Elements of ND-TLUD Design: Gas Burner Diameter and Preheating Secondary Air

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Pyrogas Burners and a ND-TLUD

A natural-draft, top-lit updraft gasifier (ND-TLUD, top right) with small (1x TLUD diameter), medium (1.2x), and large (1.5x) pyrogas burners. The collar on the burners was used to attach a cylinder for preheating secondary air.

Abstract

Gas burners for a natural draft, top-lit updraft gasifier (ND-TLUD) were assessed for visible flame characteristics and their effect on gasification rate. Two main design options were tested: diameter of the burner and preheating secondary air. Burners were tested on wood chip fuel that varied in moisture content, and primary air was adjusted to get very low to maximal rates of gasification. Preheating secondary air had no visible effect on the gas flame nor did it alter gasification rate. Increasing the size of the gas burner from 1x to 1.2x the diameter of the TLUD significantly improved gasification rate, reduced flame height, and reduced visible smoke production. Further increasing burner diameter to 1.5x TLUD diameter didn't cause a further increase gasification rate, and made the reaction unstable at low rates of primary air and high fuel moisture contents. Increasing the diameter of burners to at least 1.2x looked very promising for improving TLUD operation. Burners of 1.5x may be suitable for TLUDs that only run at high gasification rates. Larger diameter burners will likely cause less air pollution, and should be tested for CO and particulate emissions.

Introduction

Background

- Although natural draft, top-lit updraft (ND-TLUD) cookstoves have low emissions of CO and particulates, there have been problems with soot deposits on the bottom of pots.
- Sooting happens with incomplete combustion, and/or when the gas flame contacts the bottom of the pot.
- Many ND-TLUD stoves have a tall, cone-shaped gas flame that can cause sooting.
- There are a number of options in gas burner design that could reduce soot production.
- This study looks at how burner diameter and preheating secondary air affected gasification rate and basic flame properties when using moist fuel.

Diameter of Gas Burner

- Previously, we observed that pyrogas rising from the fuel moved outward toward the underside of secondary air holes in the side walls of the gas burner and became entrained in jets of secondary air. This radial movement of gas could allows us to make the diameter of the burner larger than the TLUD.
- Increasing the diameter could create a flatter gas flame, with improved mixing of pyrogas and secondary air at the base of the flame.
- On the other hand, as the diameter of the gas burner increases it will have less influence in shaping the flame. If the draft above the TLUD declines, the rate of gasification could be reduced.

Preheating Secondary Air

- Secondary air can be preheated by enclosing the TLUD and the bottom of the gas burner in an open-bottomed cylinder. Secondary air is heated by the walls of the TLUD and gas burner.
- Preheating secondary air may improve pyrogas combustion by increasing the initial temperature of reactants in the gas flame.
- Preheating can use gas buoyancy between the TLUD and the outer cylinder to push secondary air into the burner.
- However, heating air decreases its density, so air velocity must increase to maintain the quantity of oxygen mixing with pyrogas.

Design Elements Tested

Diameter of gas burner

Preheated or non preheated secondary air

Test Conditions

Increasing TLUD primary air supply

Increasing fuel moisture content

Methods

Components

ND-TLUD reactor (foreground), 1.2x gas burner (right) with a ring (to prevent vertical flamelets) that fitted inside the burner above the secondary air holes, and an open sleeve (left) for preheating secondary air, that attached to the collar of the burner.

Power curves were created by using a series of TLUDs that varied the area for primary air intake from 1.3, 2.5, 3.7, 4.8, 8.3 to 20.7% of the reactor area (RA).

Bottom view of double-walled TLUDs. (Note: Although power curve is largely determined by total area for primary air intake, the arrangement of holes affects the evenness of air supply in the fuel bed, so this method can create ‘bumps’ in the power curve as we add holes.)

Willow wood chip fuel was moistened to 5, 9, 12 and 16% H_2O/wet weight

Wood chips passed a 9 mm mesh screen and had fines removed through a sieve with 4 mm holes. After drying to 5% moisture in the sun, moisture was increased with a fine spray of water. The fuel was stored in the dark for one week prior to use.

Test Conditions

The ND-TLUDs + gas burners were operated in still air, and surrounded by a 20-cm diameter shroud to protect it from external air turbulence.

