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Mechanical dewatering and water leaching pretreatment of fresh banagrass, guinea grass, energy cane, and sugar cane: Characterization of fuel properties and byproduct streams

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ABSTRACT

Tropical biomass feedstock candidates, banagrass (*Pennisetum purpureum* × *Pennisetum glaucum*), guinea grass (*Panicum maximum*), energy cane (*Saccharum spontaneum*), and sugar cane (*Saccharum officinarum* L.) (as reference) were harvested and processed using pressing and leaching techniques to improve fuel properties for thermochemical conversion. Test results are reported that summarize the impacts of treatment methods on fuel properties and provide detailed data on mass and element partitioning between process streams to inform system design. The processed fuels had lower ash contents, improved heating values, higher ash deformation temperatures, and higher volatile matter to fixed carbon ratios than the parent materials. The liquid streams generated by the process were characterized for chemical oxygen demand, sugar content, total solids, total suspended solids, and major and trace elements. At least 20% of the initial fuel dry matter was partitioned to the byproduct liquid streams as total solids under the combined influences of leaching and mechanical processing. Analytical results support the land application of liquids as a nutrient recycling option. Element partitioning between solid and liquid process streams was determined and material and element mass balances were performed. Chemical equilibrium calculations based on the elemental composition of the parent materials and processed fuels and steam gasification conditions predicted substantial reductions in concentrations of K, Cl, S, Na, and Mg in the product gas.

1. Introduction

Using biomass to produce fuels, power, and chemicals in biorefinery applications is of increasing importance in addressing issues of global warming and sustainability. Thermochemical conversion systems will play an important role in large scale implementation of biomass based systems either as a primary platform using biomass directly or as a secondary conversion system to handle residue streams from biochemical processes. Fuel properties of biomass vary depending upon their source and will dictate the degree of processing required for a targeted thermochemical conversion application.

In a typical plant, minerals or organo-minerals that support growth, development, and health, may include K, P, Ca, Mg, S, Na, Si, Fe, Ti, Al, and Cl as major elements, and Be, Mn, Cd, Cu, Zn, Pb, etc. as trace elements [1]. These elements, extracted by plants from soils, applied fertilizers, or persistent anthropogenic chemical compounds in the environment, may contribute to operating difficulties at thermochemical biomass conversion operating temperatures or impact downstream materials and equipment [2]. Alkali metals (Na and K), for example, which typically have higher concentration in biomass plants compared with coal [3], can react with other elements (S, Cl, Si, Ca, Mg, etc.) at elevated temperatures to cause ash deposition, fouling, or corrosion, and agglomeration in fluidized beds. Vapor phase alkali metals are limited to 50 to 100 ppb in fuel gas [4,5] to protect gas turbines [6,7]. A stricter tolerance, <10 ppb, is cited for both alkali metals and hydrogen chloride (HCl) in syngas supply for Fischer–Tropsch synthesis [8]. In addition, trace elements present in fuel gas have adverse effects on catalysts in fuel/chemical synthesis and solid oxide fuel cells (SOFC) [2]. Therefore, removing troublesome elements from biomass fuel should be given priority for fuel improvement [9].

Mechanical dewatering followed by water washing or leaching has been applied in lab scale tests for fuel improvement on banagrass (*Pennisetum purpureum* × *Pennisetum glaucum*) [9]. The process was demonstrated to be effective as a way to reduce ash content by removing a high percentage of water soluble minerals from solid parent material into liquid byproducts. The processed banagrass fuel has characteristics

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similar to sugarcane (*Saccharum officinarum* L.) bagasse, a common boiler fuel in sugar factories. Water washing/rinsing is also effective in processing other biomass crops or wastes, such as wheat and rice straw [10–14], corn stover [13,14], switch grass [13], wood waste [12,14], and olive-oil processing residue [15]. The processed fuels are reported to have better performance than the parent materials and to avoid rapid and undesirable ash deposition and/or agglomeration problems in bench-scale and lab-scale fluidized bed gasifiers and combustors [10,15–18]. The process generates some volume of liquid containing water soluble ions and organic matter (juice or pulp), which requires evaluation prior to recovery or disposal. Yu et al.'s [13] analyses of leachate samples found that inorganic and organic materials removed by the leaching process were as high as 4.6% and 15.4% of dry matter, respectively, and that biomass type played a role. Jenkins [19] studied rice straw leachate treatment by reverse osmosis and obtained a clear advantage for water recycling and brine reduction in disposal.

