Charing Wheat Straw in Natural Draft Gasifiers

An Account of Some Informal Trials

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Problems with Wheat Straw in Micro Gasifiers

A good fuel for micro-gasification should burn hot, for a long time, without pollution, and preferably cost nothing. Tropical grasses have been used successfully in natural-draft, gasifier cookstoves when they have been loaded in bundles, with air movement around the outside of the bundles (Paal Wendelbo *pers com*; Haiti Reconstruction, 2013). Can a similar thing be done with morphologically finer grasses, such as wheat straw?

Previous tests showed that when wheat straw was loosely loaded into a micro-gasifier, gasification was complete within minutes, so the straw was neither useful source of heat, nor an efficient source of biochar. When the straw was packed tightly into the gasifier, the air circulation through the straw was poor limiting the convection of oxygen and heat. The result was a slow-burning, smouldering fire that produced little heat, and smoke that would not ignite. What was needed was a way to increase fuel bulk density, whilst allowing for sufficient air movement. Preliminary tests of the bundle method on wheat straw showed that the fire burned cleanly but didn't last very long.

Following discussions at stoves@lists.bioenergylists.org, we tested a modification of the bundle method by packing wheat straw into a micro-gasifiers with a hole up through the centre of the straw bed to allow passage of air. Tests were run in a 4.3-L paint-can gasifier, then scaled up to a 118-L steel drum gasifier.

Methods

Paint Can Gasifier

A micro-gasifier was made from a 16.8 cm diameter, 19.4 cm tall paint can (4.3 L) by boring holes in the bottom for primary air (Fig. 1), and placing a gas afterburner on top made from similar-sized can with ring of holes for secondary air near the bottom and a chimney on top (Fig. 4).

Air-dry wheat straw (stored indoors at 60% relative humidity) was used. To make the bed of fuel, a 6.5 cm diameter cylinder was placed in the centre of the paint can (Fig.2). Wheat straw was packed as tightly as possible around the outside of the cylinder, then the cylinder was removed. This produced a cylinder packed wheat straw with a hollow core in the middle through which air from primary air holes could flow (Fig. 3). Four replicate tests were made igniting the straw at the bottom-centre, or on the top. Ambient air temperature was 4-6°C.

Figure 1. Primary air holes in the bottom of the paint-can gasifier.

Figure 2. Packing wheat straw around a central cylinder.

Figure 3: Hollow-core packed straw with primary air holes visible at the bottom.

Figure 4. Top-lit, hollow-core straw – the gas fire went out before all straw volatiles had gasified.

Figure 5. Bottom-lit, hollow-core straw just after ignition. The gas fire died down and burned to completion after 10-13 minutes.

Figure 6. Charcoal fire in a bottom-lit, hollow-core straw after all fuel's volatiles had gasified.

Drum Gasifier

A drum gasifier was made by boring holes (Fig. 7) in the bottom of a 118-L (30 US gal.), 46 cm diameter, 69 cm tall, steel drum, which was nested in a larger 200-L (55 US gal.), 57 cm diameter, 84 cm tall, steel drum that had its bottom cut out. Primary air entered through the holes in the smaller drum (Fig. 7). Secondary air entered at the bottom of the larger drum and passed up between the walls of the two drums, entering the fire zone over the upper lip of the smaller drum. This route for secondary air prevented gusts of wind from entering the gasifier, and can preheat the secondary air (Anderson et al., 2007) if the out wall of the inner barrel gets hot. A lid with an 20-cm diameter afterburner chimney (after D. Yarrow) was placed on top of the larger drum (Fig. 8).

The same straw that was used with the paint-can gasifier was loaded into the 118-L drum. Two tests were run. (1) Straw was packed loosely packed into the drum but without a central hole (ambient air was 2°C). (2) Straw was formed into a hollow core bed, by packing the straw around a 15-cm diameter stove pipe then removing the pipe (Fig 9). The lid was placed on the reactor and the fuel ignited by poring 150 mL of alcohol-soaked, burning wood pellets down the hole. Ambient air was 6°C.

Figure 7. Primary air holes in the bottom of the 118-L drum.

Figure 8. Nested drum gasifier with a venturi afterburner.

Figure 9. Hollow-core bed of compressed wheat straw in the drum gasifier.

Results

Paint-Can Gasifier

Trial 1

The hollow cylinder of straw was **lit from the top**. The reaction got off to a good start with a strong gas fire that shot out of the chimney. The ignition fire partially followed the path of incoming fresh air down the hole in the middle of the straw, but did not establish at the bottom of the fuel. Unfortunately, after one minute, the flames went out and the gasifier emitted smoke (Fig. 4). The smoke could be burned with a propane torch, but would not stay alight on its own. This experiment was repeated by igniting alcohol-soaked wood pellets placed on top of the straw, with the same results. **A top-lit, hollow core bed of straw was unsuccessful**.

