3 STOVE TESTS

November 15, 2014

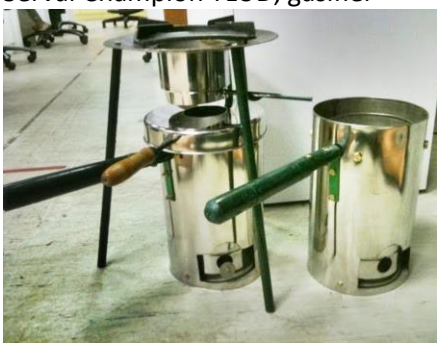
Hi Pearly, Cary, Timothy

We did a number of stove tests last week. The results were quite interesting.

We tested 3 wood stoves and we did a similar test with a modern natural gas range.
A quick summary of the test: we used the same type and amount (750 grams) of wood for each stove. We lit the fires at the same time. We put identical pots with 5 liters of water on each stove. We timed how quickly the fires lit, how long it took to reach boiling, how long each pot simmered at 100°C (212°F) and how long until the fire was all gone.
We observed visible smoke during the test and looked at what was left of the wood at the end.
We also measured the outside surface temperature of the stoves during the process.

The 3 wood stoves we tested and 1 gas stove were:

1. Serval Champion TLUD, gasifier



2. SilverFire Hunter, gasifier with chimney

3. SilverFire Survivor, rocket stove

4. Viking Professional natural gas stove. 17,000 BTU burners (4.92 Kw).

Summary of results:

The Hunter was the fastest and lasted the longest. It was even faster than the gas stove. Of course the gas stove can last longer. All the stoves were easy to light. We were told not to use a starter liquid in the Survivor so it took a little more fooling around to get started. The fires on all stoves took about 5 minutes to reach a level of flame where we put the pot on.

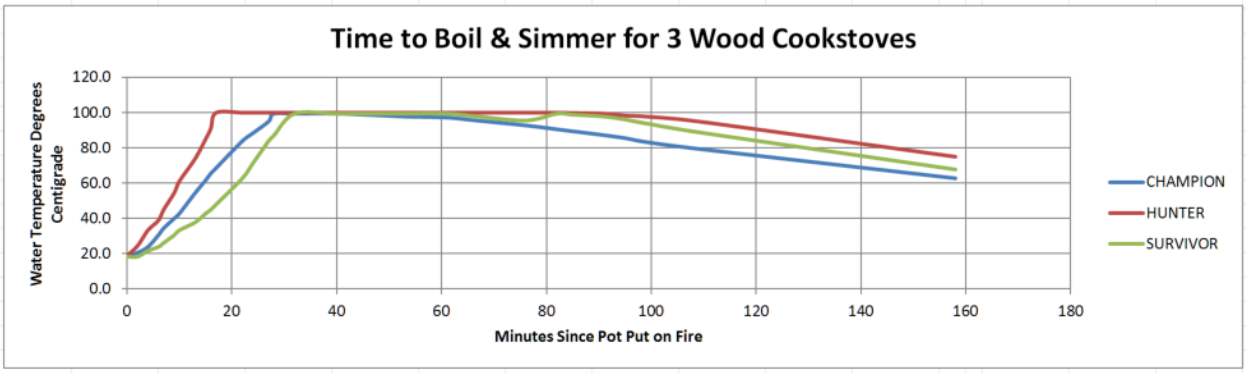
Here are the times to reach a boil for each stove.

	Hunter	Viking gas	Champion	Survivor
Minutes to boil	17	20	28	30

It was impressive how quickly the Hunter brought water to a boil. It was equally impressive how long it kept the pot at boiling temperature.

The Survivor was impressive in how little fuel it used to get the water to a boil. However, to keep it boiling we had to continue adding fuel. It required a lot of attention and we didn't pay close enough attention. Sometimes we added more fuel than was necessary, getting the fire hotter than a simmer and wasting fuel. Other times we forgot to add fuel and the pot cooled down. We then added more fuel which caught quickly and heated the pot again.

Here is a record of the temperatures each stove achieved and maintained.



Notice that the Hunter stayed at full boiling temperature for an hour and 8 minutes. It stayed pretty hot (above 95°C for 1 hour 32 minutes. The Hunter could have gone longer but the fuel chamber was not filled as 750 grams was the maximum the Champion could hold and we used the same amount for all stoves. If we filled the Hunter chamber it would have burned longer.

