CLAY TESTING PROTOCOL
for Ceramic Water Filters

TOOLS NEEDED:

1. gram scale
2. 1/3 and 1/2 cup measuring cups
3. bowl
4. spoon
5. eyedropper or syringe
6. ruler in centimeters
7. water cup
8. wooden mold 4.5 cm x 15 cm x 1 cm deep
9. pencil
10. magic marker
11. ware board

MAKING THE TEST BARS

1. Dry, crush and screen the clay through a 25 or 30 mesh screen. Screen the sawdust.
2. For one bar, weigh 1/3 cup of sawdust and note this amount; this will be your standard weight. If you have enough materials for more than one bar, multiply this amount by the number of bars of each sample you will make.
3. For one bar, weigh 1/3 cup clay and note this amount; the weight will vary for each sample. Multiply this by the number of bars you are going to make.

Steps 2 and 3

4. Mix the clay and sawdust together thoroughly.
5. Layer the mixture into the bowl. Fill the eyedropper with 10 gr (ml) of water. Sprinkle water from the eyedropper after each layer, leaving the top layer dry.

Step 5

Step 5

Step 5

6. Mix, adding water as necessary until sticky. The amount of water necessary to make the mixture into a ball is the goal. This amount is somewhat subjective, but all samples should have a consistent feel. Dry is better than wet, because pressed filters use a dry mix.

Step 6

Step 6

7. Note the amount of water used.
8. Oil the mold with cooking oil.

Step 8

9. Pinch and smoosh the mixture into the mold. For those familiar only with processed clays, it should be noted that natural clays are more difficult to make into a slab. Often they cannot be rolled or slapped out; it is necessary to pinch, prod, encourage and cajole the clay into the desired shape. Clay mixed with sawdust will be even more difficult to work with. Once the mixture has become a bar in the mold, tap it lightly with the back of the spoon to compact the particles.

Step 9

Step 9

Step 9

Step 9

10. Eject the slab from the mold. Pinch and smooth the edges to remove cracking. Place the slab back into the mold in reverse. Tap lightly to compact and burnish with the back of the spoon. Eject the bar from the mold.

Step 10

Step 10

11. Smooth and compress the edges with the spoon.

Step 11

12. Draw a line 10 cm long, clearly marking the ends of each line. Write the sample code on the bar. Reverse and do the same on the other side.
13. Weigh each bar and note the amount.
14. Dry slowly, turning regularly to avoid warping.

Step 12

Step 12

Step 12

Bars drying

FIRING THE TEST BARS

Once the test bars have thoroughly dried, it is necessary to fire them to evaluate their suitability for filters. Each series of tests will be fired 4 times, to cones 016, 014, 012, and 010. (Cone 016 should fall around 825 C; cone 010 around 919 C.) Testing within a 100 degree C. range will give a good understanding of the optimal firing temperature and general fired characteristics of each clay evaluated.

Since the bars are to be fired four times, it is necessary to use the same cones in all of the firings. Cones are more accurate than temperature readings because they experience the effects of both time and temperature, known as “heat work”, in the same manner as the clay itself. Therefore, the cones used must experience all the firings that the clay does in order to accurately reflect the amount of heat work to which the clay has been subjected throughout all of the firings.

Make a cone pack of cones 016, 014, 012, and 010 set into a coil of clay. (The picture illustrates the cone pack after the first test firing). The firing schedule should follow the ideal firing schedule for filters. That is, the kiln should be maintained below 100 degrees C. until the bars are dry. Thereafter, the kiln should rise at the rate of 100 degrees C. per hour up to 400 degrees C. It should be maintained at this temperature for one hour to allow the sawdust to burn out. After one hour, the firing can proceed until the end at the rate of 100-150 degrees C. per hour. A normal firing schedule will last about 8 hours total.

The first firing will terminate when the first cone, 016, falls (see picture). When the bars have cooled, remove them from the kiln, measure the length of the lines inscribed on them, and note the results. Weigh each bar carefully, and note the results. See “Assessing hardness (durability)” below and note the results. Boil a sufficient amount of water to accommodate all the bars, and submerge the bars in the boiled water. After three hours, remove the bars one by one, dry the surface with a damp sponge, and weigh them noting the results. Once again, evaluate the bars for hardness and durability. The following section will explain the calculations necessary to analyze the weights and measures thus obtained.

When the bars have thoroughly dried, fire them again until the next cone drops. Be sure to use the same cone pack that was used in the previous firing(s). When the kiln has cooled, perform the measurements described in the paragraph above. Repeat this procedure four times, one for each cone, and analyze the data as noted in the next section.

