Fuel Processing Technology 134 (2015) 116–121

Contents lists available at ScienceDirect

Fuel Processing Technology

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

Effect of poplar fuel wood storage on chipping performance

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A R T I C L E I N F O

Article history:
Received 15 September 2014
Received in revised form 16 January 2015
Accepted 20 January 2015
Available online 2 February 2015

Keywords:
Biomass
Chips
Decay
Moisture content
Power
Productivity

A B S T R A C T

Similar feedstock consisting of poplar stems and tops was fed to a commercial drum chipper, before and after a 12-month storage period. The chipper was fed alternately with poplar stems and tops, in order to determine the effect of piece size, tree part and storage period on machine performance. At the end of the storage period, both stems and tops were still almost as wet as at the beginning, and they showed visible signs of decay. Before storage, net chipping productivity was 72 $m^3\ h^{-1}$ with stems and 30 $m^3\ h^{-1}$ with tops. After storage, net chipping productivity dropped to 56 and 21 $m^3\ h^{-1}$, respectively for stems and tops. Power and torque requirements were also reduced. Chip quality degraded with storage, as particle size distribution veered towards a larger incidence of the smallest fractions. In particular, fines (particles < 3.15 mm) increased four-fold, reaching the proportion of 11% and 23% in weight for stems and tops, respectively. In general, storage effects were stronger for tops than for stems. Specific fuel consumption was not affected by tree part, storage or their combination.

1. Introduction

Increased global competition for fossil fuel and the need to mitigate climate change have made renewable energy a main priority [1]. Ambitious targets have been set for biomass use, boosting the demand for wood fuel [2]. Wood fuel is available in many forms and in all parts of the world, allowing the deployment of bioenergy almost everywhere [3].

However, diachronic supply and demand create a need for a fuel buffer to secure a steady energy output at all times [4]. Biomass fuel can be stored in many ways, depending on biomass type and local conditions [5]. Biomass stores can be built at the user plant, at wood terminals or directly near the source [6].

Wood fuels are generally comminuted before use, and they can be stored before or after comminution. Immediate comminution improves fuel handling quality and simplifies logistics [7]. Unfortunately, wood chips are very vulnerable to microbial degradation during storage, which often leads to high dry matter losses, reduction of energy value, risk of self-ignition, and potential human health risk due to exposure to airborne microspores [8,9]. A number of storage techniques have been proposed for comminuted wood fuel, aimed at reducing degradation. This can be minimized by storing chips under aerated sheds, or protecting them with transpiring covers [10]. Unfortunately, such measures are quite costly and the advantages gained do not always justify the expense. The problem is especially urgent for short rotation forestry (SRF), which is one of the pillars of the European Union biomass strategy [11]. Tree plantations are generally established with fast-growing species such as willow and poplar, which produce a less durable wood than obtained from other slower-growing species. As a result, poplar chips cannot be stored over long periods, without suffering severe degradation [12].

Storage before comminution still remains among the most effective techniques for minimizing biomass degradation, regardless of tree species [13]. Uncomminuted storage generally implies natural drying, as a result on the negative moisture gradient between the wood and the ambient air. This is the traditional drying system applied to firewood, and it is very effective if handling and storage conditions are properly managed [14]. Drying improves fuel quality, which generally reflects on price [15].

Drying does alter the original properties of wood, and therefore uncomminuted storage may have an effect on the comminution process itself. When drying, wood gets harder and may as a result be more difficult to comminute. This effect may combine with other alterations of wood quality, which are often difficult to predict. Alterations incurred during storage may affect chipper performance and chip quality, eventually reflecting on product cost and value. These effects must be considered carefully when balancing options, and especially when deciding between immediate comminution and delayed comminution. That is crucial to optimizing wood fuel supply chains, in order to reduce the cost of collection, processing and transportation [16]. In this endeavor, chipping represents a key element, because it is a main source of financial and energy cost [17].

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http://dx.doi.org/10.1016/j.fuproc.2015.01.023
0378-3820/

The goal of this study was to determine the effect of storage on chipping efficiency, when dealing with SRF poplar. In particular, this study gauged the eventual differences occurring with power use, productivity, fuel consumption and product quality (e.g. moisture content and particle-size distribution).

2. Materials

The experiment was conducted using a Pezzolato PTH 700/660 (www.pezzolato.it) mobile chipper. This machine was an industrial drum chipper, powered by a large farm tractor, capable of delivering a maximum power of 231 kW. The drum was of the closed type and carried two full-length re-usable blades [18]. The drum measured 660 mm in diameter and 700 mm in width. Cut length was set to 20 mm, and the machine was equipped with a 60 × 60 mm re-size screen, designed to reduce the production of oversize particles. A self-propelled loader was used to load the wood on a steel belt conveyor, which moved it to the feed rollers for pushing against the drum (Fig. 1).

