



Energy densification of sugarcane leaves through torrefaction under minimized oxidative atmosphere

Angelique T. Conag, Jaye Earl R. Villahermosa, Luis K. Cabatingan *, Alchris W. Go *

Department of Chemical Engineering, University of San Carlos, Talamban, Cebu City 6000, Philippines



ARTICLE INFO

Article history:

Received 21 July 2017

Revised 28 November 2017

Accepted 28 November 2017

Available online xxxx

Keywords:

Energy densification

Combustion indices

Higher heating value

Sugarcane leaves

Torrefaction

ABSTRACT

Worldwide, the annual energy content of sugarcane leaves (SCL) amounts to 4.21 EJ. However, its direct use as a solid fuel is hindered by its inherent characteristics, such as its low bulk density, low energy density, and hygroscopic nature. These characteristics of SCL could be improved through torrefaction. However, in addition to these characteristics, combustion and flow characteristics, expressed in their respective indices, should also meet their desired values as they have direct influence in the later performance of boilers and furnaces. Torrefaction of SCL at various temperatures (250–350 °C) and times (0–75 min) under minimized oxidative atmosphere was investigated in this study to improve its characteristics as solid fuel. The torrefaction performance was not only assessed through the mass and energy yields, but also changes in the combustion and flow indices. Torrefaction at 300 °C & 45 min led to the increase in fixed carbon to as much as 21 g for every 100 g of raw SCL being torrefied, which originally contains 18 g of fixed carbon. Devolatilization during torrefaction not only involves the volatilization of the volatiles but also the formation of additional fixed carbon. The higher heating value (HHV) of SCL increased to as much as ~22 MJ/kg after the torrefaction. The resulting SCL torrefied at 300 °C for at least 45 min was found to be suitable for industrial and domestic applications having fuel ratio (FR), combustibility index (CI), volatile ignitability (VI), Hausner ratio (HR), and Carr compressibility index (CCI) falling within prescribed values of 0.5–2.0, 12–23 MJ/kg, >14 MJ/kg, <1.34, and <25, respectively.

© 2017 International Energy Initiative. Published by Elsevier Inc. All rights reserved.

Introduction

Sugarcane is the second most produced crop in the world after rice paddy with a total production of 1.88×10^9 tons in 2014 (Food and Agricultural Organization of the United Nations Statistics Division and FAOSTAT, 2014). During harvesting of sugarcane, its leaves and tops, which are undesirable during milling, are removed from the stalks. Collectively, sugarcane leaves and tops are referred to as sugarcane trash (SCT). For every ton of sugarcane harvested, about 140 to 180 kg of SCT is produced (Paes & M., 2005). In order to prepare the fields for the next cropping season, sugarcane leaves and tops left on the field are usually burned. Pre-harvest burning is commonly practiced by sugarcane farmers to remove the leaves prior to harvesting. However, this is discouraged to avoid deterioration of the available sugars (Mendoza, 2015). Both pre-harvest and post-harvest burning of SCT are highly discouraged since these pose several environmental

problems and violate various environmental laws. During burning of SCT, carbon dioxide (CO₂) and other greenhouse gases (GHGs) are released to the atmosphere.

Based on the sugarcane production in 2014, ~264 million tons of SCT, with an HHV of 15–17 MJ/kg, the total amount of energy which could have been recovered would sum up to as much as 4.21 EJ of energy when burned. Sugarcane trash is mainly comprised of approximately 97% sugarcane leaves (SCL) or straw (Hassuani, Leal, & de Carvalho Macedo, 2005). This amount of energy can be recovered when SCL is utilized as a solid biofuel. However, the direct utilization of SCL as solid fuel is hindered by its regular availability and physico-chemical characteristics. Although sugarcane is produced in large quantities, it is, however, a seasonal crop, with its harvesting only done from the months of November to April. Its low bulk density and high moisture content pose a problem in its transport and storage. Moreover, when tapped as an energy source, its utilization would best be distributed so to have a constant and stable supply of energy. The storage of SCL may potentially be hindered by its high moisture content (13.5 to 70%) (Hassuani et al., 2005) and hygroscopic nature. These characteristics of sugarcane residues make it susceptible to biological degradation through microbial activities during storage and results in poor burning characteristics when used as solid fuel. In addition, the high moisture content of SCL leads to a low heating value and would require an energy-intensive drying step, resulting in a low energy conversion

Abbreviations: SCL, sugarcane leaves; TSCL, torrefied sugarcane leaves; HHV, higher heating value; FR, fuel ratio; VI, volatile ignitability; CI, combustibility index; HR, Hausner ratio; CCI, Carr compressibility index; M, moisture; VM, volatile matter; FC, fixed carbon; db, dry basis.

