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Research article

Increasing wood fuel processing efficiency by fine-tuning chipper settings

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ABSTRACT

Latest chipper models feature new in-feed and evacuation systems that can be adjusted on the fly to match variable work conditions. Proper adjustments of the two systems are expected to produce significant effects in terms of productivity, diesel fuel consumption and chip quality. The study verified such claims by testing one of these new machines in a controlled experiment, conducted under two alternative in-feed and evacuation system settings on two different feedstock types ($2 \times 2 \times 2 = 8$ treatment combinations). Each treatment was repeated 5 to 10 times, depending on feedstock availability. The study showed that feedstock type has a dominant effect on all the studied parameters, whereas in-feed mode has no effect on any of them. In contrast, blower setting has a significant effect and offers a strong potential for increased wood fuel processing efficiency. In particular, decreasing blower speed when full ejection power is not necessary allows reducing diesel fuel consumption between 6 and 16%, while increasing chip integrity by 20%.

1. Introduction

Modern wood-to-energy chains require that wood fuel is comminuted before conversion, i.e. reduced in granular form by chipping or grinding [1]. Processing solid wood into small fragments requires much energy. Studies indicate that comminution is the largest energy user in wood fuel supply systems, and it may represent up to 60% of the total energy consumption along the supply chain [2]. Regardless of exact figures, energy does account for a large share of the overall wood fuel processing cost, and contractors are always looking for ways to reduce their energy bills [3].

Several actions can be taken for improving energy efficiency, productivity and product quality. One step is to match the right machine with the right job [4] and optimize operation layout [5]. Another step is to replace knives at proper intervals to reduce the effect of knife wear, which may cause a significant increase of energy consumption [6]. Finally, productivity, energy efficiency and product quality can be improved by proper adjustments of the chipper work settings, and especially screen size [7,8] cut length [9,10] and chip discharge system [11,12].

This third step is somewhat similar to the fine-tuning now commonly available on modern power packs, where the engine work settings are automatically adjusted to power demand, in order to maximize energy efficiency and minimize emissions [13]. Of course, one cannot adjust the work settings of a chipper as quickly and easily as the settings of a modern diesel engine. However, some of the newest chipper models are equipped with optimized management interfaces that allow rapid adjustment of some devices, and namely: the in-feed and the evacuation systems. These systems are hydraulically powered, which makes it relatively easy to adjust their work settings. Productivity and chip size might be manipulated by managing feeding speed, whereas adjustments of the evacuation system may impact both energy use and chip size.

In all professional chippers, the in-feed system may work according to two separate modes: on-off and proportional. In the on-off mode, feeding speed is constant, but feeding is stopped when the rotational speed of the engine falls below a certain threshold, to avoid stalling the engine. Feeding is then resumed when the engine regains its target speed. In the “proportional” mode, feeding speed varies along with the engine rotational speed, in order to achieve uninterrupted feeding and even workload. However, if the rotational speed of the engine falls below the set threshold despite all efforts to modulate workload, feeding will be momentarily stopped as with the classic on-off mode. Theoretically, proportional feeding should allow a faster work pace, but there is a risk that a continuously variable feeding speed may result in an increased variability of chip size, which would detract from product quality.

Disc chippers do not feature a separate chip evacuation system, but chips are ejected by the power of the disc itself [9]. That makes it impossible to adjust the evacuation system without interfering with the disc. In contrast, drum chippers incorporate a separate evacuation system

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consisting of a blower, which throws the chips through a pipe and into the receiving containers. Moreover, newer drum chipper models are equipped with hydraulic blowers, which allow easy manipulation of rotational speed. Running the blower at a high speed is expected to result in high energy consumption and severe chip fragmentation, but also in a long ejection range, which can be very useful when filling long chip vans from their rear gates. On the other hand, running the blower at low speed is expected to result in low energy consumption, high chip integrity and low product spills when topping up a load from above.

Unfortunately, no solid data are available on the actual benefits of specific in-feed and blower settings. Manufactures and operators can only guess about the benefits of any given setting, but they cannot quantify such benefits, which restrains their ability to optimize chipper settings.

Therefore, the goal of the study was to determine the effect of feeding mode and blower speed on productivity, energy use and chip quality for one of the newest drum chipper models. Since the chipper used for the study was a mobile model powered by a diesel engine, diesel fuel consumption was taken as the reference for energy use.

2. Materials and methods

The mobile chipper used for the experiment was a Pezzolato PTH 1400/820 Allroad (www.pezzolato.it). The machine was powered by a 405 kW Euro 6 Scania engine. The chipper unit featured a 3.5 t drum, with a width of 1400 mm and a diameter of 820 mm. The drum was of the closed type [14], but had 5 staggered small knives instead of the classic two full-length knives. Knives were of the conventional re-usable type [15].

The in-feed system consisted of a lower steel conveyor and an upper feed roller, which pinched the wood and pulled it towards the drum. The system could be adjusted to work alternatively in the on-off and in the proportional modes. In the on-off mode, feeding was stopped when the rotational speed of the engine fell below 115 rad s^{-1}. The chip evacuation system used a hydraulic blower with adjustable speed, varying between 55 and 110 rad s^{-1}.

