An Annular Cross-Current Burner for a Natural Draft, Top-Lit Updraft (ND-TLUD) Gasifier

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Abstract

An annular cross-current gas burner (AB) for a ND-TLUD was designed with a central distributor for secondary air to increase the mixing of pyrogas and secondary air at the base of the gas flame. However, it was expected that this central distributor would create a resistance to the flow of hot gasses, thus slow down the rate of gasification in the TLUD. The central distributor could also reduced the area of gas flame 'visible' to the bottom of a cooking pot, so it could reduce the efficiency of radiant energy transfer from the flame to a cooking pot. Tests were run to compare the AB to a peripheral cross-current burner (PB) designed to minimized these limitations. The AB did slow down the rate of gasification compared to the PB, but the AB made the TLUD safer to use by preventing excessive gasification rates. Energy-transfer was compared by placing thermocouples above the gas flame. The temperature of the AB was slightly lower than the PB at any given rate of gasification, so it was predicted that under actual cooking conditions, the AB will be moderately less efficient than the PB. However, any decrease in efficiency may be a small price to pay if the AB is shown to make substantive reductions in the emission of hazardous CO and fine soot particles.

OBJECTIVE: to evaluate a new burner for its effect on basic TLUD function.

Two types of cross-current pyrogas burners were compared on a natural draft, top-lit updraft (ND-TLUD) gasifier:

(1) Peripheral burner (PB)

(2) Annular burner (AB)

The PB had been designed to support a wide range of gasification rates. It was practical, yet "fast" burner that could show what gasification rates were possible, and thus serve as a basis of comparison for the AB.

The AB was a test-of-concept prototype that needed basic evaluation for its effect on TLUD function.

The burners were compared for their effect on **gasification rate** and **temperature** above the gas flame.

The peripheral burner on top of a natural draft, top-lit updraft gasifier. To the right is a riser extension that increased total riser height to 20 cm.

Two Cross-Current Gas Burners

(1) **Peripheral burner (PB)**: was traditional style that introduced secondary air through holes around the circumference of the riser. It has supported gasification rates up to 50 g-fuel dry matter per m² TLUD area per second.

(2) **Annular burner (AB)**: introduced secondary air from air holes around the circumference as well as from a central distributor. The purpose of the central distributor was to increase mixing of secondary air and pyrogas at the base of the gas flame.

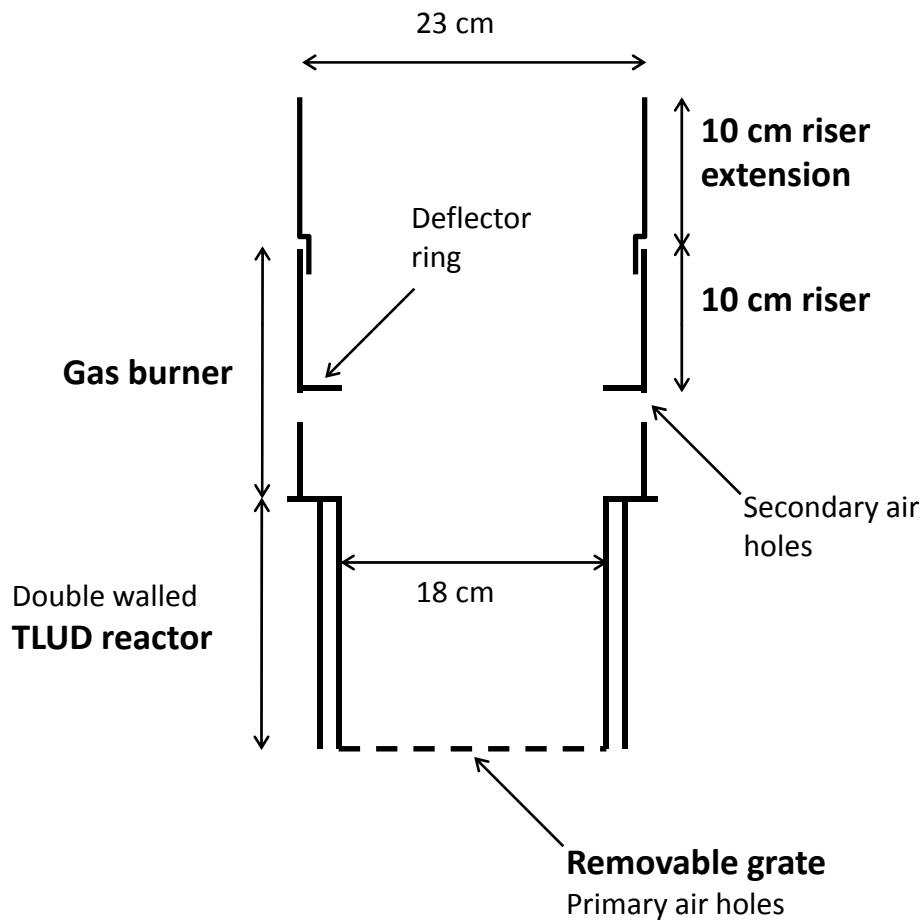
The AB's distributor could create resistance to the flow of hot gasses, slowing down gasification in the TLUD. It could also reduced the area of flame 'visible' to the bottom of a cooking pot, reducing radiant energy transfer from the flame to a cooking pot. Those problems were minimized in the PB design.

