Insulative ceramics for improved cooking stoves

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Conversion factors

Many of the graphs in this article use imperial units – to convert to metric units, use the following:
1lb = 0.45kg
Celcius = (Fahrenheit −32) × 0.5555

Why it is important to use insulating clays

Multiple tests of the Lorena stove, beginning in 1983, showed that placing materials with high thermal mass near the fire can have a negative effect on the responsiveness, fuel efficiency and clean burning of a cooking stove. (High thermal mass materials are those – such as mud – that absorb a lot of heat.) Because of this, when stoves are built from sand and clay, their efficiency, when tested in the laboratory, is not much better than that of the three-stone fire.

What other materials can be used? More efficient stoves, such as the Rocket stove (see *BP47*, page 36), produce such high temperatures in the combustion chamber (where the fire burns) that even metals can be destroyed, including stainless steel. Don O'Neal (HELPS International) and Dr Larry Winiarski, Aprovecho Technical Director, have found that cast-iron combustion chambers, though longer lasting, conduct heat so well that it makes the fire hard to start. They eventually located an alternative material: an inexpensive Guatemalan ceramic floor tile, called a *baldosa* in Spanish.

The *baldosa* is about an inch thick so the combustion chamber only weighs 18.5 lbs (Figure 1). Like all Rocket combustion chambers, it is surrounded by insulation – either wood ash or pumice rock.

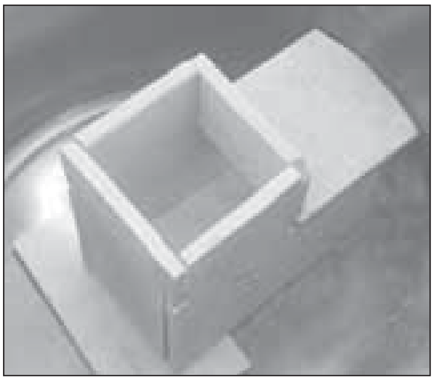

Figure 1 *Baldosa* being used to form Rocket stove combustion chamber

Recipes for making insulative ceramics

These recipes are intended to assist stove promoters to make insulative ceramics for use in improved wood-burning cook stoves. The clay insulation makes a good combustion chamber material for any type of stove and will improve efficiency. Each of these materials incorporates clay, which acts as a binder.

The clay forms a matrix around a filler which provides insulation. The filler can be a lightweight fireproof material (such as pumice, perlite or vermiculite), or an organic material (charcoal or sawdust). The organic material burns away leaving insulative air spaces in the clay matrix.

In all cases, the clay and filler are mixed with a predetermined amount of water and pressed into forms (moulds) to create bricks (Figure 2). The damp bricks are allowed to dry (which may take several weeks) and then fired at temperatures commonly obtained in pottery or brick kilns in Central America.

Our test samples were made using low-fired *raku* clay obtained from a local potters' supply store. In other countries, the best source of clay would be the kind used by local potters or brick makers. Almost everywhere, people have discovered clay mixes and firing techniques which create successful ceramics.

Figure 2 Stages in construction of a Rocket stove using low-density bricks

Insulative ceramics need to be lightweight (low density) to provide insulation and low thermal mass. At the same time they need to be physically durable to resist breakage and abrasion due to wood being poked into the back of the stove.

These two requirements oppose each other. Adding more filler to the mix will make the brick lighter and more insulative, but will also make it weaker. Adding clay will usually increase strength but makes the brick heavier. We feel that a good compromise is achieved in a brick having a density between 0.8 gm/cc and 0.4 gm/cc.

The recipes in Table 1 indicate the proportions, by weight, of various materials. We recommend these recipes as a starting point for making insulative ceramics. Variations in locally available clays and fillers will probably require adjusting these proportions to obtain the most desirable product.

Insulative ceramics used in stoves undergo repeated heating and cooling (thermal cycling), which may eventually produce tiny cracks that cause the material to crumble or break. All of these recipes seem to hold up well to thermal cycling. However, the only true test is to install them in a stove and use them for a long period under actual cooking conditions.

