Fabricating a 200 L Biomass Gasifier for Making Enhanced Water Filter Biochar

Contents

Terminology and Abbreviations

Biochar / Charcoal / Char
"Biochar" refers to the practice of applying charred biomass to agricultural soils in order to increase crop yields, and/or to sequester carbon in the soil. "Charcoal" refers to a biomass-derived char product most often used as cooking fuel. "Char" is a nonspecific term used for convenience referring to biochar or charcoal.

Biomass / Feedstock
Here, "biomass" refers to any woody or cellulosic material (e.g. wood, agricultural and forestry residues) that serves as the precursor, or "feedstock," for making char.

Gasifier
A device for heating biomass in order to cause it to evolve volatile and flammable gases, which are then combusted to provide energy, typically for cooking or space-heating.

Micro-porosity / Surface Area
A "micro-porous" material possesses very fine pore structure at the nanometer to micrometer (10^{-9} – 10^{-6} m) scale. "Surface area" refers primarily to internal surface area, i.e. within micro-pores.

Pyrolysis
The process by which char is generated, wherein biomass is heated under restricted oxygen atmosphere. Distinct from combustion ("burning") wherein biomass is heated with sufficient oxygen present, leaving only ash as the solid residue.

SOC	synthetic organic compound
TLUD	"top-lit, up-draft" – referring to a mode of operation of biomass gasifier units

Introduction

Contamination of drinking water sources by synthetic organic compounds (SOCs – e.g. pesticides, pharmaceuticals, fuel compounds) is a growing worldwide problem. Many of these chemicals bio-accumulate in the human body and cause cancer, birth defects and diseases of the reproductive system, and disrupt endocrine and neurological systems. Treating water by filtration using charcoal is an ancient practice that continues today, and may provide locally obtainable and cost effective removal of SOCs from drinking water in rural and remote communities.

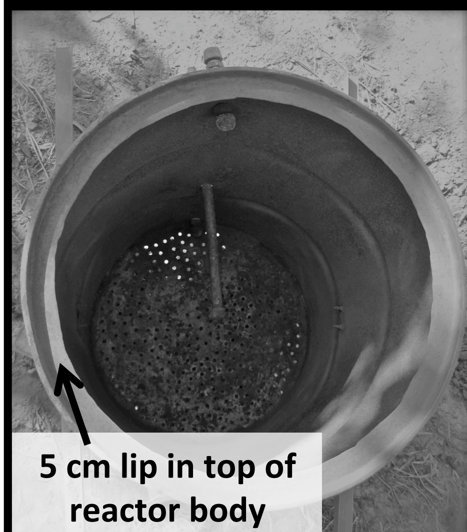
Unfortunately, charcoal production by traditional kiln systems is highly polluting, energy-inefficient, and time- and labor-intensive. Furthermore, traditional charcoals vary widely in quality and effectiveness for water filtration. Low cost, energy efficient, environmentally sustainable and scalable local production of optimal water filter char from a wide range of agricultural and forestry wastes and by-products (including small grained, chipped or pelletized biomass) can be accomplished with biomass gasification.

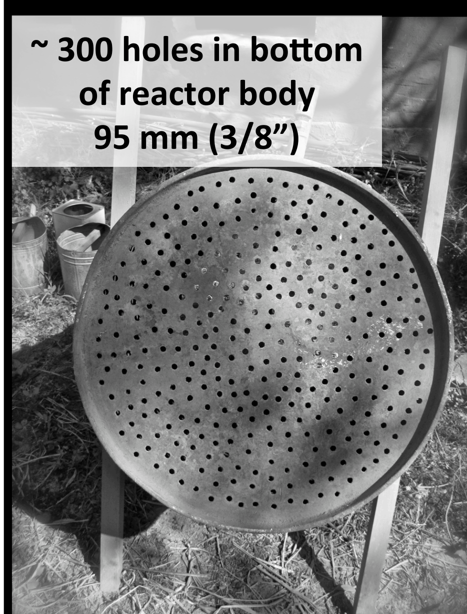
Gasifier char production is favorable from environmental and energy standpoints when compared with traditional charcoal manufacture since pyrolysis gases are combusted within the unit rather than emitted as pollutants, thereby providing the energy that drives pyrolysis and obviating the need for an external heat energy source. Also, biomass gasifiers can be readily coupled with other unit processes for waste heat utilization.