METHODS:
Peripheral Cross-Current Burner

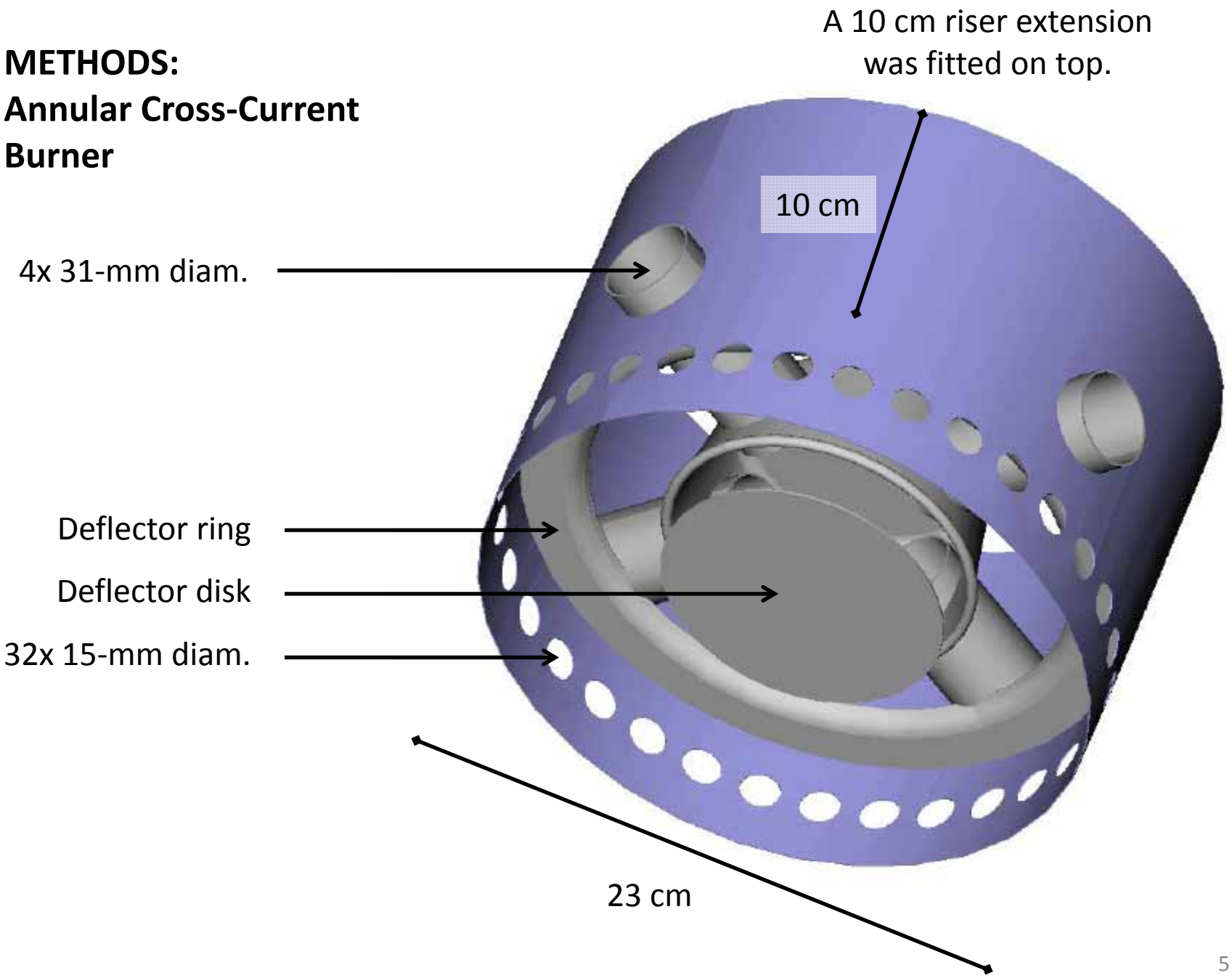
The Peripheral Burner (PB) was designed to support a wide range of gasification rates by providing low resistance to the vertical flow of hot gases:

1. It was 1.3 times wider than the reactor to give space for horizontal expansion of the flame.
2. There was a deflector ring to prevent flamelets running up the riser sidewalls.
3. Peripheral air holes and the deflector ring made a "concentrator ring" unnecessary.

Twenty-four, 1.9 cm diameter secondary air holes had a total area equivalent to 27.6% of reactor cross-section, and was in a 4:1 ratio with primary air holes when the grate aperture was 6.9% of reactor area.