The Survivor could have kept temperature at boiling for almost as long but did not because we didn't monitor the fuel carefully enough (the need to monitor is a drawback to the Survivor). The Survivor stopped boiling because we used a fixed amount of fuel, the same for all stoves. It could have boiled for as long as we want if we added more fuel. Shortening or extending burn time is an advantage of the Survivor rocket stove.

The Champion dropped below boiling about 12 minutes after it reached a boil. The temperature dropped more quickly than the other stoves.

Here is the record kept of temperature increase over time for each stove.

	Temperature Deg C							
	Therm 2	Therm 3	Therm 4		Exterior stove body temperature Deg C: Top, Mid, Bot			Chimney Temp C
ELAPSED TIME	CHAMPION	HUNTER	SURVIVOR	Comment	CHAMPION	HUNTER	SURVIVOR	HUNTER
0	18.9	18.9	18.3	prior to start				
0	18.9	18.9	18.3	Start fire				
0	18.9	18.9	18.3	Put pot on Champion & Hunter				
2	20.6	24.4	18.3	Put pot on Survivor				
4	23.9	33.3	21.7	Smoky fire in Survivor				
6	30.6	38.9	23.9					
7	34.4	45.0	26.1					
9	40.0	54.4	30.6					
10	42.8	61.1	33.3					
13	54.4	73.9	37.8	Add wood, more smoke Survivor	86,49,29	69,76,42		
15	61.7	85.0	42.8				39,33,34	
16	65.6	91.1	45.0					
17	69	100.0	48	Hunter boiling. Champ flame blowing around				
22	83.9	100.0	62.8	Hunter fast boil. Champ pot 197F(92C)		118,48,32		
24	88	100	71		177,171,110			
27	95.0	100.0	83.9	Survivor cast iron 540F (282C)			74,63,66	
28	99.4	100	87	Champion is boiling. Survivor: let too much wood burn to coals, added wood. Inefficient				
32	99	100	99.4	Survivor: boiling, 1/3 fuel left		92,41,31		88
40	99.4	100.0	99.4					
49	98.3	100.0	99.4					
53	97.8	100	99					
61	97.2	100.0	99.4					85
66	96	100	98			71,39,28		
76	92.8	100.0	95.6	air temp 60F. Survivor restarting w new wood				
82	90.6	100.0	99.4	Survivor: added last wood, boilding again				
85	89	100	99	Survivor cast iron 325F (163C)	49,41,31	61,33,29	64,43,50	
91	87.2	99.4	97.8					
95	85.6	98.3	96.1					
99	83.3	97.8	93.9					
109	79.4	95.0	88.9					
158	62.8	75.0	67.8					

Note: boiling temperature for the Champion and Survivor is 99.4°C because the thermometer is slightly off. i.e. the thermometer reads 99.4°C when the temperature is 100°C.
Thermometers off by ~ 1 degree. Therm #2 & #4 boiling at 211°F
Heating of rocket stove, Survivor, irregular because fuel was not added consistently. Fire would die down. Then we added more fuel. Sometimes added too much and wasted fuel.
Outdoor air temperature was 60°F at start
55°F at 4:47 PM, not a lot colder at 6:00 but didn't measure

Design Notes

- The flame of the Hunter was confined under the pot. Exhaust gases went up the chimney. It seemed like this may have been part of the reason it heated more quickly. The flame under the pots for the Champion and the Survivor was in the open air on its

way to the pot, hit the pot and then quickly slipped out into open air, i.e. much more exposed and seemed like it mixed a lot with cold air.

- The Chimney on the Hunter seemed a striking advantage. The Survivor especially gave off a lot of smoke if the fire was not perfectly attended. The Champion gives off smoke if the flame goes out due to wind or other cause. It can then be relit. All the stoves, including the Hunter give off smoke during startup. However, the Hunter is more quickly covered and directs smoke up the chimney. It seemed like the chimney might also contribute to the fast heat up and greater efficiency of the Hunter as noted above.
- It is hard to empty ashes from the Hunter. Figuring out ash handling is something to think about. It could be improved in all the stoves. But Hunter was most difficult.
- At least for us all the stoves would have been much more convenient if they were at waist height. The Survivor especially was difficult to feed and monitor, requiring going down on hands and knees at various times.
- Insulation. The outside temperature of the body of the Champion was much hotter than either the Hunter or Survivor. Both of them are insulated with expensive ceramic fiber insulation. The Champion only has an air gap between the inner and outer cylinders. The hottest temperature we measured on the Champion body was 350°F (?°C). This would suggest that fiberglass insulation, which is relatively cheap, might be used outside the body of the Champion, although the temperature might go up considerably higher with the fiberglass insulation in place.
- We might want to use 2 stoves in a kitchen. They could both be of the same type or one could be a gasifier, batch loaded and the other like a rocket where fuel can be added or reduced. This solves several problems. More flexibility. You can be cooking 2 things at once or you can shift from one to the other. Or you can use the gasifier for stewing something that you bring to a quick boil and then simmer for a long time. And you can use a rocket stove (the 2nd stove) for sautéing something or cooking something small quickly.
- I am looking forward to another round of tests that include the RocketWorks ZamaZama stove which has been recommended, has good performance numbers, is cheap, can be fabricated locally and fuel can be fed or removed during cooking. It does not have a chimney but one could be adapted. I would also like to test the variation of the Champion TLUD devised by Kirk Harris. It has tested more efficient than the Serval Champion we tested.

