Fuel Processing Technology 129 (2015) 168–173

Contents lists available at ScienceDirect

Fuel Processing Technology

journal homepage: www.elsevier.com/locate/fuproc

Effects of thermal treatment on energy density and hardness of torrefied wood pellets

Jianghong Peng [a], Jingsong Wang [a,b], Xiaotao T. Bi [a,*], C. Jim Lim [a], Shahab Sokhansanj [a,c], Hanchao Peng [a,d], Dening Jia [a]

[a] Clean Energy Research Centre and Department of Chemical & Biological Engineering, University of British Columbia, Vancouver V6T 1Z3, Canada
[b] School of Metallurgical and Ecological Engineering, University of Science and Technology Beijing, Beijing 100083, PR China
[c] Environmental Science Division, Oak Ridge National Laboratory, P. O. Box 2008, Oak Ridge, TN 37831-6422, United States
[d] Department of Mineral Engineering, University of Toronto, Toronto M5S3E3, Canada

ARTICLE INFO

Article history:
Received 22 October 2013
Received in revised form 1 September 2014
Accepted 5 September 2014
Available online 27 September 2014

Keywords:
Pellets
Torrefaction
Effect
Quality

ABSTRACT

Three types of wood pellets samples, including two types of commercial pellets and one type of lab-made control pellets were torrefied in a fixed bed unit to study the effect of thermal pretreatment on the quality of wood pellets. The quality of wood pellets was mainly characterized by the pellet density, bulk density, higher heating value, Meyer hardness, saturated moisture uptake, volumetric energy density, and energy yield. Results showed that torrefaction significantly decreased the pellet density, hardness, volumetric energy density, and energy yield. The higher heating value increased and the saturated moisture content decreased after torrefaction. In view of the lower density, lower hardness, lower volumetric energy density, and energy yield of torrefied pellets, it is recommended that biomass should be torrefied and then compressed to make strong pellets of high hydrophobicity and volumetric energy density.

1. Introduction

In view of the low energy density, off-gassing, self-heating, poor water-resistance associated with the transportation, storage, and handling of regular wood pellets, thermal pretreatment by torrefaction has been considered as a promising method to make stable wood pellets of higher energy density and hydrophobicity [1–4]. There are at least two pathways to make torrefied pellets: torrefaction followed by densification or densification followed by torrefaction. In the torrefaction–densification process, wood is first torrefied and then followed by grinding, if needed, and densification of torrefied powders into pellets. However, recent researches indicated that torrefied sawdust was more difficult to be compressed into reasonably strong pellets under the same densification conditions as was used to make regular wood pellets [2,5–10]. The die temperature has to be increased to a higher value ranging from 170 to 230 °C (compared to 70–110 °C for regular pellet compression) or the torrefied sawdust has to be pre-conditioned to a moisture content of around 10% to make dense torrefied pellets, at the expense of increased mechanical energy consumption [8]. To overcome these difficulties in compressing torrefied sawdust into pellets, the densification–torrefaction procedure has also been explored for making torrefied pellets by thermally treating regular wood pellets [11], a method which has been widely practiced in the making of biochar briquettes. The mechanical energy consumption associated with compression of torrefied sawdust into pellets is expected to be reduced, but the pellet density, durability and volumetric energy density may become lower than those made from the torrefaction–densification approach. So far, there has been limited information and no systematic research reported in the literature on the performance of torrefied pellets prepared following the densification–torrefaction pathway. In view of the low weight loss of 20–30% in torrefaction process, compared to more than 60% weight loss in the carbonization process for biochar production, it is important to investigate whether a high quality of torrefied wood pellets can be produced from the thermal treatment of regular wood pellets.

In the present work, two types of commercial wood pellets and one type of control pellets prepared in a laboratory single-die pelleting unit were thermally treated in a fixed bed unit under the torrefaction conditions. Density, heating value, hardness, saturated moisture content, volumetric energy density, and energy yield of those torrefied pellets were then determined. The densification–torrefaction procedure was further evaluated by comparison with the quality of torrefied pellets made from densification of torrefied sawdust.

2. Experimental

2.1. Samples preparation

White commercial wood pellets from Premium Pellets Ltd., brown commercial wood pellets from Shell Premium Pellets, and pine

* Corresponding author. Tel.: +1 604 822 4408; fax: +1 604 822 6003.
E-mail address: xbi@chbe.ubc.ca (X.T. Bi).

http://dx.doi.org/10.1016/j.fuproc.2014.09.010
0378-3820/

woodchips from FPInnovation were used in the present work. Pine woodchips were crushed in a hammer mill (Glenmills Inc., U.S.A.; Model: 10HMBL) installed with a 3.18 mm size screen to prepare sawdust. A press machine (Measurement Technology Inc., U.S.A.; Model: MTI 50 K) was used for compressing pine sawdust into control wood pellets. For making control wood pellets, the die temperature was maintained at 70 °C with 125 MPa compression pressure and 1 min holding time, and the maximum pressure was set at 156 MPa [8].