Sawdust/clay

In this formulation, fine sawdust was obtained by running coarse sawdust (from a construction site) through a #8 (2.36 mm) screen. Clay was added to the water and mixed by hand to form thick mud. Sawdust was then added,

Theme

Table 1 Insulative Ceramics

Type	Filler Grams	Clay (damp) Grams	Water Grams	Fired at Centrigrade	Density gr/cc
Sawdust	490	900	1300	1050	0.426
Charcoal	500	900	800	1050	0.671
Vermiculite	300	900	740	1050	0.732
Perlite mix	807	900	1833	1050	0.612
Pumice mix	1013	480	750	950	0.770

and the resulting material was pressed into rectangular moulds. Dried bricks were fired at 1050 °C.

Excellent insulative ceramics can be made using sawdust or other fine organic materials such as ground cocao husks or horse manure. The problem with this method comes in obtaining the large volumes of suitable material necessary for a commercial operation. Crop residues can be very difficult to break down into particles small enough to use in brick making.

This method would be a good approach in locations where there are sawmills or woodworking shops, which produce large amounts of waste sawdust.

Charcoal/clay

In this formulation, raw charcoal (not briquettes) was reduced to a fine powder using a hammer and grinder. The resulting powder was passed through a #8 screen.

Clay was hand mixed into water and the charcoal was added last. A rather runny slurry was poured into molds and allowed to dry. It was necessary to wait several days before the material dried enough that the mold could be removed. Dried bricks were fired at 1050 °C.

Charcoal can be found virtually everywhere and used where other filler materials are not available. Charcoal is much easier to reduce in size than other organic materials. Most of the charcoal will burn out of the matrix of the brick. Any charcoal which remains, is both lightweight and insulative.

Charcoal/clay bricks tend to shrink more than other materials during both the drying and firing processes. The final product seems to be lightweight and fairly durable, although full tests have not yet been run on this material.

Vermiculite/clay

In this formulation, commercial vermiculite (a soil additive) which is #8 (2.36 mm) and smaller in size is mixed directly with water and clay and pressed into moulds. Material is dried and fired at 1050 °C.

Vermiculite is a lightweight, cheap, fireproof material produced from natural mineral deposits in many parts of the world. It can be made into strong, lightweight insulative ceramics with very little effort. The flat, plate-like structure of vermiculite particles makes them both strong and very resistant to heat.

Vermiculite appears to be one of the best possible choices for making insulative ceramics.

Perlite mix/clay

For best results, perlite must be made into a graded mix before it can be combined with clay to form a brick. To prepare this mix, first separate the raw perlite into three component sizes: 3/8′ to #4 (9.5–4.75 mm), #4 to #8 (4.75–2.36 mm), and #8 (2.36 mm) and finer.

Recombine (by volume) two parts of the largest size, one part of the midsize, and seven parts of the smallest size to form the perlite mix. This mix can now be combined with clay and water and formed into a brick, which is dried and fired at 1050 °C.

Perlite is basically the mineral obsidian which has been heated up until it expands and becomes light. It is used as a soil additive and insulating material. Perlite mineral deposits occur in many countries, but the expanded product is only available in countries which have commercial ‘expanding’ plants. Where it is available, it is both inexpensive and plentiful.

Perlite/clay bricks are some of the lightest usable ceramic materials we have produced so far.

Pumice mix/clay

Pumice, like perlite, produces the best results when it is made into a graded mix. Care should be taken to obtain the lightest possible pumice to prepare the mix. Naturally occurring volcanic sand, which is often found with pumice, may be quite heavy and unsuitable for use in insulative ceramics. It may be necessary to crush larger pieces of pumice to obtain the necessary small sizes.

The mix is prepared by separating pumice into three sizes: ½′ to #4 (12.5–4.75 mm), #4 to #8 (4.75–2.36 mm), and #8 (2.36 mm) and smaller. In this case, the components are recombined (by volume) in the proportion of two parts of the largest size, one part of the midsize, and four parts of the smallest size. Clay is added to water and mixed to form thin mud. The pumice mix is then added and the material is pressed into moulds.

Considerable tamping or pressing may be necessary to work out the air and form a solid brick. The mould can be removed immediately and the brick allowed to dry for several days before firing at 950 °C.