Description of each stove

1. **Champion**.
    a. The Champion was easy to light.
    b. It is light weight and easy to move around.
    c. Easy to dump out ash.
    d. We didn't preserve the charcoal but let it burn out. This is not recommended by the manufacturer. They say the use of the charcoal is inefficient because it is far from the pot and the heat transfer is radiant. They sell an attachment for burning charcoal, or you can quench the charcoal (in an air tight can or with water or ?) and burn it later in a charcoal stove. Or you can use it as a soil amendment or in composting toilets. They say burning the charcoal will shorten the life of the stove.
    e. The stove should be relatively inexpensive, but buying it in the U.S. is expensive $120-150. It could probably be easily made in Besongabang. The principle item of cost would be the stainless steel.

f. It boiled water slower than the Hunter and a small amount faster than the Survivor.
g. It cooled off rather quickly and didn't cook as long as the other stoves.
h. Didn't require any attention. Just lit it and watched it go through it burn cycle. Although burn time can't be extended it is possible to control the intensity of the flame in the early stage by controlling the primary air. We didn't do this but just set the primary air to give a flame that looked adequate and not too big, i.e. that would send flames way outside the pot.
i. You can't extend cooking time. This is solved by having 2 stoves (but don't need 2 combustors and chimneys) and moving one into place when the other is burned out. This would not really be a smooth transition because the stove first cooks hot and then cools off for lower heat cooking. If you switch a second fuel canister into place you are changing from low heat cooking to high heat. Also, how soon do you decide to stop the low heat cooking which gradually goes lower and lower?
j. The outside of the stove body got quite hot. It might be worth considering insulation for the outer cylinder. It seemed that the temperature was low enough to consider use of fiberglass which would be inexpensive. The other stoves used high temperature ceramic fiber insulation which is quite expensive.

2. SilverFire **Hunter**.
   a. Easy to light.
   b. Somewhat heavy but still easy to move around if you want to.
   c. Hard to dump ash. Didn't see any easy way to get it all out.
   d. It boiled faster than the other stoves and faster than a gas stove. Impressive performance.
   e. It kept water boiling for a long time and cooled down slower than other stoves.
   f. Seemed extremely clean. But we didn't do any emission testing, just watched smoke.
   g. The pot didn't get any soot on the outside. That is because the flame and all exhaust gases are contained inside the stove and then directed up the chimney. That seemed like a nice result. The other stoves got a lot of soot on the outside of the pot. Interestingly the bottom of the Hunter had much less soot.
   h. The chimney seems a dramatic plus as any smoke or emissions (which seemed to be low) can be directed out of the kitchen (or away from your face in an outdoor cooking situation).
   i. Some smoke gets into Kitchen during lighting of the stove and if you added wood during the burning cycle smoke would get in the room also.
   j. The Hunter seemed to be a big winner. The downsides were the inability to adjust cooking time or fuel quantity and to change from high simmering to high fire cooking. The Survivor solved both of those problems but was much slower and dirtier. However, Todd Albi, the owner of SilverFire said fuel can be added to return to high fire power and to extend cooking. That would remove one of the principle drawbacks. Todd said, "You can add fuel at any time to increase fire power, There are gasification ports mid-way of the combustion chamber, above the flame at the top of the chamber and the primary ports below the grate. It will gasify at all times and adding fuel will quickly return it to high power. Low fire power requires time however, to reach a simmering steady state.
   k. There was some charcoal left over after the fire went out. In the other stoves there was only a small amount of ash and no charcoal. That is surprising since it

did more cooking than the others and still had some fuel left. If we had opened the primary air inlet maybe the last of the charcoal would have burned.

l. The outside of the stove stayed relatively cool.
m. It is relatively expensive.
n. Can't be fabricated locally.
o. Changes and adaptations we'd like to make:
    i. Bigger chimney, run further horizontally to take it out of the kitchen. Heat from the chimney is kept out of the kitchen and might be used for drying wood or something else.
    ii. To dump ash the stove must be disconnected from the chimney. This is difficult to do and would probably be impractical with the built in arrangement we'd like to have for an indoor kitchen.
    iii. Improve ash removal. Currently must dump the stove in 2 directions and this doesn't empty it fully.
    iv. Find solution to smoke coming into the kitchen during lighting.

