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**Charcoal Stoves for Haiti**

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**Photo 1: Stove Camp '10 participants.**

Fifty two high energy participants (Photo 1) attended Stove Camp this year at Colgan's Island, camping near the river, making and testing stoves, and listening to Fred's Big Band harmonize so beautifully. Fred and his volunteers cooked breakfast every morning and dinners at nighttime parties on Rocket and TLUD institutional stoves. Nick Salmons (Photo 2) from International Lifeline Fund made a very successful Haitian charcoal stove that was voted "Best in Class" by his peers!

**Photo 2: Prize winner Nick Salmons with his Mamamusa stove.**

Stove Camp provides a venue for a gathered scientific community (Photo 3) to advance knowledge of biomass cook stoves. Participants made new stoves and tested them daily for fuel use and emissions. Every morning the test data was shared and new stoves were constructed.

**Photo 3: Dr. Larry Winiarski introducing his rocket stove design principals.**

This year, a great deal of progress was made on charcoal stoves for Haiti. Camp participants, some of whom have worked in Haiti, designed a two-hour Water Boiling Test for Haiti, which uses a Haiti pot and mimics a typical cooking task, cooking rice and beans. Charcoal stoves were constructed that used less fuel and produced less carbon monoxide compared to traditional Haitian stoves.

The experiments done at Stove Camp are helpful to guide the construction of better performing stoves, but it is important to remember that it takes at least three identical tests with a low coefficient of variation to confidently determine performance. The data in this report are from single experiments that only show what results were seen by folks trying to improve the stoves.

## Stove Camp Water Boiling Test Protocol

### Cooking Task

Prior to Stove Camp, the Aprovecho staff tested traditional charcoal stoves by adapting the Standard Water Boiling Test protocol to local cooking conditions in Haiti. The pot used for all tests is a 7 liter aluminum rounded-bottom pot that was sent to Aprovecho from Haiti by Trees, Water, and People. In general, the stoves tested were unable to boil 5 liters of water with no lid, so the protocol was changed to boil 2.5 liters with no lid and then simmer for 30 minutes. For several stoves, we varied the amount of charcoal loaded from 300 to 700 grams. The amount of charcoal required to complete the cooking task for some stoves is more charcoal than other stoves can even hold.

It became apparent that there is an ideal fuel load specific to each stove. If a stove is loaded with less charcoal than necessary, it may not be capable of producing enough firepower for long enough of a duration. If a stove is loaded with more charcoal than necessary, it may become clogged with charcoal, which effectively impedes airflow and lowers firepower. In either case, the stove will take longer boil water or it will not be able to complete the simmering task. Figures 1 and 2 show how variation in the amount of fuel loaded changes the performance of each stove. These results suggest that a series of tests varying the fuel load should be done on each stove in order to find its optimum initial fuel load so that the stoves can be more accurately compared.

