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Full Length Article

Application of air classification and formulation to manage feedstock cost, quality and availability for bioenergy

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HIGHLIGHTS

- Biomass varies in quality affecting yields and costs of conversion processes.
- Cost effective methods are needed to adjust quality prior to conversion.
- Air classification removes exogenous ash from biomass feedstocks.
- Light fractions of air classified biomass have application in biopower.
- Heavy fractions of air classified biomass are applicable to biochemical conversion.

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ABSTRACT

Biomass such as agricultural residues, energy crops and yard waste has significant potential to be used as renewable feedstocks for production of fuels, chemicals and energy. However, in a given location, biomass availability, cost and quality can vary markedly. Strategies to manage these traits must be identified and implemented so that consistent low-cost and high-quality feedstocks can be delivered to biorefineries year round. In this study, we examine air classification as a method to mitigate high ash concentrations in corn stover, switchgrass, and grass clippings. Formulation techniques were then used to produce blends that met ash quality and biomass quantity specifications at the lowest possible cost for biopower and biochemical conversion applications. It was found that air classification can separate the biomass into light fractions which contain concentrated amounts of elemental ash components introduced through soil contamination such as sodium, alumina, silica, iron and titania; and heavy fractions that are depleted in these components and have relatively lower total ash content. Light fractions of corn stover and grass clippings were found to be suitable for combustion applications since they had less propensity to slag than the whole biomass material. The remaining heavy fractions of corn stover or grass clippings could then be blended with switchgrass to produce blends that met the 5% total ash specifications suggested for biochemical conversions. However, ternary blends of the three feedstocks were not possible due to the high ash content of grass clippings. It was determined that air classification by itself was not suitable to prepare these feedstocks for pyrolysis due to high ash content.

1. Introduction

Renewable non-food lignocellulosic biomass such as agricultural residues, energy crops and yard wastes are important contributors to the more than one billion tons of biomass that could be sustainably available in the United States by 2030 [1,2]. To contribute significantly to U.S. energy independence, these feedstocks will need to be available at low cost, in large quantities, and be of consistent quality. Unfortunately, the composition and quality of these biomass sources can vary widely depending on weather patterns, agronomic practices, harvest methods and geographical location [3,4]. Current quality specifications applicable to many conversion processes include flowability (ability to feed to the reactor), particle size (reactivity), moisture (grinding, densification, transport and aerobic storage stability), convertible organics (yield potential) and cell wall structure (convertibility) [5]. However, composition and chemical differences in biomass can impact yield

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and convertibility in different ways among conversion processes depending upon chemistries and reaction conditions employed. Examples include ash content, ash composition, biocatalyst inhibitors such as acetate and soluble phenolics, and heteroatoms that foul or poison inorganic catalysts such as sulfur and phosphorus [6–8].

Biomass ash is comprised of ‘‘physiological ash”, derived from the plant tissue, and non-physiological ash or ‘‘exogenous ash,” from soil contamination during the harvest [9]. Physiological ash in corn stover is typically 5–6 wt%, while exogenous ash from multi-pass harvesting can exceed 20% [9]. Switchgrass tends to be lower in physiological ash because it utilizes water efficiently [10], and lower in exogenous ash because it is cut 10–15 cm above the ground for improved drying times and less introduction of soil during windrowing and baling [11]. Grass clippings, a common yard waste, have been shown to have high ash content [12]. For thermochemical conversions, ash content and composition are of concern due to slagging, fouling and corrosion (for biopower and gasification [8,13]), bio-oil yield decreases (for uncatalyzed fast pyrolysis [7]), and catalyst fouling (for catalyzed fast pyrolysis and gasification [7,8]). In biochemical conversions, the abrasive nature of the silica and alumina ash components leads to excessive equipment wear, and disposal of the non-convertible ash incurs costs [9].

Local feedstock depots [3,4] offer the opportunity to adjust feedstock quality before the feedstock reaches the biorefinery [14]. Air classification is a low-cost separation technology that could be used in a depot to alter feedstock quality. The technology takes advantage of differences in shape, size and density of particles to separate them into unique fractions [15], and has been demonstrated to concentrate and remove exogenous ash from chipped pine forest residues [16]. Herbaceous biomass is comprised of different tissue types, each having unique physical and chemical properties that lead to differences in particle density, shape and size when ground [17], and thus may be well suited for air classification. Differing physical and chemical properties of these fractions may increase their value in conversion pathways, and could make them useful feedstock blend ingredients to meet quality specifications.