METHODS:
Annular Cross-Current Burner



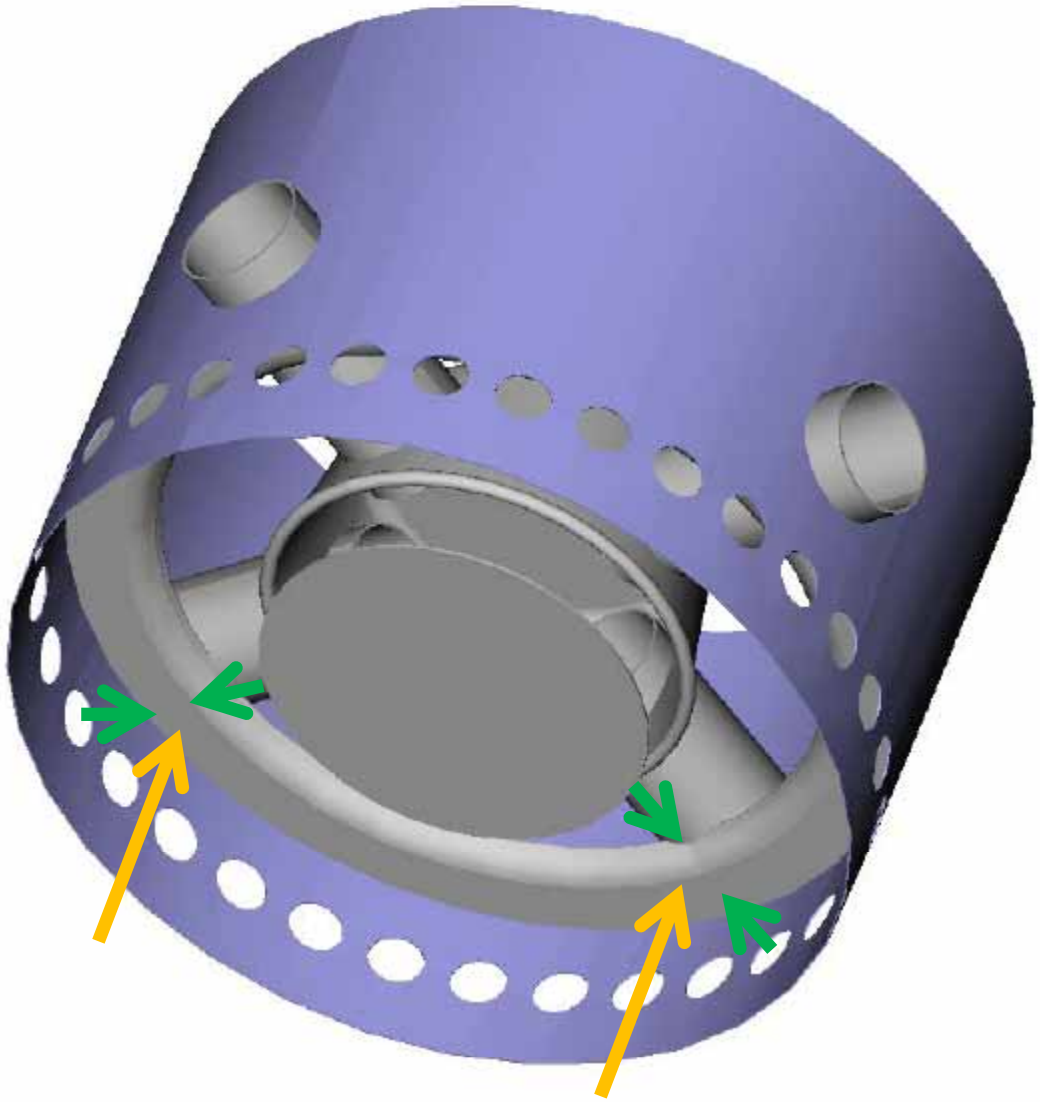
METHODS:
Annular Cross-Current Burner

The Annular Burner (AB) introduced secondary air (green arrows):

1. from the periphery through air holes in the sidewall of the riser, and
2. from the center from a central distributor connected to the exterior by four pipes (after K. Harris's *Wonderwerk Strata Stove*).

Pyrogas (yellow arrows) rising from the ND-TLUD reactor had to pass through the opposing cross current streams of secondary air.

The principle behind the design of the AB was that we will get more complete combustion of pyrogas if we can increase mixing of the secondary air and pyrogas at the base of the gas flame. In theory, early mixing will reduce zones of sub-stoichiometric oxygen that favor soot formation, and increase flame temperature favoring soot destruction.