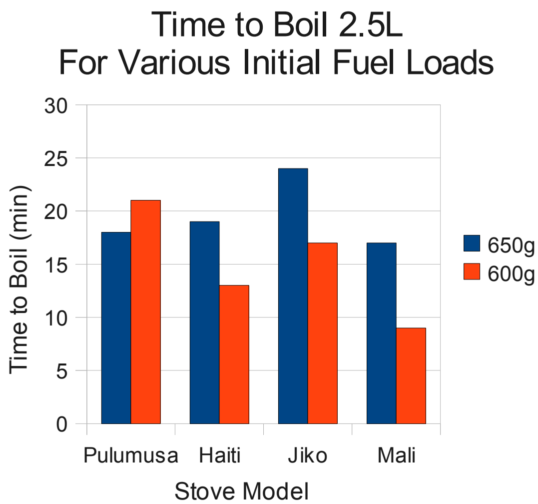


*Figure 1: Detrimental effects of overloading stoves.*

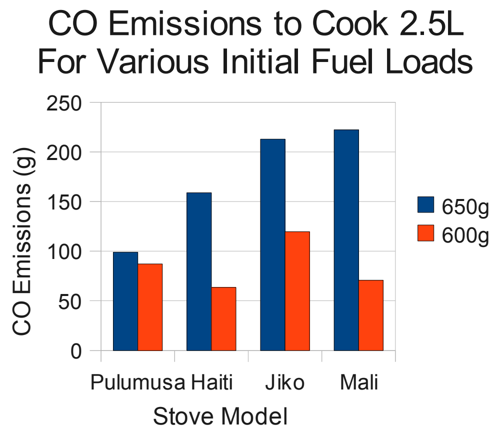


*Figure 2: Detrimental effects of overloading stoves.*

At Stove Camp, participants decided on a WBT protocol for Haiti that simulated cooking rice and beans. The Stove Camp WBT protocol for Haiti was to boil 5 liters of water with a lid and then simmer. The total cooking time must be 2 hours minimum. By using a lid, heat loss is reduced, and a lower firepower is required during the boil and especially the simmer phase.

Lighting Procedure

Prior to Stove Camp the charcoal was lit by putting it inside a metal chimney designed for lighting charcoal briquettes. The chimney has holes in the bottom so air can flow up through it. The draft accelerates the lighting process and helps the coals to light uniformly. Fifty grams of lighter fluid were applied, lit, and allowed to burn for 10 minutes before pouring the charcoal into the stove and starting the WBT. Lighting the charcoal outside the stove was based on the hypothesis that it would reduce variability by consuming the same amount of charcoal for every test.

However, by standardizing the lighting procedure the lighting performance of the stove is ignored. Stove geometry determines the stove's natural draft and the shape of the charcoal pile. Therefore, some stoves light faster and more uniformly than others, which could be a desirable feature. For this reason, the lighting process adopted for Stove Camp was to light the charcoal in the stove.

Stove Camp participants experimented with different methods to light the charcoal in the stove including soaking wood chips in lighter fluid, soaking the charcoal in lighter fluid, fanning the charcoal, and using a riser chimney (for example: a bottomless coffee can). As a result of Stove Camp testing, the proposed lighting procedure is to apply a ratio of 1 gram of lighter fluid for every 10 grams of charcoal that is loaded into the stove. The pot is placed on the stove once the lighter fluid has burned off and the coals are glowing (this takes 5 to 7 minutes).

If a riser chimney is placed on top of the charcoal, the draft increases and the charcoal lights faster and more uniformly. However, unless the riser is the same size for every test it, it will create variation in the results.

We look forward to experimenting further with lighting methods that are suitable to do under the emissions hood so the emissions and fuel consumption during the lighting process can be included in the PEMS data output. The lighting process appears to consume about one fifth of the total fuel, and probably emits more emissions than the boil and simmer phases combined. All of this happens before the pot is even placed on the stove. By including the lighting process in the WBT, the true emissions of a cooking task will be better represented.

Performance Measures

Most performance measures come directly from the *Standard Water Boiling Test*: "Boil Time", "Fuel to Cook", "Carbon Monoxide to Cook", "Energy to Cook", and "Carbon Dioxide to Cook". The standard performance measure "Particulate Matter to Cook" was omitted because charcoal stoves emit very low particulate matter. These performance measures alone may not characterize charcoal stove performance because they are based on data collected only during the boil and simmer stages when the pot is on the stove—effectively ignoring the emissions and fuel burned during the lighting stage and after the cooking task is over.

The performance measure of "Fuel Loaded" was added in order to capture how much fuel needs to be purchased to complete the cooking task. During the boil and simmer stages, a stove may consume only half of the fuel that was initially loaded, but the stove needs that initial large fuel load to produce enough firepower to complete the cooking task. The remaining fuel still burning at the end of the cooking task may or may not be used for another task or quenched for later use.

The "Turndown Ratio" seems to be an important performance measure, which is the ratio of the firepower at boil to the firepower at simmer. It shows how well a stove can throttle up to boil and down to simmer.

## **Design Elements**

The task of developing a better charcoal stove for Haiti involves understanding and improving several different design elements to reduce fuel use and carbon monoxide emissions. Design elements discussed in the following text are: 1) skirts, 2) hot coal bed, and 3) air control. Test results from Stove Camp suggest that stoves with these three features produce lower CO and have lower fuel consumption.

