Powder Technology 301 (2016) 737–746

Contents lists available at ScienceDirect

Powder Technology

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

Size, shape and flow characterization of ground wood chip and ground wood pellet particles

Hamid Rezaei [a], C. Jim Lim [a], Anthony Lau [a], Shahab Sokhansanj [a,b,*]

[a] Chemical and Biological Engineering Department, University of British Columbia, Vancouver, BC V6T 1Z3, Canada
[b] Environmental Science Division, Oak Ridge National Laboratory, Oak Ridge, TN 37381, USA

ARTICLE INFO

Article history:
Received 20 April 2016
Received in revised form 13 June 2016
Accepted 9 July 2016
Available online 11 July 2016

ABSTRACT

Size, shape and density of biomass particles influence their transportation, fluidization, rates of drying and thermal decomposition. Pelleting wood particles increases the particle density and reduces the variability of physical properties among biomass particles. In this study, pine chips prepared for pulping and commercially produced pine pellets were ground in a hammer mill using grinder screens of 3.2, 6.3, 12.7 and 25.4 mm perforations. Pellets consumed about 7 times lower specific grinding energy than chips to produce the same size of particles. Grinding pellets produced the smaller particles with narrower size distribution than grinding chips. Derived shape factors in digital image analysis showed that chip particles were rectangular and had the aspect ratios about one third of pellet particles. Pellet particles were more circular shape. The mechanical sieving underestimated the actual particle size and did not represent the size of particles correctly. Instead, digital imaging is preferred. Angle of repose and compressibility tests represented the flow properties of ground particles. Pellet particles made a less compacted bulk, had lower cohesion and did flow easier in a pile of particles. Particle shape affected the flow properties more than particle size.

1. Introduction

In recent years, the governments of Canada and the US adopted regulations to phase out coal-fired power plants by 2020 [1]. The power plants have devoted considerable resources to investigate the feasibility of utilizing biomass in order to reduce GHG emission. Woody biomass may be used in the form of wood chips or wood pellets [2–4]. Wood chips are mostly used in the fast pyrolysis process, whereas the wood pellet is a promising option for power boiler that is compatible with existing coal-firing facilities. The Atikokan and Thunder Bay power generation stations in Ontario, Canada are two examples of this replacement. Wood pellets have higher bulk density and more homogenous physical properties than wood chips [5,6]. Wood pellets provide a more convenient form in terms of its handling, storage and feeding to the pyrolysis and combustion reactors [4,7]. Due to heat and mass transfer limitations, it is recommended to grind the pellets and large chips to particles that are smaller than 2 mm before feeding to a pyrolyzer or combustion chamber (power boiler) [8–13]. Wood pellets can be crushed by the pulverizer/roller mills, then the crushed powder can flow with the re-circulated hot gas in the pipe lines leading to the boilers. The size, shape and density of the biomass particles are known to affect the feeding system, flow properties, ignition temperature and kinetics of drying and thermal decomposition [5,13–16].

Accurate, fast and inexpensive method of particle size analysis is desirable in the industries that handle particulate materials. The American Society of Agricultural and Biological Engineers (ASABE) developed mechanical sieving (S424.1, 2007) as a standard method to determine particle size distribution of biomass particles. Particle size distribution is obtained from the mass percent of particles retained on each sieve [17]. Particles pass through the sieves based on their width, whereas the length of the particles is ignored in the sieving process.

Biomass particles are mostly irregular and heterogeneous in size and shape [18]. Hence, two particles that pass through the same sieve may have different shapes, and the information obtained from the sieving process may not represent the size and shape characteristics of irregular-shaped biomass particles. Moreover, conducting the mechanical sieving for a number of samples is laborious [19], and the results may not be consistent [20].

Machine vision is an alternative approach to mechanical sieving. It is a more advanced technique to analyze the particle size and shape using image analysis [21]. Image analysis is a practical method to determine the actual dimensions and shape of single particles. It is not subjective and is repeatable over the same picture [17,22]. The shortcomings of image analysis is two dimensional analysis that omits the thickness of particles [20,22]. Tannous et al. [18] suggested that picturing and measuring the thickness of a single Douglas fir particle is not practical and reliable, and assumed that the thickness of particles is 30% of its width.

Literature review indicates that a series of shape factors have been established to describe and evaluate the shape, form and structure of

* Corresponding author.
E-mail address: shahab.sokhansanj@ubc.ca (S. Sokhansanj).

http://dx.doi.org/10.1016/j.powtec.2016.07.016
0032-5910/

the particles. Shape factors provide quantitative information about the particle shape. Riley [23] stated the difficulty of 3D picturing of particles and introduced projected shape factors that are based on width, length, inscribed and circumscribed circles. Trottier et al. [24] defined shape factors using two or three dimensions of an individual particle and categorized the shape factors using four parameters: (1) dimensional ratios, (2) sphericity that indicates the deviation of a particle from a sphere/circle, (3) roundness and circularity that show angularity and sharpness of corners, and (4) roughness that shows surface structure. Fig. 1 illustrates the concept of various shape factors associated with a single wood particle.

Comprehensive information about the actual size, shape and density of biomass particles is crucially important in the industrial application that handle the particulate materials. Predicting the pressure drop across a bed of particles is one example of the applications [25]. Hoppers, screws, pneumatic transportation in pipelines and feeding systems in thermochemical conversion processes are other examples. Physical properties such as particle size, particle shape and surface roughness affect the flowability of biomass particles [18,26–30]. 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 system of a gasifier is a common industrial issue [31,32].

