Testing Cookstoves

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In June of 2003, approximately twenty people met at the Aprovecho Research Center near Eugene, Oregon to compare various wood burning cooking stoves used in either Central America or Africa. The stoves were examined using a Water Boiling Test. This test has been used at Aprovecho for many years. Energy in the fire heats water up to boiling and by measuring the sensible (by rise in water temperature) and latent heat (by amount of steam generated) the thermal efficiency of the stove is determined. The amount of heat entering the pot, divided by the total amount of heat released from the burning wood, results in a percentage. Higher percentages indicate a stove that has improved thermal efficiency. This test is frequently called Percent Heat Utilized (PHU).

After comparing the performance of many stoves side by side, doubts about the approach forced a re-examination of the literature on testing. In the Aprovecho water boiling tests, stoves that burned at high power exclusively, using up fuel quickly, scored higher than other stoves that boiled food as quickly but then simmered the water at slightly less than full boil for much longer time periods. The same amount of wood was used in all tests and it seemed reasonable to expect that the stove that kept food at near boiling temperatures for the longest time would be the most fuel efficient when cooking food. The PHU test did not seem to be predictive of success at cooking food.

After the seminar, Dr. Alan Berick took the results from nine stoves and looked at how long the stove was able to keep the pot's water above 98C. One stove that had high marks on the PHU test operated for 4500 seconds. Another stove that scored relatively poorly could have cooked food for 6500 seconds using an equal amount of fuel.

Damon Ogle took a standard pot and determined approximately how much steam boils off per minute at 95½ C, 98 C, and 99½ C. All of these temperatures are within the specifications of the VITA 85 International Testing Standard protocols for simmering. As temperature increases greater amounts of steam are produced. It was found that simmering at 99½ C produced 56% more steam than simmering at 95½ C. If a stove was operated at low power, so that the water simmered but not much steam was made, the result was a lower score on PHU. Producing excess steam, wasteful when cooking, resulted in higher marks.

Rereading Baldwin, Prassad, Visser and the VITA 1985 International Standards, an undivided wall of opinion confronted the bemused and embarrassed Aprovecho testers. The decades old books and articles explained that the PHU test did not accurately predict success at cooking, even though the use of the test today continues to be almost universal. The VITA 1985 International Standards, for example, propose a different approach to testing stoves that determines the wood used in both high and low power operation of the cooking stove. As Prassad points out, knowing the rate of wood used at high power (when the water is being quickly brought to boil) and at low power (when the water temperature is kept steady while simmering) can be used to more accurately predict fuel use for different cooking tasks.

Aprovecho published a booklet "Guidelines on Evaluating the Fuel Consumption of Improved Cookstoves, (1981) pointing out serious problems in the PHU test, concluding that, "… boiling water tests do not directly measure cooking efficiency; they should not be used to project fuel savings…(Page 79). Bussmann in "Field Studies: Woodburning Cookstoves" (1984) states, "…stoves should have high efficiency numbers, but this alone is not enough. Stoves also should be able to supply power outputs which are in agreement with the heat needed for cooking. In other words, it is the combination of efficiency and power output which determines whether a stove saves fuel or not." (Page 20)

The VITA '85 authors stress (Index A) that it is necessary to use more than the Percent of Heat Utilized equations to compare stove performance. Using other equations to find the specific fuel consumption, power limits and evaporation fill in the picture of stove performance. The Controlled Cooking Test, which compares the fuel used when cooking a standard meal, is required both to check the results of the WBT but also stands alone as more reliable.

Sam Baldwin "Biomass Stoves: Engineering Design, Development and Dissemination", (1987) explains that Specific Consumption, the amount of wood used to boil and simmer water more accurately parallels the actual cooking process. He is careful to explain that three series of equations are needed to frame an understanding of stove efficiency. The first is Firepower, the second Specific Consumption and the third is Percent Heat Utilized. Specific Consumption and PHU do not necessarily correlate. Between PHU and SC perhaps Specific Consumption is a more accurate predictor. Certainly PHU by itself is misleading.