<u>Skirts</u>

A skirt is a metal surface that surrounds the pot and creates a narrow channel gap for exhaust gases to flow through. The skirt forces heat into the pot. Whether it is forcing hot exhaust gases to scrape against the side of the pot, or whether it is reflecting radiation from the combustion chamber to the pot, the skirt improves the heat transfer into the pot. In Figure 3, the Henson has the lowest fuel use. It is also the only stove with a skirt. In Figure 4, the Benin has the highest fuel use and it is the only stove without a skirt. It is probable that the skirt caused better heat transfer, and in turn, caused the stoves to complete the cooking task using less fuel. See Appendix B for photos of all the stoves.

For all skirted stoves at Stove Camp, the channel gap width was between 5 and 10 mm. The ideal channel gap width is a compromise between heat transfer and firepower. A smaller channel gap has better heat transfer by forcing heat closer to the pot, but causes lower firepower by restricting air flow through the stove. Although it is generally agreed that a skirt can decrease fuel use by increasing efficiency, the ideal channel gap width for charcoal stoves has to be determined. Aprovecho staff are working on this problem.

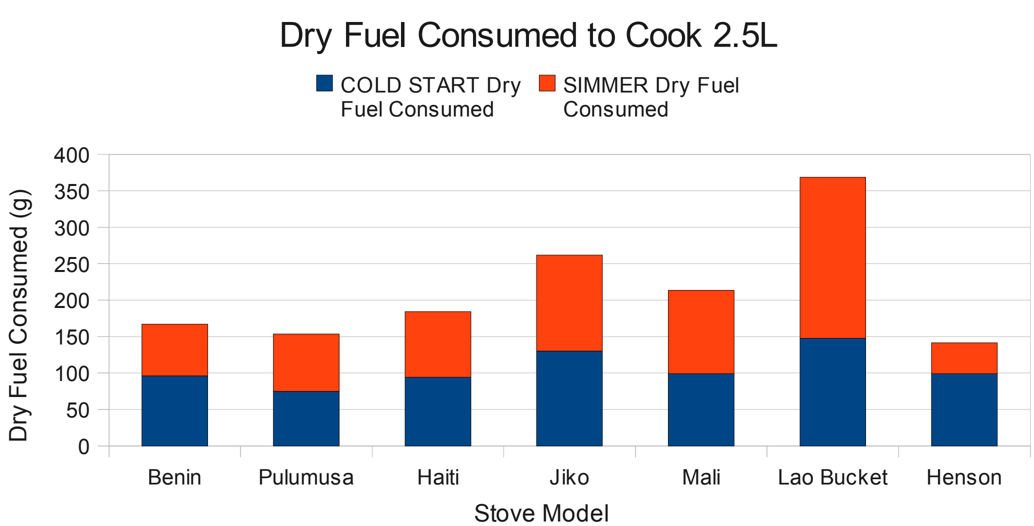


*Figure 3: Performance of the fully skirted design compared to stoves with no skirt.*

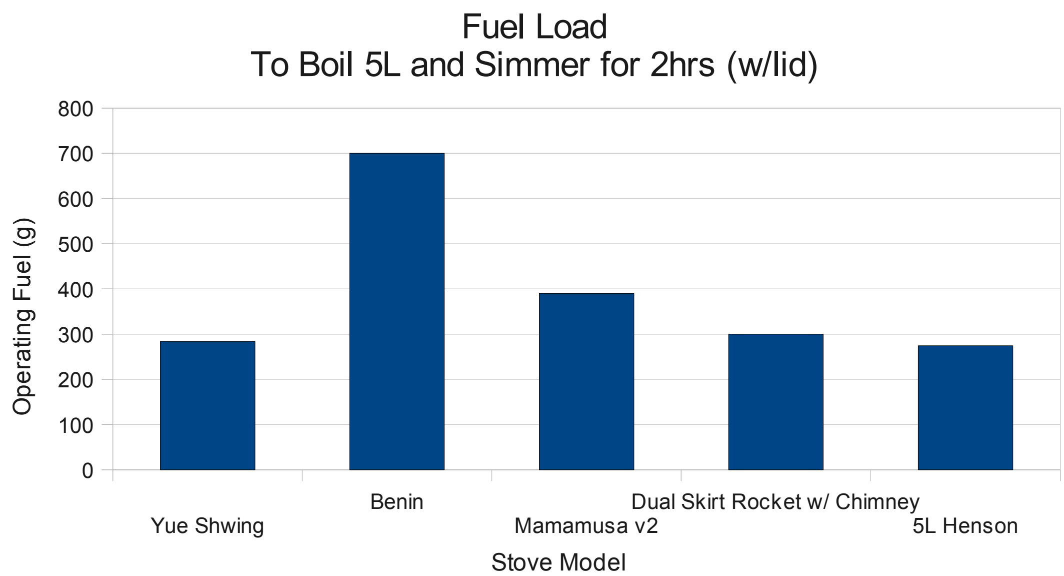


*Figure 4: Performance of stoves with skirts compared to Benin, a benchmark stove for GTZ.*