Trial 2

The hollow cylinder of straw was **lit at the bottom** of the central hole, either by lighting the straw through the primary air holes, of by dropping a match on a few alcohol-soaked wood pellets at the bottom of the hole. Both methods of lighting produced similar results, however adding wood pellets ignited the fuel faster.

A bottom-lit, hollow core bed of straw was successfuly charred with little visible smoke. Similar to Trial 1, the burn started with strong gas fire above the fuel (Fig. 5), but unlike Trial 1, in Trial 2 the gas fire was stable and persisted for 10-13 minutes until all volatiles in the fuel were combusted. About 2-3 minutes into the burn, gas fire has settled down to a ring of flames above the straw. Towards the end of the gas fire, a small amount of unburnt smoke was produced symptomatic of some localized patches of oxygen-deprived smouldering within the bed. When the flame went out, a charcoal fire was visible at the bottom of the central hole (Fig. 6). The charred straw had not collapsed downward, but remained up to the top of the can. In a separate trial, the fuel was initially top-lit with wood pellets as in Trial 1; when the gas fire went out the straw was relit at the bottom and completed the gasification as in Trial 2.

Barrel-Gasifier

Trial 3

A solid bed of wheat straw was lightly packed into the 118-L steel drum and ignited from the top creating a ‘top-lit updraft’ (TLUD) process. The reaction got off to a roaring start with flames coming out of the chimney, but after two minutes, the gas fire went out, and only smoke was produced (Fig. 10). The smoke could not be ignited with a propane torch. Three hours later, the smoke stopped, and the reaction was quenched with water. The barrel was full of charred straw.

Figure 10. The gas fire above top-lit, loosely packed, solid bed of straw went out two minutes after ignition, and smoked for thee hours.

Figure 11. Although the gas fire from a bottom-lit, hollow core straw remained lit for fifteen minutes, when it went out, most of the straw had not been charred.

Trial 4

The bed of straw was packed with a hollow core (Fig. 9), and bottom-lit. The result was a substantial improvement on Trial 3. The initial ignition fire burned hot for several minutes, and the gas fire persisted for fifteen minutes without smoke (Fig. 8). When the gas fire went out, the reaction was quenched with water. When the contents of the 118-L drum were dumped out, we were surprised to find that **much of the fuel had not combusted** (Fig. 11).

Discussion

In an earlier paint-can tests, a solid beds of straw were either loosely or tightly packed, and lit from the top creating a TLUD process, but the TLUD didn't work well with wheat straw, because the smoke produced would not sustain a gas fire. The problem was insufficient air movement within the fuel which resulted in a cool, smouldering combustion. Also, when a packed bed of straw is lit, the primary air can find a preferential path to the top fire, and the fire can follow that path down to the bottom of the can, spread out over the primary air holes, and produce bottom-lit updraft gasification. Bottom-lit, updraft gasification of solid beds of wheat straw had also produced unburnable smoke.

Making a hole up the centre of the straw bed allowed for sufficient air movement analogous to the bundled tropical grasses used in micro-gasification stoves. Bottom lighting the straw establishing a strong central fire that moved hot gases up through the central core of the fuel bed. An ignition fire may have moved centrifugally out from the central hole, but it was likely that the main movement was from the bottom of the bed upwards, because that would be the shortest route for the primary air. Heat from an ignition fire and burning charcoal could raise the temperature in some of the straw above to cause non-flaming pyrolysis. A proper understanding of the process, however, will need observations from thermocouples and gas samples.

Given the success of bottom-lit, hollow core method in the paint-can, we tried the same method in the 118-L drum. Although the reactor burned properly for fifteen minutes, this test was not successful, because a large amount of fuel was unburned when the gas fire in the secondary air went out. One reason for this may be that the primary air holes were too small. It was also likely that when the fuel bed was scaled-up from 4.3 to 118 L, the path length for air in the straw became too long and the resistance to gas flow to high. That would limit convective flow of both oxygen and heat. More trials are needed to see if we can get complete high-temperature charing of the fuel by increasing the size of primary air holes, packing of the straw less densely, making a larger hollow core, or probing multiple holes in the bed.

In summary, wheat straw does not gasify well by the TLUD method, even if there is a central hole in the bed of fuel, because restricted gas movement through the straw causes it to shoulder and produce unburnable smoke. Wheat straw can produce combustible smoke in an updraft gasifier if the bed has a hollow core that is lit from the bottom. However, even if this method is used in cookstoves, loose wheat straw is not an ideal fuel because it burns too quickly. It may need to be compressed into briquettes of pellets.

References

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