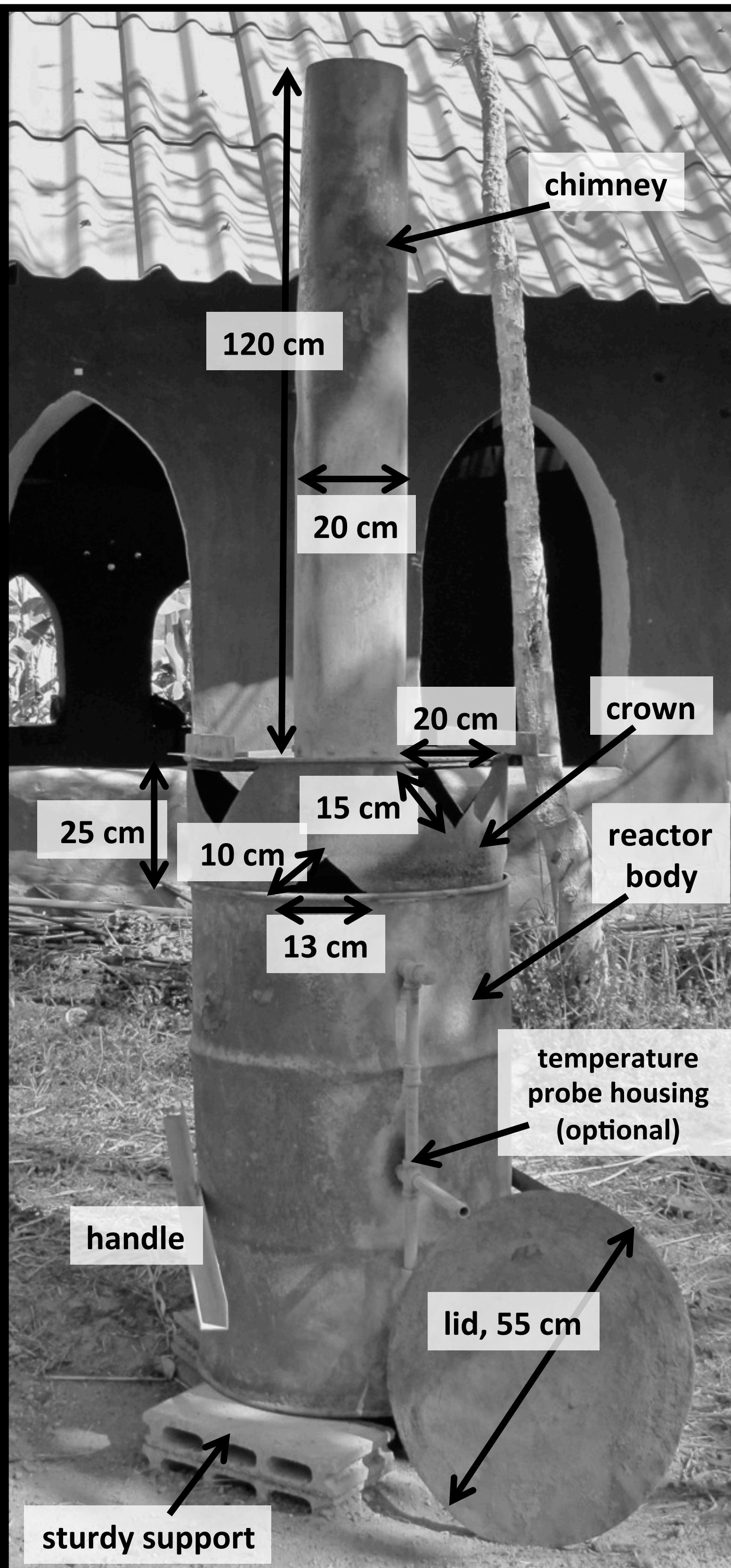
Our research has shown that gasifier chars consistently achieve high temperatures (750-950 °C) required for substantial development of surface area and micro-porosity in the char product. Accordingly we have shown that gasifier chars are more effective than traditional kiln charcoals for removal of SOCs such as herbicides from water. Therefore, gasifier biochars are a promising appropriate, low-cost and sustainable technology for affordable decentralized water treatment in rural and developing communities.