* Corresponding authors.

E-mail addresses: lkcabatingan@usc.edu.ph (L.K. Cabatingan), awgo@usc.edu.ph (A.W. Go).

efficiency. Moreover, the direct use of wet SCL increases the risk of corrosion in combustion systems owing to the wet flue gas produced during combustion (Bach & Skreiberg, 2016). Although moisture in SCL could be addressed through various strategies including sun drying and/or thermal drying with the aid of waste heat, liberated gas during pyrolysis and/or supplemented with excess low-grade biomass (Kiel, Janssen, & Joshi, 2015), these strategies would not prevent the later reabsorption of moisture during storage (Pimchuai, Dutta, & Basu, 2010; Supramono, Devina, & Tristantini, 2015). The capability of biomass, like that of SCL, to reabsorb moisture is attributed to the presence of hydroxyl groups in its chemical structure which forms hydrogen bonds with water. The capacity of the biomass to reabsorb moisture is minimized through the elimination of the hydroxyl groups and the formation of unsaturated structures which can be achieved through a thermochemical treatment referred to as torrefaction (Bergman, Boersma, RWR, & JHA, 2005). These problems are not unique to SCL but are common among agricultural biomass tapped for energy production. Torrefaction, a thermal pre-treatment process, has been found to improve not only the hydrophobicity but as well as the combustion characteristics of the torrefied biomass in view of its use as fuel.

Coal is the most widely used solid fuel in power generation systems, thus related combustion systems have been designed to operate based on the ignition and combustion characteristics of coal. Considering that the use of agricultural residues, like that of SCL, as a replacement for coal, it would be best that their fuel characteristics are similar so not to jeopardize the performance of the combustion system. Industrially used coal typically has a fuel ratio (FR) ranging from 0.5 to 2.0 (Makino & Tanno, 2015; Ohm, Chae, Kim, & Oh, 2015). Presence of high volatile matter (VM) content results in low FR and a fuel which is prone to either emit high amounts of smoke or a fuel which rapidly burns, posing a challenge in controlling the ignition flame. High FR as a result of low VM is also not desired as it would entail difficulties in ignition and flame stability (Engineering Foundation (U.S.), Conference (1993: Solihull et al., 1994). In view of volatile ignitability (VI), this measure estimates the gross calorific value of the total volatiles (volatile matter and moisture) in the solid, considering that fixed carbon (FC) is solely made up of carbon atoms. This measure is determined to be >14 MJ/kg for most coals used (Asthana, 2015; Magasiner, van Alphen, Inkson, & Misplon, 2001). Combustibility index (CI) on the other hand, is a measure considered when mixing solid fuel alternatives for co-firing with coal, which is found to range from 12 to 23 MJ/kg for applications in coal fired power plant (Ohm et al., 2015). Apart from combustion indices, its flow characteristics as described by Hausner ratio (HR) or Carr compressibility index (CCI) should be <1.34 and 25, respectively, for use in fluidized bed combustion systems (Tannous, Lam, Sokhansanj, & Grace, 2013).

In view of SCL, torrefaction studies have been limited. Although its use has been recognized by researchers (Soponpongipat, Sittikul, & Sae-Ueng, 2015), detailed investigation on its torrefaction behavior has not been looked into. A study by Soponpongipat et al. (Soponpongipat et al., 2015) reported the improvement in HHV of sugarcane leaves from 17.9 to 21.7 MJ/kg after torrefaction at 280 °C for 60 min. However, the effects of time and temperature on the fuel characteristics were not investigated in detail. Moreover, the mass yield and energy recovery after torrefaction of SCL were not looked into. These are important measures needed in the later assessment of the process feasibility and practical application.

