Fuel Processing Technology 173 (2018) 89–102

Contents lists available at ScienceDirect

Fuel Processing Technology

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

Research article

Wood pellet milling tests in a suspension-fired power plant

Marvin Masche[a,*], Maria Puig-Arnavat[a], Johan Wadenbäck[b], Sønnik Clausen[a], Peter A. Jensen[a], Jesper Ahrenfeldt[a], Ulrik B. Henriksen[a]

[a] Department of Chemical and Biochemical Engineering, Technical University of Denmark, 2800 Kgs. Lyngby, Denmark
[b] Amagerværket, HOFOR A/S, Kraftværksvej 37, 2300 Copenhagen S, Denmark

ARTICLE INFO

Keywords:
Wood pellets
Roller mills
Specific grinding energy consumption
Particle size
Particle shape

ABSTRACT

This paper investigates the milling behavior of two industrial wood pellet qualities (designated I1 and I2 as per ISO 17225-2:2014) in large-scale coal roller mills, each equipped with a dynamic classifier. The purpose of the study was to test if pellet comminution and subsequent particle classification (i.e., the classifier cut size) are affected by the internal pellet particle size distribution obtained after pellet disintegration in hot water. Furthermore, optimal conditions for comminuting pellets were identified. The milling behavior was assessed by determining the specific grinding energy consumption and the differential mill pressure. The size and shape of comminuted pellets sampled from burner pipes were analyzed by dynamic image analysis and sieve analysis, respectively. The results showed that the internal pellet particle size distribution affected both the milling behavior and the classifier cut size. I2 pellets with coarser internal particles than I1 pellets required more energy for milling, led to a higher mill pressure drop and showed a larger classifier cut size. Comminuted pellet particles sampled from burner pipes were notably finer than internal pellet (feed) particles. At similar mill-classifier conditions, characteristic particle sizes of 0.50 mm for comminuted I1 pellets (compared to 0.83 mm for material within I1 pellets) and of 0.56 mm for comminuted I2 pellets (compared to 1.09 mm for material within I2 pellets), respectively, were obtained. Pellet comminution at lower mill loads and lower primary airflow rates reduced the mill power consumption, the mill pressure drop, and the classifier cut size. However, this was at the expense of a higher specific grinding energy consumption. Derived 2D shape parameters for comminuted and internal pellet particles were similar. Mill operating changes had a negligible effect on the original elongated wood particle shape. To achieve the desired comminuted product fineness (i.e., the classifier cut size) with lower specific grinding energy consumption, power plant operators need to choose pellets with a finer internal particle size distribution.

1. Introduction

Wood pellets as a renewable energy commodity for heat and power generation have experienced tremendous growth over the past decade in Europe [1,2]. European energy policies have driven this development to mitigate greenhouse gas emissions by 20% by 2020 [3]. In particular, USA, Canada, and Russia have responded to the increasing demand for wood pellets by enhancing pellet production, with many large-scale pellet plants being constructed for the European market [4]. When tons of solid biomass need to be transported overseas, pelletized biomass is more cost-efficient than wood chips because of higher energy and bulk density [5]. Furthermore, pelletization improves storage and handling characteristics with fewer dust emissions [6] that may increase the risk of explosions during transshipment [7]. To mitigate industrial greenhouse gas emissions, retrofitting power plants from coal to wood pellets by utilizing the existing milling equipment and auxiliary infrastructure offers a cost-efficient and practical option at low capital investment [8]. Furthermore, the converted plants preserve grid reliability compared to intermittent renewable energies like wind and solar [9]. Countries, like Denmark and United Kingdom, have already converted, or are currently converting their existing suspension-fired power plants from coal to operate 100% on biomass, mostly wood pellets [8].

The size reduction of solid particles is a significant process in suspension-fired power plants and is commonly performed in hammer mills or roller mills [8,10] to achieve a homogenous fuel distribution that is pneumatically transported to the burners. Previous studies [11–13] showed that roller mills were not capable of producing a product as fine as hammer mills. Regarding the particle shape, Trubetskaya et al. [12] found no difference between roller-milled and hammer-milled particles. However, roller mills required less power for

* Corresponding author.
E-mail address: marv@kt.dtu.dk (M. Masche).

https://doi.org/10.1016/j.fuproc.2018.01.009
Received 25 September 2017; Received in revised form 9 January 2018; Accepted 9 January 2018
Available online 03 February 2018

grinding than hammer mills [12,13]. The energy needed for milling biomass depends on the feed moisture, particle size reduction ratio, feedstock characteristics [14], feed rate and mill operating parameters [15]. Comminuting fibrous and orthotropic elastic wood that is capable of absorbing energy before size reduction [16] requires more energy than coal regardless of mill type [17].

The comminuted particle size and shape are essential properties for suspension-firing, as they influence the particle dynamics, particle heat and mass transfer [18]. For proper combustion control, the finer and more uniform the fuel is, the higher the chance to achieve complete combustion in the available boiler residence time [19]. To provide control over the fineness (i.e., the cut size) of the comminuted product conveyed to the burners, coal roller mills apply static or dynamic classifiers [8,20], which classify particles based on their shape, size, and density [21]. The cut size is based on Stokes' law [22] that is only valid for the drag force of a spherical particle [23]. Williams et al. [17] found that the classification system of a ring-roller mill for the comminution of densified biomasses followed the Stokes' law, indicated by an increasing sphericity with decreasing particle size. In large-scale mill classifiers, there are particle size limits for coal suspension-firing. In particular, 75% of pulverized coal needs to pass a 200 mesh sieve (75 µm) [24]. Equivalent limits for woody biomass particles have not been established. However, a size reduction to the same level as coal may not be required due to the higher volatile content of biomasses in combustion systems [19]. Esteban and Carrasco [10] recommend 95% of wood particles (dry weight basis) to be below 1 mm for optimal combustion. Adams et al. [25] found that 25% of biomass (dry weight basis) below 100 µm was ideal for excellent flame stability.