200 L Top-Lit Up-Draft (TLUD) Biomass Gasifier

For Generating Enhanced Water Filter Biochar





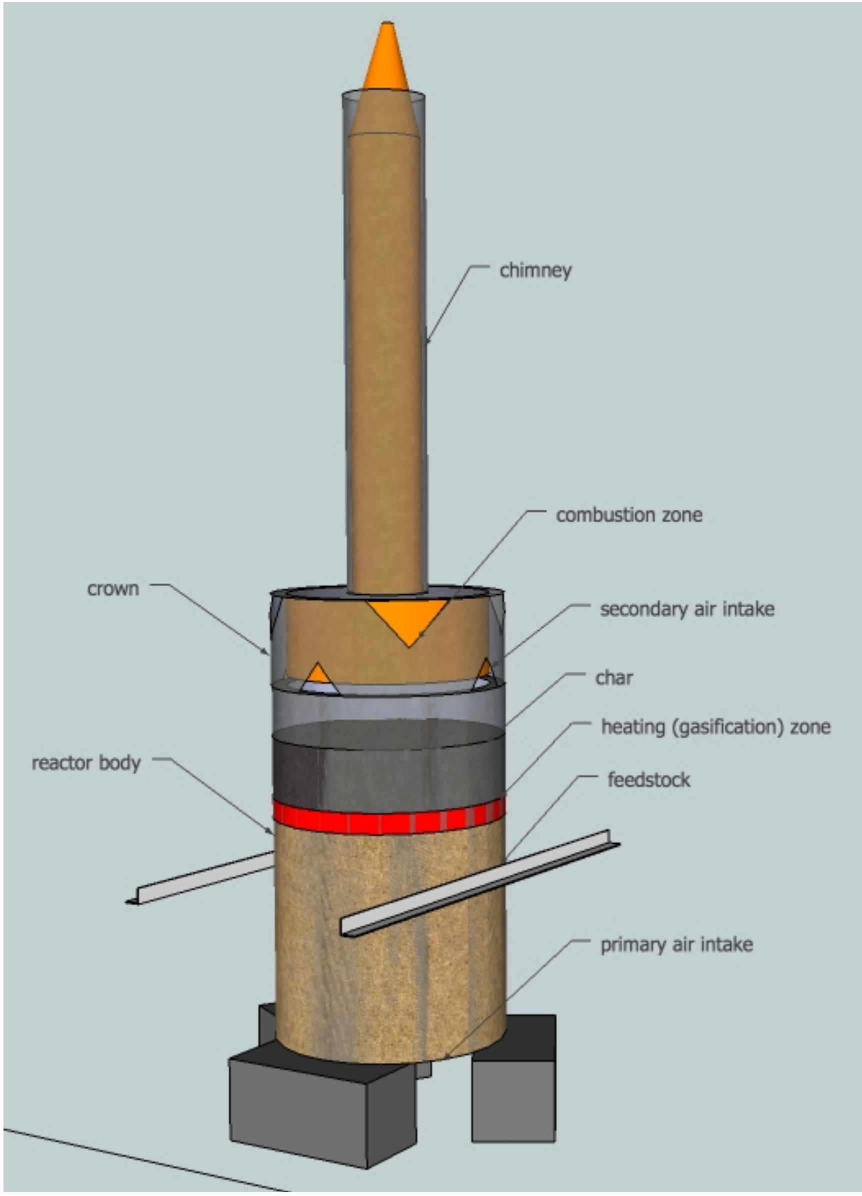


An instructional video explaining the conceptual background, construction, and operation of this unit can be accessed from the Aqueous Solutions website: www.aqsolutions.org.

I. Conceptual background

The process of creating char from biomass – pyrolysis – involves heating the woody starting material ("feedstock") in an oxygen-restricted environment. The key to generating enhanced water filter biochar (i.e. char with substantial micro-porosity and surface area for the effective uptake and binding of synthetic organic pollutants) is reaching hot enough temperatures (i.e. 700-1000 °C) to remove the naturally occurring tarry and oily components of biomass while converting the remaining carbon-rich material to a graphite-like structure. In biomass gasification, high temperatures are obtained by ensuring a strong air draft through the feedstock. A strong draft supplies oxygen for a small amount of the feedstock to combust thereby providing heat to gasify and carbonize the adjacent remaining feed. The draft also sweeps the tarry and oily vapors away from the carbonizing feedstock, which allows for the development of extensive porosity in the char.