In this study, the effects of time and temperature of the torrefaction of SCL under minimized oxidative conditions were investigated in relation to mass and energy yields of the process. Moreover, in this study, a possible mechanism and kinetics to describe the torrefaction process of sugarcane leaves is also proposed. Furthermore, the hydrophobicity of torrefied SCL was also assessed by looking into the equilibrium moisture reabsorption. Related fuel quality indices (FR, CI, and VI) and the bulk density of the torrefied

SCL were also determined to assess its potential use for domestic and industrial applications.

Material and methods

Sugarcane leaves from sugarcane (*Saccharum officinarum* x *Saccharum spontaneum*) were obtained from the fields of Bogo, Cebu during the month of September 2016 before the harvesting season. Collected SCL samples were determined of its initial moisture content as received and dried in an oven at 60 °C for 3 to 4 days or until the moisture content is $7.05 \pm 1.07\%$ w/w (dry basis). Dried SCL were milled using a Wiley mill (Thomas-Wiley Model 4, New Jersey, USA) with a 2 mm mesh aperture screen. This was done to have samples of uniform particle distribution ($d = 0.55 \pm 0.01 \mu\text{m}$) for later torrefaction experiments. Milled dry-leaves were then stored in polypropylene containers at room temperature for subsequent characterization and torrefaction experiments. Locally produced coconut shell charcoal briquette (Charcoal A) and wood charcoal (Charcoal B) were also acquired for comparison.

Bulk density and compressibility index

Adopting the procedures described by Tannous et al. (Tannous et al., 2013), around 1–2 g of biomass samples were introduced using a funnel to a pre-weighed dry graduated cylinder (10 mL or $10 \times 10^{-3} \text{ dm}^3$) without compacting. The loose volume was read off directly from the cylinder. The graduated cylinder containing the sample was then weighed to the nearest 0.1 mg. The loose (untapped) bulk density (ρ_{Lb}) was calculated using Eq. (1):

$$\text{Loose Bulk Density, } \rho_{\text{Lb}} \left(\text{g/mL or } 10^{-3} \text{ kg/m}^3 \right) = \frac{m_{\text{gs}} - m_{\text{g}}}{V_{\text{L}}} \quad (1)$$

where m_{g} is the mass of the empty dry graduated cylinder, m_{gs} is the mass of the graduated cylinder containing the sample and V_{L} is the loose (untapped) volume. For the tapped bulk density, the graduated cylinder containing the sample was tapped at least 300 times or until a constant volume reading was achieved. The tapped bulk density (ρ_{Tb}) was calculated using Eq. (2):

$$\text{Tapped Bulk Density, } \rho_{\text{Tb}} \left(\text{g/mL or } 10^{-3} \text{ kg/m}^3 \right) = \frac{m_{\text{gs}} - m_{\text{g}}}{V_{\text{T}}} \quad (2)$$

where V_{T} is the tapped volume. The Hausner Ratio (HR) was calculated using Eq. (3) while the Carr Compressibility Index (CCI) was calculated using Eq. (4).

$$\text{Hausner Ratio, } HR = \frac{\rho_{\text{Tb}}}{\rho_{\text{Lb}}} \quad (3)$$

$$\text{Carr Compressibility Index, } CCI (\%) = \left(1 - \frac{\rho_{\text{Lb}}}{\rho_{\text{Tb}}} \right) \times 100 \quad (4)$$

Proximate analysis

Proximate analysis was carried out according to the procedures described by the American Society for Testing and Materials (ASTM), method D1762–84 (ASTM International, 2013) for chemical analysis of wood charcoal. About 2 g of raw or 1 g of torrefied sample (weighed to the nearest 0.1 mg) was weighed into a pre-fired and pre-weighed porcelain crucible and was placed in an oven at 105 °C for 2 h. The crucible containing the dried sample was then transferred into a desiccator and allowed to cool for an hour before weighing. The above drying procedure was repeated until the decrease in weight of consecutive weighing was 0.0005 g or less. Moisture content (M) of the sample was calculated using Eq. (5).

$$\% \text{ Moisture, } M (\% \text{ w/w}) = \frac{m_{\text{s}} - (m_{\text{cs}, 105^\circ \text{C}} - m_{\text{c}})}{m_{\text{s}}} \times 100 \quad (5)$$

Download English Version:

<https://daneshyari.com/en/article/7453715>

Download Persian Version:

<https://daneshyari.com/article/7453715>

[Daneshyari.com](https://daneshyari.com)