudes into the interior of the kiln, and place a cone pack on the brick inside of the kiln.

Close-Up of Rotated Brick Platform

6. Light a small "candle" fire in the lower opening of the fireboxes.

Tending a Small "Candle" Fire in the Lower Firebox for Four Hours

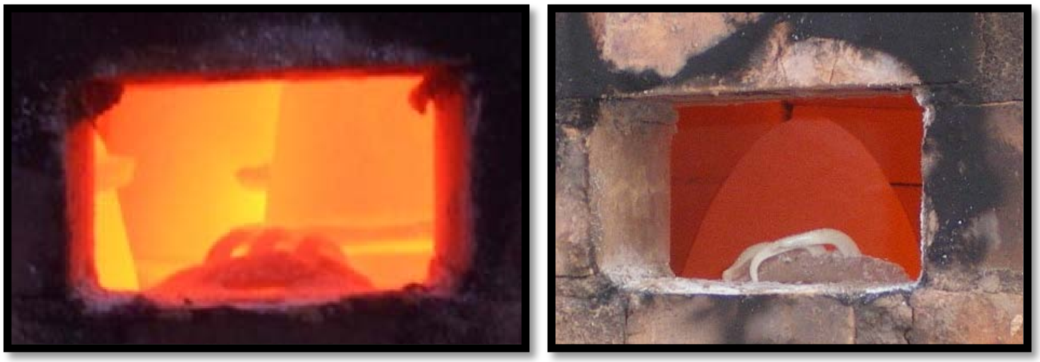
7. Gradually increase the size of the fire over the course of four hours. Use the iron rake to maintain a flat bed of coals in the lower box and to remove excess coals from the base of the kiln. Use water from the plastic bucket to extinguish the excess coals.
8. Black smoke should arise from the chimney; this signals the combustion of the rice husk inside the clay mix.

9. When a temperature of 250 °C has been reached inside the kiln, seal up the kiln door completely.

Left: Pyrometer Temperature Read-out, Right: Pyrometer Read-out with Wire to Probe

10. Check the seams of the kiln for smoke, and use mortar to patch over as many smoking areas as possible. This will help keep the heat from escaping from the kiln.
11. When either a period of four hours since beginning firing has elapsed, or the pyrometer reads 400 °C, begin rapidly increasing the heat inside the kiln by adding wood to the lower and upper fireboxes. Continue maintaining a bed of coals in the lower firebox while adding wood to both fireboxes.
12. During the latter four hours of firing (i.e., the rapid firing), check the pyrocones in the spyhole at least once every hour by removing the brick over the spyhole. Replace the brick after each observation and re-mortar the joint.
    a. The target temperature for completion of firing is 877 °C. The cone packs, however, measure heat absorption rather than absolute temperature, and are a better measure of the maturity of the filters than a strict temperature gauge.
    b. Wear thick gloves and be very careful when removing the brick over the spyhole, as the brick is extremely hot and can burn.

13. When the 013 cone bends, begin checking the spyhole approximately once every fifteen minutes. When the 012 cone bends, firing is complete; no more wood should be added to the fire.



Melted Pyrocones Viewed Through Spyhole, Left: Flower Pot Filters, Right: Paraboloid

14. Rake out the remaining coals and extinguish them.
15. Leave the filters inside the kiln to cool overnight; leave the kiln door sealed shut to prevent drastic cooling, which can create cracks in the filters.
16. In the morning after firing, remove the mortar from the kiln door. Remove the bricks, and stack them in such away that the bricks may easily be replaced in the same order during the next firing. The door requires half-bricks on every other level, which is why stacking them in an orderly fashion is useful.
17. Carefully remove the filters and spacers.
18. Note the position of the cone packs, and the degree of melting. If the cone packs have melted to different degrees (as is the case in the photo below: note that the lower-right-hand-corner cone pack is unmelted), consult with kiln designer, Emmanuel Hernandez as to how to modify the kiln design to achieve more uniform heating. Filters adjacent to a cone pack in which the firing cone (i.e., cone 012) has not melted may not be sufficiently durable and should be discarded.

