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Sawdust as an effective binder for making torrefied pellets

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HIGHLIGHTS

- Torrefied pine sawdust was produced in a fixed bed reactor.
- Torrefied sawdust was made into strong pellets with raw sawdust binder.
- Torrefied pellets had high density, hardness and energy density, and low moisture uptake rate.
- Raw sawdust was a low-cost and effective binder for making torrefied pellets.

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ABSTRACT

In this study, torrefied sawdust produced from pine sawdust in a fixed bed reactor was mixed with different binders in a ratio of 5–30 wt.%, and then compressed into pellets in a single die press to explore the feasibility of making torrefied pellets from torrefied powders. The quality of torrefied pellets was examined based on pellet density, higher heating value, hardness, saturated moisture uptake, and energy density. Results showed that torrefied sawdust particles prepared under typical torrefaction conditions (280–300 °C for 10–30 min) could be made into strong pellets by compression at a die temperature higher than 220 °C or by introducing biomass binders such as untreated sawdust, starch or lignin at a lower die temperature. The pellets density and bulk density made at a low die temperature with binders were slightly lower than those made at a die temperature of 220 °C or higher without the binder, and the energy density of torrefied pellets was similar to the control pellets made from untreated sawdust. Since the raw sawdust is abundantly available and much cheaper than lignin and starch, it is recommended as a low-cost and effective binder for densifying torrefied sawdust into torrefied pellets.

1. Introduction

Biochar is a kind of charcoal produced at moderate to high temperatures from forest residues, agricultural residues, or organic wastes via torrefaction, pyrolysis or gasification. Biochar has many advantages such as high heating value, slow degradation, and low greenhouse gas emissions [1]. One major disadvantage of biochar is its low volumetric energy density, which increases the transportation cost that limits its final uses. Other problems are fines and dust generated during handling and transportation that may potentially cause fires and explosions. Densification (also called pelletization) of biochar powders into pellets/briquettes may solve those problems.

To densify biochar powders, a mechanical force is applied to compact particles into pellets. Rumpf and Knepper [2] classified the densification mechanism of particles into five major categories: attraction forces between solid particles, interfacial forces and capillary pressure to move liquid such as water onto surfaces, adhesion and cohesion forces between particles, formation of solid bridges, and mechanical interlocking to form closed bonds. Binders that contained in the particles play an important role in the densification process [2]. During densification, the natural adhesion forces particles to contact closely, the mechanical load makes particles inter-locked, followed by the development of solid bridges via solidification of glass transition components in particles by heating and compression [2–5]. Lignin is the most

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important natural binder in biomass. The solidification of softened or melted lignin during densification can lead to the development of solid bridges, which interlock between particles. Other binders that contained in particles include water, starch, protein, and fat. Preheating biomass and adding water will help lignin to reach the glass transition at lower temperatures. Normally, the glass transition temperature of lignin is 100–140 °C. Kaliyan and Morey reported that the transition temperature could be reduced to 60–100 °C at a moisture content of 8–10 wt.% [6]. Water also increases capillary pressure and interfacial forces. The pressure can reduce the distance of particles to increase attraction forces (van der Waal's, electrostatic, and magnetic forces) between particles. To improve pellet quality and reduce energy consumption, additives or binders can be added into the feedstock with a suitable portion before densification. In general, the additives are synthetic binders (also called chemical binders) such as crude glycerol, gelatinized starch, lignosulfonate, molasses, and heavy pyrolysis oil [6–10]. The fraction of added binders normally ranges from 0.5 to 20 wt.%, or more for biological binders. The fraction of the added binders is limited by its cost and the potential emissions released during the end use of pellets. Added binders are widely used in the industries for the production of pharmaceutical tablets and animal feeds [11].

The quality of pellets, as determined by pellet density, heating value, hardness, moisture uptake, and energy density, strongly depends on the feedstock quality and the densification condition. Biochar can be produced over a wide range of temperatures (250–600 °C) with a residence time ranging from a few minutes to a few hours. Although densification has been practiced commercially in large-scale pellet plants, in view of the difference in properties of biochar from its raw material, the densification of biochar into pellets still needs to be investigated to identify suitable operating conditions. In recent years, torrefied pellets have attracted great attention as a potential next generation wood pellets to overcome the problems associated with the regular wood pellets, such as the poor water resistivity, low heating value and short shelf life (Peng, [17]). Torrefaction typically takes place over a temperature range of 220–300 °C, with a biochar yield (defined as the mass of solid product divided by the dry feedstock mass) ranges from 70 to 90 wt.%. A number of studies have attempted to densify those torrefied powders into torrefied pellets, which have a better quality than regular pellets. Most researches showed that a high die temperature, a high compression pressure and more mechanical energy were required to make strong torrefied pellets with the torrefied powders preconditioned [12–16]. Both Phanphanich and Peng reported that the quality (density and hardness) of torrefied pellets made from torrefied sawdust preconditioned with water was poorer than control/normal wood pellets [12,17]. Peng et al. systematically investigated the effect of the densification parameters (die temperatures from 70 to 280 °C, compaction pressures from 125 to 249 MPa, and preconditioned sample moisture contents from 0.8 to 16.1 wt.%), and concluded that a die temperature of 220 °C or above was needed for making high quality torrefied pellets from torrefied sawdust prepared at 70 wt.% biochar yield [15]. Verhoeff et al. even suggested that to make comparable pellets, the die temperature should be only 20–30 °C below the biochar production temperature in order for the high temperature die to soften the remaining lignin to create the solid bridges that interlock between particles for making strong pellets [13].