Hot Coal Bed

Maximum heat transfer to the pot occurs when the temperature of the heat source beneath the pot is highest. In order to maximize radiative heat transfer, the GTZ benchmark Benin stove reduces the distance between the heat source and pot--the pot sits on the coals. Whether or not zero distance offers maximum heat transfer when convective heating is accounted is uncertain. Zero distance may also cool the coals, hence decreasing radiative output, more so than if some space is provided. Stove designs at Stove Camp explored two methods to maximize the surface temperature of the coals instead of minimizing distance to the coals: 1) insulation around the combustion chamber, and 2) a fixed air path through the fuel charge dubbed, "the Henson pig tail" (an open metal coil in the pile of charcoal that provided air to the top of the pile.)

**Insulation Around the Combustion Chamber**

In Figure 5 the Yue Shwing and Mamamusa are shown to have low fuel consumption compared to the Benin stove. The Mamamusa insulates the bottom of the stove with a perforated heat reflector though which primary air is directed. In this configuration some of the heat radiating from the bottom of the reflector plate is carried back toward the pot by the now pre-heated primary air stream. The Yue

Shwing employs secondary air to recover heat in a similar way around the entire circumference of the combustion chamber. Both stoves are insulated on the side with rock wool. In both cases the insulation should help to provide more heat to the pot. Whether insulation is an important design feature is another interesting area of study.

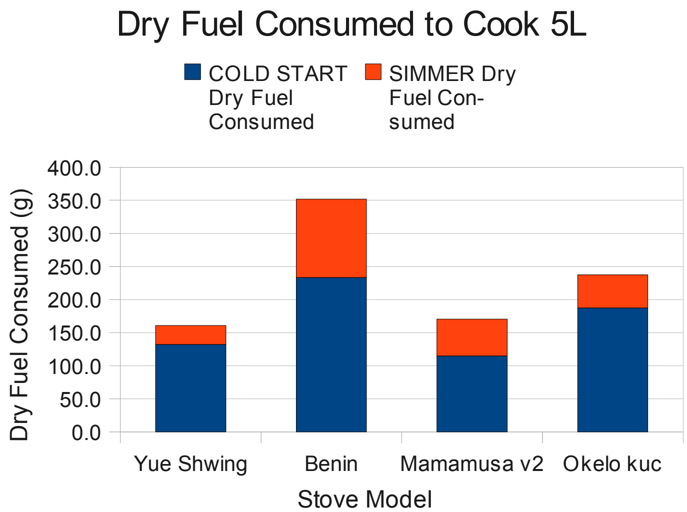

*Figure 5: Stoves with insulated combustion chambers.*

## The Henson "Pig Tail"

All of the stoves in Figure 4 which out-performed the Benin stove featured a coiled wire in the center of the combustion chamber to provide a continuous supply of air through and to the top of the fuel charge. Further testing with variable fuel sizes is required to determine the extent of this features significance.

## Air Control

Stoves seem to be dramatically improved by managing the air introduced to the burning charcoal. By controlling when, where, and how much air is added to the system, significant progress can be made to improve fuel efficiency and emissions. At Stove Camp there were two methods of air control that seemed to improve stove design: 1) a high turndown ratio and 2) the addition of secondary air.

## Turndown Ratio

The turndown ratio is the ratio of boil firepower to simmer firepower. A stove with a high turndown ratio can throttle up to high firepower for a fast boil, and throttle down to low firepower to simmer with a lid. When simmering with a lid, there is relatively little heat loss from the pot, and a very low firepower is required to maintain simmering temperatures. The firepower is adjusted by controlling the air flow rate through the stove by means of a door on the air intake. Charcoal will continue burning with very little primary air and yet still produce enough heat to maintain a simmer with a lid. It takes a tight sealing door to decrease the firepower enough so that it is not excessive when simmering with a lid. Having a high turndown ratio may be one of the most effective ways to reduce both fuel use and CO emissions. As the primary air is reduced, the combustion reaction slows down, less fuel is consumed, and proportionally less CO emissions are produced.

