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Full Length Article

Investigation of co-milling Utah bituminous coal with prepared woody biomass materials in a Raymond Bowl Mill

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A R T I C L E I N F O

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A B S T R A C T

The operational performance of a Combustion Engineering 312 Raymond Bowl Mill has been investigated while milling a blend of Utah bituminous coal and prepared Manti-La Sal woody biomass. The research focuses on identifying the differences between the various biomass pretreatment methods regarding to co-milling behavior in a pilot scale bowl mill. Torrefied chips, torrefied pellets and steam exploded pellets were evaluated with a mass ratio of 15% biomass and 85% coal and compared to the measured pure coal mill performance. The milling process was monitored by recording the mill power requirement, inlet and outlet temperatures, fluidization air flow rates, fuel moisture content, milled product particle size distribution and SEM analysis of the particles. It was found that the blend with steam exploded pellets is the most suitable for co-milling due to it shows particle size distribution (PSD) close to the case of 100% coal while the grinding energy significantly decreased. A decreased power requirement was also noticeable when milling the blend with wood chips torrefied at 325 °C and pellets torrefied at 325 °C when compared with pure coal, but the mass fraction of large particles in the product increased for these blends. Co-milling coal with wood chips torrefied at 210 °C was not possible in these experiments. The pretreatment of woody biomass materials has the potential of co-firing at higher biomass rates in existing pulverized coal fired power plants without performing significant modifications.

1. Introduction

Co-firing beetle kill wood, or any dead woody biomass in coal-fired boilers is an attractive method for utilities to manage their carbon footprint and to help maintain the health of forests. This technology is being pursued by many groups as a viable power production alternative, with applications ranging from biomass-coal blends to a complete conversion to biomass firing [1–4]. Ideally, biomass can be prepared and utilized as a coal replacement. In this simplest of scenarios, the biomass would be blended with coal upstream of the mill and would be processed by existing conveying and milling equipment associated with the coal power station [5,6]. Since the fibrous nature of raw wood materials does not behave well in traditional coal mills [7], the main goal of this experimental study is to evaluate the co-milling of differently treated dead woody biomass materials blended with Utah bituminous (Sufco) coal at pilot scale (1 t/h) and select the most desirable pretreatment method for a full scale co-firing tests in utility boilers.

Various woody biomass pretreatment methods have been developed [8]. One advantage of the physical upgrade of a biomass material is that it significantly improves its characteristics for both feeding and grinding [9,10], both of which impact the milling process. Torrefaction is a thermal process which removes moisture, densifies the material and breaks down the cellulose cell wall structure [9]. This process typically takes place at relatively low temperatures of 200–300 °C in an anaerobic environment [9]. Several studies describe biomass torrefaction [8–16] as well as the subsequent pelletization process [16,17] in depth. Steam explosion [8,18–20] is a pretreatment method where the biomass undergoes a sudden decompression from an equilibrium state at high pressure, resulting in the rupture of the cellulose cell wall structure. The medium for pressurizing the biomass is steam. The resulting cake of biomass must then be rinsed (potentially removing alkali metals) and dried. Pelletizing steam exploded material is a common process which further increases the energy density.

The grindability of different raw and pretreated biomass materials have been investigated by several researchers [21–30]. However, there is limited information available concerning the milling behavior of treated woody biomass materials blended with coal at pilot or full scale. Gil at al. [10] published a study where chestnut woodchips torrefied at 280 °C was selected for co-milling with coal at lab scale. The biomass ratio in blends ranged from 0 to 100%. Based on the particle size

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distribution of different cases the authors concluded that the grindability of blends up to 15% biomass is similar to that of 100% coal. Savolainen [31] published a study concerning co-firing coal and sawdust in a 315 MW_{th} power plant. In this study it was shown that grinding coal and wood in the form of sawdust had negative effects on the coal fineness. It was concluded that only sawdust or other biofuels with small particle sizes can be utilized when applying simultaneous feeding of coal and biofuels. Zuwala at al. [32] described a trial test carried out in a 1532 MW_{th} power plant. Coal blended with 9.5% (mass basis) sawdust was sent through an unmodified bowl mill. They concluded that energy efficiency and emission levels of the boiler were not significantly impacted. However, grinding the fuel blend impacted the coal fineness, shifting the size distribution towards larger particles, negatively impacting the burn-out efficiency of the fuel. Tillman [6] reviewed the influences of co-firing on the combustion process including the scenario of blending biomass with coal on the fuel pile. It was observed that the most significant impact of the biomass coal blend was to the pulverizer, increasing the mill power consumption and affecting feeder speeds. In fact performance of the mill limited the maximum concentration of biomass that could be processed. It was also observed that co-firing 5% (mass basis) wood waste blended with coal resulted in less than acceptable particle size distribution of the milled product.

To the best of the authors' knowledge, no detailed reports are available investigating the co-milling of bituminous coal blended with pretreated dead woody biomass materials at pilot or full scale. This paper investigates the co-milling of Utah bituminous (Sufco) coal blended with differently treated dead woody biomass materials by utilizing a pilot scale (1 t/h) bowl mill for a purpose of selecting the most desirable pretreatment method for a full scale co-firing tests in utility boilers.