The tests were conducted at the CRA ING experimental farm in Monterotondo, Rome. Before the experiment, 60 trees were harvested from the same SRF plantation established at the farm with hybrid poplar (*Popul*us × *Canadensis* Monch, clone "Neva") eighteen years earlier. Each tree was separated in two parts by crosscutting it where its diameter reached 20 cm. The portion between the base cut and the 20 cm crosscut point was defined as stem, whereas the remaining upper portion with a diameter smaller than 200 mm was defined as top. The study material was then separated in four batches, two per tree part. Each batch contained 30 pieces (stems or tops). One batch of stem and one of tops were chipped immediately after harvest, in March 2012. The remaining two batches were stored in two separate piles, about 2 m tall. Both piles were built at the field edge, near the roadside, and rested on the naked turf. The piles were uncovered, and remained stored in the open air for a year, until they were chipped in March 2013. The elevation of the site was 165 m. Annual precipitation site was ca. 1000 mm, with lows in Summer (ca. 100 mm) and highs in Autumn (over 300 mm). Mean annual temperature was 7.6 for the minimum and 20.3 for the maximum. During both chipping tests (2012 and 2013), the chipper was alternately fed with stems and tops, in order to spread the eventual effect of blade wear [19]. Before starting each test, the operator installed a new set of blades.

3. Methods

The study consisted of four treatments, obtained from the intersection of two tree parts (stem or top) with two periods (before or after storage). Repetitions consisted in the chipping of one piece, either stem or top. The experimental design included 30 repetitions per treatment, for a total of 120. Repetitions were sequenced in blocks of 10, due to field management constraints. Therefore, 10 fresh tops would be fed to the chipper in a sequence, before switching to a new sequence of 10 fresh stems. Blocks were sent to the chipper in random sequence, and the small number of pieces in each block made it unlikely that such grouping would bias the experiment through the effect of knife wear.

The volume of each stem and top was determined right before chipping, with a caliper and a measure tape. Stem volume was calculated on the diameter at both ends (Smalian's formula), whereas top volume was calculated based on the diameter at mid-length (Huber's formula) [20]. These were considered the most suitable methods for the two different tree parts. Total top volumes were obtained after summing the individual volumes of all branches forming each top.

The rotational speed and torque of the power-take-off shaft were measured with a transducer, at a rated accuracy of 3 kNm and a scan rate of 10 Hz. Speed and torque readings were used for calculating power output. Data were processed in real time and therefore researchers could check them as they were acquired [21]. This method has already been used in other studies about chipping, proving quite reliable [22,23].

Fuel consumption was determined after each repetition, by refilling the tractor tank from a can and weighing the can with a precision scale, before and after refilling. Fuel consumption was also determined for the idling chipper, in order to determine a base fuel consumption level.

Effective time consumption was determined at the end of the study, using the power graphs [22]. When a chipper is processing small batches, direct observation cannot accurately determine actual chipping time. Due to the delay between chipping and evacuation, an external observer will see chips coming out of the chipper for a few seconds after the chipper drum is running empty. In contrast, power and torque figures are much better indicators of actual chipping time, because they will be above the baseline power and torque values just for as long as the chipper is actually engaging wood. Once the drum is running empty, power and torque will drop back to the initial baseline values. Therefore, all time when torque or power was above baseline levels was counted as actual chipping time, and used for estimating net chipping productivity.

Three one-kilogram chip samples were collected from each 10-piece block and used for determining chip size distribution. The five following chip length classes were separated: > 45 mm (oversize particles), 45–17 mm (large-size chips), 16–9 mm (medium-size chips), 8–3.15 mm (small-size chips), and <3.15 mm (fines). Furthermore, five additional samples per block were collected in order to determine moisture content, which was done with the gravimetric method according to EN 14774-2. All the chips produced from each batch of ten repetitions were weighed on a certified weighbridge in order to calculate wood density. Dry density was estimated by discounting moisture content.

Data were analyzed with the Minitab statistics software. In particular, the software was used for estimating a general linear model (GLM), especially suited to the factorial experiment just described. Analysis of variance (Anova) tables were calculated, and the sum of squares was distributed between main effects and interactions. Data were transformed before the analysis, if their distribution did not satisfy the normality assumption. Non-parametric techniques were used if transformation did not succeed in bringing data distribution back to a normal bell-shaped curve.

4. Results

The average piece volume of the stems and tops chipped before storage was 0.64 m^3 and 0.25 m^3, respectively. In contrast, the average piece volume of the stems and tops chipped after storage was 0.45 m^3 and 0.13 m^3, respectively (Table 1). It was unclear whether this volume difference was a consequence of decay occurred during storage, or it resulted from an unwanted stratification of the sample stems and tops during collection. As an average, tops were between 2 and 3 times smaller than stems. Average moisture content before storage was 52% for the stems, and 49% for the tops. After storage, moisture content decreased to 49% and 42%, respectively. All piece size and moisture content differences proved significant at the 5% level, according to the Kruskal–Wallis non-parametric test. Green wood density ranged between 700 and 760 kg m^{-3}, while density expressed on a dry basis ranged between 350 and 440 kg m^{-3}. Dry density was higher for tops than for stems, but the difference had no statistical significance. After storage, dry density was unaltered for stems, but it increased by 20% for tops, although this difference was only significant at the 8% level.

Chipping stems required 2.5 times more power and torque than chipping tops. That matched the stem to top volume ratio, which was also 2.5. Neither ratios varied after storage. However, storage resulted in a 20% decrease of both mean torque and power, which was experienced equally for both stems and tops.

Variations were lower for peak torque and peak power. Peak torque and peak power increased between 60% and 80% of the baseline values