Pumice is widely available in many parts of the world and is cheap and abundant. Close attention to quality control is required, and this could be a problem in many locations. It is very easy to turn a lightweight insulative brick into a heavy non-insulating one through inattention to detail. Pumice (and perlite as well) is sensitive to high heat (above 1100 °C). Over-firing will cause the pumice particles to shrink and turn red, resulting in an inferior product. Despite these concerns, pumice provides a great opportunity to

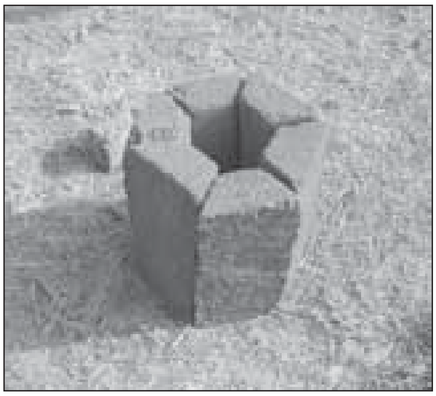

Figure 3 Pumice/clay combustion chamber

supply large numbers of very inexpensive insulative ceramics in many areas of the world (Figure 3).

Why it is important to use insulating clays

Appreciating that clay seemed a promising base material for Rocket combustion chambers, teams of researchers conducted more comprehensive testing to determine strength, durability, insulative quality, etc. This research resulted in several 'home-made' insulative clay recipes. In the Rocket stove combustion chamber, six insulative clay bricks (11½″ high by 2½″ thick) make up a hexagonal cylinder surrounding a 4″ diameter chimney. Sticks of wood enter the bottom of the chimney through a hole sawn in the bricks.

Making the Rocket combustion chamber from separate bricks has resulted in a reduced tendency to crack. The bricks have held up so far in durability tests and they help to make a hot, clean burning fire.

Tests have been done of same-sized brick combustion chambers made from adobe, home-made clay insulation, common brick, *baldosa*, and light-weight metal.

The following four graphs show the average results of three tests using each of the four materials. They reflect how heat passed into the four materials as 1½ lbs of wood was burnt.

Results

Shown in Figures 4–7.

Findings

The average temperatures ½ inch from the fire within the home-made clay insulation reached 906 ˚F. At the same place the *baldosa*/vermiculite combination rose up to 764 ˚F with the sensors ½ inch within the adobe. The more massive walls inside the heavier combustion chamber are much cooler. Cooler fires make more smoke.

In these tests, the graph shows that the better insulator allows a steep rise to higher temperatures. Also, the three lines on the graph for the better insulator are further apart, i.e., heat passes more slowly through the material so there are bigger differences in the temperatures recorded at a increasing distance from the heat source. The maximum difference between the furthest apart sensors in the home-made clay insulation was 839 ˚F. In the *baldosa*/vermiculite test the maximum difference was 439 ˚F. But in both the common brick and adobe combustion chambers the greatest difference was much lower (275 ˚F and 173 ˚F) – this tells us that heat is escaping more quickly through the walls, instead of going to the pot.

Fuel efficiency was affected by the weight of the combustion chamber, for 5 lbs of water being boiled. However, it can be seen that the differences in fuel efficiency created by the four earthen materials are not large and all four ceramic materials are satisfactory (Figure 8).

Each Rocket stove with any material in the combustion chamber did better in laboratory tests than the three-stone fire (the pot 'skirt' helps to raise efficiencies). A larger difference is seen in an additional test of a sheet metal combustion chamber which was appreciably faster than the ceramic types.

Noting the success of the very low mass sheet metal combustion chamber reinforces the design principle of lowering the mass of material around the fire.

The responsiveness of the stove and the speed at which water boiled was dramatically affected by the material used. The 5 lbs of water boiled at the following times:

- Adobe 16.5 minutes
- Common Brick 17.5 minutes
- Baldosa 19.2 minutes
- Home made clay insulation 12.7 minutes

