# Why you shouldn't use "efficiency" numbers to choose a stove

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People are naturally drawn to the word "efficiency" and understandably think that improved thermal efficiency predicts decreased fuel use when cooking food. Unfortunately choosing a stove based on thermal efficiency can result in the selection of a stove which is neither fuel saving nor user friendly.

Some sort of water boiling test is usually used to determine efficiency. There are many versions of water boiling test. Obviously varying test methods result in numbers for "efficiency" which are not readily comparable.

A more fundamental problem comes in the definition and calculation of "efficiency". In stove work, there are several types of "efficiency", but usually what people are referring to is Thermal Efficiency. This can be thought of as "the energy that got into the pot" divided by "the energy that was in the wood".

The "energy that got into the pot" has two parts: (1) energy used to heat water and (2) energy used to vaporize water. The problem comes with the vaporization of water, which uses energy but in most cases (unless you are steaming something) does not help to cook food. Making a lot of steam raises thermal efficiency scores but only wastes fuel when cooking.

Novice stove testers are often surprised when they weigh hot water because the weight diminishes. The water is losing weight at a fairly rapid rate as it vaporizes. Water in a standard open 7 liter test pot, held at 5 degrees below the boiling point, will lose about 14 grams of weight per minute. The longer it is held at that temperature, the more weight it will lose.

At recent stove camps in India, the steam lost while bringing water to a boil in identical open pots averaged about 10 grams per minute. Different stoves had different total "times to boil" but were similar in their rate of water loss.

The formula used to compute efficiency is usually some close variation of the following:

$$efficiency = \frac{\lfloor 4.186 * w_i * (T_f - T_i) \rfloor + [2260 * w_v]}{[f_d * LHV]}$$

Where;

$w_i$ = initial weight of water (grams)

$T_f$ = final temperature of water (°C)

$T_i$ = initial temperature of water (ºC)

$w_v$ = water vaporized (grams)

$f_d$ = fuel consumed (in grams, corrected for moisture content and charcoal left)

LHV = Lower Heating Value (energy content of wood in Joules/gram)

To visualize the problems of "thermal efficiency", let's look at two stoves which perform the same task. The task is to bring 5 liters (5000 g) of water from a starting temperature of 25ºC to boil in an open pot. For comparison, we will assume that both stoves consume 1000 grams of wood to do the task and both stoves average 10 grams/minute of water vaporization during the task. Stove 1 does the task in 10 minutes while stove 2 requires 100 minutes to do the same task. To simplify our calculations, hypothetical (but not unrealistic) numbers are given for the performance of the two stoves. Actual stoves giving very similar test numbers do exist.

| Stove 1 | | Stove 2 | |
|---|---|---|---|
| Time to boil | 10 minutes | Time to boil | 100 minutes |
| Wood burned | 1000 grams | Wood burned | 1000 grams |
| Water vaporized | 100 grams | Water vaporized | 1000 grams |
| Water remaining | 4.9 liters | Water remaining | 4.0 liters |

Calculation of Thermal Efficiency

| | |
|---|---|
| $efficiency = \frac{\lfloor 4.186 * w_i * (T_f - T_i) \rfloor + [2260 * w_v]}{[f_d * LHV]}$ | $efficiency = \frac{\lfloor 4.186 * w_i * (T_f - T_i) \rfloor + [2260 * w_v]}{[f_d * LHV]}$ |
| $eff = \frac{[4.186 * 5000 * (100 - 25)] + [2260 * 100]}{[1000 * 18000]}$ | $eff = \frac{[4.186 * 5000 * (100 - 25)] + [2260 * 1000]}{[1000 * 18000]}$ |
| $eff = \frac{[1569750] + [226000]}{[18000000]}$ | $eff = \frac{[1569750] + [2260000]}{[18000000]}$ |
| $eff = 9.9\%$ | $eff = 21.3\%$ |

Stove 2 would be the obvious stove to choose based on "thermal efficiency", but is this an optimal stove for cooking? Both stoves in the example used the same amount of wood. Stove 2 takes 100 minutes to produce 4 liters of the desired product (boiling water/food). Stove 1 takes only 10 minutes to boil and produces almost 5 liters of the same product. Most cooks might prefer Stove 1, even though it is less "efficient".

An alternative approach, "Specific Consumption" replaced thermal efficiency in the 1985 VITA International Testing Standard. Specific Consumption is the fuel used per unit of product produced. The unit of product could be bowls of beans or loaves of bread or in this case, liters of boiling water representing cooked food. Remember, we are talking about the weight of finished product, not starting weight!

