Basic Operating Parameters of a Natural Draft, Top-Lit Updraft Gasifier (ND-TLUD)

A ND-TLUD is a batch-fed, biomass gasifier that is loaded with a wood or densified biomass, ignited at the top, and underfed with primary air from a grate at the bottom. The ignition front travels down through the fuel by radiating heat into the raw fuel, drying it, and initiating pyrolysis. Released volatiles are ignited by the flame. The reaction is sometimes called a "migratory flaming pyrolytic front" (MFPF). Residual char is left on top of the fuel bed as the MFPF moves down. The MFPF creates draft for primary air.

The MFPF leaves behind char rather than ash for two reasons: (1) as the MFPF moved downwards, it includes new fuel at a rate faster than there is oxygen in the primary air to combust it, and (2) pyrolysis and the combustion of volatiles are orders of magnitude faster than the combustion of char.

Produced gas emerging from the char is usually combusted with secondary air in a burner on top of the reactor. Gas buoyancy in the burner is mostly satisfied by secondary air, but is can also accelerate primary air. Therefore, there is a positive feedback between size of the gas flame, primary air flow, and gasification rate in the reactor. This system of natural drafts and its feedbacks are central to ND-TLUD function and design.

The grate aperture regulates the flow of primary air, and is the key control point for a ND-TLUD. However the effect of grate aperture on gasification rates, maximum reactor temperature, and yield of char had never been systematically characterized. This research attempted to fill that gap in our knowledge using a variety of fuels (wood chips, wood pellets, tree sticks, and chopped lumber) with water contents ranging from 7 to 20% (ww).

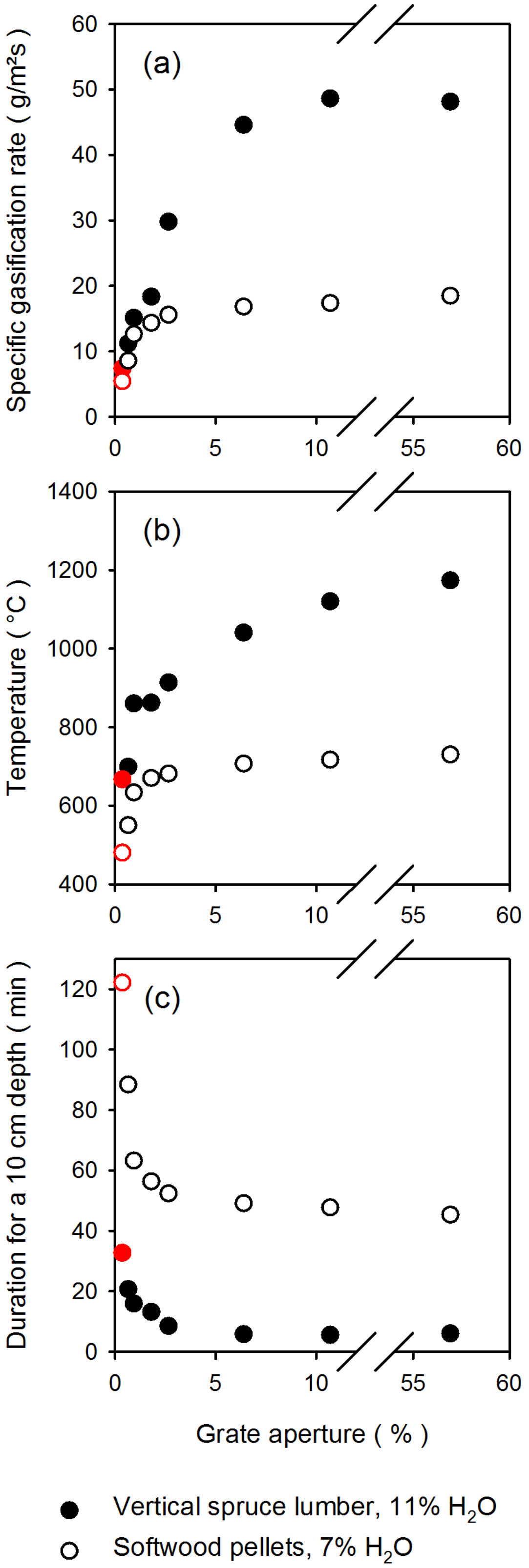

Figure 1. Effect of grate aperture on gasification of two contrasting fuels. Each point represents the mean of two batch runs with a single fuel and a fixed grate aperture (% of reactor cross-sectional area). Red points signify insufficient produced gas to support a gas flame above the char. The fuels were (**1**) Softwood pellets having a fuel bed with a high bulk density, and an irregular pore space of < 6 mm pores. Air flow through the fuel bed was very uniform, but resistance to air flow may become a limiting factor for gasification rate. (**2**) Pieces of spruce lumber (2 x 2 x 20) cm placed vertically in the reactor. Pore space in the fuel bed was vertical, promoting rapid vertical movement of gases and strong buoyancy in the flaming pyrolysis.

