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Big Improvements For Small Cooking Stoves: The Benefits of Heat Recycling

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These days so much is known about combustion that efficient and nearly complete combustion can be basically taken for granted, even if the knowledge has not been put into practice. Combustion geeks now focus to making incremental improvements in the removal of unwanted combustion products, largely PICs and CO.

If you are seeking a major advance in system performance it will be found in the realm of heat transfer efficiency and fire size. By heat transfer I mean capturing more of the heat that comes from the fire and, if that heat is to be used efficiently, reducing the size of the fire in inverse proportion to the improvement in heat transfer. I you double your transfer efficiency, you can halve the size of the fire.

Other opportunities are for increasing a stove's capacity to burn multiple fuels, different fuel sizes and reducing the start-up time to a useable heat.

I will comment only on the first topic: the implications of increased heat transfer efficiency on required fire size.

In order not to waste fuel, a stove with a high combustion and a high heat transfer efficiency must have a comparatively smaller fire. The lower limit of a fires' size for any given type of stove is ultimately set by the ability of the stove to preheat the primary and secondary air supply. I have considered this rather categorical claim and I think it can stand up to scrutiny.

For any given minimum viable fire size, it can be further reduced by increasing the temperature of the primary and secondary air supply. There are upper limitations to this but we are nowhere near them with biomass-fired cookers.

Two approaches to reducing fire size emerge: 1. Control the air supply to a large fuel load; 2. Control the amount of fuel while balancing the amount of air.

The first is a gasifier and the second involves preheating the air by some means.

Even assuming we have taken care of preheating and being able to limit the heat production by choking or fuel metering, there remain still other downstream issues. Probably the most important are stove life, transportability, ease of use, marketability and cost. I will address the first.

Preheating the incoming air by drawing it through or along components of the stove body chills the parts, most importantly the combustion chamber. Sheet metal chambers have short lives when temperatures are high. With the Vesto, it is important to keep the 3CR12 stainless steel chamber below 550 degrees C which we have achieved, and it should extend the working life to several years. So far we don't know for sure; it is too soon to tell.

Another method of reducing chamber wall temperature and heating the air supply is to feed the air through a number of holes punched through the chamber wall. This is a good method of adding velocity to incoming secondary air. There is a formula for optimizing the heat transferred to the air as it passes through a hot plate which can be applied to maximize the power transfer rate.

Maintaining a wall temperature that is well below the flame temperature may seem difficult to do, however there are two things you can do which help:

1. Making the chamber reflective and
2. Keeping the heat concentrated in a central column or vortex of turbulent fire insulated from the walls by air which is still working itself towards the centre. In other words, a central vortex, about which much has been said on the internet in the past week, is key to preventing heat diffusion throughout the chamber.

The varied experiences people reported are specific to the device they were testing so I ask your indulgence for a moment and let be present my view of how the vortex helps.

In any stove in which there is a fairly even distribution of fire, air, flame and heat, the conditions at most points in the chamber can be thought of as being uniform or "ideal". Calculate the average heat flux in the chamber to give a value H.

This will give some or other combustion efficiency figure, PIC content and CO/CO2 ratio.

If you then chill the chamber walls, entrain the fuel, flame and fresh air in a central vortex, while maintaining the same total heat flux H by preheating the injected air, there are immediate benefits:

1. If the heat flux is the same on average, then the central core containing the flame is necessarily hotter than with a dispersed fire.
2. The vortex is more turbulent than a smooth upward flow giving better mixing.
3. The combustion chamber life is extended from mere months to several years.
4. Heat is channeled to the center of the pot maximizing the chance of boiling the center point with a small amount of heat thus creating a torordial flow within the pot.
5. PIC's dwell for a longer time in the high temperature center and are more likely to be broken down.
6. Pre-heated secondary air can be blown at the rising column to maintain combustion over a longer travel and help maintain the vortex, taking advantage of the tendency of a vortex to

concentrate kenetic energy at its centre. This creates shear within the column encouraging mixing.
7. Heat transfer from the resulting small hot spot on at the pot centre is greater than for diffused heat striking the whole bottom because the heat transfer path is as long as possible.

In the Vesto, preheated primary air and a small grate at the bottom of the combustion chamber ensures nearly complete burning of the fuel including small pieces of charcoal. Heat potential wasted in the form of unburned charcoal is typically 2% of the original heat value of the fuel.

A central flame vortex allows for a larger turn-down ratio than normal because the fire continues to burn with a small diameter in the 'hot zone' without going out.

The provision of different access points for preheated secondary air allows the quantity supplied to be largely self-regulating. The greater the flame intensity, the greater the draft. Turning down the primary supply immediately increases the amount of secondary air drawn into the chamber.

Heat drawn through the body and returned to the fire assists in the burning of loose and light value biomass fuels such as dung and briquettes. Preheating ensures faster ignition of densified biomass.

The amount of heat recycled in the Vesto is about 15% of the heat generated in the fire, i.e. between 300 and 750 watts. You can imagine how much better your fuel will burn if there is a 500 watt heater placed immediately under it.

It appears that creating a hot air supply, directing as much heat as possible to a central zone and spinning the hot column allows for a significant reduction in the size and heat output of the fire.

This addresses the emerging requirement for small, efficient fires to match the increases in heat transfer being realized by the use of heat shields, optimized pot-stove gaps, new pot materials and insulation.

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