Rocket Stoves with Extended Fuel Chambers

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Clearing the Air Over Cookstoves, by Johnson and Bryden

• Such parallel activities are often completed outside the kitchen, drawing the cook’s attention away from the fire for periods as long as up to 15 minutes. To keep an unattended fire from smoldering, women in the village prefer to stoke a fire with large amounts of wood. Improved cookstoves, however, don’t allow for that. Since they are engineered with an eye toward better performance and reduced emissions, improved cookstoves generally have small, well ventilated combustion chambers, meaning they require regular attention. Participant observations suggested that the constant attention they require is part of the reason these ostensibly improved stoves were used infrequently in the village.

A tier 1 stove that people love and use makes more difference than a tier 4 stove that people don’t use.
What makes a stove “easy to use”? (Comments in parentheses)

• Easy to light. (Rocket stoves are pretty good in this respect.)
• Can use whatever fuel is available, without much fuel processing. (If the door isn’t too small, rocket stoves are pretty good in this respect.)
1672 grams of useless wood
• Easy to see fire. (Rocket stoves may or may not be good in this respect.)
If the stove has an easy line of sight to fire, fire tending is easy, even on the ground.
If the stove has a difficult line of sight to the fire, fire tending is more difficult.
• Can burn wet wood (this is a tough challenge).
• Fuel tending is easy, and infrequent. (Rocket stoves may or may not be good in this respect).
Current Water Boiling Test

• Is very idealized, good for comparing stoves, and for getting best possible performance, but maybe not for designing a practical stove.
Current Water Boiling Test Idealizations
(with others options in parentheses)

• Wood is straight, small, dry. (Also use natural wood that is branchy and of typical wetness.)
• Don’t put a lid on the pot (also test with lids).
• Maintain simmer by holding at 3° below boiling. Really! (Maintain simmer by maintaining simmer).
• Test is done on a nice comfortable bench (also test on the floor, depending on cultural practices)
• Use water to simulate food (also test with real food, of a common type).
• Indoors, no wind (use fan to simulate wind, if stove is used outdoors).
• No limit to how much the fire is tended. (Test with specified intervals between fuel tending).
Introducing the Walkaway Test

• Like the water boiling test, but after you tend the fire, walk away for 10 or 15 minutes. No matter what happens, let it be.

• Test with and without lids, maintaining steady simmer.

• Measure time to boil, total time tending the fire, total fuel use.

• In the simmering phase measure number of times simmer was lost, and how far below boiling the temperature dropped.
# Introducing the Andreatta Scale for Flame Size

<table>
<thead>
<tr>
<th>Fire Size</th>
<th>Smoke Level</th>
<th>Heat Transfer Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A handful of fire.</td>
<td>Virtually none</td>
</tr>
<tr>
<td>2</td>
<td>Starting to go up riser.</td>
<td>A little.</td>
</tr>
<tr>
<td>3</td>
<td>Consistently below pot.</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Touching bottom of pot.</td>
<td>Modest amount.</td>
</tr>
<tr>
<td>5</td>
<td>Covering bottom of pot.</td>
<td>Modest amount.</td>
</tr>
<tr>
<td>6</td>
<td>Start to flow up sides of pot.</td>
<td>Lots.</td>
</tr>
<tr>
<td>7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Reaching top of pot.</td>
<td>Really lots</td>
</tr>
</tbody>
</table>
Andreatta Scale for Coals

• 1 = 1 handful of coals.
• 2 = 2 handfuls of coals.
• 3 = 3 handfuls of coals.
• Etc.
Rules of Thumb for Fire Tending

• If the sum of the fire size and the coals size is 4, tending the fire is easy, just push in the wood.

• If the sum is 3, it may be easy.

• If less than 3, or if the fire is 0, you’ll probably have trouble. Add small pieces, blow on fire, wait for it to build up, then add bigger pieces.
• The ideal situation is to have a flame that burns steadily for the entire time, at the right level, and then after 10 or 15 minutes there is enough flame and coals to easily build up the fire again.
Ordinary Rocket Stove

Fuel opening is 11 cm by 7.5 cm.
Notes from previous slide

• At the end of the 10-15 minute time interval, the fire often burns back to the area around A, and the fire does not go into the stove. The fire is usually small at this point and makes little smoke, but white smoke often “boils” off the back end of the wood outside the stove, and does not get pulled into the stove and burned.
Preliminary Designs

• In the following 3 slides, some preliminary designs are shown, without insulation.
• They each performed reasonably well in terms of producing a steady fire, but not as well as the final design.
Options that didn’t work as well-1: Constant diameter rocket elbow.

When wood burns here, fire is good.

When fire burns back to here, fire is steady, but too weak for good cooking.
Options that didn’t work as well-2: Multi-diameter rocket. This worked almost as well is the final design. A window would be needed to see the fire properly.
Options that didn’t work as well-3: Ceramic stove with added tunnel, and window in the tunnel. This worked almost as well as the final design.
Rocket Stove with Extended Fuel Chamber (Final prototype with insulation removed)

Fuel opening is 13 cm by 9 cm.
• Ideally, the fire starts at the region of A, then burns steadily back to B. After 10-15 minutes the wood near A is reduced to ash or char, and the wood can be pushed in nearly 30 cm. At this point the fire starts again at A and burns back to B.

• The actual situation is not too far different from the ideal.

• The fire was never observed to burn outside the stove, as it did with the standard rocket stove.

• In use, this prototype stove would be wrapped in layers of insulation, welding cloth on the inside and aluminum foil on the outside. This probably serves as reasonably good insulation.