In a top-lit up-draft (TLUD) gasifier, air draft enters through holes in the bottom of the reactor body and rises upwards through the feedstock ("up-draft"). The fire burns from the top of the reactor body downward ("top-lit"). (See schematic below.) The zone of pyrolysis thus moves from the top to the bottom of the reactor body over the course of the burn. The upward-moving air draft (termed "primary air") supplies limited oxygen to keep the process going but not enough to combust all of the hot feedstock. As primary air draft moves through the pyrolysis zone within the reactor body it sweeps combustible gases rapidly upwards into the combustion zone within the crown and chimney. Vents in the crown admit ample air (termed "secondary air") for complete combustion of the hot pyrolysis gases. The hot combusting gases move upwards through the chimney, augmenting the primary air entering the bottom of the reactor body.



Schematic of TLUD gasifier interior showing feedstock gasification/carbonization in the heating zone and combustion of the rising pyrolysis gases when combined with secondary air in the combustion zone. The heating/pyrolysis zone proceeds from the top to the bottom of the reactor body during firing. (Illustration by Nathan Reents.)

A well-operating TLUD gasifier should emit little or no smoke, since the vapors and particulates that constitute smoke are completely combusted within the unit. This is what makes the process more energy efficient and environmentally friendly than traditional charcoal manufacture. In traditional charcoaling, pyrolysis gases – which include methane, carbon monoxide, nitrogen oxides, particulate matter, and other products of incomplete combustion – are released in large quantities as problematic air pollutants. Furthermore, in traditional charcoaling a separate fuel source in addition to the feedstock is required to provide the heat energy for pyrolysis. TLUD gasifiers solve both of these problems simultaneously by completely burning the pyrolysis gases, releasing primarily only CO_2 and water vapor to the atmosphere, while powering the conversion of the feedstock stock to char. Moreover, gasifiers are less time-consuming to operate: the burn period of a traditional-style 200 L steel drum kiln is typically 5-8 hours with a 12-hour cooling period; the 200 L TLUD gasifier burns for 1-2 hours depending on the feedstock, and takes another 1-2 hours to cool to handling temperatures.

II. Materials and tools

Note that the TLUD gasifier design described here is an open architecture – feel free to modify as needed to achieve desired performance. We invite your feedback on the construction and use of this and similar units. Please send comments to josh@aqsolutions.org.

Materials required include: two 200 L (55 gal) steel drums for the reactor body, crown and lid; scrap metal (square tubular or angle iron) for handles; sheet metal or flue pipe for chimney (NOT tin, aluminum, or thin galvanized steel as these will melt or quickly break down); concrete block or similar to form a study support base; assorted bolts, nuts and washers. Helpful tools include an angle grinder and drill/bits or cold chisel for cutting metal, and a basic welding setup.

III. Construction

Drum #1 will become the reactor body and drum #2 will become the crown and lid.

Cut a circle out of the top of drum #1 leaving a 5 cm lip around the edge. Drill about 300 evenly spaced holes 9-10 mm in diameter (3/8") in the bottom of drum #1. Alternately, cut radial slots into the bottom of the drum giving a similar total cross-sectional area of openings. Cut some pieces of angle iron or square tubular steel at least 120 cm long for handles. Weld or bolt these securely to the sides of drum #1.

If you don't have ready access to flue pipe, the chimney can be fabricated by rolling a rectangular piece of sheet steel, then clamping and welding the seam.

Cut the upper and lower triangular vents evenly spaced around one end of drum #2: four upper vents 15x20 cm and four lower vents 10x13 cm offset from the upper vents (see diagram at the beginning of this section). Then cut around the perimeter of drum #2 to make the crown 25 cm tall. Cut a tabbed opening in the center of the crown face, bend the tabs outward and attach the chimney by bolts or welds. Cut the lid out of the other end of drum #2 – about 55 cm in diameter, or large enough to overlap the lip cut in the top of drum #1 by 2-3 cm while still fitting inside the rim.

Cut two 2 m lengths of angle iron or metal tubing to use for removing the hot crown.

Place the reactor body onto concrete blocks or other sturdy support allowing an ample gap with the ground for airflow to the bottom of the drum. Place the crown/chimney on top of the reactor body, with the crown resting on the lip in the top of the reactor body inside the rim of the drum. A snug fit is good. Make sure everything is level, sturdy, and will not tip over during operation.

IV. Operation

For best results making TLUD gasifier char, draft must be optimized. Too much draft results in high temperatures but too much combustion of the feedstock and thus low char yields. Too little draft results in insufficient temperatures for the onset of effective gasification – the feedstock smolders, produces a lot of smoke, and does not char well.