(**a**) Specific gasification rate is the amount of biomass (dry weight) volatilized per unit area of reactor per second, and can be used to design reactor area for power output. (**b**) The maximum temperature in the pore space of the fuel bed averaged from four locations down the central axis of the ND-TLUD reactor, which will affect char yield (Fig. 2) and properties. (**c**) Duration is the time it takes to complete pyrolysis in a 10-cm dept of fuel, and can be used to decide how tall a reactor should be.

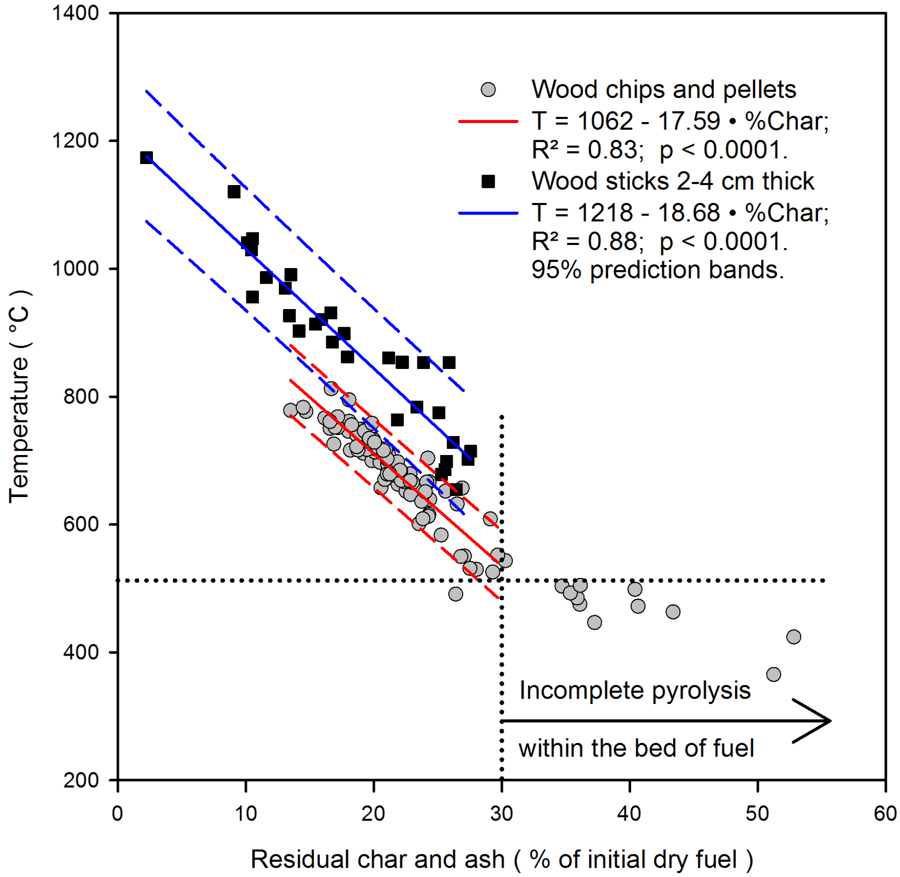

Figure 2. Relationship between maximum pore space temperature (MT) in the fuel bed, and the residual char at the end of batch pyrolysis. The temperature of pyrolysis affects the partitioning of biomass between volatiles and char; the higher the temperature the more volatiles and less char. Residual char is easy to measure, therefore we may be able to use it to estimate the causal temperature. A number of fuels were studied (ash ca. 2-3%). Two linear regressions were found that placed fuels into two groups (**1**) wood chips (3-10 mm thick, 8-20% moisture; *Populus balsamifera*) and softwood pellets (5 mm diam., 7-12% moisture; *Picea mariana* and *Pinus banksiana*), and (**2**) miscellaneous hardwood sticks (9-15% moisture) and sticks of spruce lumber (2-4 cm thick, *Picea glauca*). The distinguishing feature between these two groups was their thickness, and inter particle space. Larger fuels have a larger inter particle space for flaming and gas flow, compared to dense beds of pellets and chips. The thickness of the MFPF increases with particle thickness. Varying fuel moisture content was not a substantive factor in determining the relationship between temperature and char. When maximum TLUD temperature in chips and pellets was below 512 °C, we observed yields of >30% char indicating that some of the fuel was incompletely pyrolyzed.

The key findings were:

1) Most of the regulation of ND-TLUD operation is done in a narrow range of low grate apertures, 1-3% (Fig. 1). A maximum grate aperture of 10% may be sufficient for most fuels.
2) Increasing fuel moisture slowed down the specific gasification rate (SGR), but did not substantively affect maximum fuel bed temperature (data not shown). With moister fuel it takes longer to dry the fuel ahead of the MFPF.
3) The response of specific gasification rate (SGR; Fig 1a) and maximum temperature (MT: Fig 1b.) to increasing grate aperture were similar for a given fuel and fuel moisture content.
4) There was a strong linear relationship between % char yield and reaction temperature for two size classes of fuel (Fig 2). This may allow estimation of MT from %Char.