Binders have been explored to improve the quality of torrefied pellets. Wu investigated the use of lignosulphonate and starch as binders for the pelletization of torrefied sawdust produced from southern pine at 300 °C [18]. Mallory also investigated the use of starch as a binder to improve the quality of torrefied pellets [19]. The most widely used binders such as starch and lignin can increase the adhesion forces between particles, but they are expensive and starch is also part of the food supply. Other suitable binders, which are not food-based and/or inexpensive, need to be explored for making strong torrefied pellets.

In the present work, we explored the raw biomass as a potential low-cost binder for torrefied pellets production based on the hypothesis that the large fraction of natural lignin in the raw biomass can be used as a natural binder for densification of torrefied sawdust. The performance of biomass binder and the quality of resulted torrefied pellets were investigated in comparison with lignin and starch binders, which have been examined extensively in the literature as effective binders for biochar densification and used commercially. To examine the feasibility of the proposed biomass binder, biochar prepared from pine sawdust under typical torrefaction conditions in a fixed bed reactor was densified into pellets with raw pine sawdust as a binder at different proportion. The quality of torrefied pellets was then assessed based on the pellet density, higher heating value, hardness, saturated moisture content, and energy density.

2. Experimental

2.1. Samples preparation

Pine woodchips from FPInnovation were used as the test raw material in the present work. Pine woodchips were prepared by drying in a THELCO laboratory PRECISION oven (Thermo Electron Corporation, U.S.A.; Model: THELCO laboratory PRECISION) at 105 °C for 24 h and crushing in a hammer mill (Glenmills Inc., U.S.A.; Model: 10HMBL) installed with three different size screens (0.79, 3.18, and 6.35 mm) to produce three size pine sawdust samples. The PRECISION oven also was used to evaluate the moisture content for all samples. A 25 mL glass cylinder was used to determine the bulk density for all samples. A multipycnometer (Quantachrome Instruments, U.S.A.; Model: MULTIPYCNOMETER Revision A) was used to measure the true density (also called the particle density) for all samples. The higher heating value (HHV) was measured by a calorimeter (Parr Instrument Company, U.S.A.; Model: 6100 Compensated Calorimeter) for all samples. The proximate analysis was conducted using a TG analyzer (SHIMADZU, Japan; Model: TGA-50). The elemental analysis was done in an elemental analyzer (Fisons, Germany; Model: EA 1108) located in the Chemistry Department at the University of British Columbia for all samples. The chemical composition was measured by FPInnovations using a high-performance liquid chromatography (Dionex Corporation, U.S.A.; Model: ICS-3000 Ion Chromatography System) following the ASTM E1758-01 procedure [20]. Particle size distributions were determined by a Ro-Tap sieve shaker (Tyler Industrial Products, U.S.A.; Model: RX-94-CAN). Sieves of 5, 7, 10, 14, 18, 25, 35, 45, 60, 80, 100 and 120 meshes with corresponding opening sizes of 4.00, 2.80, 2.00, 1.41, 1.00, 0.707, 0.500, 0.354, 0.250, 0.177, 0.149 and 0.125 mm were used for particles crushed in a hammer mill installed with 3.18 and 6.35 mm screens. For particles crushed with a 0.79 mm hammer mill screen, sieves of 18, 25, 35, 45, 60, 80, 100, 120, 170 and 230 meshes with corresponding opening size of 1.00, 0.707, 0.500, 0.354, 0.250, 0.177, 0.149, 0.125, 0.088 and 0.063 mm were used. Sieving time was controlled at 5 min for each test. In total, two replicates were measured for each sample. Fig. 1 shows the measured particle size distributions of three pine sawdust samples. Table 1 shows the properties of three pine sawdust samples.

In the present work, untreated pine sawdust, lignin and starch were used as binders for the densification of biochar. The untreated pine sawdust includes three different sizes for examining the particle size effect. Starch in the powder form was purchased from Save-on-Foods store. Lignin in the powder form with an average