Measurements and Calculations

- Measured
  - Mass wet fuel (F, g) and water content (W, %/100)
  - Duration of pyrogas production (T, min:sec)
  - Mass of char remaining (C, g)
  - Reactor cross-sectional area ($A = 54.1\ cm^2$)
- Calculated: specific gasification rate (G)

  $G = (F \bullet (1-W)) – C) \bullet 1000 / T / A = mg/min/cm^2$

  the rate of fuel mass loss per unit area of TLUD

Experimental Design

- Factorial Treatments

  Three burner diameters

  Preheated or unpreheated secondary air
- Six rates of primary air
- Four levels of fuel moisture

For each combination of burner, preheating, primary air, and fuel moisture there was one observation.

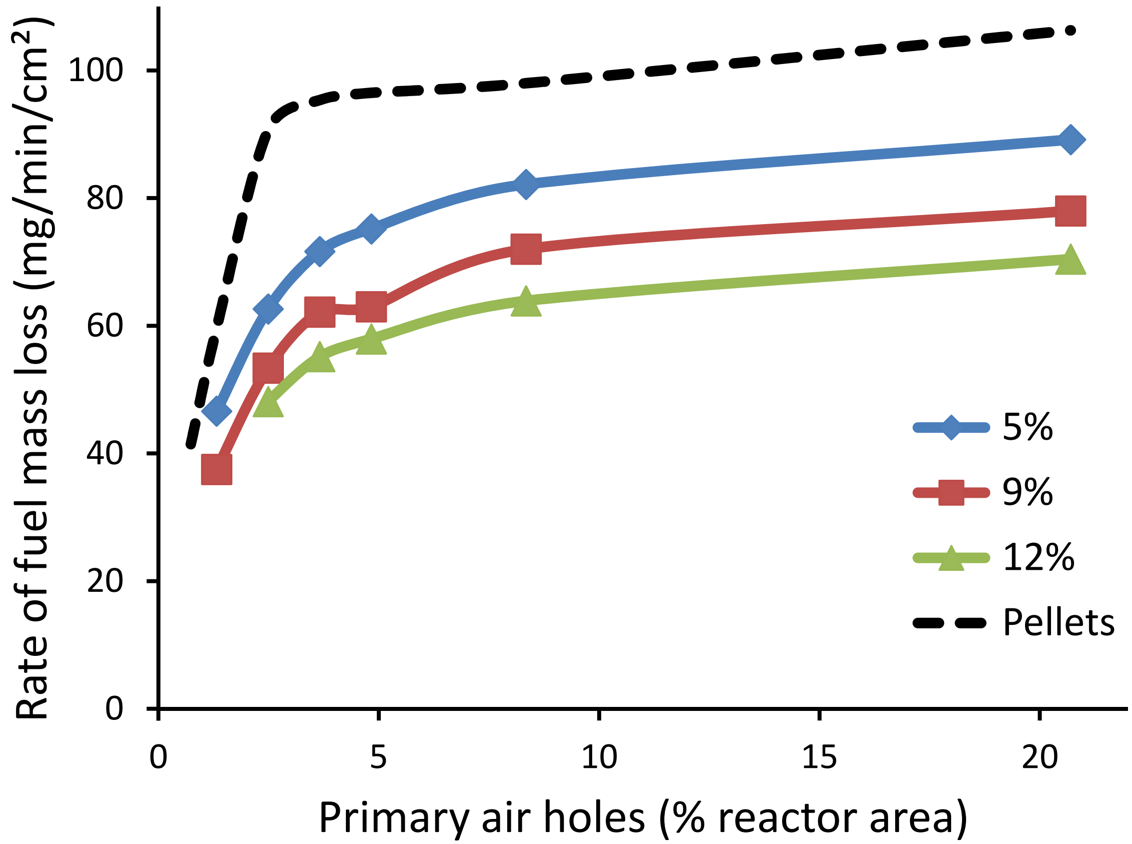
Results

Analysis of Variance for Gasification Rate

	Degrees of freedom	Mean Square	Significance Pr(>F)
Burner diameter	2	685.9	0.001 ***
Preheating air	1	8.5	0.336 n.s.
Burner x Preheat	2	17.4	0.155 n.s.
Fuel Moisture	2	2211.6	0.001 ***
Primary Air	4	1580.2	0.001 ***
Residuals	78	9.1	