METHODS:
Annular Cross-Current Burner

Types of Deflector Disk

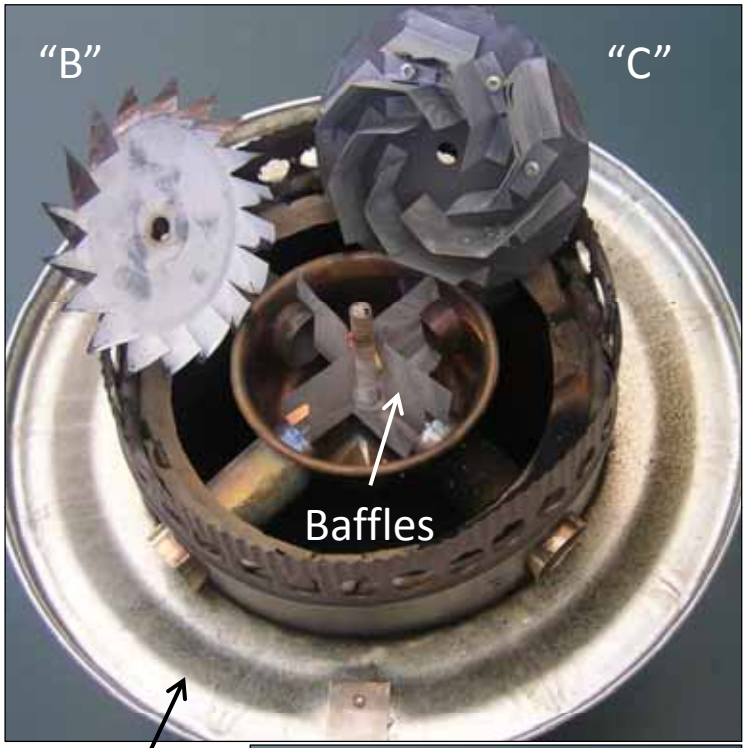
Various types of deflector disks can be attached to the underside of the central distributor using a bolt through the centre of the distributor bowl.

A. **A simple, flat circular plate**: creates a sheet of secondary air, but the distribution of air can be asymmetrical with more exiting in one quadrant than another.

B. **Fine fins and central baffles**: baffles inside the distributor bowl help keep the flow of air symmetrical; the fine fins break-up the sheet of air to form flamelets. (Used in this research.)

C. **Coarse fins** and no central baffles: the coarse fins don't need central baffles.

Secondary air flow was faster with coarse fins than fine fins. Neither of these fin arrangements created a swirling flame.



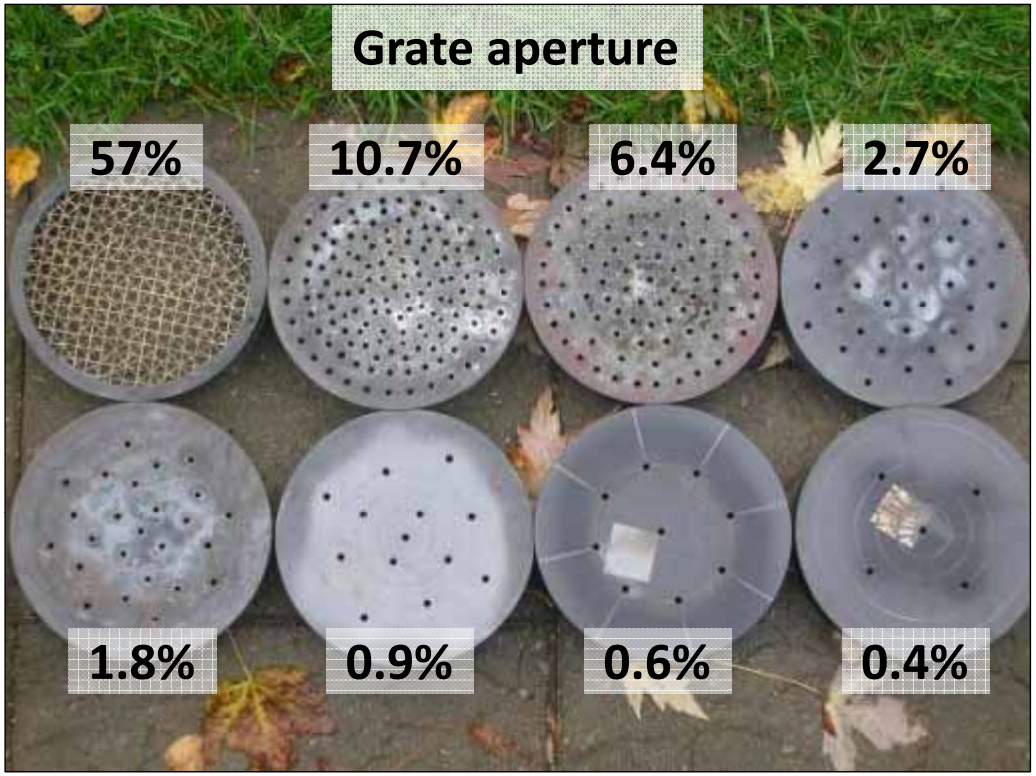
This flange is the cap of a cylinder used for preheating secondary air. It was used only in the final, high-power trial with spruce lumber fuel.