Piet Visser "Testing Procedures for Woodstoves: Simple Waterboiling Tests", (2003) uses an alternative approach suggested in earlier publications. Prasad, Sanger, Visser, Verhaart, et al , reasoned that the performance of a cooking stove could be figured from two measures, high and low power and the fuel efficiency of both. Since low power is used for a much longer period the stove with adequate turn down (the authors recommend 6 to 1) should save fuel.

Why was the good advice, by established experts in the field, represented in the VITA International Standard test, the result of several well funded international conferences, obscure in 2003? Both the Indian and Chinese governments developed tests of their own widening the scope of PHU to include power, rate of evaporation, time. Visser (2003) published a version of a water boiling test based on efficiency and appropriate power for boiling and simmering. What motivated this parallel activity? Why isn't the VITA test in more general use?

When the VITA protocol was tried at the Fall Stove Seminar at Aprovecho two out of three teams were not able to produce valid results. The International Standard calls for quickly weighing water and charcoal in between high and low power tests. The pot must be carried to the scale, charcoal removed and weighed and replaced in the combustion chamber, before water cools below 95C. Even though testers were told to act quickly only the team that could weigh the stove with the charcoal inside the combustion chamber could begin simmering with water that was above 95C. Repeated testing convinced the Aprovecho team that only a trained expert could perform the acts required. The protocol is difficult for novice testers. Having to move very quickly is unpleasant and creates a nervousness that distresses scientists hoping for the careful methodology which testing implies. Although an alternative method, allowing for more deliberate action is suggested in the Standard Test, perhaps this simple misstep has caused enough uneasiness to block penetration into common use.

The use of PHU over the years may have masked the importance of adequate turn down in stoves. Prassad and Visser have explained repeatedly that only a small part of the energy used in bringing water quickly to boil is necessary to keep water simmering, when replacing the energy lost from the pot. Stoves that do not have the ability to deliver small amounts of heat will not simmer food efficiently. Much of cooking is simmering, which can occur for an hour or two. Scoring well on the PHU test requires producing excess energy during the entire burn. A test that does not reward successful turndown in a stove ignores a reality of cooking.

In sailboat racing boats are often built to rules that define the characteristics of the yacht. If the rules are out of step with nature, entire fleets can be lost in races when storms challenge construction. The use of PHU may well have had somewhat the same effect on generations of fast burning stoves that cannot perform adequately at low power. Better tests could result in better built stoves.

This year Rob Bailis, Damon Ogle and myself under the direction of Dr. Dan Kammen at RAEL, UC/Berkeley have revised the VITA tests hoping to make their use more practical. The work was funded by the Shell Foundation. We separated the high and low portions of the test so that quick action was unnecessary. We also specified that simmering should occur at two degrees below boiling instead of anywhere between 95 to 100C. We also revised the Controlled Cooking Test and the Kitchen Performance Test. Damon located a pot used by the United Nations which will be used in all tests. All equipment used for testing is standardized and will be used to test Shell Foundation pilot project stoves.

Reading about testing exposes the reader to the vast, thoughtful expertise of the researchers who spent decades studying cooking stoves. Two unfortunate problems become apparent. For some reason, perhaps simple or not, the suggested transition to a more predictive testing method has not penetrated into general awareness. While a great deal of agreement exists in the literature concerning how to improve testing, and both heat transfer and combustion efficiency, this hard won knowledge does not seem to have resulted in a generation of stoves with the improved characteristics. The apparent consensus that defined good engineering practice does not seem to have reached the ears and minds of stove builders. Making best use of the invaluable body of knowledge, from authors such as Baldwin, Prassad, Visser, Verhaart et al., that could benefit those in need, seems more likely, today. Hopefully, the retarded passage of knowledge into practice adds a momentum to some degree fueled by twenty years of missed opportunity.

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