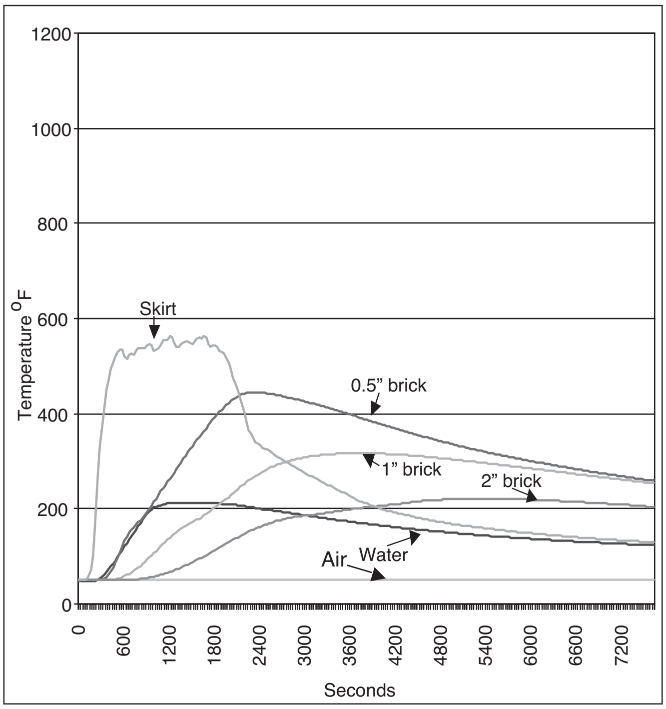

Figure 4 Average of three adobe brick tests

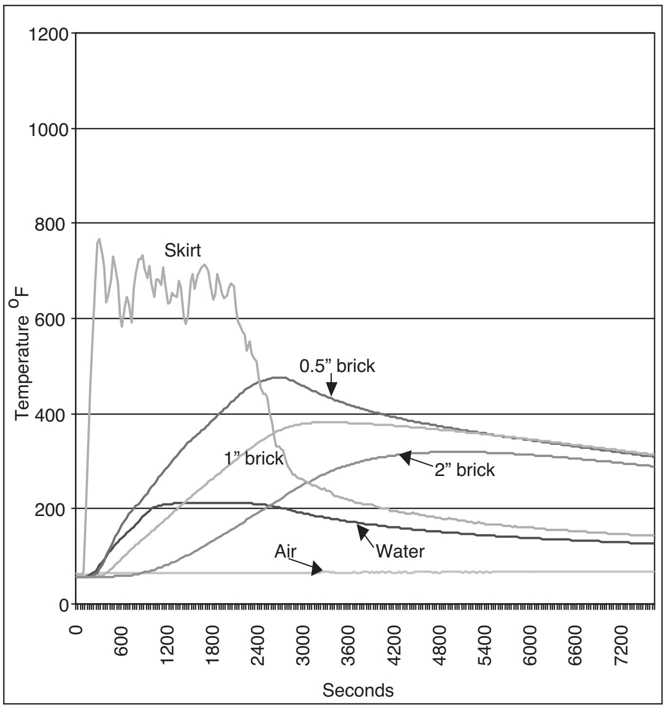

Figure 5 Average of three common brick tests

Theme

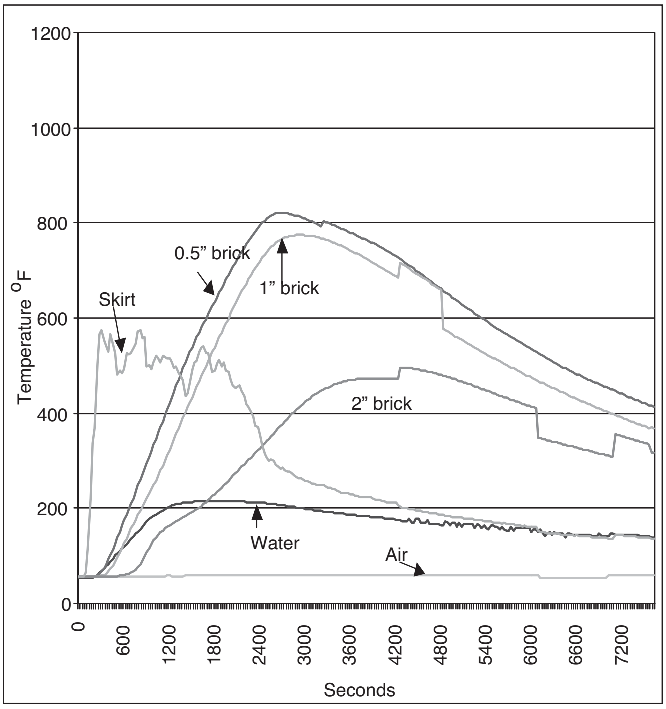

Figure 6 Average of three *baldosa* tests

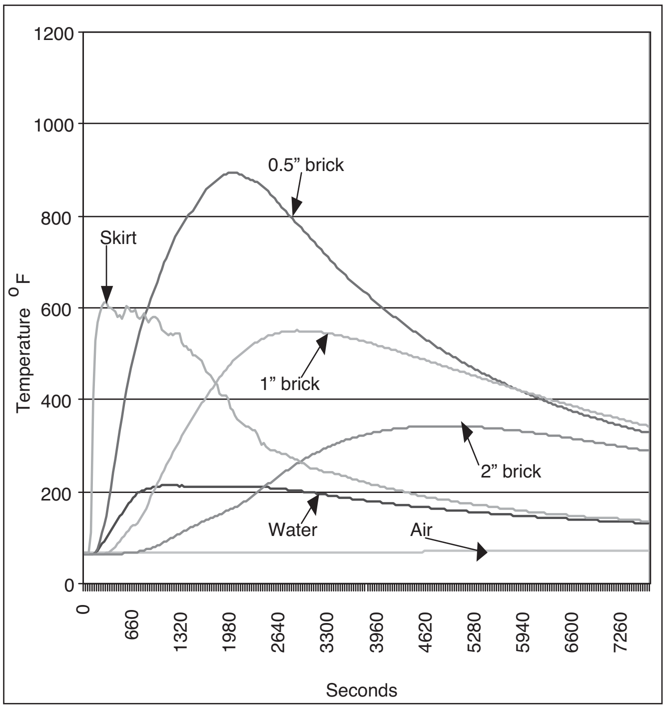

Figure 7 Average of three home-made clay insulation tests

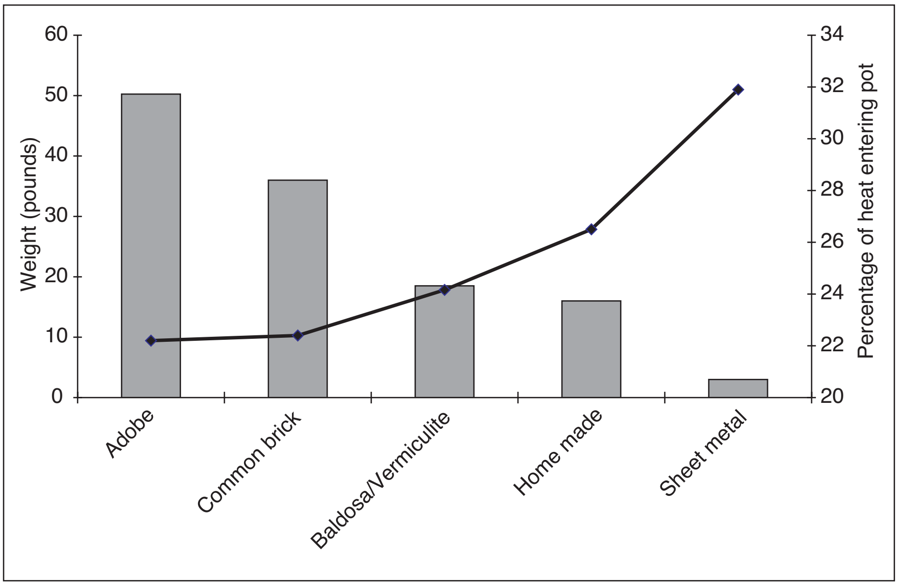

Figure 8 Percentage of heat entering the pot

Does material choice affect combustion temperatures?

Follow-up tests were performed on the clay insulation, adobe and low mass metal combustion chambers. The stoves were fired as hot as possible without creating excess smoke or charcoal. During a 45-minute period, temperatures were recorded using PICO software at 3″, 8″ and 11″ up from the bottom of the combustion chamber, at the inside face of the Rocket combustion chamber and at the top of the chimney for both the adobe and clay insulation combustion chambers. The results of this comparison showed that temperatures are higher in an insulated combustion chamber.

Distance	Adobe	Home-made clay
3″	1123 °F	1383 °F
8″	513 °F	1148 °F
11″	622 °F	1113 °F
Exit	1148 °F	1573 °F

It was not feasible to drill into the low mass stove to replicate the tests done on the two ceramic stoves. But exit temperatures found during a similar test reached 1592 ˚F.

Conclusions

Replacing heavy clay and sand materials next to the fire with lightweight ceramic insulation helps any type of stove to burn hotter and cleaner. More of the heat from the fire goes into the pot, not into the body of the stove. Local potters and brick makers can make the clay insulation by changing recipes. Making bricks that form combustion chambers helps to reduce cracking because the space between the bricks allows them room to expand and contract as they are heated and cooled.

If you want to see more about how to make insulative clay combustion chambers and have access to the web, visit http://www.ecoharmony.net/hedon/insulation.php

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