Cone Packs Arranged to Represent their Relative Position inside the Kiln

8 Filter Flow Test

The principal quality control measure at ceramic pot factories around the world is a test of the initial flowrate of filters; if the filter flows too fast, the filter likely has cracks. Cracked filters are discarded and used as input material for grog.

Equipment:

- 1 L measuring cup or graduated cylinder (100 mL, 250mL, or 500 mL)
- Ceramic spacers (half as many spacers as filters)
- Large plastic buckets (half as many buckets as filters)
- Municipal water (or other clean water: "dugout" water not acceptable)
- Pure Home Water filter containers, ring lids (ring lids must be cut to hold filters)
- Rulers (30-cm, plastic: as many rulers as filters)
- Watch (or other timing device)

Procedure:

1. Place two filters in each bucket, right-side-up, separated by a ceramic spacer.
2. Fill the buckets with municipal (i.e., clean) water.

Filters Soaking with Municipal Water in Large Plastic Buckets

3. Allow the filters to soak for at least 24 hours, so that the pores are completely saturated by water (van Halem, 2006).
4. Place each saturated filter in a Pure Home Water Filter Container. Place a 30-cm plastic ruler in each filter as well.
5. Procedure for first initial flowrate test:
    a. Fill each filter to the top, and start a timer.
    b. After one hour, measure the amount of water collected in the bottom of the filter container, and the decrease in water height.

    c. Currently, the initial flowrate of these types of filters, with and without grog added, using turbid water, is between 1.5L/hour to 3 L/hour.
        i. The flowrate for these types of filters using municipal water will likely be faster than the flowrate with turbid water. If most of the filters seem to have reasonable flowrates, assume that they are un-cracked, and determine the average flowrate of these filters, and the associated average decrease in water height.
            1. Recommend this average initial flowrate and the associated average decrease in water height as the factory standard which all new filters of these types will be compared to.
6. Procedure for subsequent flowrate tests:
    a. Fill each filter to the top with clean water, and start a timer.
    b. After one hour, measure the decrease in water height.
    c. If the decrease in water height is much greater than the recommended decrease in water height determined in Step 5c, assume the filter is cracked and discard it.
7. Allow the un-cracked, satisfactory filters to completely dry before they are impregnated with colloidal silver.

9 Method of Silver Impregnation

There are three ways that ceramic pot filter factories around the world impregnate filters with colloidal silver for disinfection: dipping, painting and incorporating the silver in the clay mix. Pure Home Water has chosen to dip the filters, which allows the interior, exterior and pores of the filters to be coated with colloidal silver.

Equipment:

- Colloidal silver (powder from Argenol[3] in Spain)
- Drying rack
- Large plastic buckets
- Municipal water ("dugout" water no acceptable)

Procedure:

1. Determine how much colloidal silver is needed to impregnate all of the filters.
    a. The target concentration of silver is 800 mg/L (Oyanedel-Craver and Smith, 2009).
        i. This concentration results in more silver being added when the pots are dipped than when filters are painted, but when the filters are being dipped, there is more surface area of pores to coat and thus more silver is needed.
        ii. The Argenol powder from Spain is 70% pure.
    b. Each filter roughly has 1L of pore volume, and will absorb roughly 1L of water when dipped.
        i. The plastic bucket needs to be at least half full to fully submerge the filter, which is roughly 40L of water; 40L of additional colloidal silver solution need to be prepared for the filters to be dipped.
            1. This is not a waste, because the remaining solution can be used for future batches of filters if stored properly with a labeled lid.
        ii. Measure 1L of water for each filter to be dipped, in addition to the 40L required to maintain the bucket half full.
            1. If many filters need to be dipped, this can be done in several buckets. 40L of extra diluted colloidal solution is not required for each bucket, only for one. When the level of colloidal silver solution in a bucket gets low, it can be poured into another bucket.
        iii. Determine the total amount of water to be added.
            1. To achieve an 800 mg/L colloidal silver solution, 1.14 g of 70% pure Argenol colloidal silver powder must be added for each L of water added.
2. Measure the colloidal silver powder.
    a. After determining the total amount of colloidal silver needed, use an accurate scale to weigh enough colloidal silver in the laboratory.
    b. Store the colloidal silver in Whirl-Pak® bags.

