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Secondary comminution of wood pellets in power plant and laboratory-scale mills

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ABSTRACT

This study aims to determine the influence of mill type and pellet wood composition on particle size and shape of milled wood. The size and shape characteristics of pellets comminuted using power plant roller mills were compared with those obtained by using laboratory-scale roller- and hammer mills. A 2D dynamic imaging device was used for particle characterization. It was shown that mill type has a significant impact on particle size but an almost negligible effect on the shape of milled wood. Comminution in the pilot plant using a Loesche roller mill requires less energy than using a hammer mill, but generates a larger fraction of coarse particles. The laboratory-scale roller mill provides comparable results with the power plant roller mill with respect to particle size and shape.

1. Introduction

Biomass firing is used for power generation and is considered as an important step in the reduction of greenhouse gas emissions. The anthropogenic CO_2 emissions can be decreased by the substitution of biomass in the pulverized combustion due to the lower regeneration time of biomass compared to bituminous coal. Thus, CO_2 released using biofuels will be reconsumed faster by other plants via photosynthesis than the time needed to regenerate coal. The milling process is a necessary step in suspension fuel firing [1]. Size reduction improves conversion processes due to the creation of larger reactive surface areas [2,3]. Biomass is due to its fibrous structure difficult to mill. An increased energy input into biomass comminution affects the total efficiency of power plants, and often causes problems with flame stability and burnout when large particles remain after milling.

The common method for preparing biomass for suspension firing is to pelletize lignocellulosic materials, and then pulverize the biomass pellets using coal roller mills [4]. A number of studies [3,5-10] have investigated the influence of mill type on both the particle size and shape. Momeni [5] showed that comminuting woody pellets in hammer and roller mills produced significantly different sized particles. In other investigations [6,8], higher fractions of fine particles were obtained after comminution in a hammer mill compared to milling using a knife mill. In agreement with this observation, the energy consumption of the knife mill was found in all cases to be smaller than that of the hammer mill [7,8]. The feedstock type (hardwood, straw, corn cobs and corn stover) affected the energy consumption of the hammer and disk mills [9]. The energy consumption for the comminution of dry pellets was lower for the hammer mill than for the disk mill, and the particle size distribution was broader with larger particle aspect ratios after comminution in the hammer mill [10]. In addition, it was reported that a high moisture content ($>20\%$) increased the specific energy consumption by 50% [10]. It appeared that different feedstocks (switchgrass, corn and soybean) showed differences in the particle size and shape during comminution and generated particles with various morphological properties [11]. Previous investigations of biomass comminution demonstrate disagreements in terms of the effect that mill and feedstock type have on particle shape. Bond [12] and Heywood [13] reported that fuel type has a stronger influence on the particle shape than mill type, whereas Rose [14] showed that mill type mainly affects particle shape. Generally, little is known about the effect of mill type on particle shape and size when lignocellulosic materials are milled.

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Nomenclature

A	particle area (m^2)
A_{real}	particle projection area (m^2)
A_{convex}	particle convex area (m^2)
AR	aspect ratio
b	particle width (m)
$Conv$	convexity
d	diameter (m)
l	particle length (m)
m	number of size classes
P	perimeter of a particle projection (m)
q_3	frequency particle distribution, based on volume (% mm^{-1})
$\bar{q}_3$	histogram (% mm^{-1})
Q_3	cumulative particle distribution, based on volume (% mm^{-1})
r_1, r_2	distances from the area center to the particle edges (m)
$SPHT$	circularity (sphericity)
$Symm$	symmetry
V	volume (m^3)
$x_{Ma,\min}$	Martin minimum diameter (m)
$x_{Fe,\max}$	Feret maximum diameter (m)

Subscripts

i	number of the size class with upper limit x_i

In this study, the impacts of mill and feedstock type on particle size and shape were investigated. Wood pellets are comminuted using a laboratory-scale roller mill, a laboratory-scale hammer mill, and power plant roller mills. Particle size and shape of milled pellets were characterized using sieving and 2D dynamic imaging analysis. The objective of this study was to gain knowledge concerning the impact of mill type, fuel type, and pelletization method on both particle size and shape of milled biomass.