3. SilverFire **Survivor**.
    a. A little awkward to light but maybe solved with more skill. Started about as fast as the others.
    b. Heavier than Champion but easy enough to move around.
    c. Dumping out ash was problematic because it had to be fished out from under the grate or tip the stove in 2 directions which is awkward.
    d. It was the slowest to come to a boil but that was probably due to our inexperience in operating the stove.
    e. Control of cooking time and intensity. It could cook for as long as you want because you just add more fuel. How this impacts efficiency we didn't test. You can increase the flame to high temperature any time you want or reduce it. This was maybe the biggest advantage of this stove.
    f. It takes a lot of attention to keep the stove operating smoothly. You need to add fuel at short regular intervals to keep the stove at even temperature. It takes a good deal of skill to operate well. It is easy to add too much fuel or too little and to add it too soon or too late.
    g. We used the same length fuel as was used in the other stoves. This isn't what is most natural for the Survivor which is thought of using longer (but similar width) fuel. The longer pieces and cooking style is closer to what people are used to in Besongabang which might be a benefit.
    h. Soot and emissions. We got a lot of smoke and a lot of soot from the Survivor. Significantly more than with the other stoves. This was due in significant part to our inexperience in operating the stove. Each time we added wood there was an increase in smoke for a while. We let it die down at various points (need to pay close attention) and that increased smoke.
4. **Viking natural gas stove**.
    a. This one boiled fast but not as fast as the Hunter.
    b. Control. You can turn it to high temperature or simmer essentially instantly at any time. You can shorten or lengthen the cooking time and cut off fuel use essentially instantly at any time.
    c. Emissions. By reputation (we didn't do any testing) it is cleaner than any of the wood stoves. With a chimney and the relatively clean burning of the Hunter it is not clear from a health or comfort standpoint how much better this is than the Hunter.

d. Too expensive. Neither the fuel nor the stove (nor infrastructure) would be affordable in Besongabang.
e. It is not clear that the use of natural gas is environmentally superior to wood when harvested sustainably and used in the cleaner burning stoves and with possible use of charcoal as soil amendment resulting in carbon negative fuel use.

[Test photographs by Pete & Mimi Srivarom]

Soot on the pots

Hunter (completely clean), Champion (soot about 1/3 way up side), Survivor (heavy soot almost to the top of pot)

Pot bottoms. Hunter (left), Champion (middle), Survivor (right)
Interestingly the Hunter had less soot on the bottom of the pot which was exposed to the flame. Presumably this was because the flame was cleaner. The bottom of the pot on both the Champion and the Survivor was completely black with soot. However, the buildup on the Survivor was greater.

Thin stainless steel 8 quart pots. One portion of the pots was painted black (not shown in this picture) so that the temperature could be measured with the infrared thermometer.

Pot showing placement of temperature probe (in the center of the pot about 1 ½” from the bottom) and the digital readout. The digital thermometer allows setting an alarm to go off when the probe reaches a predetermined temperature. It also has a countdown timer.

This is one batch of wood, the same for all stoves. The wood is very dry douglas fir (no moisture measurements were taken but wood was old (not green) and stored in a dry location for 1-4 weeks). It is 7” long and ½”-1 ½” thick. The size distribution as the same for all batches of wood.

Wood in the fuel chamber of the Champion.

Paper with charcoal lighter fluid used to start the Champion.

Paper with charcoal lighter flued used to star the Hunter.

The Hunter getting started.

The Champion is started and the concentrator lid has just been put on.

Starting the Survivor. It was awkward to get a match in to start the fire (we dropped it in from the top). Using the short 7” pieces of wood was not so convenient with the Survivor. It is designed for longer wood. With the short pieces of wood we closed the door most of the time. That may have increased efficiency.

Flame established in Champion, ready to put on pot.