[3] Laboratorios Argenol, http://www.laboratorios-argenol.com/

        i. If multiple buckets are anticipated, store enough colloidal silver for each bucket in separate Whirl-Pak® bags, as there is no scale on site.

3. Measure the appropriate amount of water, and add the water to the buckets.
4. Add the colloidal silver powder to each bucket, so that there is 1.14g of colloidal silver powder for each L of water.
5. Submerge each filter in the bucket for 45s (Oyanedel-Craver and Smith, 2009).
6. Allow the filters to completely dry before using them to filter water.
    a. Store the filters in a safe space away from dust, as this is the final product that will be delivered to the user free of bacteria.

10 Further Recommendations

Before Pure Home Water pursues the manufacture and distribution of its filters, Quanti-Tray® analysis should be performed on effluent water from the CPFs, for purposes of comparison with the membrane filtration studies performed by Miller (2010).

Furthermore, the recipe recommended in Section 3 represents the recipe which, in the opinion of Miller (2010) and Watters (2010), is the best choice for immediate production. Because Pure Home Water is in possession of a test kiln, further research into the effect of compositional variation on the durability, flow rate, and removal efficiency of the filters may be desirable. For further details, consult the recommendations included here in abbreviated form of Miller (2010) and Watters (2010), included here in abbreviated form as APPENDIX A and APPENDIX B.

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APPENDIX A: RECOMMENDATIONS FOR FURTHER RESEARCH: REMOVAL PERFORMANCE

Recommendations for Coagulation

Due to the inability of any of the filter designs to remove influent turbidity satisfactorily, even at very low flowrates, additional methods to reduce turbidity should be pursued. According to a drinking water consumer choice survey in Northern Ghana completed by Vanessa Green (2008), both urban and rural consumers prefer clear water to turbid water. Coagulation is an effective method for reducing turbidity, and several products exist to effectively at the household level in Northern Ghana, most notable alum. Although the water may appear clear after coagulation with alum, it is important that households also filter their water to remove any microorganisms that were not settled out during coagulation.

Recommended Further Research

That the turbidity removal results of filters in Miller (2010) are poor and do not directly relate to total coliform removal results is a troubling phenomena. Johnson (2007) reported that ceramic water filters manufactured in Accra and sold by Pure Home Water in Northern Ghana from 2005-2007 were capable of reducing on average 92% of turbidity, with a resulting average filtered water turbidity of 11NTU. The filters studied by Johnson (2007) greatly outperform the turbidity removal of filters in this study, even though they have similar total coliform removal. At worst, the mismatch in total coliform removal and turbidity removal in this study could mean that indeed the performance of rice husk filters at removing total coliform is over-estimated, which would change the recommended filter design. To test if the higher turbidity of filtered water does not impact the total coliform removal results, filters with recipes 3 and 4 should be tested for additional months using the Quanti-Tray®[4] method of coliform analysis. The Quanti-Tray® method is a most probable number method that is available at the Pure Home Water Laboratory in Northern Ghana and does not require filtration. Thus it would likely have reduced interference by turbid water. Some of the Quanti-Tray® results should be compared to membrane filtration results in an attempt to detect differences in counts as a result of the two testing methods.

It would also be useful to determine the particle size distribution of the suspended solids in the influent water using a hydrometer. The analysis could be done according to ASTM D422 - 63 Standard Test Method for Particle-Size Analysis of Soils. This way, the necessary filter pore size to screen suspended solids causing turbidity could be determined. Alternatively, sequential filtration, described by Losleben (2008) could be used.

[4]Quanti-Tray® is a product of Idexx Laboratories, Inc. http://www.idexx.com/view/xhtml/en_us/water/quanti-tray.jsf?selectedTab=Overview

As part of the further research, filters made in Accra, paraboloid filters and filters made with different clay types should be studied comparatively. A flaw of this study is the lack of a control. To remedy that for future studies, testing filters made in Accra concurrently with filters made in Tamale could provide useful comparisons. It would be useful to compare input combustible material in Accra-made filters to those used in this study to determine if that can account for differences in turbidity removal performance. Differences in clay may also be a factor.

