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Research paper

Pressurized hot water treatment of sugar maple and yellow birch wood particles for high quality fuel pellet production

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ABSTRACT

This study was conducted with the aim of converting low quality hardwoods into high quality fuel pellets by using hot water as a pretreatment method. Hardwood particles from sugar maple and yellow birch trees were first pretreated with hot water at 150 °C, 175 °C and 200 °C for 30 min in a batch reactor. The solid fractions following hot water treatment were then compacted into pellets using a single pelletizer. The produced pellets exhibited a number of enhanced properties as compared to those obtained from untreated wood particles. The increases in density and energy content of pellets reached approximately 30% and 40%, respectively. Compressive strength was increased by three times or more. Results also indicated that pellets of high water resistance were obtained using material treated with hot water at a temperature of about 200 °C for both sugar maple and yellow birch wood. In addition, considerable reduction in friction in the die was observed when treated wood particles were used.

1. Introduction

Wood pellets used for the production of heat and power are standardized and traded at both national and international levels [1–3]. The global wood pellet consumption currently is around 25 million metric tonnes [4], and forecasts show a rise between 50 and 80 million tonnes by 2020 [5]. In 2014, 28 countries of the European Union (EU) produced 13.3 million tonnes and imported about 6.5 million tonnes of wood pellets for their domestic needs [4]. The largest wood pellet exporters to the EU are the USA and Canada. As part of this, Canadian wood pellet exports reached 1.6 million tonnes in 2014 and represented 84% of total wood pellet production in Canada [4]. Demand for wood pellets in the EU has been driven by policies to reduce emissions of greenhouse gases and increase the use of renewable energy. The technical reasons explaining such a strong and dynamic development of the global wood pellet market in recent years, both in terms of production and consumption, includes the advantages of using wood pellets such as environmental benefits, high energy content, and relative convenience of transportation and storage. Furthermore, solid biofuel combustion technology has been developed resulting in much cleaner and efficient combustion [6]. Solid biofuel in the form of pellets, could thus become a more important energy commodity in the near future [7] and [8].

The need to improve the quality of the fuel pellets has become increasingly important [9,10]. The current major challenges in the development of high quality commercial wood pellets are the improvement of mechanical durability and the reduction of hygroscopicity [1,11]. The affinity of wood pellets to water is a serious concern [12,13], especially when one considers that exported wood pellets can travel long distances across oceans [12]. Therefore, minimizing the break-up of pellets upon moisture adsorption and improving their mechanical strength are as important as increasing their energy content.

Research has been conducted worldwide to develop new technologies for the generation of high quality biofuels from renewable resources [14–16]. In the literature, a number of studies were performed with the purpose of improving the mechanical durability and water resistance of fuel pellets. A recent research by Craven et al. [13] reported that the reduction of moisture absorption of wood pellets could be obtained by adding a coating layer of hydrophobic substances (paraffin oil, mineral oil and linseed oil). These authors also reported that the treatment of wood pellets with oil did not change the initial pellet strength and it may have the drawbacks of oil treatments such as the risks of contamination to both humans and environment. Other studies reported that hydrothermal treatment and torrefaction are two promising pretreatments that can be employed for converting biomass into solid

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biofuels [9,10,17].

Torrefaction, a thermal treatment process performed within a temperature range from 200 °C to 300 °C in an inert atmosphere has been reported as a potential approach to upgrade many fuel properties of both torrefied wood material and its densified pellets. More specifically, several properties of wood change following torrefaction. As the wood becomes more fragile, it is easier to grind, its heating value increases, moisture absorption is reduced and dimensional stability is improved. The main drawbacks of torrefaction include its negative impact on density and mechanical durability of wood pellets [18–21].

Hydrothermal treatment, also known as hot water extraction or hot water treatment (HWT) is an important step in the pretreatment of woody biomass and in wood-based products manufacturing. The solid fraction after HWT process has a higher energy content, higher dimensional stability, higher compressibility and lower springback, higher resistance to biodegradation, and lower pollutant emissions during combustion [22–27]. Moreover, the hydrophobicity of wood material was remarkably improved after HWT [28,29], which implies that water can be removed more easily from the material using mechanical processes such as pressing, centrifugation and filtration compared to untreated material [30]. Therefore, hot water treated woody biomass could be used as a bio-derived material and fuel [10,14,23,30,31]. In addition, the HWT process could be used to extract valuable chemicals from the biomass which can be converted into high-value products [14,32].