The Yue Shwing, a modified StoveTec stove with an almost airtight door, has a remarkably high turndown ratio (Figure 6). The Benin benchmark stove, on the other hand, has a low turndown ratio because there is no mechanism to dampen the air intake. See Figure 7 as follows.

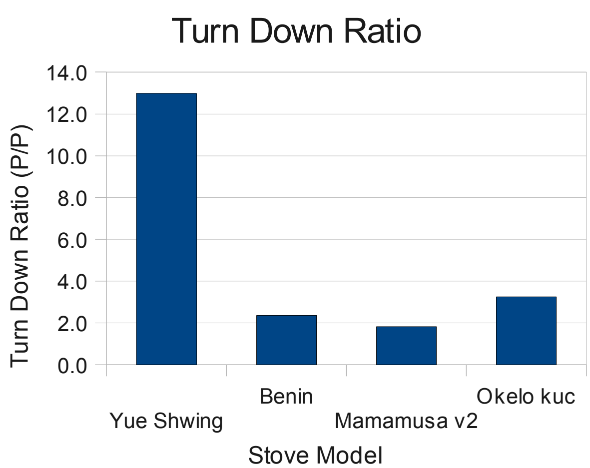


*Figure 6: Superior turn down ratio.*

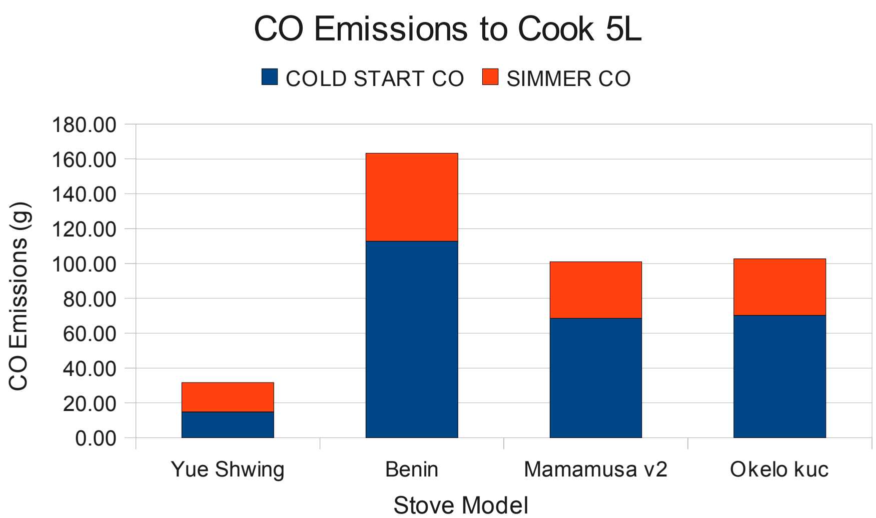


*Figure 7: Lowered CO emissions due to controlled air supply.*

*Secondary Air*

Primary air goes into the combustion chamber passing straight through the coals, while the secondary air enters the combustion chamber above the coals. Secondary air may provide additional oxygen ($O_2$ ) to the combustion reaction zone which can combine with unburned CO to complete combustion by forming $CO_2$. Secondary air may reduce CO emissions and also reduce fuel use, because CO releases energy when it is completely combusted into $CO_2$.

The ability of secondary air to lower fuel use and CO emissions may depend on how and where it is mixed into the system and how well it is preheated. Further research needs to be done on how to best mix the secondary air into the reaction. Questions such as ‘How far above the coals should it be introduced?’ and ‘How much secondary air is necessary?’ need to be answered. Research also needs to be done to test the hypothesis that preheated secondary air is more effective at lowering fuel use and CO emissions than non-preheated air. In Figure 7 the Yue Shwing is the only stove with secondary air.