The Pure Home Water factory will likely produce more paraboloid filters than flower pot filters as a result of the easier production process with the permanent press. Thus, before marketing the filters, triplicates of paraboloid filters made with recipes 3 and 4 should be tested using Quanti-Tray®. For comparison, paraboloid filters made with recipes 9 and 10 should be tested concurrently.

The total amount of clay available from the current source of Gbalhai clay is unknown, and other clay sources are available. Given that, the clay from each source should be characterized using Atterberg limits and particle size distribution techniques and classified. If a clay source has a high clay content and high plasticity, the performance filters made with that source of clay should be tested.

APPENDIX B: RECOMMENDATIONS FOR FUTURE RESEARCH: DURABILITY

Data Acquisition

In attempting to improve the durability of the CPF, difficulties arose due to the lack of information as to the failure modes causing breakage of the pot. During subsequent follow-up monitoring investigations, it is recommended that:

1. A photo log of broken pots be maintained, including plan and isometric views of the fracture surface(s).
2. User testimony as to the conditions of failure should be recorded.
3. If possible, all pieces of fractured pot should be recovered, and pieces from the same pot should be labeled and maintained together, distinctly from pieces from other pots, so as to be useful to future researchers.

Collection of such information will facilitate determination of primary failure mechanisms and targeted efforts to strengthen future CPFs against said mechanisms.

Compositional Variations

1. A manufacturing process that utilizes *only* the fine product from the hammermill, which is thereafter sieved, creates mixes with very high bending strength relative to the manufacturing process that combines the waste and fine product from the hammermill. The filtering rates of the resulting filters, however, were unacceptable. Being that there is a demonstrated relationship between flow rate and combustible mass, the manufacturing process should be applied to various other recipes with higher proportions of combustible. This will reveal whether the strength gains realized in the manufacturing process can be coupled with an acceptable flow rate. A set of sample recipes is proposed in the following table. Such samples should be tested for bending strength, flow rate, turbidity removal, *E. coli* removal, and total coliform removal using the methods of Watters (2010) and Miller (2010), respectively.

Table 11-1: Sample Recipes for Testing of Flow Rates and Durability through Filters Manufactured with Exclusively Fine, Sieved Combustible

ID	Combustible Type	Hammermill Product	Grog Added?	Clay Mass (kg)	Fine Combustible Mass (kg)	Waste Combustible Mass (kg)	Total Mix Mass (kg)
1	Rice Husk	Fine, Sieved	No	11	2.75	0	13.75
2	Rice Husk	Fine, Sieved	No	11	3.00	0	14.00
3	Rice Husk	Fine, Sieved	No	11	3.25	0	14.25
4	Rice Husk	Fine, Sieved	No	11	3.50	0	14.50
5	Rice Husk	Fine, Sieved	No	11	3.75	0	14.75
6	Rice Husk	Fine, Sieved	No	11	4.00	0	15.00

Firing Recommendations

The experiments of Watters, 2010, demonstrated a variation in bending strength dependent upon a sample's position within the Pure Home Water test kiln. It is recommended that Pure Home Water make every effort to monitor and enforce the uniformity of the firing in the kiln. The author recommends that witness cones be used in every firing and that their condition at the end of firing and their position be documented photographically. Communication must be maintained with the kiln designer, Emmanuel Hernandez (e-mail: joliga146@yahoo.com, phone: 1-815-501-2407) to implement changes to the interior configuration of the kiln in order to create a more even heat distribution.

Impact Testing

It would of course be fortunate if the increases in bending strength due to compositional variation were accompanied by increases in impact resistance. One may confirm or deny this phenomenon by employing the ASTM C368-88, Standard Test Method for Impact Resistance of Ceramic Tableware. However, until impact failures from pots made with the recommended compositional and geometrical alterations are observed, it is not recommended that this test be performed.