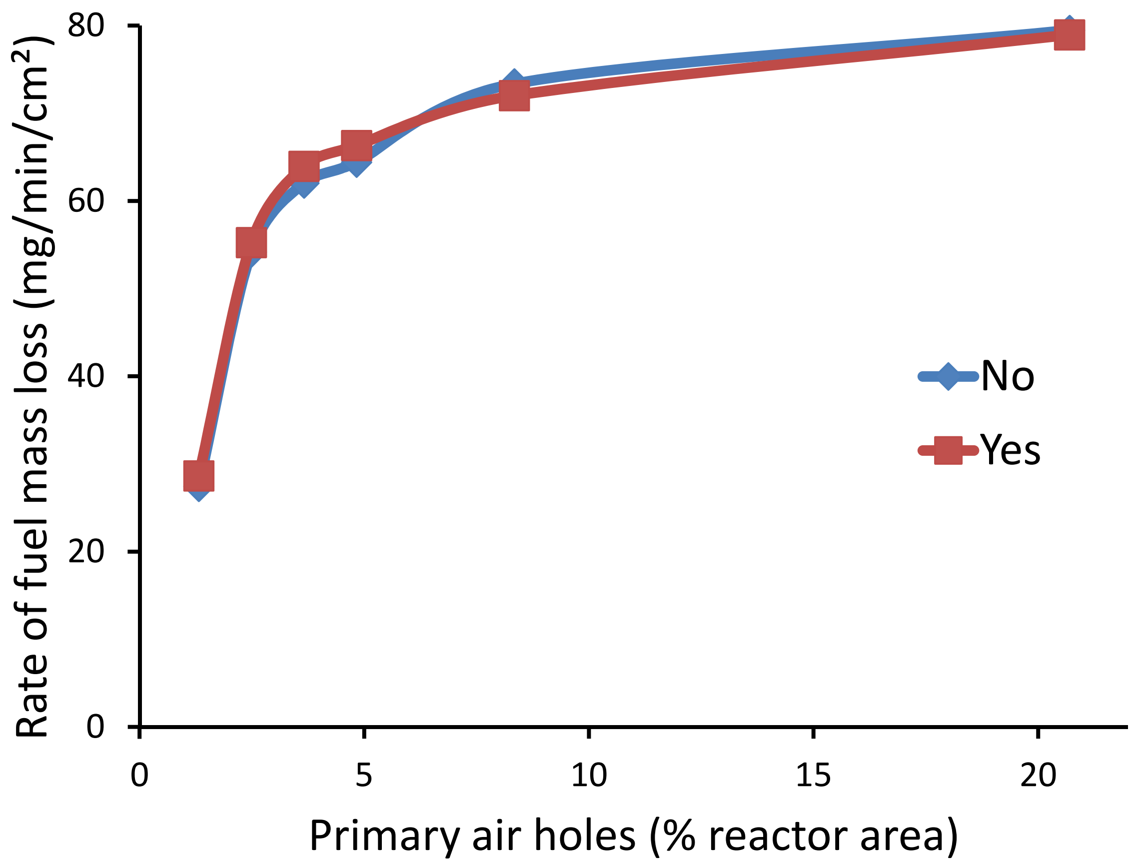
Note: for a balanced design, only water contents of 5, 9, and 12% were used in the analysis, as well as primary air holes of 2.5% RA and larger.