METHODS:
Primary air control and TLUD operation

Primary Air Control: was by exchanging grates on the bottom of the TLUD reactor.

Conducting a Unit Trial: The ND-TLUD was fitted with a grate, then loaded with 2300 g of 6 mm diameter softwood pellets having 7% (ww) moisture. One hundred grams of pellets moistened with 6 g kerosene, then 6 g isopropyl alcohol, was placed on top and lit. To minimize air turbulence, trials were run inside a 0.64 m tall, 0.37 to 0.42 m diameter, bottomless, steel cylinder. The reaction was stopped at the end of pyrolysis, when the gas flame turned from yellow to blue, or extinguished. The remaining char was weighed.

Average **Specific Gasification Rate** (SGR: g/m^2s) = mass of dry fuel mass / area of TLUD / duration of a trial



Reactor grates used to regulate primary air flow. While grate aperture restricts the flow of primary air, that actual flow rate also depends on buoyancy and resistances to gas flow within the TLUD reactor and gas burner. (Apertures expressed as % of reactor cross sectional area)

(NOTE: The arrangement and diameter (4.76 mm) of holes affected air flow and would yield slightly different power curves than other methods for air control with the same grate aperture. The "57%" grate was a wire mesh.)

METHODS:

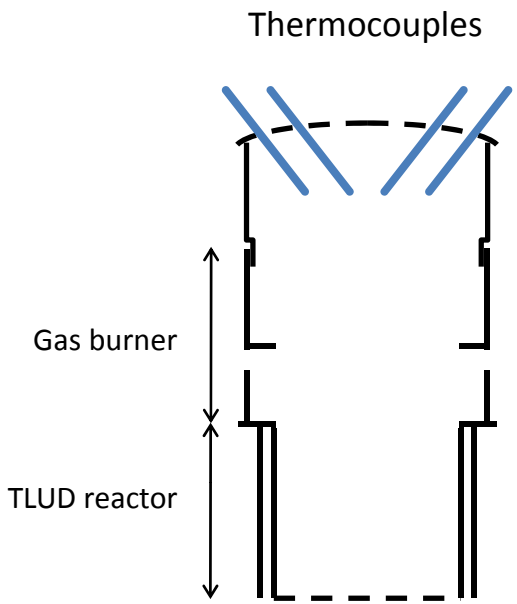
Riser Temperature

Temperature at the top of the riser was measured as a surrogate (indicator) for heat transfer from a burner to a cooking pot.

A perforated cap was placed on the top of the riser to simulate a pot (Pemberton-Pigott, pers com). The total aperture of the perforations was 80% of the burner cross sectional area.

Four K-type, 1/8 inch, stainless steel thermocouples probes were positioned 15 cm above the deflector disk. Readings were logged and averaged every 5 seconds.

The temperature readings from the thermocouples were a function of convective heat from hot gases, as well as radiant energy from the gas flame, and toward the cooler riser walls and perforated cap.