2. Equipment

The Industrial Combustion and Gasification Research Facility (ICGRF) at the University of Utah (USA) has industrial-scale equipment used to mill solid fuels for pilot-scale combustion and gasification experiments. The milling equipment includes: a crusher (capacity: 1 t/h, motor power: 11 kW), a 312 Combustion Engineering Raymond Bowl Mill (capacity: 1 t/h, motor power: 19 kW), a static classifier, a cyclone, a baghouse filter, an air recycle fan (power: 15 kW) and an electric heater (power: 105 kW). The equipment configuration and points of measurement relevant for this study are detailed in Fig. 1. Typically mills of this variety are used in direct-fired configuration, where the material being processed by the mill is continuously delivered to the boiler and immediately fired. The configuration used for this research differs as it is used for pulverizing and storing the fuel for later use in combustion systems.

Air is circulated in a closed loop through the mill, cyclone/filter, fan and heater and can be preheated up to 120 °C before entering the mill. A portion of the air in the closed loop circuit comes out of the system just before entering the mill and is replaced by fresh air in the mill classifier overturning the air in the system over time. This "refreshing" of the air impacts its moisture content by carrying out water evaporated during the milling process. The particle size distribution can be tuned by manually adjusting the air flow rate in the loop and/or the position of the vanes at the inlet to the classifier. The system is typically adjusted to produce a particle size distribution where 70% (mass basis) of the sampled product passes through a 200 mesh (75 µm) sieve.

The maximum capacity of the mill system is 1 t/h of pulverized coal. The milled product is loaded into a plastic lined super sack using a screw auger. The bag is purged with nitrogen during the operation in order to inert the product. Bags that are typically used have the dimensions of 90 × 90 × 90 cm with a maximum storage capacity of 1 t.

3. Measurement and materials

Woody biomass representative of beetle kill, deadfall and slash piles was collected in cooperation with the U.S. Forest Service [33]. The biomass was sourced in the Wasatch Mountains near Tibble Fork in American Fork Canyon and the main species were pinyon pine (Pinus edulis), juniper (Juniperus) and spruce (Picea). The material was shredded to a particle size of about 12 mm minus. The shredded material was separated into 6 portions and each portion was prepared using specific conditions, resulting in 6 configurations of prepared biomass. These are detailed in Table 1, where each is provided a descriptive name for future reference and the preparation conditions and methods are summarized. The 210°C, 248 °C, 290 °C and 325 °C samples were torrefied in rotary kiln with a residence time of 10 min at temperatures found in the sample name. Pellet 1 sample represents a configuration where the shredded biomass was first pelletized without using any additives and then torrefied at 325 °C. Pellet 2 sample represents a configuration where the shredded biomass was first steam exploded (conditions: 20 bar saturated steam, ≈15 min residence time), then the exploded product was rinsed, dried and pelletized. Typically, both type of pellets are 10 to 20 mm long with a diameter of 6.5 mm. The biomass handling and preparation was done by individual companies. Proximate and ultimate analysis was performed on the 6 prepared biomass materials and the raw coal. The results of these analyses are presented in Table 2, where the higher heating value (HHV) of each material is also listed. The composition of Pellet 1 was assumed to be the same as the wood chips torrefied at 325 °C. The temperature of the materials fed into the crusher was ambient.

Each configuration of prepared biomass was mixed with a Utah

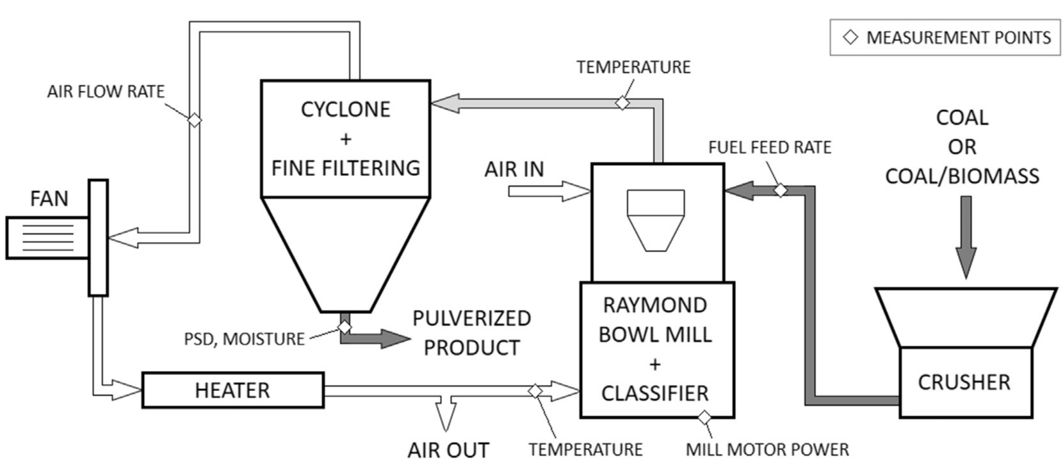

Fig. 1. Schematic illustration of the milling system including the measurement points.