Feedstock depots also have the ability to receive both high- and low-quality biomass which increases the quantity of total biomass available. Through formulation and blending, more biomass will be available at specification to biorefineries [14]. Feedstock formulation is already used in many market sectors including coal power generation, grain, animal feeds, and biopower where formulation is used to reduce costs and improve product quality [18–21]. For bioenergy applications, formulation and blending of different biomass types and/or fractions of biomass types obtained through preprocessing may be required if targets for quality and quantity are to be achieved cost effectively [14].

In this paper, we present the results of air classification of corn stover, switchgrass and grass clippings into high and low ash fractions. We then consider formulation and blending strategies to meet feedstock cost and quality specifications for three conversion technologies including biopower, biochemical conversion to ethanol, and uncatalyzed fast pyrolysis.

2. Materials and methods

2.1. Materials

Corn stover was harvested single-pass in Story County, Iowa in 2012. The bales were ground with a Vermeer BG480 grinder (Pella, Iowa) fitted with a 6-in. (152.4 mm) screen and then dried to approximately 8.3% moisture. Alamo switchgrass bales harvested 2012 in Garvin County, OK were size reduced with the Vermeer BG480 grinder fitted with a 2-in. screen (50.8 mm) and later ground through a Bliss Hammermill (Eliminator E4424; Ponca City, OK) fitted with a 1-in. screen. The samples were dried to approximately 10% moisture. Kentucky bluegrass clippings were collected in 2014 from Bonneville County, Idaho. These samples were stored at 4 °C and dried from approximately 60% to 10% moisture within 48 h. No size formatting was required for this material.

For each of the biomass sources, the ground and dried (corn stover and switchgrass) or dried (grass clippings) were thoroughly mixed and then successively split into representative 3–5 kg fractions using a custom eight-way rotary splitter. These samples were placed into indoor storage until utilized for air classification. Ash content and ash speciation analyses were completed by Huffman Laboratories (Golden, CO), as previously described [16].

2.2. Air classification

A 2× Air Cleaner (Key Technologies, Walla Walla, WA) equipped with an Iso-Flo dewatering infeed shaker set to 58 Hz was used for air classification. Fan speeds were selected to best separate the biomass feedstocks into anatomical or visually unique fractions. For corn stover, fan speeds were 7.5 Hz, 10 Hz, 15 Hz, 18 Hz and 28.5 Hz; with approximate air velocities of 73 m/min, 111 m/min, 186 m/min, 231 m/min, and 389 m/min, respectively. Fan speeds used for switchgrass and grass clippings were 7.5 Hz, 10 Hz and 15 Hz. For each separation, the fan was set to the lowest selected speed and the shaker table turned on. A bag (3–5 kg) of biomass was manually poured onto the infeed shaker table such that it was one layer thick as it passed over the classifier's air stream. The upward flow of air separated the sample into a light and heavy fraction. The fan speed was increased and the heavy fraction was fed through the air classifier to generate a new light and heavy fraction. This process was repeated until light fractions were collected for all fan speeds and the remaining heavy fraction was collected. During the experiment, smaller and denser particles fell through the blower screen and into the fan ducting. This fraction, referred to as the ‘‘below screen” or ‘‘BS” fraction, was collected from the ducting for each feedstock. This procedure was repeated in triplicate. A layer of fine, dark particles was observed in the 7.5 Hz light fraction and it was size fractionated through a #80 sieve (0.18 mm) to isolate this visually unique fraction. The fine fraction recovered through the sieve is referred to as ‘‘7.5 Hz sieved” in this paper and the fraction retained on the sieve is ‘‘7.5 Hz.” Collected fractions were analyzed for total ash and elemental ash (Huffman Laboratories; Golden, CO). This system is rated at 40 m^3/h, which at an assumed corn stover bulk density of 80 kg/m^3, gives a mass load of 3.4 tons/h. Because our goal was to determine how good a separation could be achieved at each fan speed, the heavy fraction was passed through the air stream repeatedly until no further fines were collected, and the final collected masses of lights and heavies were recorded. We operated well below rated mass load to obtain the best possible separation.

2.3. Feedstock formulation

Blends that meet ash specifications were developed using WinFeed 2.8 (www.winfeed.com). This software provides least cost formulation blends for animal feed where inputs include a database of animal feed ingredients, their composition, nutrients and the costs. The user specifies criteria such as nutrients, moisture, fiber and protein; and a linear programming algorithm produce blends that meet user specified constraints at the least cost. For this study, the database was altered to include corn stover, switchgrass and grass clippings, air classified fractions of these feedstocks, the ash and