Pot on the Survivor (note paper label on pot, painted black for use with infrared thermometer)

Pot on Viking gas stove. Trying to figure out why the Hunter could boil water faster than the Viking we hypothesized that the unenclosed flame might be part of the reason. It is also possible that the flame from the Hunter is stronger. The Viking has a higher power flame than the usual residential gas stove. It is 17,000 BTU (manufacturer's rating, presumably in BTU/hour) or 4.52 Kw.

Pot boiling on the Survivor

Pot boiling on the Champion

Pot boiling on the Hunter. Note how clean everything is.

The Champion (far left) and Hunter (middle) are ready for their pots. The Survivor (right) will be ready in about 2 minutes.

Pots are on all 3 stoves. Note that you can see the flames in the Champion (far left). You see no flames on the Hunter (middle) because it is all contained within the body and all exhaust gases go up the chimney. Flames are also visible for the Survivor (far right) but not in this picture due to the angle.

Coals in the Hunter after all flames (burning gases) have disappeared.

Here is the test procedure we used:

1. Stoves to test are:
    a. Serval Champion TLUD, gasifier
    b. SilverFire Hunter, gasifier with chimney
    c. SilverFire Survivor, rocket stove
    d. We don't have yet, but will soon have a RocketWorks ZamaZama hybrid rocket stove/gasifier. We will test it later.
2. Prepare 3 identical batches of wood for the 3 different stoves:
    a. Each batch the same weight: 750 grams (this about the weight of dry douglas fir that the Serval Champion TLUD will hold using 7" sticks of wood, 1" shy of top of inner cylinder) (A full load weighed 1 lb 11.2 oz = 27.2 oz = 771 grams, we used 750 grams for the tests) Note: Fuel cylinder for the Serval Champion TLUD is 8" high x 5 ¾" diameter; SilverFire Hunter is 9 ¼" high x 6 ½" diameter. SilverFire Survivor rocket stove's fuel chamber is 4 ¾" wide X 2 ¾" high X 8 ½" deep and the wood has be fed piece by piece (i.e. can't fill it with the 750 grams at one time).
    b. Using the same wood (same species, same moisture content)
    c. Split to approximately the same width (in this case ½"x ¾" to ¾"x 1 ½") and cut to the same length (7").
3. Fill 3 identical pots with 5 liters of water (3" down from top rim in the pots I got) . Pots have a lid.
4. Put black paint or masking tape on part of the outside of each pot and each stove to facilitate taking IR gun temperature readings.
5. Put a thermometer in each pot (Oneida® Digital Probe Thermometer with Timer, wire and probe). Make sure each thermometer is at the same position in the pot, not touching bottom or sides, about the middle of the water.
    a. Calibrate thermometers before to check that they are all the same. Check temperature in cold water then heat water to boiling and check again. Check with all thermometers in the same pot at the same time.
6. Use the same amount of paper (? Grams) or kindling with the same amount of charcoal lighter fluid (? Squirts) to light each stove. Note: no charcoal lighter fluid was used to light the SilverFire Survivor rocket stove as the stove instructions said not to.
7. Light the stoves at the same time and keep track of what happens. The lighting procedure for the Survivor rocket stove was different and could not be done at exactly the same time. Pot was put on the fire to start heating of water was started about 2 minutes later than other stoves.

    a. Plot temperature of water over time, noting when water reaches boiling, how long it stays there and when the fire goes out.
    b. Take pictures and video of each step of the process. (It would help to have more than 2 people to take photos, read thermometers, tend fire).
    c. Measure temperature of the outside of the stove and pot.
8. Check what is left over: ash? Charcoal?

Equipment needed:

1. 3 - 8 quart pots with lids. The pots we used are very thin stainless steel with lid. They are 9" diameter, 8" high.
2. 3 – digital thermometers with probe: Oneida® Digital Probe Thermometer with Timer. $20/each from Bed Bath & Beyond.
3. Holders for thermometers in pot. We made from wood with holes to insert thermometer probe.
4. Infrared temperature gun. Etekcity® ETC-8550 Digital Infrared Thermometer range -58F to 1022F,12:1 D:S,Non-contact, Instant-read Laser Temperature Gun, FDA/FCC/CE/ROHS Approved. $19 Amazon.com
5. High temperature paint. Used to paint shiny metal sides of pots and stoves so that the infrared thermometer could be used to measure surface temperature. The shiny metal has low emissivity in the infrared and cannot be accurately read with the infrared thermometer. Flat black durable to 2000°F.
6. Stoves
7. Wood
8. Charcoal lighter.