Draft is directly influenced by how the feedstock packs into the reactor body. This depends on the size and shape of the feedstock. Ideal materials are dry (not freshly cut) wood branches and bamboo poles 2-5 cm in diameter cut to 10-15 cm lengths. Corncobs are a good size and shape. Smaller branches and twigs, small lumber scrap, chipped and broken coconut shells, and coarse wood chips can also be used. Biomass pellets work well if they are not too small. Small pellets, fine wood chips, rice husks, saw dust and wood shavings are too fine and inhibit draft unless a supplemental fan or blower is applied to enhance primary air supply. Thick materials can be used but need to be thinly cut – whole logs do not char thoroughly. Mixtures of different materials, sizes and shapes, work fine.

The best water filter char comes from woody feedstocks with high lignin content. Switchgrass, straw, and rice husks are mainly composed of cellulose and mineral matter and do not produce good water filter char. Corncobs produce mediocre water filter char and do not require processing (i.e. cutting or chipping) prior to loading into the reactor.

Place the reactor on the concrete block supports and load it uniformly with cut or chipped feedstock. If using dense wood as the primary feedstock, a 5-10 cm layer of chopped bamboo or corncobs can be loaded into the top portion of the reactor body to accelerate the initial heating and gasifying of the wood. Set the crown/chimney firmly in place and stuff a few handfuls of straw inside the crown as kindling. (Accelerants such as kerosene or lighter fluid are not necessary and should be avoided.) If there are any air gaps where the chimney is attached to the crown seal them with mud.

Light the straw through the vent holes of the crown. The material at the top of the reactor body will begin to burn. A small amount of smoke may be emitted from the chimney during this stage. Once sufficient temperatures have been attained for gasification, the feedstock glows while a yellow-orange "fireball" should appear hovering near the top of the reactor body, inside the crown and inside the lower chimney. In preparation for shutdown, make a mud pit adjacent to the reactor body large enough to readily accommodate the drum, and save an additional 1-2 buckets of mud for sealing the top of the reactor.

A candle or chunk of wax can be rubbed on the outside of the reactor body to indicate where the pyrolysis zone is located. When the pyrolysis zone reaches the bottom of the reactor body a red glow will be visible through the primary air holes. The yellow-orange color of the "fireball" in the crown will fade to a clear, bluish flame. This indicates that all wood gases have been burned off from the feedstock and char combustion is commencing. Char combustion occurs at much higher temperatures than gasification (in excess of 1400 °C compared with 700-900 °C typical for gasification). It's undesirable to let char combustion continue for too long since the desired char product is being destroyed, and because the very high temperatures may result in the structural failure of the reactor body. The appearance of a blue flame along with the fading of the yellow-orange flame is thus a dependable visual indicator of when it's time to shut down the process.

Shutting down the gasifier requires two persons. (See photo series below.) Wear study leather work gloves. Place the 2 m lengths of metal tubing or angle iron through the vent holes in the crown to act as handles. With a person on opposite sides of the gasifier, lift off the crown/chimney and set it aside.

Place the lid on top of the reactor body, then grasp the handles of the reactor body, lift and set it in the adjacent mud pit to seal the bottom. Use the mud set aside to seal the lid on the top of the reactor body. Allow the reactor to cool at least 1-2 hours, then remove the mud and collect your biochar!

[Note: An alternative shutdown method involves dousing the hot reactor and contents with copious water. This may alter the sorption properties of the product char in favorable or unfavorable ways. We are currently investigating the effects of "wet shutdown" on char properties and cannot recommend for or against this procedure at this time.]

During the charring process the feedstock sinks, subsides, and shifts in the reactor – for making optimal water filter char it is normal and desirable for the volume to have shrunk to ⅓ to ½ of the drum. The mass of char product should be about 15% of the mass of the original feedstock – e.g. a 40-75 kg batch of feedstock yields 6-12 kg of char.

Photo series showing shutdown procedure: When bottom of drum begins to glow (a) and blue flames appear in crown (b) then pyrolysis is nearing completion. Remove the crown and chimney (c) and (d). Put on the lid and move the reactor body to the adjacent mud pit to seal the bottom (e) and (f). Seal the top with mud to prevent air leaks (g) and (h). (Photography by Lyse Kong.)

Photo by Lyse Kong

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