Wood Chip Water Content



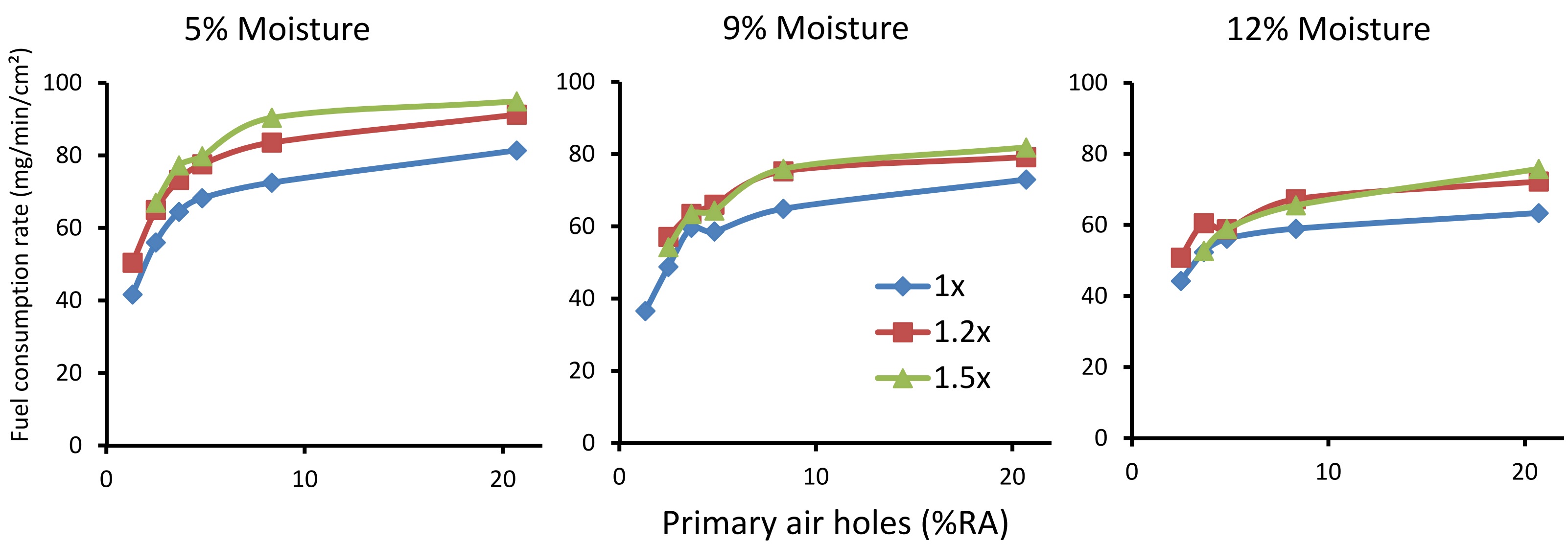
Increasing wood chip water content from 5 to 12% decreased ($p<0.001$) the gasification rate (points are means of burner sizes, and preheating treatments). At 16% moisture, only the 1.2x burner functioned at high primary air. For comparison, the curve for a hardwood pellet fuel at 5% moisture is shown using the 1.2x burner.

Preheating Secondary Air



Preheating secondary air had no effect ($p > 0.1$) on the gasification rate of wood chip fuel. (Points are means of burner sizes and moisture contents of 5, 9, and 12%).

Increasing Gas Burner Diameter



Increasing burner diameter TLUD diameter caused a significant increase in gasification rate ($p < 0.001$). There was significant increase going from 1x to 1.2x burners, but no significant difference ($p > 0.05$) between 1.2x and 1.5x burners. (Points are means of preheating treatments.)

- At 9 and 12% fuel moisture the 1x burner produced visible smoke.
- At 9 and 12% fuel moisture the 1.5x burner didn't work at the lowest primary air.
- At 16% fuel moisture, only the 1.2x burner worked, and only at the highest primary air.

Flame Properties in Gas Burners

1x Burner

- The bulk flame was taller than with other burners, with a central peak.
- Good flamelets from the secondary air ports existed when the fuel was dry, but some flamelets failed intermittently when the fuel moisture content increased. When this happened, the burner was smoky. The fuel/air mixture may have been too lean at these secondary air holes.

1.2x Burner

- The bulk flame was flatter that the 1x burner, and had multiple peaks at lower rates of primary air. Multiple peaks tended to coalesce into a central peak as primary air rate became high, and with drier fuel.
- Flamelets arising from the secondary air ports were always present, except at the lowest rate of primary air.

1.5x Burner

- Flame height was lower than with other burners.
- Flamelets from secondary air ports did not exist, or were intermittent, except at the higher rates of primary air.
- No or intermittent flamelets resulted in a bulk gas flame that was less well structured, and its shape fluctuated more than the in the 1.2x burner.
- Draft suction above the TLUD may be insufficient at low primary air.

Conclusions

Burner Diameter

- A small increase in burner diameter to 1.2x the diameter of the TLUD could have a substantive effect on increasing gasification rate and maintaining the momentum of gasification at low rates of primary air.
- Increasing burner diameter flattened the bulk flame, but when the burner was 1.5x, the secondary air holes became less important for structuring the bulk flame.
- Although the 1.5x burner was not as reliable at low rates of primary air and high moisture fuel, it may result in more complete combustion of pyrogas than the 1.2x burner when gasification rates are high.
- Both 1.2x and 1.5x burners should be tested for CO and particulate emissions.

Preheating Secondary Air

- There was no effect of preheating secondary air on gasification rate or gas flame properties.
- However, preheating secondary air may be important in other TLUDs that don't have double walled reaction chambers as used here, so heat transfer would be greater.
- Even though preheating secondary air had no effect on TLUD function in this experiment, it could still have an effect on combustion efficiency so preheating should be tested for CO and particulate emissions.