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Research paper

# Effect of grinder configuration on forest biomass bulk density, particle size distribution and fuel consumption

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The effect of the grinder configuration, bit type and screen size, on bulk density and fuel consumption when processing forest harvest residues for energy purposes is analyzed. Residues were divided in three size classes based on the piece diameter and length and were processed in a six treatment structured randomized test using a horizontal grinder. For each treatment the basic density, moisture content, bulk density, particle size distribution, fuel consumption and bark and other non-wood substances content was estimated. No effect of bit type or screen size on bulk density was found when processing branches-and-tops size class residue. For the pulpwood and butt-log-chunks size classes, the knife-edge bits tend to produce a denser material explained in part by their cutting capabilities across the grain compared to the normal hammering process using carbide hammer bits. Fuel consumption was only affected by screen size when processing the branches-and-tops size class. For pulpwood and butt-log-chunks size classes, the use of carbide hammer bits for processing increased fuel consumption between 42 and 48% compared to knife-edge bits. Bark and other non-wood substances content accounted for 11% of the total grinding mixture in the branches-and-tops size class compared to 2.5% in grindings from pulpwood and butt-log-chunks size classes. The branches-and-tops size class residue produced denser bulk material compared to the other classes and consumed less fuel due in part to the higher basic density and increasing amount of fine particles compared to the other analyzed size classes.


## 1. Introduction

Roadside forest biomass recovery operations from harvest residues require the use of processing machinery, such as grinders, to reduce the heterogeneity and increase the bulk density of the mixed residues to facilitate handling and transportation. Grinders, compared to chippers, are less susceptible to contaminants thus making them a feasible alternative for processing harvest forest residues [1,2]. The grinding process reduces the size of the residues by hammering the material using bits (teeth) mounted in a cutting rotor. The residue is then forced to pass through screens until it is finally discharged onto a conveyor. The bit type and the opening size of the screens are two controllable factors that determine the particle size distribution and bulk density of the final product [3]. After processing, the grindings are usually dumped into chip vans that consist of a truck tractor and an open top trailer. Although larger trailers (>24 tons of capacity) are preferable in forest operations, low-standard roads, tight curves and adverse grades can limit access to sites where the residues are being comminuted [4,5]. Since using a larger trailer is often not feasible, other factors such as bulk density and moisture content must be managed to increase truck dry weight payload. Increasing the bulk density of the material in the trailer could reduce transportation cost by increasing the delivered dry wood per trip, thus decreasing the overall cost of the biomass operation. In addition to bulk density, the particle size distribution is important in terms of quality of the final product. In heating plants, oversize particles (>100 mm) can cause bridging problems that may stop the wood flow [6]. Fine particles may also cause a reduction in combustion and affect boiler performance [7,8]. The European Standard for fuel specification and classes of solid biofuels CEN/TS-14961 has defined different categories of wood chips and hog fuel based on the particle size [9]. For liquid

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fuels production, the particle size distribution may influence how downstream processing will be configured to identify the fractions with high carbohydrate content and isolate portions with no sugar content such as soil particles. The amount of bark is also important to quantify, since it contains a lower amount of sugars and several inorganic and extractives components that reduce the energy yield [10].

In grinding operations, both bulk density and the particle size distribution of the final products can be influenced by adjusting the bit type and screens. Carbide hammer bits have dulled edges that are especially designed for processing dirty material due to their high abrasion wear-resistant capabilities. They are made of steel covered with carbide granules to increase abrasion during the cutting. Knife-edge bits do not contain a carbide cover. Knife-edge bits have knife type edges that cut/batter the material against the screens. Knife-edge bits are more suitable to process cleaner material and tend to produce a more homogeneous and denser product [11]. Increases in productivity and decreases in fuel consumption can be expected using knife-edge bits but their useful life is shortened by contaminants [12].

Screens are located in the cutting chamber in the periphery of the cutting drum. Since the area around the cutting rotor is large, several screens are needed to cover the different sections. Different screen pieces can be combined to reduce oversized particles and manage the particle size of the final product [13].

Previous studies have provided some insight about the effect of grinder configuration on forest biomass particle size and bulk density [3,14,and15], however, these studies are often based on observations of active industrial operations as compared to structured tests. In observational studies, uncontrollable and confounding elements can hide or affect the main effects of the factors under study such as bit type or screen size. From these studies some authors have reported that fewer oversized pieces were obtained when using small screens compared to larger ones [3,16]. Fuel consumption tended to increase when using smaller screen sizes as compared to larger screens [3,14], although other authors have reported increases in fuel consumption as screen size increases [16]. In this paper we performed a controlled test to decrease the variation of the system and isolate the effect of bit type and screen size on the particle size distribution and bulk density in order to understand potential trade-offs of some treatments in relation to fuel consumption. Understanding the grinding factors affecting bulk density will help to improve strategies to increase the amount of solid material per trailer per trip in order to decrease transportation costs.

