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The effect of drum design on chipper performance

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ABSTRACT

Chipper design is a main driver of production efficiency within forest fuel supply chains, but little scientific knowledge is available about the performance of different types. Two alternative drum chipper designs were tested on different feedstock types and under different knife wear conditions. The closed drum full-length knife design was more efficient than the open drum staggered-knife design, when negotiating branches, especially when knives were dull. Under these conditions, productivity was higher, fuel use lower and product quality better for the closed drum design. These differences were statistically significant. Therefore, a closed drum design is preferable when branches are the main feedstock, especially if product quality specifications are demanding. In general, the performance of both designs was significantly affected by feedstock type and knife wear.

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1. Introduction

The development of a renewable energy market has boosted the demand for fuel chips, which has grown in the past decades, and it is likely to grow even faster in the next coming years [1]. Matching this demand will require mobilizing the large unutilized forest resource available in many Countries [2]. Such ambitious endeavour can only succeed if all steps in the supply chain are profitable for all parties involved in the business. One crucial operation in the supply chain is chipping, which accounts for a large share of the overall cost [3]. Thus, there is a need to know if one chipper design is inherently more efficient than the others, in terms of productivity, energy use and product quality.

In Europe, chipping in the forest or at roadside landings is dominated by industrial drum chippers [4]. Drum chippers are less efficient than disc chippers [5], but they are less sensitive to feedstock type and offer the advantage of compact size and efficient product screening [6]. Drum chippers come in two main types, depending on drum design. Some chippers mount a closed drum, with one or more full- or half-length knives (Fig. 1A). Others mount an open drum, with multiple short knives in a staggered pattern (Fig. 1B). Both designs are very popular, and much anecdotal evidence is available on the pros and cons of each, especially for what concerns performance with different feedstock types. This anecdotal evidence offer precious insights, but cannot be generalized and adopted as a stable reference.

The aim of this study was to compare the specific effect of closed and open chipper drum design on productivity, power demand, fuel consumption and product quality, using different raw material types. This was done running both machine types under controlled conditions for a fair evaluation of what drum design was best for each specific set of conditions.

2. Materials

Two commercial chipper models were selected to represent the two drum designs. A Pezzolato PTH 700/660 represented the closed drum type, and a Mus-Max Terminator 7 the open drum type. The machines had almost identical characteristics, except for drum design. Drum diameter and drum length were about the same, and so were the dimensions of their in-feed openings (Table 1). Both machines were set for the same cut length, and equipped with a 80 × 80 mm square mesh screen. In both cases, knives were made of high-grade cold working alloy steel, of the 1.2631 type. Knives were hardened to 57 ± 1 HRC (Rockwell scale). Both chippers were

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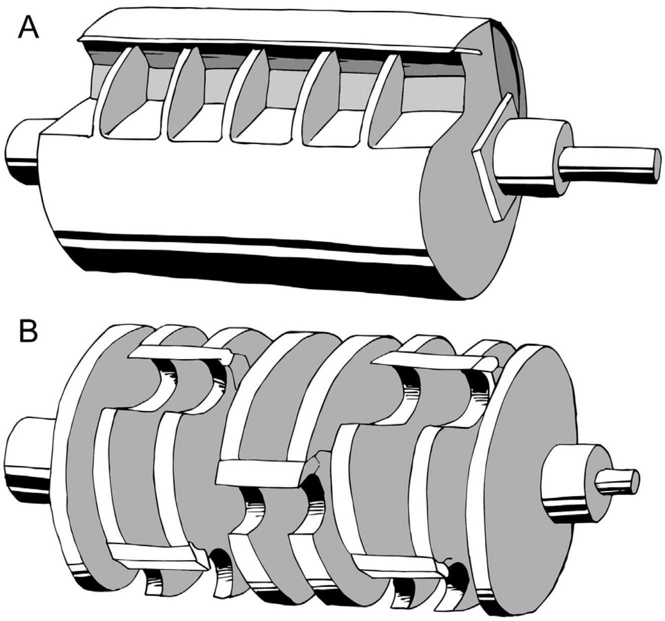

Fig. 1. The two main drum chipper designs: closed drum with full-length knife (A) and open drum with staggered short knives (B).

alternately connected to the rear power-take-off (pto) of the same farm tractor, a Case IH Maxxum 140. The rotation regime of the tractor pto was set to the 1000 rpm standard speed, as recommended by the chipper manufacturers. The maximum pto power of the tractor was 112 kW.

