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Physical and thermal characterization of ground bark and ground wood particles

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ABSTRACT

The present work reports the physical, size and shape, flowability, drying and devolatilization properties of ground wood and ground bark particles. Mechanical sieving and image processing identify the size and shape of ground particles, respectively. Ground particles are dried at initial moisture contents of 0.30, 0.50, 0.70 and 0.90 (dry mass basis) and drying temperatures of 70, 100, 130 and 160 °C. Devolatilization rate of particles is measured using a thermogravimetric analyzer. Microscopic investigations show that wood particles are longer and thinner than bark particles. More spherical shape facilitates the flowability of the bark particles. Wood particles are cohesive and have poorer flowability properties than bark particles. Bark particles have a lower internal void fraction than wood particles. Denser structure of bark particles diminishes the drying and devolatilization rate and prolongs the heat and mass transfer process compared to the wood particles.

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1. Introduction

In recent years, the power plants adopted regulations to phase out coal firing and investigate the feasibility of utilizing biomass in order to reduce GHG emission [1]. Woody biomass has a lower ash content than agricultural biomass and consequently is a preferred feedstock for thermal conversion applications. A tree as a forest-sourced biomass is divided into the internal wood, bark that covers the outer surface of the tree, and branches. For pulp and paper applications, de-barking is an essential process to obtain clean and high-quality wood chips. De-barking includes removal of bark and small branches that are not desirable in pulp making process. The bark is a waste for pulp and paper industry and consequently is a low-price feedstock. Young [2] investigated complete trees of eight species and estimated that bark (combination of bark and small branches) represents about 10–35% weight fraction of a tree.

Wood and bark are different with respect to their physical, chemical and mechanical properties. The bark is usually more exposed to the environmental dirt than wood chips. Rather than that, the bark has more mineral elements in their structure. Ruiz-Aquino et al. [3] showed that bark of two Mexican oak trees has significantly higher calcium (Ca) content than oak wood. Barta-Rajnai et al. [4] measured the mineral content of Norway spruce. They showed that the contents of all mineral elements such as Ca, K, Si, Mg, S, Mn, P and Zn in the bark is higher than wood. Biomass-fired boilers experience serious fouling problems due to minerals such as potassium, chlorine, sulfur, silicon, calcium, and magnesium [5]. Collura and Neumann [6] reported that bark of West African woody plants has a very high silica content (up to 18%) that is not present in the wood. Chow et al. [7] measured the ash content of wood and bark for seven tree species and showed that generally bark of tested species has an ash content of 3–7 times of wood. Nosek et al. [8] reported that the ash content of Norway spruce wood is 0.24%, whereas ash content of bark of the same tree is 5.25%. Wood and bark of European beech tree have 0.47% and 7.80% ash content, respectively [8].

The chemical constituents of bark are different than wood. Generally, bark contains more extractives and fewer polysaccharides than wood [3]. Chow et al. [7] reported that bark of red maple tree has lower cellulose and hemicellulose and higher lignin than red maple wood. The chemical difference is expected to affect the heating value. Ruiz-Aquino et al. [3] reported that bark of two Mexican oak trees has a lower heating value than the wood of same tree species. Nosek et al. [8] measured the heating value for wood and bark of three types of trees. For Norway spruce tree, the bark

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has a lower heating value than wood (15.6 MJ/kg versus 17.9 MJ/kg). For Weeping birch, the bark has a higher heating value than wood (23.5 MJ/kg versus 18.6 MJ/kg). For European beech, the bark has a similar heating value with wood (17.8 MJ/kg versus 17.7 MJ/kg). So, it seems that there is no agreement on the heating value of wood versus bark.