The study aims to assess the large-scale milling behavior of industrial wood pellet qualities in vertical roller mills (VRMs) at the suspension-fired combined heat and power (CHP) plant Amagerværket unit 1 (AMV1), located in Copenhagen (Denmark). AMV1 has a capacity of 80 MW electricity and 250 MW heat. Originally designed for coal, AMV1 was converted in 2010 to operate 100% on biomass, mainly wood pellets. The purpose of the study is to test if large-scale pellet comminution in VRMs and subsequent particle separation in dynamic classifiers are affected by the particle size distribution (PSD) of material within pellets, also known as the internal pellet PSD. To the best knowledge of the authors, this is the first study that compares the large-scale milling behavior of industrial wood pellet qualities. The results provided can be valuable to optimize the overall milling and combustion process for plant operators facing the problems of changing from coal to biomass pellets. Thus, the main objectives of the study are:

- To evaluate the sampling method for comminuted pellets conveyed to the burners.
- To compare the morphology (size and shape) of material within pellets with that from pellets comminuted at different mill loads.
- To analyze the influence of different pellet qualities on the milling process.
- To identify optimal conditions for comminuting wood pellets.

2. Materials and methods

2.1. Materials

Two industrial wood pellet qualities characterized in triplicate according to standardized methods were used (Table 1). The first quality fully conformed to the requirements of industrial pellets of class I1 according to ISO 17225-2:2014 [26] and was hence designated as I1. They were mainly softwood pellets made from Norway spruce (*Picea abies*) and Scots pine (*Pinus sylvestris*). They were produced in the Baltic countries. The second pellet quality met the specifications set out for industrial pellets of class I2 [26] and was hence designated as I2. They originated from the Southeastern United States and were made of ca. 93% softwood, mainly Southern yellow pine wood species, such as loblolly pine (*Pinus taeda)*, and 7% mixed hardwood species. The major difference between both pellet qualities was the internal PSD, which was obtained after pellets have been disintegrated in hot deionized water and dried in an oven [27]. Sieve analysis was then performed to determine the internal PSD of the dried material. The internal PSD of I1 pellets featured a 20% higher mass fraction of particles below 1 mm compared to I2 pellets.

2.2. Vertical roller mills and dynamic classifiers

Pellets were comminuted in three coal VRMs (type LM 19.2 D, Loesche GmbH, Germany), each equipped with a dynamic (or rotary) classifier (type LSKS 27 ZD-4 So, Loesche GmbH, Germany). The mills were denoted as M10 (mill 10), M20 (mill 20) and M30 (mill 30). The mills, i.e., the milling table, were driven by an electric motor via a vertical gearbox. A schematic representation of the design features of a Loesche coal VRM is shown in Fig. 1. The technical specifications for the mills are summarized in Table 2. The throughput rate for wood pellets is reduced due to their lower energy density compared to coal [8].

The pellet milling process comprises comminution, drying, particle classification and product discharge to the burners. As shown in Fig. 1, pellets fall from the side into the center of the rotating milling table, which is equipped with a dam ring for the adjustment of the milling bed thickness. Centrifugal forces move the pellets under two tapered, locally fixed, grinding rollers that are mounted in rocker arms. Compression force originating from the hydraulic-pneumatic, spring-loaded roller system comminutes the pellets. The rollers also achieve a sliding movement that results in additional shearing forces to comminute the pellets. To produce higher shearing forces, the existing roller mills at AMV1 were retrofitted. Holes were drilled into the roller track, and a surface material with higher hardness was applied to the roller surface. The rollers are driven by the grinding material and are moving vertically during the comminution process. As the rollers roll over the milling bed, the rocker arms, which are coupled to the pistons of the two linked hydraulic cylinders, start to move. Centrifugal forces again expel the comminuted pellet material over the rim of the milling table into the vicinity of the surrounding louvre ring. The louvre ring directs a hot primary airflow, which is tempered by a cooler to around 130 °C to avoid pellet pre-ignition and mill fires, upwards into the spinning rotor of the dynamic classifier. By this means, the comminuted pellet material is dried and lifted to the classifier [28]. The internal flow path of material from the milling table to the classifier is shown in Fig. 1.

In the classifier, drag or centripetal forces (generated by the airflow to the rotor), and mass or centrifugal forces (generated by the rotor rotation) act upon the particles [20]. If the mass force is greater than the drag force, coarse particles are rejected by the classifier and fall back to the milling table via the grit cone for further size reduction. Else, if the drag force is greater than the mass force, the primary airflow lifts the fine particles upwards in the classifier housing [29]. The balance between both forces governs the particle separation [24]. If both forces are in equilibrium for a specific particle mass, the rotor classifies the particle with 50% efficiency, which is referred to as the classifier cut size. Plant operators can control the cut size, and thus the degree of product fineness by adjusting the classifier rotor speed, dam ring height, milling table speed, airflow rate ($\dot{m}_{Air}$), hydraulic grinding pressure (HGP) of the roller, and pellet feed rate ($\dot{m}_{Pellet}$) [20,30,31]. The fines eventually leave the mill at a mill outlet temperature of 60 °C via four outlet pipes to four burners. In total, AMV1 has 12 front-wall-fired burners, each fed by a separate burner pipe distributed in three different levels, one for each mill (Fig. 2).

2.3. Sampling equipment

Wood pellets were sampled from the end of a continuously moving conveyor belt before entering the mill using a falling stream sampler.