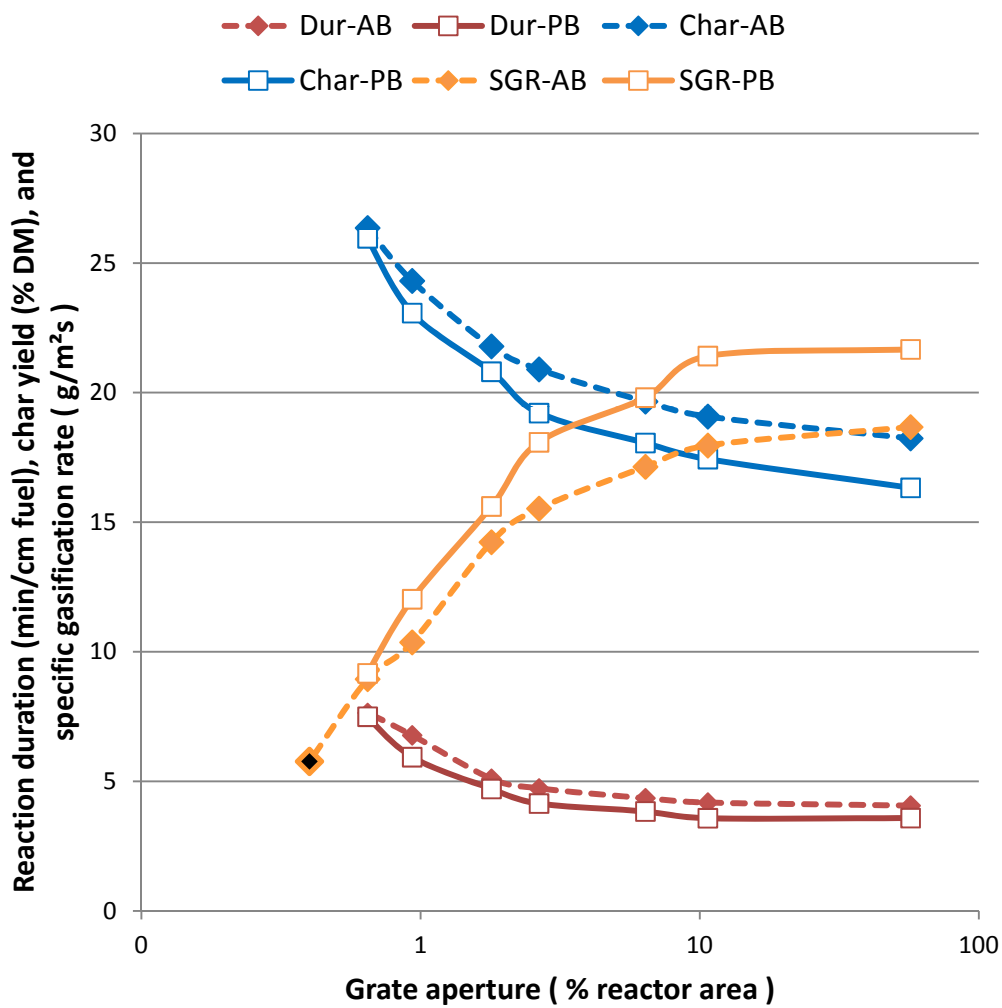
Perforated cap

RESULTS:
Gasification rate was higher for the PB than AB

The PB had a higher specific gasification rate (SGR) than the AB, resulting in a shorter duration of the reaction (Dur), and a smaller amount of residual char (Char).

The flame height was shorter for the AB than PB, so the AB could function with a shorter riser than the PB. However, a 20 cm riser could be better than a 10 cm riser if it increased the proportion of secondary air in the pyrogas mixture.

(Notes: The treatments were not replicated. The AB, alone, was tested at the lowest grate aperture (black point). The gas flame persisting for almost 120 min, but flamed-out before the gasification was completed. Secondary air was not preheated.)



RESULTS:

Riser temperature was higher for the PB than AB

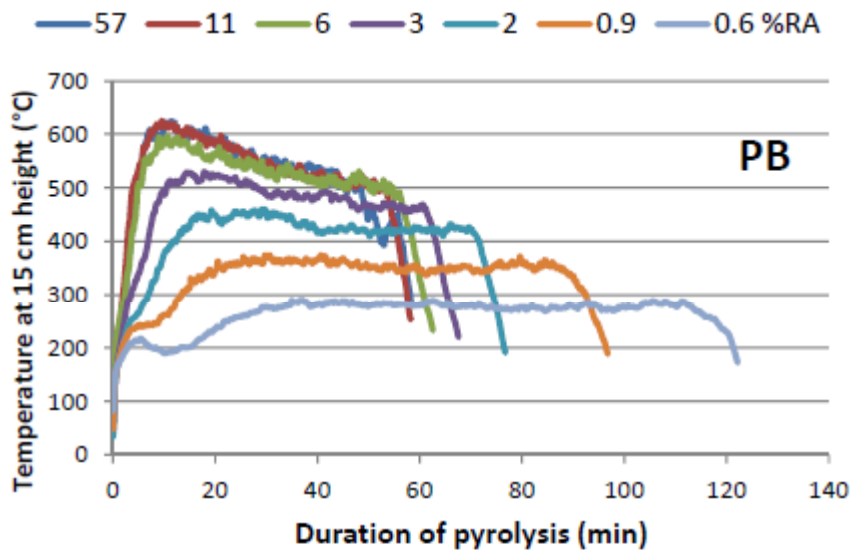
Thermocouple temperatures 15 cm above the deflectors were higher with the PB than AB, largely because the gasification was faster for the PB.

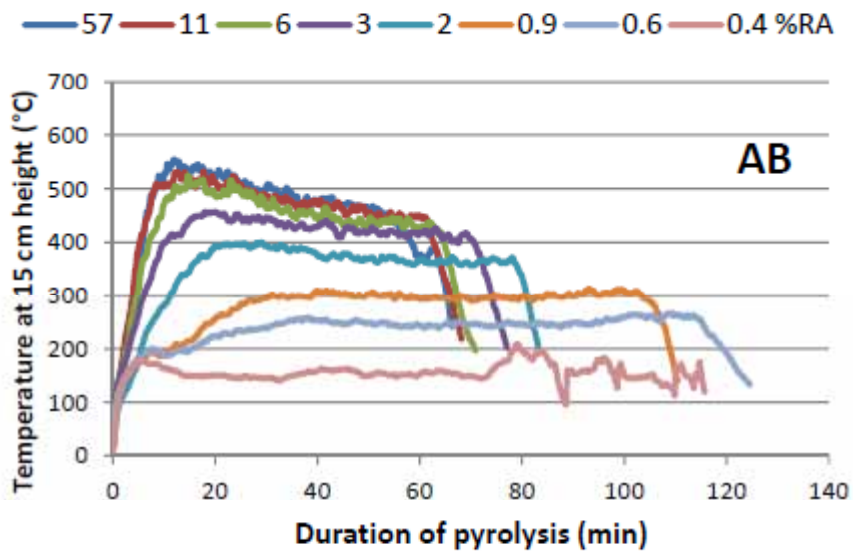
At higher grate apertures, the temperature declined over time. The reasons needs to be studied, but here are two possibilities:

1. The gasification rate slowed over time.
2. The composition of the pyrogas changed over time as the depth of char increased. As a result the gas flame became shorter and less luminous, reducing the upward flux of radiant energy.