Let's look at "Specific Consumption" for the two stoves in the example.

| Specific Consumption of Stove 1 | Specific Consumption of Stove 2 |
|---|---|
| $S.C. = \frac{fuel\_consumed}{water\_at\_end}$ | $S.C. = \frac{fuel\_consumed}{water\_at\_end}$ |
| $S.C. = \frac{1000}{4.9}$ | $S.C. = \frac{1000}{4.0}$ |
| $S.C. = 204$ grams/liter | $S.C. = 250$ grams/liter |

"Specific Consumption" results indicate that Stove 1 would be the better choice since it uses less fuel to produce a liter of boiling water. "Efficiency" rewards the production of excess steam while "specific consumption" penalizes it. The VITA 1985 International Testing Standard recommends "Specific Consumption" as the more reliable indicator of stove performance.

The power required to raise the temperature of water in an open pot increases as the water temperature approaches the boiling point. This is especially significant in the last 5 degrees below the boiling point. In a standard test pot, water at ½ degree below boiling will evaporate water at about 26 grams/minute which is 85% greater than the evaporation rate at 5 degrees below boiling.

Stove power must be sufficient to overcome heat losses through the sides of the pot and to supply the heat required for vaporization of water. The additional requirement for more energy as the boiling point is approached creates an energy "hump" which low powered stoves often have trouble overcoming. This condition will result in long "times to boil" and large losses of water through vaporization. Increased steam production produces high "efficiency" numbers.

Problems with "efficiency" become even more evident when "simmering" water. "Simmering" attempts to maintain hot water (or food) at just under the boiling temperature using the minimum amount of fuel. The best methods for simmering water (ranging from the use of pot lids and insulation up through the use of "hay boxes" which use no fuel) are most penalized because they lose very little water to vaporization.

Examining two hypothetical examples points out the difference between "efficiency" and "specific consumption". The task is to maintain 5 liters of 97 degree C water within 6º of the boiling point for 30 minutes. One of the stoves has a good turndown ability and is able to maintain the temperature of the water at 97°. The other stove lacks turndown ability and applies too much power which causes the water to reach a full boil and vaporizes lots of water. It is assumed that both stoves have equal fuel consumption per gram of water vaporized.

| Stove 1 | | Stove 2 | |
|---|---|---|---|
| Simmer time | 30 minutes | Simmer time | 30 minutes |
| Wood burned | 250 grams | Wood burned | 750 grams |
| Water vaporized | 500 grams | Water vaporized | 1500 grams |
| Water remaining | 4.5 liters | Water remaining | 3.5 liters |

Calculating "Efficiency" and "Specific Consumption" for the two stoves results in:

Efficiency of Stove 1

$$efficiency = \frac{[4.186 * w_i * (T_f - T_i)] + [2260 * w_v]}{[f_d * LHV]}$$

$$eff = \frac{[4.186 * 5000 * (97 - 97)] + [2260 * 500]}{[250 * 18000]}$$

$$eff = \frac{[0] + [1130000]}{[4500000]}$$

$$eff = 25.1\%$$

Efficiency of Stove 2

$$efficiency = \frac{[4.186 * w_i * (T_f - T_i)] + [2260 * w_v]}{[f_d * LHV]}$$

$$eff = \frac{[4.186 * 5000 * (100 - 97)] + [2260 * 1500]}{[750 * 18000]}$$

$$eff = \frac{[62790] + [3390000]}{[13500000]}$$

$$eff = 25.6\%$$

Specific Consumption of Stove 1

$$S.C. = \frac{fuel\_consumed}{water\_at\_end}$$

$$S.C. = \frac{250}{4.5}$$

$$S.C. = 55 \text{ grams/liter}$$

Specific Consumption of Stove 2

$$S.C. = \frac{fuel\_consumed}{water\_at\_end}$$

$$S.C. = \frac{750}{3.5}$$

$$S.C. = 214 \text{ grams/liter}$$

The "Efficiencies" of these two stoves are virtually identical and one would assume that there was very little difference between them. Examining the "Specific Consumptions" tells a very different story. Stove 1 would be the better choice since it uses ¼ as much wood as Stove 2 to produce the same output (liters of water which have been simmered for 30 minutes). Repeated testing at Aprovecho Research Center has shown that "Specific Consumption" is the more reliable measure of stove performance.

Problems with Thermal Efficiency have been recognized for decades and have been pointed out by Baldwin, The Eindhoven group and others. Piet Visser has shown that "efficiency" in conjunction with "power output" (at high and low power) can be used to make accurate predictions about stove performance. By using the two factors together and defining a cooking process (cooking rice for example) one can calculate cooking time, fuel use, water loss and so forth. Visser is absolutely right in his conclusions.

"Efficiency" by itself is not a reliable predictor of stove performance.

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