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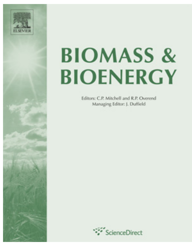

Continuous microwave drying of sweet sorghum bagasse biomass

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ARTICLE INFO

Article history:
Received 8 August 2014
Received in revised form
14 August 2014
Accepted 19 August 2014
Available online 8 September 2014

Keywords:
Sorghum bicolor (L.) topper
Microwave
Drying
Biofuel
Biomass
Energy analysis

ABSTRACT

Sweet sorghum (*Sorghum bicolor* (L.)) biomass has been touted as an important bioenergy crop that can be converted into various biofuels. In order to minimize storage losses, and to optimize the processing parameters during biochemical or thermochemical conversion, the sorghum bagasse obtained after pressing the sugar-containing juice may need to be dried to specific moisture levels. In this study, the performance of a continuous microwave drying system using a traveling wave applicator was investigated with respect to moisture reduction, power consumption, and overall efficiency. The parameters investigated were microwave power level (0, 200, 600, and 1000 W) and ambient drying temperature (25 °C and 55 °C). A control test was performed using hot air alone (25 °C and 55 °C) during sample drying. The initial moisture contents were obtained through conventional hot air oven drying at 130 °C. The drying rate of microwave drying was compared to conventional oven drying and the control. It was determined that even though the highest drying rates were obtained at the highest power setting (1000 W), when accounting for the power consumed by the drying system, including fans, motors, and ambient air heater, the highest efficiency was obtained at a comparatively low power setting (200 W) and using just ambient temperature (25 °C). The drying rate for microwave drying was significantly higher than conventional drying. The results of this study can be used to design continuous microwave drying systems that can be more efficient and with higher throughputs than conventional air-blown systems.

1. Introduction

Bioenergy is defined as a renewable form of energy derived from organic materials with lower emissions than traditional fossil fuels. However, despite many years of research into products produced from bio-based fuel sources, biomass energy still represents only a fraction of the energy produced and consumed in most industrialized countries [1,2]. For a long-term potential, alternative fuels must be produced from materials that are economically competitive with fossil fuels while minimizing impacts on agricultural food sources [3–5]. Estimates of non-food biomass availability indicate that more than 1.3 $\text{Pg}\cdot\text{y}^{-1}$ of lignocellulosic biomass, *i.e.* wood, forest

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http://dx.doi.org/10.1016/j.biombioe.2014.08.012
0961-9534/

residues, grasses, etc., [1], (or the equivalent of ~50% of annual oil consumption [6]) can be sustainably grown in the US. The potential of biofuels to fulfill a significant portion of the nation's transportation needs can be achieved only if high yields, non-food crops grown with minimal inputs are feasible to be harvested, transported, and converted [7] into infrastructure-compatible fuels, while assuring that these non-food crops are compatible with their ecosystem.

Sweet sorghum is considered one of the prime candidates for production of these bio-based fuels either via biochemical routes (ethanol via hydrolysis and fermentation, [8–13]) or thermochemically via pyrolysis [14], liquefaction [15], or gasification [16]. Traditionally, sorghum (*Sorghum bicolor* (L.) Topper) has been important in the human diet throughout the world and for forage in the United States [17]. It is commonly grown for grain, forage, syrup, and sugar while more recently it has been considered a potential source for biofuels [17,18]. Previous studies comparing various sugar crops have also indicated that sweet sorghum may have the best long range potential for ethanol production over sugarcane and beets as it can be grown over a much larger geographic region [17–19], including most of the continental United States [20]. It has high yields [21] not only for biomass (up to 35 $\mathrm{Mg \cdot ha^{-1}}$ [22]) but also for sugar (150 $\mathrm{kg \cdot m^{-3}}$ pressed juice [23]), it is more resistant than other tropical grasses (*i.e.* sugarcane [12,24–27]) to lower temperatures, heat and water stress [28,29], and it can be grown on a multitude of soils [30–32]. As such it can be grown in multiple parts of the United States [21,23], not being limited to the Deep South regions as sugarcane is. Moreover, its physical morphology is similar to sugarcane; thus, the sugarcane harvesting, transport, and processing infrastructure can be readily adapted to it [12,33,34].

After harvesting, the stalk material may be divided into three fractions: the stalk fraction, which contains most of the juice and sugar, the rind-leaf fraction or bagasse, which contains most of the fiber, and the seed heads that contain starch [18]. The juice and sugar may be directly fermented into ethanol [12] while the fiber may be converted biochemically into ethanol via pretreatment to liberate the cellulose and hemicellulose followed by hydrolysis and fermentation [8,10,29,35]. As this fibrous material is non-edible, it is the portion of the sorghum that is of particular interest for sustainable production of both ethanol and pyrolysis bio-oil. As processing efficiencies for the fermentation process are already fairly high, this study is focused on making the processing for lignocellulosic conversion more economical by improving process inefficiencies. One of the process inefficiencies relate to the very high moisture content of the bagasse fraction [36], which lead to a trifecta of negative outcomes: 1. Increase transportations costs; 2. Lead to biomass losses during long-term storage; and 3. Affect negatively thermochemical processes such as pyrolysis. Whereas a certain amount of water is desirable in pyrolysis, excessive moisture such as that present in the bagasse after milling (50% or more) may lead to formation of undesirable compounds that require the produced bio-oil to undergo extensive downstream processing prior to further utilization [37]. This drying can be performed using conventional heaters or via dielectric methods (radio frequency or microwave) which are more efficient especially at lower moisture contents [38,39].

Although a number of studies have been performed on the use of microwave energy for disinfestation or drying of sorghum grain or aiding in the germination rate of the grain [40–42], to our knowledge no studies have been conducted considering the drying characteristics or transport phenomena in microwave systems with regards to sorghum bagasse. There is also a limited amount of published data with respect to overall energy efficiencies of continuous microwave drying systems for biomass in general [43–46]. This study aims to close this knowledge gap by providing an understanding of the underlying mechanisms involved in continuous microwave drying of sweet sorghum bagasse, and by providing an engineering analysis of the energy consumption of the proposed drying system.

2. Materials and methods

2.1. *Sample preparation*

Sorghum (*Sorghum bicolor* (L.) Topper) biomass was collected from the Hill Farm Research Station in Homer, LA (32.74° N, 93.07 °W) at the Louisiana State University Agricultural Center in the Fall season of 2011. Leaves, roots and grains were immediately removed and the stalks were crushed in a roller press (Farrel Company, Ansonia, CT) three times to extract the juice. The duration between cutting and juice pressing did not exceed 2 h. The remaining fibers or bagasse were stored in sealed 7.57 L (2 gallon) bags at −20 °C in order to maintain moisture content following processing. Prior to testing the sorghum was removed from the freezer and allowed to return to room temperature for approximately 2 h (Fig. 1).

2.2. *Microwave drying*

An industrial microwave system (Industrial Microwave Systems, Morrisville, NC) with a traveling wave applicator composed of a 5.08 cm width polypropylene conveyor belt (Series 900, Intralox, LLC, Harahan, LA) running at the geometrical center along the axis of an aluminum waveguide

Fig. 1 – Processed sorghum bagasse with 1.6 cm diameter washer for size reference.