The tests were conducted in May 2013 at the wood yard of the Mombracco chip-fired power station in Envie, Northwestern Italy. Both machines were alternately fed with two different feedstock types: chestnut (Castanea sativa L.) logs and chestnut branches. Both feedstock types were fresh and came in pieces with an approximate length between 2 and 4 m. Mean large-end diameter was 26 cm for the logs and 7 cm for the branches. The average moisture content was 49% and 34% for logs and branches, respectively. These feedstock types were chosen because they were widely available in the region, and often used for chip production.

3. Methods

The study included 12 repetitions per combination of drum design, feedstock type and knife condition, totalling 96 repetitions (2 drum designs × 2 feedstock types × 2 knife conditions × 12 repetitions). Each repetition consisted of a grapple load of material,

Table 1
Technical characteristics of the two machines on test.

Type	Closed drum	Open drum
Make	Pezzolato	Mus-Max
Model	PTH 700/660	Terminator 7
Drum diameter, mm	660	600
Drum width, mm	640	600
Weight, kg	840	750
Knives, no.	2	8
Cut length, mm	20	20
Screen, mm	80 × 80	80 × 80
Infeed width, mm	600	600
Infeed height, mm	500	500
Drum speed, rpm	790	750

corresponding to ca. 100 kg for branches and 200 kg for logs. The amount of material used was kept small, in order to contain the effect of blade wear and to guarantee that the machine was under continuous load for the whole duration of each test. It is difficult to feed large amounts of material to the chipper in a uniform way, and uneven feeding is likely to generate “jagged” load graphs, with peaks and lows, which are more difficult to analyze.

Feedstock types were fed to each chipper in a random sequence, in order to dampen the influence of progressive blade wear [7]. Both machines were tested under two different knife conditions: new and worn out. 24 repetitions per chipper were conducted with brand new knives, and 24 repetitions were conducted with the same knives, after artificial dulling with a grinder. A skilled technician removed 1 mm of steel from the knife tip, equally on all knives. This way, it was possible to reproduce exactly the same level of dulling on both chippers, in order to maintain even test conditions.

Torque was measured with a strain-gauge based torque meter, with a measurement accuracy of 0.7 Nm. Fuel consumption was measured with a volumetric fuel meter directly connected to the engine feed lines (send and return line), with thermocouples for calculating appropriate temperature correction factors. Fuel meter accuracy was 0.04 L h^{-1}.

All sensors were connected to a pc-based multichannel acquisition system that filtered, processed, displayed and recorded all incoming signals (Fig. 2). The sampling rate was set to 250 units per second, using 3 analogue (torque meter bridge and thermocouples) and 2 digital channels (speed sensor and fuel meter). The acquisition software was configured for real-time processing of acquired data.

Effective time consumption was determined on the power consumption graphs, rather than by timing the actual work [8]. When a machine is processing small batches, it is difficult for an external observer to accurately determine when the machine is working and when it is running idle. To determine the beginning and the end of process time, all graphs were analyzed in order to estimate a basal power and fuel consumption figure, taken as a reference for the running machine before its drum actually engaged the wood. These reference figures were adopted as the thresholds for defining actual chipping time. All test time when fuel consumption or power output was above these levels was counted as chipping time and used for calculating net chipping productivity. Average fuel consumption when chipping was also calculated on the records above the idling threshold.

Output was determined by weighing all wood chips produced within each repetition. The chips were collected in a metal bin under the chipper spout. The bin was connected to a forklift with a strap and a hook. The hook contained a 100 kN load cell, with a rated accuracy of 10 N, which downloaded all weight data into the main pc-based multichannel acquisition system.

A single one-kg sample was collected from each repetition for determining moisture content and particle size distribution. The former was obtained with the gravimetric method, according to European standard CEN/TS 14774-2; the latter with the oscillating screen method. Five sieves were used to separate the six following chip length classes: >100 mm, 100–63 mm, 63–45 mm, 45–16 mm, 16–3 mm, <3 mm. Each fraction was then weighed with a precision scale.

Power (kW), time (s t^{-1}), fuel (l t^{-1}) and energy consumption (J t^{-1}) per oven dry tonne were used as response variables in the statistical analyses. General linear models in SAS were used for the analyses of the factorial design, and treatment means were compared with Tukey hsd tests [9]. Results were considered as significant if $p < 0.05$. Due to the interaction effects in the analysis of the full data, separate analysis for each drum design was made as

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