## Final Remarks

When the experimental task was determined at Stove Camp to build a charcoal stove for Haiti that would boil 5 liters of water, with a lid, quickly, and cook for a duration of two hours on a single load of fuel, with low fuel consumption and CO emissions, the Aprovecho staff wondered if participants would succeed. It was great to see so many small groups develop stoves that seem so promising. Watching a large group make good progress on a problem in one week reinforced how fast and effectively iterative design and testing can progress while folks are also having a lot of fun.

After such a good start, the Aprovecho staff continues to test and evolve improved prototype charcoal stoves. Charcoal burning stoves are like many technologies used by the poor, not much scientific effort has gone into their development. One of the themes of Stove Camp is for many people to experience together how relatively easy it is to improve appropriate technologies. Many times it is the energetic amateur who makes the most progress. A dedicated and perhaps stubborn person can make much better stoves by making prototypes and testing them in the lab and field. It’s a straightforward process that normal, talented, and inspired people can easily do, helping to make a better world. Stove Camp 2010 was filled with so many talented folks who worked hard and succeeded to make progress on charcoal stoves for Haiti and the world. It was great to be with them!

## Appendix A

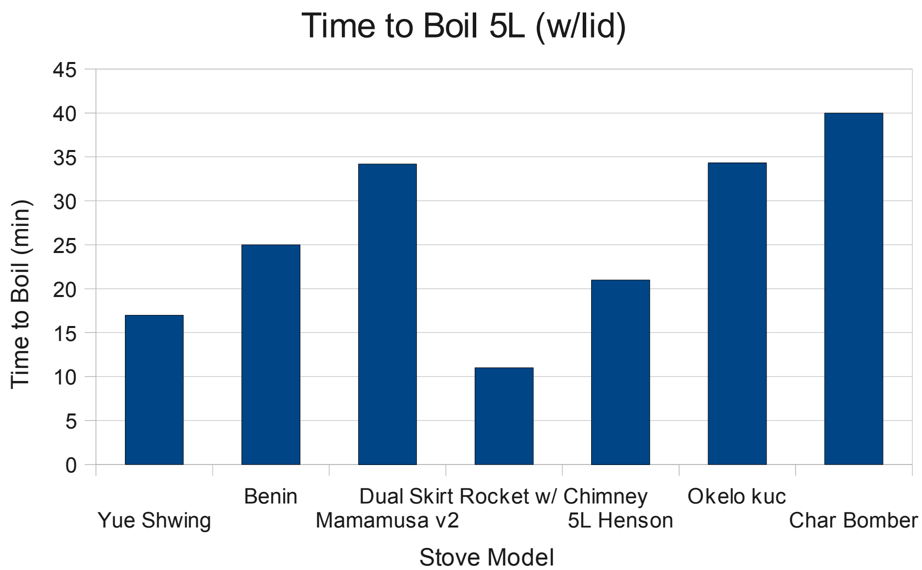


*Figure 8: Stoves tested at Stove Camp.*

## Appendix B

Pictures of Stoves

**Photo 4: High pot supports of the Jiko with open door.**

**Photo 6: Yue Shwing with partially open door and pot specific skirt.**

**Photo 5: Secondary air control plate and pig tail of Yue Shwing.**

**Photo 8: Haiti stove with open door.**

**Photo 7: Removable fuel bowl of Haiti stove.**


**Photo 9: Close fitting skirt of the Henson.**


**Photo 11: Sunken pot in the Henson.**


**Photo 10: Pot specific skirt of the Mamamusa with open door.**


**Photo 12: Perforated reflector plate of Mamamusa with rock wool wall insulation.**


**Photo 13: Conical fuel bed of Mamamusa.**

Photo 14: Air intake of Lao Bucket.


Photo 15: Air intake of Benin benchmark stove.

Photo 16: Fuel bed and pot supports of Lao Bucket.

**Photo 17: High pot support of Mali stove with door.**

**Photo 19: Half skirt of 5L Henson.**

**Photo 18: Fuel canister with pig tail offset to show air intake of 5L Henson.**

**Photo 21: Pot receptacle of Dual Skirt Rocket.**

**Photo 20: Chimney of Dual Skirt Rocket**

**Photo 23: Air intake of Pulumusa.**

**Photo 22: Pot riser of Pulumusa with secondary air and conical fuel bed.**