Comprehensive information about the actual size, shape, and density of biomass particles is crucially important in the industrial applications that handle the particulate materials. Biomass particles are cohesive; they may stick together in a flowing stream of particles and cause a variety of flow issues. Bridging of biomass particles in the feeding systems is a common industrial issue [9,10]. Compressibility evaluation of biomass particles and angle of repose (AOR) are the convenient analyses to conduct the flow characterization of biomass particles [11–21]. During the tapping process, the bulk of biomass particles undergo a compression [21]. A larger difference in the bulk density before and after the compression implies the particles having more tendency to make a compact bulk. The physical properties of biomass particles such as particle size, particle shape, particle density and moisture content influence the compressibility of material [14,15,22]. Stasiak et al. [23,24] showed that the woody biomass consolidates under the tension and their flowability properties change. The dimensionless numbers "Hausner ratio (HR)"and "Carr-compressibility index (CCI)" quantify the bulk compression [21]. In a comprehensive fluidization review, Geldart [25] showed that particles with HR less than 1.25 are free-flowable and easy to fluidize; particles with HR greater than 1.4 are cohesive and difficult to fluidize, and particles with HR values of 1.25–1.4 have partial properties of both groups. The CCI values between 5 and 15, 12–16, 18–21, and 23–28% indicate excellent, good, fair, and poor flowability, respectively [21].

AOR is the angle of piled particles with respect to the horizontal surface. AOR indicates the failure properties of particles under gravity [26]. The cohesive and sticky particles do not tend to flow on each other and create a pile with higher AOR. In the literature, an increase in particle size is accompanied by a decrease in cohesiveness [11,21]. Rezaei et al. [27] showed that the shape of particles significantly influences the AOR. The more spherical ground pellet particles have a significant lower AOR than long and thin ground wood chip particles [27].

1.1. Objectives

All types of biomass feedstocks that are prepared to be converted thermally should be ground below 2 mm to minimize the internal heat and mass transfer limitations [28–34]. In power generation stations, ground particles flow with the re-circulated hot gas in the pipe lines leading to the pyrolysis/combustion chambers. Particles dry in the exposure of hot air. The size, shape, density and internal structure of the biomass particles are known to affect the flow properties in lines and feeding systems, drying rate and kinetics of thermal decomposition [15,27,33–39]. In the previous studies, Rezaei et al. [27,34,40] showed the differences between ground wood chip particles with ground pellet particles regarding size, shape, density, flowability, drying rate and thermal decomposition rate. In the current study, the purpose is to investigate the differences of ground wood and ground bark particles regarding their size, shape, density, flowability and rate of drying and devolatilization. The output of the current study facilitates understanding the physical, chemical and thermal properties of bark particles.

2. Material and methods

2.1. Materials

Pine wood chips (3 × 3x1 cm) and barks (with of 1–6 cm and length of 3–15 cm) are supplied by Fiberco. (North Vancouver, BC, Canada) and Timber West Forest Corporation (Vancouver, BC, Canada), respectively. The received wood chips and barks have a moisture content of about 50% and 40% (wet basis), respectively. Upon their arrival at the lab, the materials are dried in a THELCO laboratory PRECISION oven (Thermo Electron Corporation, Model 6550) at 80 °C down to 6–8% moisture content. After cooling, both wood and bark samples are crushed in a hammer mill (Glen Mills Inc., USA; Model 10HMBL) installed with a grinder screen size having circular perforations of 3.2 mm. Fig. 1 shows both wood and bark materials before and after the grinding. The received bark sample includes some pieces of wood, too. It seems that some pieces of wood are inevitably removed from a tree in the debarking process. The fraction of wood is not known, but the visual observations confirm that the wood content is negligible.

Calculated amounts of water are sprayed on the particles to adjust their initial moisture content (M_0) to 0.30, 0.50, 0.70 and 0.90 dry mass basis. Moistened particles are stored in sealed vessels and kept in a refrigerator (~4 °C) for at least 3 days to reach to a uniform moisture distribution. As the bulk density of GW and GB are different, about 40 g of ground bark particles and 20 g of ground wood particles for each desired moisture content were stored in the fridge.

The moisture content of each conditioned sample was examined three times using a moisture analyzer (AND, model: MF-50, the

Fig. 1. Picture of bark and wood chips before and after grinding.

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