2. Materials and methods

Raw pellets, without additives or binding agents, were provided by the companies LatGran (Latvia) and Heatlets (Estonia). The pellets were produced in the process shown in Fig. 1. Wood logs with diameters of 5–60 cm and length of 3–4 m were initially dried, and then shredded in a mobile shredder to 8–45 mm. The primary comminution includes the milling of wood chips to the particle size of 0.5–2 mm in diameter and 1 cm in length by a knife ring flaker and a drop feed chipper, and sawdust milling in a hammer mill to obtain a homogeneous and fine material below 1.5 mm in size. The sawdust before being pelletized, contained 75% particles following the process described in Fig. 1 and contained 25% coarse bark sawdust residues from comminution on a disk mill.

The pellets were produced using ring die pellet machines in which a die ring runs around fixed rollers [15]. The sawdust was added to the roller sideways and pressed through the holes of the die [15]. The string of pressed material leaving the die was broken off into 22 mm long pellets, and then the pellets were cooled down from 90 °C to room temperature for stabilization and hardening.

The pellets were transported to three power plants including Herningsværket (HEV), Avedøreværket (AVV) operated by DONG Energy A/S, and Amagerværket (AMV) operated by HOFOR A/S (formally Vattenfall). Secondary comminution was then carried out either in the hammer (HEV) or in the horizontal Loesche roller mills (AMV and AVV). Pulverized wood was sampled from the pipeline (running to the burners) through a side opening by using a vacuum cleaner or a rotorprobe. The pellets underwent additional milling in the laboratory-scale roller mill at TU Clausthal. The particle size and shape of the milled pellets were characterized by light microscopy, scanning electron microscopy (SEM), sieving and 2D dynamic imaging.

3. Particle size and shape characterization

3.1. Light microscopy

Light microscopy of sawdust and disintegrated pellets was conducted using a Microscope Heating Stage 1750 (Leica Microsystems, Germany) in order to characterize the particle shape.

3.2. SEM microscopy

SEM analysis of milled pellets was conducted using an Inspect microscope (FEI Company, USA) with a tungsten filament under high vacuum in order to obtain information on char structural properties. Prior to the analysis, milled pellet samples were coated with a thin layer of carbon (40 s, 5 mA) using a 208 Carbon Coater (Cressington, Germany) to avoid sample charging.

3.3. Sample preparation

Prior to the particle size and shape analysis, biomass samples were divided into equal 100 mg fractions using a micro-riffler PT100 (Retsch Technology, Germany).

3.4. Sieving

A vibrating sieve shaker Retsch AS 200 (Retsch Technology, Germany) comprising seven sieves ranging from 0.25 to 4 mm in opening size and a bottom pan (< 0.25 mm) was used. The sieving analysis is described in EN ISO 17827-2:2016. Particles remaining on each sieve and in a bottom pan were collected and weighed using an electronic top pan balance (± 0.01 g accuracy). The cumulative retained undersize is the mass passed from the previous sieve minus the mass retained on the current sieve [16]. Sieving was conducted for 15 min at 3 mm amplitude [17].

3.5. 2D dynamic imaging analysis

The particle size and shape were measured using the CAMSIZER (Retsch Technology, Germany), designed for particles ranging from 0.03 to 30 mm in size. Particle shadows were captured by two cameras; a zoom camera, designed for the analysis of smaller particles, and a basic-camera that was able to detect larger particles. The particles' projected area was determined using CAMSIZER 6.3.10 software (Retsch Technology, Germany). The particle size distribution, based on volume, is represented by the $x_{Ma,\min}$ diameter. For the particle size analysis, ca. 100 mg of a dry sample was used.

The Martin minimal ($x_{Ma,\min}$) and Feret maximal ($x_{Fe,\max}$) diameters are suitable parameters to represent the biomass particle width and length. The Martin diameter is a characteristic length that divides the projected particle area into two equal halves [18], as shown in Fig. S-1.1 of the supplemental material. The minimal Martin diameter ($x_{Ma,\min}$) is determined from the smallest Martin diameter of the particle projection [19]. The Feret diameter is the distance between two tangents placed perpendicular to the measurement