The convenient analyses to conduct the flow characterization of minerals are mostly used for biomass particles, too [16,18,28,29,33–39]. Loose and tapped bulk densities represent a very quick method to estimate the flowability of particles [16,35]. In the tapping process, particles re-arrange and change the packing condition [35]. A larger difference in the bulk density before and after the tapping process would imply the particles having more tendency to make a compact bulk. The dimensionless numbers “Hausner ratio (HR)”and “Carr-compressibility index (CCI)” quantify the increase in bulk density during the tapping process [18]. Bulk density can change with the size and shape of particles, the way that particles are arranged in the bulk and friction among the particles [16,35,40]. Wu et al. [26] showed that the bulk density of wood pellets is about 2–3 times that of wood chips, but they did not compare the bulk density of ground chip and ground pellet particles. Lam et al. [16] measured the bulk density of wheat straw and switchgrass as a function of physical attributes. Tapping the bulk compressed the longer particles more than shorter ones. The exact HR and CCI values depend strongly on the technique to determine the tapped bulk density, dropping height and the number of taps. Tannous et al. [18] showed that more tapping increases the tapped bulk density and the HR value. Thus, the published values of tapped bulk density are seldom comparable. Nevertheless, it is important to implement a consistent procedure of bulk density measurement to study the relative compressibility of different samples.

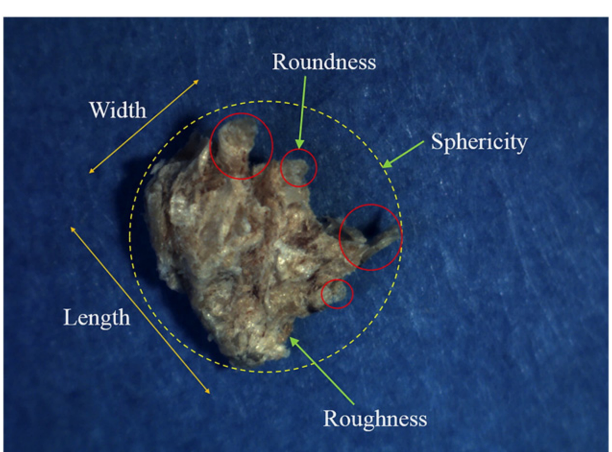

Fig. 1. Particle shape characterization in terms of dimensional ratios, sphericity, roundness and roughness.

In a comprehensive fluidization review, Geldart et al. [41] showed that particles with HR < 1.25 are free-flowable and easy to fluidize; particles with HR > 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 5–15, 12–16, 18–21, and 23–28% indicated excellent, good, fair, and poor flowability, respectively [18]. Tannous et al. [18] showed that HR and CCI values for Douglas fir particles decreased with decreasing particle size. By decreasing the particle size in the Sauter diameter range of 74-781 μm, HR and CCI values decreased from 1.85 to 1.32 and from 45.84 to 24.06, respectively. Besides, smaller particles packed more with tapping and have poor flow properties than larger particles.

The angle of repose (AOR) is another test to study the relative flowability of samples. AOR is the angle of piled particles with respect to the horizontal surface, and it indicates the failure properties of particles under gravity [30]. AOR depends on the cohesiveness and stickiness of particles. In the literature, an increase in particle size is accompanied by a decrease in cohesiveness [18,33]. It is suggested that an AOR below 30° shows good flowability, 30–45° some cohesiveness, 45–55° true cohesiveness and above 55° very high cohesiveness [33]. In some other studies [34,37,42], 40° AOR was mentioned as the criteria for free flowability. Yet, there is no general agreement on the test procedure and the scale of AOR equipment. Geldart et al. [33] showed that variable amount of material may change AOR values. Wu et al. [26] worked with wood chips (lengths of 20, 40 and 100 mm) and wood pellets (diameters of 6, 8 and 12 mm), and showed that wood pellets with AOR values of 35–38° were more flowable than wood chips with AOR values of 44–46°. Wu et al. [26] did not measure the AOR of ground chip and ground pellet particles.

1.1. Objectives

The size, shape and density of the biomass particles affect their heat and mass transfer properties and flow properties. Due to the increasing application of ground chip particles in fast pyrolysis and crushed pellet particles in power boilers, the authors believe that further study is needed to determine their relative physical properties. Literature review shows that there is limited information on the comparative physical characterization of biomass particles in the form of ground chip versus ground pellet, in regard to their actual dimensions, shape, density and flow properties.

The objective of the current research was to study the size, shape, density and relative flow properties of ground pine chip and ground pine pellet particles. Digital image analysis was used to determine the dimensions, shape and some pre-defined shape factors. Compressibility analysis and the angle of repose test were used to evaluate the relative flow properties of the ground chip and ground pellet particles. The characterization results express a functional relationship between the physical properties and flowability of biomass particles. In particular, results for the dimensions and shape of biomass particles may be used to predict the pressure drop within a bed of ground particles [25]. The outcomes of this study will help towards using more precise input information in modeling the thermochemical conversion of single particles, as well as the design and optimization of the feeding system in power plants.

2. Material and methods

2.1. Sample preparation

Pine wood chips (30x30x5 mm) and commercially produced pine wood pellet (diameter of 6 mm and lengths of 12–24 mm) were supplied by Fiberco Inc. (North Vancouver, BC, Canada). Upon their delivery to the lab at UBC, the pine chips were dried in a THELCO laboratory PRECISION oven (Thermo Electron Corporation, Model 6550) at 80 °C down to 4–5% moisture content. After cooling, the dried chips were crushed in