Our hypothesis was that bulk density, particle size distribution and fuel consumption are affected by (a) grinder bit type; (b) grinder screen size; and (c) feedstock size class. The objectives of this study were to: (1) estimate the effect of two types of bits and three different screen sizes on the bulk density of the ground material, particle size distribution and fuel consumption for three feedstock size classes; and, (2) quantify the percentage of bark and other non-wood substances in each of the feedstock size classes. In this study we performed a controlled experiment with fully randomized treatments to minimize the effect of uncontrollable factors in our response variables (bulk density and fuel consumption) and to isolate the effect of the factors of interest (bit type and screen size) for 3 different feed piece classes.

## 2. Material and methods

### 2.1. Forest harvest residue collection and classification

We collected and transported approximately 180 tonnes of Douglas-fir (*Pseudotsuga menziesii*) wet residues from a harvest unit located 25 km north of Springfield, Oregon, USA (44°11′21″N, 122°59′15″W). Residues came from a 40 year-old stand harvested between March and April 2013. Unprocessed residue was transported from the forest to a pulp and paper mill yard using an end-dump truck with a capacity of 76.5 $m^3$. The study was conducted between July–August 2013. At the pulp and paper mill, residues were sorted in three different size classes using a John Deere 200 LC (104 kW) excavator loader.

The separation criteria of the residue were based on the size of collected residue (diameter of the piece and length) and its relation to the available markets for pulpwood and timber. In pulpwood markets with high demand it is expected that logs with diameters greater than 10.0 cm and length of 3.6 m or longer would be removed from the logging site [17] and not available as harvest residues. In non-active pulpwood markets, logs with top diameter ranging from 15 cm to 20 cm may be left in the forest as residues. In addition to the pulpwood and non-pulpwood residue, large diameter butt log chunks can be available. These latter pieces are usually the result of the resizing process of the logs at the landing, particularly to meet export log requirements.

Based on these criteria and the available residue, we established three size classes to separate the residue material (Fig. 1). The branches-and-tops size class consisted of limbs and tree tops with an average diameter of less than 10 cm and an average length of 1.0 m. This class represented the commonly available residue material in active pulpwood markets. The pulpwood size class was comprised of pieces with a diameter ranging from 10 to 30 cm with and an average length ranging from 1.2 to 4.3 m. In low demand pulp and paper markets this material would also be available as residue. The butt-log-chunks size class consisted of pieces greater than 30 cm with an average length of 50 cm. This class was comprised of pieces from the base of the tree and leftovers from the log manufacturing process. We analyzed the effect of bit and screen size combination in each of the three size classes.

### 2.2. Experimental design

A Peterson 4710B (570 kW) track-mounted horizontal grinder was used to process the residues. The cutting rotor of this machine was equipped with 20 bits to hammer the material and force it to pass through the screen area. The screen area consisted of four screens sections aligned next to each other.

In this type of machine the material is first compressed by an in-feed roll that permits a continuous feeding at a constant speed. Once the material is inside the cutting chamber, it is reduced to small pieces by the cutting rotor where the bits are mounted. The bits in the cutting rotor hammer/cut the harvest residue and force the particles to pass through the screens (Fig. 2).

The grinder in-feed speed was set to 6.1 m $min^{-1}$. Cutting speed was fixed to 33.3 Hz. The machine was remotely operated by the same operator in all the trials. We tested two different bit types, carbide hammer and knife-edge (Fig. 3), and three different screen sizes of four hexagon-type grates with opening sizes of 5.0, 7.6, 10.2 and 12.7 cm respectively (Fig. 4).

The machine utilized four screens, two at the top and two at the bottom of the cutting chamber. We tested three different screen size combinations 5.0–7.6 cm (small), 7.6–10.2 cm (medium) and 10.2–12.7 cm (large). The first number in each pair indicates opening size of the two screens that are set at the top of the machine. The second number indicates the screen opening size of the other two screens that are placed below the upper screens. In a combination of screens, the smaller section is usually placed at the top to reduce the proportion of long thin pieces (spears). The larger screens located below the top screens help to avoid significant decreases in productivity [18].