A comparison of the results from the four firings should indicate the optimal firing temperature for each clay. In general, clays will change from brittle and porous at lower temperatures to hard with less porosity as temperatures rise. Another series of tests might be run, altering the proportions of clay and sawdust to learn more about how the clays will react under other conditions. Hard clays with low porosity may require more sawdust and/or lower firing temperatures; conversely, soft, brittle clays of higher porosity may require less sawdust and/or higher firing temperatures. Run the series of tests again on test bars with proportions between 40/60 and 60/40 clay/sawdust ratios (by volume) to acquire greater understanding of the capabilities of each clay at a variety of mixtures and temperatures.

DATA CALCULATIONS AND ANALYSIS USING THE TEST BARS

Test for water of plasticity

This test determines the amount of water required for a clay to become workable at the desired consistency. Clay with a finer grain structure will require more water and will therefore shrink more during drying (Rhodes 1973). Carrying out this test periodically will identify changes in clay characteristics that might affect filter mixture ratio and the flow rate of the filter, because the amount of water required to achieve a plastic mixture is one determinant of the pore structure.

Calculate the amount of water of plasticity using the following formula:

$$\text{Percent water of plasticity} = \frac{\text{Weight of water}}{\text{Weight of dry clay}} \times 100$$

Test for shrinkage

The amount of shrinkage is an important characteristic of any clay and will be partly determined by the amount of nonplastic material in the clay, the particle size, and the water content. A clay with a high shrinkage rate (more than 15% total shrinkage) probably will not be useful because it will warp and crack during drying and firing. Knowing the total shrinkage rate of the filter mixture will be useful for designing molds of the proper dimensions so that after firing the filter element will fit precisely inside the available receptacle. Shrinkage tests should be carried out regularly on both the source clay and the filter mixture to monitor the consistency of raw materials.

Dry shrinkage

Once dry, re-measure the length of the scratch.
Determine dry shrinkage using the following equation:

$$\text{Percent linear shrinkage} = \frac{\text{Plastic length - dry length}}{\text{Plastic length}} \times 100$$

Firing shrinkage

Firing shrinkage is usually determined on samples that have been fired to several different temperatures (for filters, small cones 016, 014, 012, and 010 will give a good range of information), following the standard firing schedule. This gives an idea of the progressive shrinking of the clay as the temperature is increased.

1. Mark each bar made for the previous tests with a test firing temperature.
2. Fire the dried bars: three bars of each recipe should be fired to each test temperature.
3. Measure the length of the scratch on the fired bar.
4. Calculate the firing shrinkage using the following equation:

$$\text{Firing shrinkage} = \frac{\text{Dry length - Fired length}}{\text{Dry length}} \times 100$$

Total Shrinkage

Total shrinkage is how much the clay or filter mixture shrinks from its plastic state to its fired state and can be calculated using the following equation:

$$\text{Total shrinkage} = \frac{\text{Plastic length - fired length}}{\text{Plastic length}} \times 100$$

A good total rate of shrinkage for filters will be in the range of 6.25- 7.25%.

Water of Absorption (Porosity)

The firing temperature of a clay can be assessed by evaluating total shrinkage (see above) and absorption test results. During the ceramic change (approximately 600°C), the chemically-bound water fires out leaving leaves spaces where the water was, thus making the ceramic porous. As firing continues, the clay shrinks and these spaces fill up (vitrification). As a clay body vitrifies, it becomes less porous. Therefore, the degree of water absorption of the fired clay, or percentage porosity, is also a measure of the maturity of a fired clay body. Earthenware clay, by definition, will have a greater than 5% porosity when fired to maturity. Porosity of filters has been measured to range from 30-44% (van Halem 2006; Oyanedel-Craver and Smith 2008).

1. Use the test bars fired to different temperatures from the firing shrinkage test above.
2. While still warm from the kiln, carefully weigh the fired pieces to the nearest centigram.
3. Submerge the bars in hot water for three hours.
4. Dry the surface of the bars with a damp sponge and weigh each one again.
5. Calculate the absorption, using the following equation:

$$\text{Percent absorption} = \frac{\text{Saturated weight - dry weight}}{\text{Dry weight}} \times 100$$

Assessing Hardness (Durability)

It is important the the fired clay be durable enough to give service in the household. To this end, the hardness of the fired clay can be assessed by scratching it with the fingernail. Rank each sample on a scale of 0 - 10, with 0 being very soft and crumbly, and 10 being very hard and durable.

The easiest way to do this is to line up the test bars on a ware board with the softest on one end and the hardest on the other, in order of perceived hardness. Then a relative numerical ranking can be assigned to each sample.

After all testing is done, the bars' durability can be further assessed by breaking them with the hands, estimating the relative amount of force needed. This should reveal those clay samples too weak to serve for filters.