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Simplifying pyrolysis: Using gasification to produce corn stover and wheat straw biochar for sorptive and horticultural media☆

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ABSTRACT

Biochar is a renewable, useful material that can be utilized in many different applications. Biochar is commonly produced via pyrolysis methods using a retort-style oven with inert gas. Gasification is another method that can utilize pyrolysis to produce biochar. This method has significant processing advantages; it can be carried out in normal atmospheric conditions, eliminating the use of inert gas, is more amenable to scale up, and provides heat that can be used to generate power and/or help recoup processing costs. In this work, a simple gasification process using a top-lit updraft style cookstove was used to produce biochars from corn stover, wheat straw, and wheat straw treated with glycerin, which were then compared to biochars made using the more conventional retort oven pyrolysis process. The glycerin-treated wheat straw biochar from the gasification process had carbon content > 70% and an ash content of 25% which was equal or better than the same biochar produced using the retort oven. This biochar has also shown successful use as a peat moss replacement in horticultural applications. This shows that gasification is a simpler, more cost-effective means to produce biochars and should be considered for horticultural and other similar applications.

1. Introduction

Biochar is a renewable natural resource that can be produced from waste biomass. For many years now it has been researched as a significant means to combat greenhouse gas emissions by sequestering carbon in the soil, where it is stable for thousands of years (Ennis et al., 2012; Matovic, 2011). However, this versatile material can also be used in other applications. Biochar is a naturally porous material, and processing modifications can enhance its porosity even further (Azargohar and Dalai, 2008). Because of this, sorptive media (water purification and toxin filtration) is one market where biochar could potentially replace traditional sources such as activated carbon. Several studies have shown that biochar is successful sorptive media for various toxins such as heavy metals (Beesley et al., 2010; Uchimiya et al., 2010), pesticides (Wang et al., 2012; Zheng et al., 2010), and estrogen containing compounds (Peterson et al., 2013). Another potential market that takes advantage of the porosity of biochar is horticultural potting substrates. Ideal potting substrates have slow degradation rates, high water holding capacity, and low bulk density (Bilderback et al., 2005), all physical characteristics that could be met by biochar. Sphagnum peat moss is a highly valued potting substrate because it also meets all of these physical characteristics, but its production is environmentally unfriendly due to its extremely slow growth rate (Barkham, 1993; Robertson, 1993). Substituting its use with biochar could be both environmentally favorable and cost effective as well.

Recently there has been research in using microwave radiation to produce biochar (Luque et al., 2012; Macquarrie et al., 2012; Salema et al., 2013), although currently it is still much more common to produce biochar by the use of a retort process, in which the biomass feedstock is thermally treated in an atmospherically controlled oven with nitrogen or some other inert gas present to eliminate oxygen and allow pyrolysis to occur (Meyer et al., 2011). Retort methods are effective at excluding oxygen to facilitate pyrolysis but can be costly during scale-up because of the need to control the atmosphere with sealed systems in conjunction with the use of inert gas. Atmospheric control also requires these systems to be operated as batch reactors and therefore they cannot be run with a continuous stream of feedstock.

☆ Mention of companies and/or trade names are necessary to report factually on available data; however, the USDA neither guarantees nor warrants the standard of the product, and the use of the name by the USDA implies no approval of the product to the exclusion of others that may also be suitable. This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

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An alternative method of biochar production with a much simpler and accessible process design is a gasification cookstove. In this design, biochar can be created under atmospheric conditions because the cookstove is designed so that continuous combustion is kept spatially separated from where pyrolysis of the feedstock occurs. This method of biochar production has numerous advantages over the retort process. First and foremost, it can run in atmospheric conditions and does not require the use of any inert gas. Secondly, it can be scaled up and configured to run with a continuous stream of feedstock, so throughput is greater than batch methods (Anderson et al., 2007). Gasification also involves an exothermic release of heat, which can be captured and used to offset processing costs. In fact, the original design and intent of the gasification cookstove, as the name implies, was to provide a heat source for cooking food in underdeveloped areas. In designing cookstoves for this function, goals are reducing bottom-line cost along with eliminating the need for external power sources so that the most people can benefit, but the same basic top-lit updraft (TLUD) design can be easily modified to increase and improve biochar production.

In this work we compared biochars produced by both retort oven and gasification cookstove in terms of physical properties that would be important for the applications of sorptive media and potting substrates. For feedstock, we chose to work with corn stover and wheat straw, since they are the two largest crop residues in the United States (Energy, 2011), and therefore provide a plentiful, renewable, and cost-effective feedstock for biochar production.

2. Materials and methods

2.1. Materials used

Corn stover (CS) containing stems, leaves, and cobs was obtained from a farm located near Farmington, IL, and dried to approximately 6% moisture content. Prior to pyrolysis treatment in the retort oven, it was processed through a Retsch mill and screened through a 10 mesh (2 mm) sieve, so there were many short fibers and the CS had a visual appearance similar to sawdust. CS for gasification was not milled because this would have made the material too dense for proper air flow through the gasifier. Pelletized wheat straw (WS) and pelletized wheat straw treated with glycerin (WS + G) were both provided by Hydrostraw LLC, Manteno, IL. The WS and WS + G pellets were the same size, cylindrical in shape and approximately 6 mm diameter by 8–10 mm long. These two feedstocks were used as-is in both pyrolysis and gasification biochar production methods.