Table 1 shows the properties of three wood pellet samples. The single pellet density was calculated from the measured mass and volume of each wood pellet, averaged over 50 pellets. A 1000 ml glass cylinder was used to measure the bulk density of wood pellets. The moisture content was determined by drying the sample at 105 °C for 24 h inside an oven (Thermo Electron Corporation, U.S.A.; Model: THELCO laboratory PRECISION). The higher heating value (HHV) was measured by a bomb calorimeter (Parr Instrument Company, U.S.A.; Model: 6100 Compensated Calorimeter). The volatile matter, fixed carbon, and ash content were measured by a thermogravimetry analyzer (Shimadzu, Japan; Model: TGA-50). The elemental composition was determined by an elemental analyzer (Fisons, Germany; Model: EA 1108) in the Department of Chemistry at the University of British Columbia. The chemical composition of control wood pellets was measured by FPInnovations using a high-performance liquid chromatography (Dionex Corporation, USA; Model: ICS-3000 Ion Chromatography System) following the ASTM E1758-01 procedure [12]. The chemical composition of two commercial wood pellets was measured by the University of Science and Technology Beijing using a liquid chromatography (Shimadzu, Japan; Model: LC-20AT) following the ASTM E1758-01 procedure. From Table 1, it can be seen that the properties of both the control wood pellets and the white commercial wood pellets were very similar. The HHV and the ash content of the brown commercial wood pellets were slightly higher than the white commercial wood pellets and the control wood pellets because of the high bark content in the raw material of the brown commercial wood pellets.

2.2. Pellet torrefaction

A bench-scale fixed-bed tubular reactor unit was used for the torrefaction (thermal treatment) of three wood pellet samples. The tubular reactor has an inside diameter of 27 mm and is 575 mm in length, located inside an electrically heated furnace. The unit also includes an electrical gas heater with a temperature controller and a power supply (booster) to preheat the nitrogen gas, a cooler and a condensate receiver to remove tar, and a computer for acquiring temperature data [8]. In the present work, five pellets were placed into the tubular reactor and held by a pellet holder.

Table 1
Properties of three wood pellet samples.

	White commercial wood pellets	Brown commercial wood pellets	Control wood pellets
Diameter, mm	6.4	6.0	6.5
Length, mm	16.5	20.2	15.8
Single pellet density, kg/m^3	1190	1230	1150
Bulk density, kg/m^3	650	680	630
Moisture content, %wt	8.9	6.7	9.5
Higher heating value, MJ/kg	18.5	18.9	18.8
Proximate analysis			
Volatile, %wt	82.8	80.9	82.8
Fixed carbon, %wt	16.9	18.4	16.8
Ash, %wt	0.3	0.7	0.4
Elemental analysis, %wt			
C	50.3	50.9	50.7
H	6.2	6.0	5.9
O (by difference)	43.2	42.4	43.0
N	<0.1	<0.1	<0.1
Chemical composition			
Cellulose, %wt	29.1	28.9	36.7
Hemicelluloses, %wt	34.4	29.0	26.3
Lignin, %wt	26.6	27.5	33.6
Extractives, %wt	9.6	13.9	3.0

The optimal torrefaction conditions were found to correspond to a weight loss of around 30% at the reaction temperature, ranging from 250 to 350 °C for a treatment time of 30–60 min [1,4]. Based on our previous studies of the torrefaction kinetics [13], two parameters, temperature and residence time, were selected for investigation. The residence time is defined as the torrefaction reaction time, excluding the time required for pre-heating the sample from room temperature to target temperature. For the two commercial wood pellet samples, the temperature was chosen to be 270, 280, 290, 300, 310, 320, 450 °C with the residence time of 30 min. More torrefaction conditions were tested for the control pellets, with a residence time of both 30 min and 52 min. For each sample, at least two replicates were tested for each torrefaction condition.

The weight loss (WL, %wt) was determined by measuring the pellet mass (M_o) before torrefaction, the residue mass (M_t) after torrefaction, and the moisture content (MC, %wt) of the untreated wood pellets based on the following equation:

$$WL = 100 \times \left[1 - \frac{M_t}{M_o} \times (1 + MC)\right]. \quad (1)$$

2.3. Meyer hardness measurement

The Meyer hardness of wood pellets was also measured by the MTI 50 K press machine. The Meyer hardness (H_M) was applied to characterize the durability of alfalfa cubes with a flat surface [14]. Peng et al. modified the Meyer hardness for wood pellets that laid horizontally on a flat surface [9]. With a 6.35 mm hemispherical probe on the MTI 50 K press machine vertically moving downward at a speed of 1 mm/min, both the force and displacement of the probe were recorded by the MTI 50 K press machine control system. The equation for calculating H_M for a hemispherical probe and a cylindrical pellet was given below:

$$H_M = \frac{F}{\pi\sqrt{Dh - h^2}\sqrt{\frac{D_p^2}{4} - \left[\frac{\frac{D_p^2}{2} + \frac{D \cdot D_p}{2} - D \cdot h - D_P \cdot h + h^2}{D + D_p - 2h}\right]^2}} \quad (2)$$

where, F is the maximum force to break the pellet in N, D is the probe diameter in mm, h is the indentation depth corresponding to the piston displacement before the pellet breakage in mm, and D_p is the pellet diameter in mm.

2.4. Moisture uptake measurement

A humidity chamber (ESPEC CORP, Japan; Model: LHU-113) was used for the measurement of the saturated moisture content of pellets. Before the moisture uptake tests, wood pellets were dried in the THELCO laboratory PRECISION oven at 105 °C for 24 h. Then, wood pellets were placed in a Petri glass dish and put into the humidity chamber. During the weight measurement, the Petri dish was covered with a glass cap to reduce the moisture loss. For the saturated moisture content, wood pellets were placed in the chamber at 30 °C and 90% relative humidity for at least 48 h [8].

3. Results and discussion

3.1. Pellet torrefaction

Fig. 1 shows the three torrefied wood pellet samples made from the torrefaction of regular wood pellets. As the torrefaction temperature