• On the top of the stove is a top plate (sometimes called the cone deck because it is somewhat conical in shape) from a commercial rocket stove. This is similar to the standard rocket, shown previously. The gap between the pot and the top of the stove should be near ideal, and the tapering shape of the passage should also be near ideal.
Rocket Stove with Extended Fuel Chamber
(showing viewing window for fire)
Notes from previous slide

- The window in the top of the stove is for viewing the fire, so that, even with the deep firebox, the user can tend the fire without getting their nose down on the ground. The window works well, but could probably be smaller, and should be closer to the “corner” of the stove.

- It’s not absolutely critical, but the window should be covered most of the time, as some fire escapes through it.
Tests Done with Each Stove

- Two walkaway tests with lid, 10 minutes between fuel tendings during high power, 15 minutes during simmer.
- Two walkaway tests without lid, 10 minutes between fuel tendings during high power and simmer.
- Total 8 tests.
- No skirts were used, because I feel current skirts are impractical.
- The same pot was used for all tests, about 23 cm diameter. This was a little smaller than ideal.
- Tests were done in a shed with no wind, typically with an ambient temperature near 0° C.
- Water started between 20 and 25° C.
- Wood was mostly natural wood, mostly crabapple, unknown moisture content.
Procedure for Walkaway Test

• Start fire, tend fire as much as necessary to get it ready to walk away.
• Walk away for 10 minutes (actually it’s OK to watch the fire, just don’t do anything with it).
• Tend the fire as much as necessary to get it going again. With an easy re-kindle this takes 30 seconds, with a difficult re-kindle this can take over 3 minutes. Record the amount of time tending the fire.
• Walk away for 10 minutes.
• Repeat until boiling is achieved. At boil weigh pot, mark time, weigh remaining fuel, estimate unburned fuel and charcoal in the stove.
• At the end of the 10 minute interval (15 minutes if you are using a lid) do the usual fire tending procedure. During this time, maintain a steady simmer, because that’s what the user would do.
• Walk away for 10 minutes (15 if you are using a lid).
• Tend the fire.
• Continue the process until the end of the 45 minutes simmer period.
• The last period will not be exactly 10 (or 15) minutes. Use judgment whether to lump it in with the previous. For example, if the last period would be 5 minutes and the simmering is still going strongly at the end of the previous time interval, don’t tend the fire and lump the last few minutes into the previous time interval.
• At the end, measure the remaining fuel, and estimate the unburned fuel (if any) and charcoal inside the stove.
Instruments for measuring temperature of fire and water.

- Shielded thermocouple for fire.
- Thermocouple on sinker for water temperature.
- Data loggers.
Measuring the Fire Temperature
Test site
Rocky the Lab Assistant

Rocky’s Calling Card
Notes on the following slide

• There is good correlation between the fire temperature and the rate of water temperature rise during the high power phase. When the fire is weak, the water temperature drops.
• This leads to longer time to boil. The time to boil was only about 30 minutes, but the water started at 26° C.
• The huge dip in the water temperature is when the thermocouple was removed from the water so the pot could be weighed at the start of boil.
• During the simmering phase, the temperature drops significantly below boiling several times.
• When the fire temperature is increasing, this is when the fire has just been tended.
• The 10-minute rule applies to the time between the end of one fuel tending and the beginning of the next one. The user “walks away” for 10 minutes.
• The boiling point measures at slightly below 100° at this location with this instrument.
Basic Ceramic Stove, No Lid

![Graph showing temperature over time for fire and water.](image-url)
Additional notes for the following slide

- Up to about the 30 minute mark, the fire size was steady at a constant 5 or 6, with modest smoke. Through this period, a small number of thick pieces of wood were used.
- Temperature rise rate of the water was steady, and the time to boil was fast.
- After 30 minutes the operator started using many pieces of thinner wood, which was a mistake. The fire was too big immediately after putting in the wood, as high as 8, with lots of smoke and way too much boiling. Then, near the end of the 10-minute interval the fire died fast and was too small, losing simmer with the temperature dropping well below boiling.
- Better selection of fuel would have made the results much better in the simmering phase.
Extended Fire Chamber Stove is

- Consistently faster in time to boil.
- Consistently worse in fuel usage (possibly due to less refined heat transfer path and less insulation).
- About the same in other characteristics, total time the fire, number of times that simmer is lost, temperature drop during simmering.
- With better technique, extended fire chamber stove should work very well.
Numerical Results (each number is the average of 2 tests)

<table>
<thead>
<tr>
<th></th>
<th>Basic Stove with Lid</th>
<th>Extended Stove with Lid</th>
<th>Basic Stove without Lid</th>
<th>Extended Stove without Lid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corrected Time to Boil</td>
<td>37.9</td>
<td>30.4</td>
<td>35.9</td>
<td>29.9</td>
</tr>
<tr>
<td># of Times to Lose Sim.</td>
<td>2.5</td>
<td>1.5</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Temp. Loss from Sim.</td>
<td>2.3</td>
<td>1.7</td>
<td>2.3</td>
<td>3.7</td>
</tr>
<tr>
<td>Tot. Time Tending Stove</td>
<td>5.8</td>
<td>6.7</td>
<td>7.8</td>
<td>7.5</td>
</tr>
<tr>
<td>Total Fuel (grams)</td>
<td>966</td>
<td>1402</td>
<td>1393</td>
<td>1901</td>
</tr>
<tr>
<td>Overall Thermal Eff.</td>
<td>0.150</td>
<td>0.119</td>
<td>0.202</td>
<td>0.154</td>
</tr>
</tbody>
</table>
Stove Stacking Witnessed in Honduras