HEAT TRANSFER: ETHOS STOVE CAMP 2004

August 20, 2004
Columbus, Ohio
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Lately, I've taken on the subject of heat transfer to the pot, attempting to increase stove efficiency. Rather than come to Cottage Grove to be with you, I've been working in my company's gas appliance lab here in Ohio, taking the week off work to do some research. I've done about 45 individual tests in the last month, about half of them this week. While it's not as much fun as being with you in Cottage Grove, I'm starting to produce some results you might find interesting. Here is a brief report of what I've done and learned so far. I'll continue my work and hopefully have more results to show in Seattle.

New Experimental Technique

I'm working with a new experimental technique that some of you might want to copy, as it's particularly useful when looking at the issue of heat transfer. I'm using natural gas to make a "pseudo wood flame", burning the gas in a non-premixed fashion much like a wood fire. I run the supply of natural gas through a flowmeter to measure the flow rate, which gives me control over the flame power and accurate knowledge of the flame power.

My burner design features a series of large holes, with a total area of about 0.35 square inches. This means the gas flows fairly slowly out of the burner without mixing with air beforehand. This is much different that a Bunsen or Fisher burner, and gives a nice yellow slow flame that looks a lot like a wood flame. See the figures for the meter, burner, and burner with flames. In the second figure, the flame had an unusually "tongued" appearance at the moment I took the picture.   Under the wrong conditions, when little excess air is available, the flame produces quite a bit of soot, much like a wood flame.


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I’ve been doing tests aimed strictly at efficiency evaluation. I do a 6-12 minute test where the final temperature is well below boiling, calculate the rate of temperature rise of the water, which gives me the power into the water, which gives me the efficiency. I measure various temperatures around the system depending on the test. This is much simpler than a full water boiling tests, and works for my purposes.

With a little effort, one could adapt this to use propane as the fuel.

Temperature Profiles

I’ve done a series of tests measuring the gas temperature at a series of locations around the pot, trying to come up with an idea of what the temperature profiles look like.

Qualitatively, what I’ve found is that on the bottom of the pot, the hot gas seems to segregate itself next to the pot, such that there is a fairly thin hot layer next to the pot. The peak temperature is nearly always about 1/8 inch from the pot, as closely as I can measure. This is true at all radial locations.

Along the sides of the pot, the situation is more complex, but in general the temperatures are much lower. Depending on how the gas flows around the pot bottom corner, the hottest gases might be right next to the pot, or somewhat farther from it.

It appears in all cases, that the bulk of the heat transfer comes through the bottom of the pot.

Here are some typical temperature distributions. All distances in inches, all temperatures in °F, measured with a small-bead unshielded thermocouple.

Pot diameter 9 5/8
Riser diameter 5
Distance from top of riser to bottom of pot ¾ to 7/8
Gas temperature at pot centerline 1700

At a radial location 1.5 inches from pot centerline

Distance from pot	Temperature
1/8	1600
¼	1600
3/8	1600
½	1600
¾	1300

At a radial location 3.75 inches from center of pot

Distance from pot	Temperature
1/8	1150
¼	1000
3/8	900
½	650
¾	250

Along the side of the pot, at a height of about 2 3/8 above the bottom of the pot

Distance from pot	Temp
1/8	530
¼	570
3/8	600
½	490
¾	450

Skirts don't help?

The common belief is that a tight skirt is one of the best ways to increase heat transfer to the pot. Common beliefs are that a tight skirt increases heat transfer to the side of the pot, and various people (including me) have done all sorts of calculations about the effects of varying the gap and other variables.

I believe the major factor in skirts is that a tight skirt reduces the amount of excess air getting to the fire, and this increases average temperatures, and thus increases the heat transfer to the bottom of the pot. Any gain in heat transfer to the side of the pot is a helpful, but secondary effect.

Without getting into too much detail for now, compare the results of 2 tests, one with a tight skirt (0.36 average gap) and one with a loose skirt (0.75 average gap). In the loose skirt test 1324 Watts went into the pot out of 3250 W at the fire. In the tight skirt test 1557 W went into the pot (17% more). Yet, the temperature of the gas coming out of the top of the skirt was slightly hotter in the tight skirt test. These facts together mean that the mass flow through the simulated stove was lower in the tight skirt test, the "average flame temperature" was higher in the tight skirt test, and the average temperature difference between the gas and pot was higher in the tight skirt test.

In the same tests I had a thermocouple measuring an "average flame temperature" which includes the excess air. This should be considered only an estimate, since previous tests showed that the temperature in the riser is highly non-uniform. The measured temperature was about 1100 °F in the tight skirt test and 900 °F in the loose. This supports what I said in the previous paragraph.

One can use these to estimate the log-mean temperature differences. For the tight skirt the LMTD is 19% higher than that of the loose skirt, but the total heat transfer is only 17% more. This suggests the tight skirt is actually slightly less efficient at transferring heat, though you get the benefit of the higher temperature to get more Watts of heat transfer.

Soot vs. Efficiency

I've found that it is easy to get high efficiency, but that often the conditions that give high efficiency lead to high soot. I've looked at various conditions of pot-close-to-fire, and large and small diameter risers, and short and tall risers. While I haven't tested them, very tight skirts would also tend to give much soot but good efficiency. I would assume that we need to be looking at conditions that give both good efficiency and low soot. This is what I'll be working on in the remainder of this week and in the next couple months.

Good luck,

Dale