All experimental tests in this paper used freshly harvested material from four types of tropical herbaceous plants, namely banagrass (*P. purpureum* × *P. glaucum*), guinea grass (*Panicum maximum*), and energy cane (*Sacharum spontaneum*), as well as sugarcane (*S. officinarum* L.) as reference. A screw press was used to mechanically dewater the samples in a continuous mode. The fuel properties of the processed solids were evaluated, including proximate analysis, ultimate analysis, ash composition, and trace element analysis. Liquid byproducts were selectively analyzed for chemical oxygen demand (COD), sugar content, mineral nutrients, and trace elements to identify potential beneficial use options, suitability for direct land application, or treatment requirements. Element partitioning between solid and liquid process streams was determined and mass balances of material and element were performed. Based on the properties of processed fuel, chemical equilibrium calculation was conducted for steam gasification conditions to predict the concentration of gaseous elements of concern in gas stream.

2. Materials and methods

Materials and methods for the fuel processing experiments are described below.

2.1. Materials

Four types of tropical herbaceous plants, in total eight material lots, were used in the tests. The material lots included four banagrass, one guinea grass, two energy cane, and one sugarcane. Lot IDs and harvest information are presented in Table 1.

2.2. Fuel processing

As shown schematically in Fig. 1, freshly harvested plants were subjected to the following sequence of processing steps; shredding, initial juice removal, water rinsing, secondary juice/water removal, and drying.

Freshly harvested plant samples were reduced to ~6 mm particles by a shredder (Model VCS-8, Vincent Corporation, Tampa, FL, USA), and then expressed using a compact screw press (Model CP-4, Vincent Corporation, Tampa, FL, USA) for initial juice removal. The shredded parent material (S0) was pressed to generate a solid fuel sample (S1) and initial plant juice (L1). The S1 samples were loaded in a basket with walls made from 100 mesh screen and immersed in a barrel filled with enough tap water to submerge all of the material. Tap water was used to leach the solid (S1) at a water to solid mass ratio of ~6.0. Leaching and draining free leachate (L2) from the material were completed in ~5 min. Previous work found that longer contact times did not result in improved leaching efficiency [9]. Once drained of free leachate, the leached solid material (S2) was subjected to a second dewatering treatment with the screw press to produce the final solid fuel (S3) and a liquid stream (L3).

The screw press operated at a constant rpm and was equipped with a pneumatically loaded cone that applied pressure to the screw discharge. For each step, the screw press was operated with the same pressure applied to the screw discharge for both the initial and second pressing. As illustrated in Fig. 2, the pneumatic cylinder (1) pulls on a lever arm (2) that applies force to the back of the cone (3). Pressure in the pneumatic cylinder can be varied up to 550 kPa. In preliminary tests, a load cell (Model: SSM-AJ-500, Interface, Arizona, USA) was placed between the cylinder piston and the lever arm to measure the force during operation. The force applied to the back of the cone was calculated using the data from the load cell and the geometry of the linkage components. Load cell measurements were made for air cylinder pressures of 69, 138, 207, 276, 345, 414, 483, and 550 kPa. For the remainder of the tests, an air cylinder pressure of 207 kPa was used.

2.3. Sample analysis

The solid and liquid byproduct streams generated by the screw press and water rinse were collected and sampled. Solid samples were dried at 105 °C immediately, and liquid samples were stored in a refrigerator at 4 °C until analysis was conducted.

Both solid and liquid samples were analyzed to obtain information on elemental composition and distribution. In addition, fuel properties of solid samples were characterized using ASTM methods for ultimate (C, H, N, S, and Cl), proximate analyses (moisture, volatile matter (VM), fixed carbon (FC), and ash content), energy content (high heating value), ash composition (SiO_2, Al_2O_3, TiO_2, FeO_3, CaO, MgO, Na_2O, K_2O, P_2O_5, SO_3, Cl, and CO_2), and ash deformation temperatures in reducing and oxidizing atmospheres.

Trace elements present in the solid fuels were quantified by preparing ash samples at 600 °C, digesting the ash, and analyzing the resulting samples using an inductively coupled plasma equipped with an atomic emission spectrophotometer (ICP-AES).

Table 1
Summary of the test material samples in the study.

Biomass samples	Variety	Sample ID	Harvest date and location
Banagrass (*Pennisetum purpureum* × *Pennisetum glaucum*)	Green banagrass	Bana	February, 2010, University of Hawaii's Poamoho Research Station, in Waialua, Oahu, Hawaii
	Green banagrass	G-Bana	December, 2010, Waimanalo, Oahu, Hawaii
	Purple banagrass	P-Bana	December, 2010, Waimanalo, Oahu, Hawaii
	Purple banagrass	P-Bana (II)	September, 2013, Maui, Hawaii
Guinea grass (*Panicum maximum*)	Guinea grass	OG03	December, 2010, Waimanalo, Oahu, Hawaii
Energy cane (*Saccharum sponteneum*)	Energy cane	E-cane	April, 2013, Maui, Hawaii
	Energy cane (II)	E-cane (II)	September, 2013, Maui, Hawaii
Sugarcane (*Saccharum officinarum* L.)	Sugar cane	S-cane	September, 2013, Maui, Hawaii