Theoretical Maximum Radiation by Improved Cook Stove

by Marc Paré
thanks to Crispin Pemberton-Pigott and Matt Redmond
for error-checking and guidance
contact: http://www.notwandering.com

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1 Introduction

A recent week-long exchange on the bioenergy mailing list[1] for improved cook stove brought up the question of radiative heat transfer improving the performance of a cook stove. Perhaps, the pronents pondered, by converting the heat available for convective heat transfer into infrared radiation the overall efficiency of a stove could be improved drastically. Some preliminary test results using a forced-air gasifier unit suggested that the effect could be dramatic, realizing a doubling of heat transfer efficiency.

The impressive red glow of the prototype emitter turns out to be misleading. A calculation using basic heat transfer principles shows that the maximum power available by radiation is about 300 watts. Even at 100% efficiency, this accounts for only about 18% of the power required to boil water in the reported time.

In other words, in most cases, it's theoretical impossible that boiling time of a stove could be significantly reduced by optimizing radiative heat transfer.

Since the fundamentals of radiative heat transfer could be useful for future stove design, the following article shows how the above conclusion was reached.

An accompanying spreadsheet includes some additional calculatons (view factor, energy to boil water) and some comments from Crispin during the development of the analysis.

2 Problem Statement

The stove analyzed consists of a burner, burner housing, dome-shaped emitter, and pot holding 1 liter of water. During operation, the emitter glows red hot, making heat available as radiation to the bottom of the pot. Figure 1 shows the stove and a labeled schematic.

[1] http://bioenergylists.org/

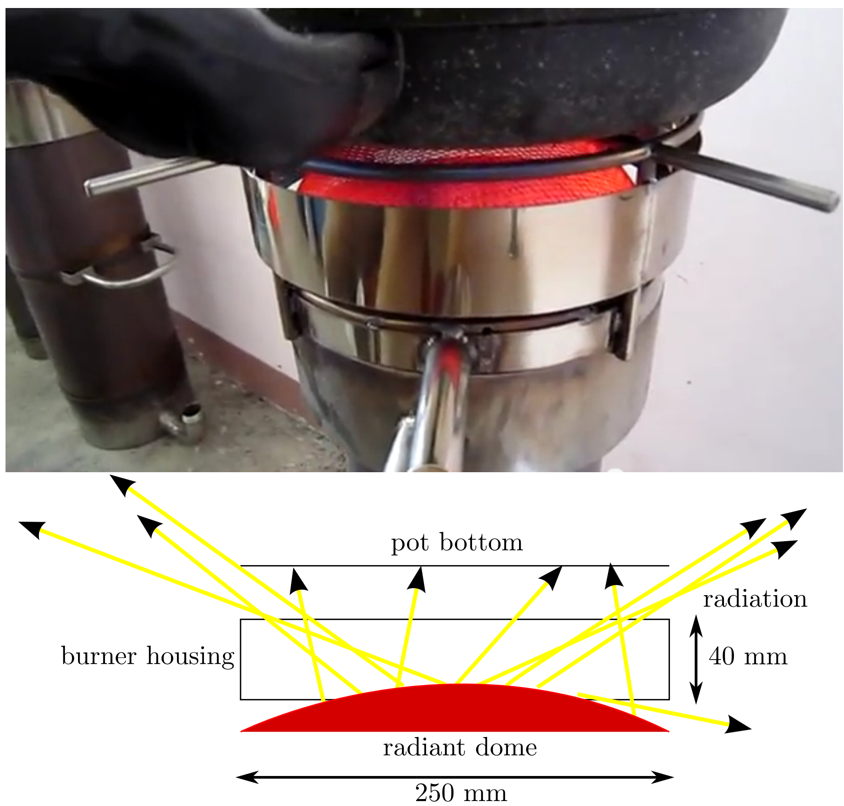

Figure 1: Schematic of tested stove with labelled dimensions.

Table 1 shows the reported test results, comparing the base case to the improved case.

Table 1: Reported Results

	Base Case	Improved (with radiant emitter)
Volume Water (L)	1	1
Time to Boil (s)	480	222 seconds
Fuel	Rice husk	Rice husk

The problem is as follows: what is the upper bound of energy transferred by radiation for the boiling task?

3 Theoretical Background

Thermal radiation results from the excited motion of particles in a heated solid. The jiggling of atoms (and their associated charge) is what generates electromagnetic radiation.

The resulting radiative power (G) is given by the Stefan-Boltzmann Law:

$$G = \epsilon \sigma A \Delta T \tag{1}$$

The unit of power—watts—is a measure of energy delivered per unit time.

The quantities in the Stefan-Boltzmann Law are ϵ–the emissivity of the surface, A–the area of the surface, and ΔT–the difference in temperature between the radiating surface and the receiving surface.

That's it! By assigning reasonable values to the quantities above, we can bound the maximum possible power available by radiation. Then, that can be compared to the power required to boil water in the reported time.

For the purpose for completeness, it is worth mentioning that in a calculation of radiative heat transfer between two bodies, you also include a view-factor constant, which quantifies what percentage of the available radiation actually strikes the considered surface. In our case, we just assume it is 100%. If you are curious what losses result from this consideration, see the bonus calculation in the spreadsheet.

4 Calculation and Results

The power resulting from application of the Stefan-Boltzmann law is: $G = 0.301$ kW. Table 2 explains the choices for the values inserted in the S-B law.

The power required to boil a 1 L pot of water in 222 s is 1.65 kW (see spreadsheet).

Table 2: Values of variables

Variable	Unit	Value	Rationale
ϵ	-	1	The maximum, assume it's a black-body.
σ	W/(m^2-K^4)	$5.67 * 10^{-8}$	A physical constant
T_{mesh}	°C	60	An average from 20 °C to 100 °
T_{pot}	°C	750	Assume a CO flame of 1100 °C. This is also reasonable if you consider the color of the dome: dark red.
ΔT	K	690	Difference between above quantities
A_{mesh}	mm^2	4908	About 10% of the mesh area is metal.

5 Conclusion

We were able to bound the maximum possible contribution by radiation at 0.301 kW. This accounts for only a small (<20%) contribution to the power required to bring the tested pot to a boil.

If you assume the base case has zero contribution from radiation and the improved case to have the theoretical maximum, the resulting reduction in boiling time would not be anywhere near the reported 218 seconds (this is an over 100% improvement!).

Clearly, then, the mechanism responsible for the test results is not thermal radiation.