The objectives of this study were (i) to investigate the effect of hot water treatment parameters on the physical and chemical characteristics of treated material, and (ii) to determine the hot water treatment and pelletization conditions required to improve pelletization performance and quality of pellets with a focus on reducing the ash content and improving the main fuel properties (e.g. energy content, water resistance and mechanical durability) of the fuel pellets.

2. Experimental

2.1. Raw material

The experiments were performed using the material from six sugar maple (*Acer saccharum* Marsh.) trees and six yellow birch (*Betula alleghaniensis* Britton) trees (three vigorous trees and three moribund trees of each species). Trees were sampled in July 2010 in two degraded hardwood stands composed mainly of sugar maple and yellow birch. The two stands were located in the vicinity of Mont-Laurier, Québec, Canada (46°39′40″N, 75°36′30″W and 46°39′05″N, 75°36′25″W). Sample trees were classified according to the tree vigor (MSCR) classification system proposed by Boulet [33] and described as follows: trees of reserve stock (class R) are those free of any symptoms of disease or damage and are considered as vigorous/healthy trees with the highest probability of survival; and moribund trees (class M) show signs of either lethal pathological infection or severe damage with high risk of trunk breakage. Moribund trees are biologically declining and are assumed to have a high probability of mortality before the next scheduled harvest.

Various types of equipment were used to convert the sample logs into wood particles with suitable size for pellets production. A band saw was used to convert the logs into sticks. Then, a chipper was used to convert the sticks into wood chips, which were air-dried in layers of about 50 mm thick to a moisture content of about 15% (dry basis). After air seasoning, the wood chips were fragmented with a hammer mill and finally processed into a Pallmann ring refiner (Type PSKM 8, Ludwig Pallmann K.G., Zweibrücken, Germany) for final size reduction.

2.2. Hot water extraction process

Dried wood particles were subjected to HWT using a 2-L batch reactor (Model 4522, Parr Instrument Company, Moline, Illinois, USA) controlled by a 4842 Parr temperature controller. The HWT process was performed at three controlled temperature levels of 150 °C, 175 °C, and 200 °C for 30 min under its self-generated pressures. In each treatment, an amount of 250 g dried wood particles (size of 0.5–1.0 mm mesh) and 1000 ml deionized water (the equivalent ratio of 4:1 w/w) was loaded into the reactor. The reactor was heated up and maintained at the desired temperature for 30 min. Self-generated pressure values of about 0.47 MPa, 0.89 MPa, and 1.55 MPa were observed corresponding to the set temperatures of 150 °C, 175 °C, and 200 °C, respectively. The reactor was cooled rapidly by immersing it in a cold water bath. The gas was released to the atmosphere. The liquid fractions were filtered from the solids and collected for further analysis. The solid fractions were then washed thoroughly with deionized water and exposed to ambient conditions for air drying. The air dried wood particles were packaged and stored for further analyses.

2.2.1. Total dissolved solids and pH value

The amount of residue remaining from a filtered liquor sample after drying the sample at 105 °C to constant weight is defined as total dissolved solids [34]. In the present study, the total dissolved solid content (TDS) was calculated from Equation (1).

$$TDS\ (\%) = \frac{W_t - W_d}{W_l} \times 100 \quad (1)$$

where Wt is the total weight of dish and extraction liquor after drying at 105 °C to constant weight; Wd is the weight of the dish, Wl is the weight of the extraction liquor sample before drying.

The pH of the HWT liquor sample was measured after cooling to room temperature using a pH meter (Accumet AB15 Basic, Fisher Scientific, Singapore). The pH of wood particles extracts in natural state was also determined from liquor samples obtained from the same amount of material as used for HWT except that wood particles were soaked in water for 30 min at room temperature (23 °C). All the experiments were performed in duplicate, with average values reported.

2.2.2. Higher heating value and ash content

The higher heating value (HHV) represents the absolute value of the specific energy of combustion per unit mass of a solid biofuel burned in oxygen in a calorimetric bomb under specified conditions. In the present study, the HHV and ash content were determined according to CEN/TS 14918 standard [35] and ASTM D1102-84 standard [36], respectively. The HHV based on the oven-dry weight of the sample, was calculated from Equation (2).

$$HHV_d = HHV_w \times \frac{100}{(100 - MC)} \quad (2)$$

where HHV_d is the higher heating value at constant volume of the anhydrous fuel, in MJ kg^{-1}; HHV_w is the higher heating value at constant volume of the fuel as received, in MJ kg^{-1}; and MC is moisture content of the sample (as percentage by mass on an air-dried basis).