With increasing grate aperture, the char layer became hotter (up to 750°C) and char particles became smaller, so surface area and resistance to gas flow may have increased.

Previously, SGR and the pyrolytic front temperature have not been seen to change much during the course of wood pellet gasification.





Temperature in the riser of PB and AB with trials run over a range of TLUD reactor grate apertures (%RA, reactor area).

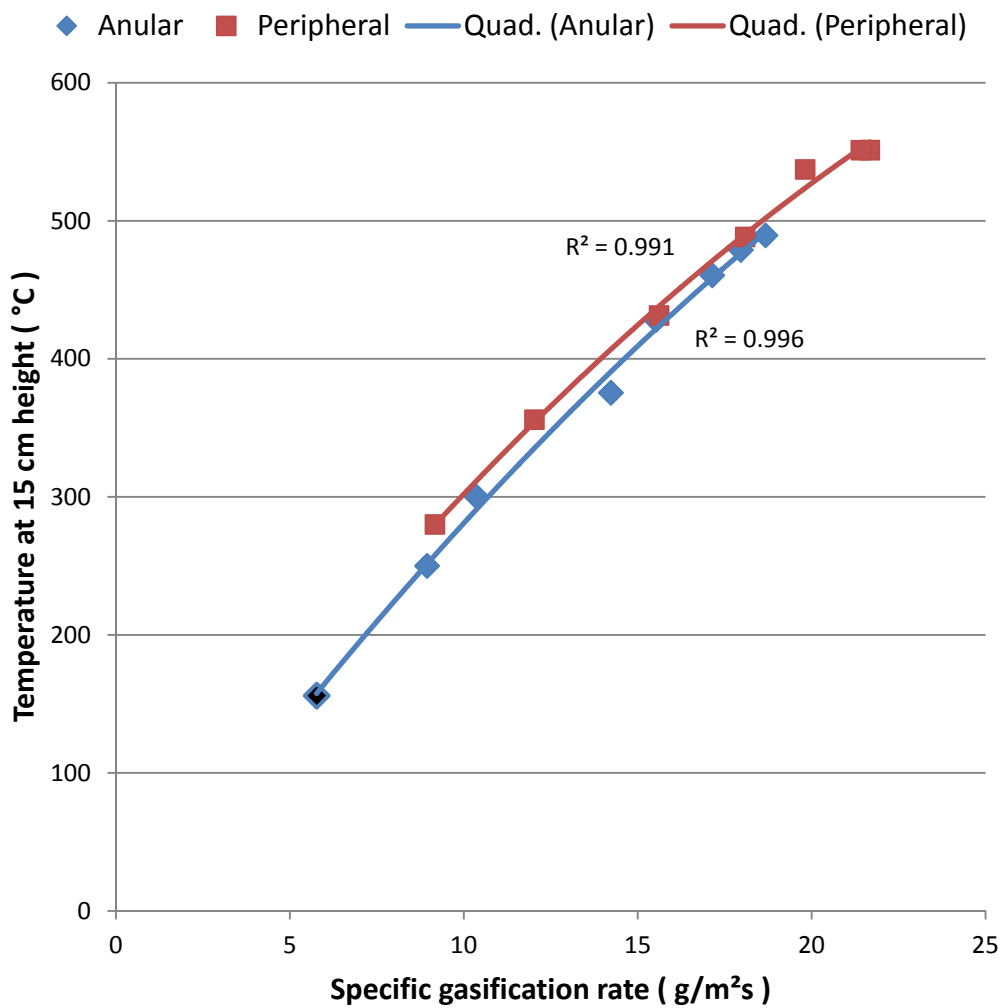
RESULTS:
Heat transfer was slightly higher for PB than AB.

When the average temperature of trials was expressed as a function of the their specific gasification rates, the two burners appeared quite similar.

The line for the AB was a little lower than for the PB, but not as much as expected, since with the PB, the gas flame was higher and broader so the riser interior should experience more radiant energy than in the AB.

Although thermocouple temperature was only an indicator of heat flux, the closeness of the curves suggests that the efficiency of heat transfer from the flame to the pot could be quite similar for both burners, despite having very different flame shapes.