Both the feeding and the evacuation systems could be adjusted on-the-fly to match variable work conditions. All setting adjustments could be made in a matter of few seconds, through a user-friendly touch screen, installed to the right side of the operator seat.

The tests were conducted in June 2015 at the wood yard of the Mombracco chip-fired power station, in Envie, North western Italy. During the experiment, the machine was alternately fed with two different raw material types: logs and mixed residues. Logs were 2 m long, and consisted of chestnut (*Castanea sativa* L.). The mixed residues consisted of 2 m long slabs salvaged from a local sawmill and 4 m long tops, complete with leaves. Both slabs and tops were hybrid poplar (Populus × Euroamericana). These raw materials were chosen because they were widely available in the area and were often used for chip production.

The experiment consisted of testing the combinations of two in-feed settings (e.g. on-off or proportional), two blower speed settings (e.g. minimum and full-speed) and two different raw materials. Since the availability of poplar residues was quite limited, only 5 replications per treatment were conducted with poplar residues (i.e. $2 \times 2 \times 5 = 20$ total replications). Chestnut logs were in large supply, and 10 replications per treatment were conducted with chestnut (i.e. $2 \times 2 \times 10 = 40$ total replications). Each replication consisted of one trailer load of chips. The same 18 m^3 trailer was used for all replications. Replications were organized in a random sequence of in-feed, blower speed and raw material type treatment combinations, which was facilitated by the fact that the two piles were quite near, and setting adjustments took few seconds only.

Cut length and screen type remained the same for the whole duration of the experiment. In particular, cut length was set at 35 mm and the sieve was a 100 × 100 mm square mesh type. All along the test, the machine was operated by the official test-driver employed by Pezzolato.

Product output was determined by taking the full trailer to the certified weighbridge available on site. The weighbridge had a rated accuracy of 20 kg. One 500-g sample was collected from each replication in order to determine moisture content and particle size distribution. Each 500-g sample was obtained after reduction of a larger sample, assembled by mixing subsamples collected at different points from the chip heap left after trailer dumping. Moisture content was determined with the gravimetric method, according to European standard CEN/TS 14774-2. Fresh weight was determined on-site with a portable scale, immediately after sample collection. Particle size distribution was determined with the oscillating screen method, using four sieves to separate the sample into five chip length classes: >63 mm (oversize particles), 63–45 mm (large-size chips), 45–16 mm (medium-size chips), 16–3 mm (small-size chips), <3 mm (fines). Each fraction was then weighed with a precision scale.

The following data was acquired directly from the CAN Bus: pure chipping time, fuel use, engine torque and speed, blower speed and the number of times the feed rollers stopped as the result of the engine rotational speed falling below the set minimum threshold. Time and fuel inputs were also checked with manual methods, by stop-watching all work time with a Husky Hunter handheld computer, and by refilling the diesel tank with a fuel pump accurate to 0.1 l at the end of each work day. This was done in order to determine if there were any major differences between the manual and the automatic records, and to apply appropriate correction factors if necessary.

The dataset was analyzed with the Minitab 16, SPSS and Statview advanced statistics softwares, in order to check the statistical significance of eventual trends. Before analysis, the data was tested for normality using Ryan-Noyer's test. Non-normal distributions were normalized using transformations. In particular, the logarithm transformation was used for time and fuel consumption data, and the logit transformation for the percent particle size data [8]. The data was then checked for homoscedasticity using Bartlett's test. Transformed data for time, fuel consumption and particle size were linear, normal and homoscedastic and were tested using a general linear model (GLM), which is especially suited to handle unbalanced datasets and is quite powerful. Multiple comparisons were then conducted with the Tukey-Kramer test. In contrast, all the other data were either non-normal or heteroscedastic (or both) and were handled with non-parametric and post-hoc tests, robust to violations of statistical assumptions, although less powerful than the GLM and Tukey-Kramer's test. In particular, the Kruskal-Wallis test was used for checking the presence of statistically significant differences between groups, and the Scheffe's post-hoc test for pinning such differences onto specific groups. Both such tests are suitable for data sets flawed by unequal numbers of observations, non-normal distribution of data and heteroscedasticity [16]. In all analyses, the elected significance level was $\alpha < 0.05$.

Table 1
Characteristics of the raw materials used for the experiment.

Species		Chestnut	Poplar
Material		2 m logs	Slabs, tops
Piece size	kg	72.0[a]	6.4[b]
Moisture content	%	47.3[a]	41.8[b]
Containers	n	40	20
Total output	m^3	1000	500
Total output	t	284.5	106.6
Bulk density	kg m^{-3}	285	213

Notes: moisture content = wet basis; m^3 = cubic meters of loose chips; different superscript letters along the same row indicate statistically significant differences between raw materials for $\alpha = 0.05$, according to Scheffe's post-hoc test.