2.2. Biochar production via pyrolysis

Approximately 100 g of feedstock was put in a ceramic pan and placed in an Across GCF Series Controlled Atmosphere Muffle Furnace (Across International, Berkeley Heights, NJ). The oven was sealed and evacuated to −10 psig and purged with nitrogen to 3 psig, and this step was repeated 5 times consecutively. The feedstock sample was then heated at 5 °C/min to a maximum temperature of either 400, 500, 600, or 700 °C, held at that temperature for 1 h, and then cooled back down to room temperature at a rate of 1 °C/min. During the entire temperature treatment the retort chamber pressure was maintained between 1 and 3 psig with a flow rate ranging from 300 mL/min to 600 mL/min of nitrogen. After cooling to room temperature, biochar samples were milled into a fine powder using a planetary ball mill and 3 mm diameter yttria-stabilized zirconia as the milling media at a 100:1 (wt media:wt biochar) ratio. Details of this milling method are described in a previous manuscript (Peterson, 2013).

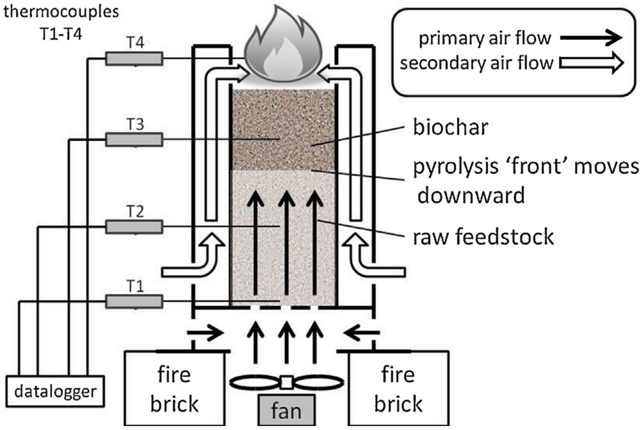

Fig. 1. Top-lit updraft microgasifier that was used to convert biomass feedstock into biochar. This apparatus consists of an inner cylinder that holds the feedstock and through which the primary air flows, and a surrounding air layer through which heated, secondary air flows to feed the combustion flame at the top. Thermocouples monitor the temperature as the pyrolysis front thermally converts the feedstock into biochar from the top down.

2.3. Biochar production via gasification

A top-lit updraft (TLUD) style gasification cookstove was obtained from Chip Energy (Goodfield, IL). A diagram of the cookstove in operation is shown in Fig. 1. CS was packed into the central cylinder as-is; WS and WS + G were both pelletized material that were loaded into the gasifier interspersed with porous lava rocks

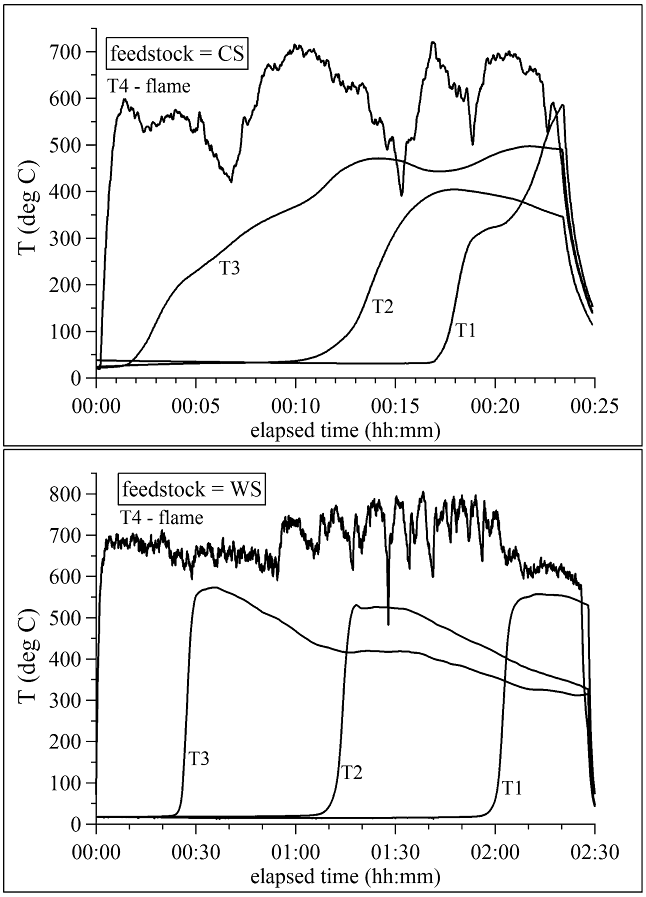

Fig. 2. Chronological temperature profile of CS and WS gasification runs. Note the significant difference in the *x*-axis of both plots. CS is gasified much more quickly than WS because it is loose and much less dense than the pelletized WS feedstock.