(Note: SGR only describes the mass of fuel converted; it doesn't account for any changes that could occur in pyrogas composition and properties of gas flame.)



The relation between average temperature and average SGR of trials was essentially linear ($p < 0.001$).

RESULTS:
The AB worked at very high gasification rates

A single trial was run to see if the AB was functional at very high gasification rates (ca. 40-50 g/m²s), or if it produced visible smoke.

Vertical pieces of spruce lumber were used as fuel. A strong draft develops within the vertical spaces in the fuel bed. Secondary air was preheated.

There were no apparent problems for the AB burner. The geometry of the burner did not inhibit the development of the flame, and the fuel/air mixture of the gas flame 'appeared' to be satisfactory.

Measuring CO and particulate emissions will be required to corroborate these observations.

DISCUSSION

1) Specific Gasification Rate: The AB had lower gasification rate than the PB at all but the lowest grate aperture (0.6%RA). That was not unexpected. Previous research on burners has shown that resistance to vertical gas flow, the size of the gas flame, and where flame buoyancy is located in the burner, affects the draft for primary air. The PB was a 'fast' burner, because there were no obstacles above the fuel bed to the top of the riser. In the AB, the central distributor moved the flame buoyancy closer to the entry points of secondary air, and created a resistance to the vertical flow of hot gases.

By lowering the gasification rate, the AB had a lower turndown ratio of SGR than the PB: highest/lowest = 18/9 = 2.0 for AB, and 22/9 = 2.4 for PB. Both these burners may achieve a lower SGR and a larger turndown ratio if pilot flames were included in the reactor, as in the *Wonderwerk Strata Stove*.

Limiting the SGR may be a good thing if it makes the AB safer than the PB. With fuels like vertical spruce lumber, the 'fast' PB can develop a SGR = 50 g/m²s, flames 0.5 m tall, and fuel bed temperatures > 1100 °C. By placing a resistance to gas flow near the base of the gas flame, the AB was able to prevent excessive buoyancy in the fuel bed, without restricting flame expansion above the deflector ring. Restrictions higher in the path of the flame can cool the reactants or strain the flame, causing emissions of CO and particulate soot.

DISCUSSION

2) Riser Temperature was measured to flag any problems with heat transfer to a cooking pot. The relationship between thermocouple temperature and SGR suggested that the AB was less energy-efficient than the PB, but the difference may not be substantively large.

For each grate aperture with wood pellets, thermocouple temperatures were lower with the AB than the PB because the gasification rate in the AB was lower than the PB.

At medium to high gasification rates of wood pellets, the thermocouple temperature steadily decreased during a trial. This may have been caused by a decrease in gasification rate over time, however, a pronounced decrease in gasification has not been seen in previous experiments. Another hypothesis is that the pyrogas changed over time, as it passed through an increasing depth of char. This may have increased cracking of tar, and gasification of char by water If cracking of tars increased over time, the flame would contain progressively less soot, and emit less radiant energy. If this second hypothesis is correct, then the ability to turn down the heat of a ND-TLUD stove will not be exclusively determined by the highest and lowest flames that a burner can support, but also by the history of TLUD reaction and the type of fuel.

DISCUSSION

2) Riser Temperature (continued)

When average temperature was graphed as a function of gasification rate, the regression line for AB was lower than the line for PB. The two regressions were parallel, so AB had a consistently lower riser temperature at all gasification rates. The higher temperature in the PB may be because flame height was higher and broader for the PB than AB, so the interior of the PB riser may have experienced more radiant energy. However, since the regression lines were not widely spaced, there may not be much difference between AB and PB for heat transfer to a cooking pot. This needs to be confirmed by direct measurements of heat flow such as with a water-boiling test.

3) Further Research: This report is the first test of the AB concept. Adoption of any of the design principles from the AB and PB will require testing these burners for CO and soot emissions, and efficiency of energy transfer to boil water. If the AB design passes emissions testing, then its architecture may be modified and its dimensions justified. Of particular importance is the size of the peripheral secondary air holes in the AB: too large and the contribution of the central distributor becomes barely significant; too small and there may be insufficient secondary air.

CONCLUSIONS

The initial evaluation of the AB concept was acceptable. Although the central distributor increased the resistance to gas flow and decreased gasification rates, that may not be bad thing if it makes the TLUD stove safer to use. The AB worked over a wide range of gasification rates, so a high energy output is possible with the appropriate fuel.

It was predicted that the efficiency of energy transfer to a cooking pot may be lower with the AB than PB, because temperatures at the top of the riser were lower. However, the temperature differences were not large, so a small loss in efficiency may be a reasonable price to pay if the AB has lower emissions of CO and particulates. The energy efficiency needs to be verified with a water-boiling test.

The ultimate success of the AB depends on measuring emissions of CO and particulates to see if they are substantively reduced. More work is needed on the architecture of burner, and its dimensions must be justified. In future testing, the PB would a good basis for comparison.

ACKNOWLEDGEMENTS

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