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Effect of Chipper Type, Biomass Type and Blade Wear on Productivity, Fuel Consumption and Product Quality

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Abstract

The study determined the time consumption, fuel consumption and chip size obtained with two different industrial chippers, working with logging residues (tops and branches), thinning material and pulpwood. Specific time consumption per oven dry tons (odt) was 83% higher for the less powerful disc chipper, and chipping forest residues resulted in a 35% increase in specific time consumption compared to chipping thinning material. What is more, the interaction between the two factors pointed at a different suitability of the two machines to chip different materials, since the difference in specific time consumption between the drum and the disc chipper was larger when chipping forest residues rather than thinning. Specific time and fuel consumption of the more powerful drum chipper increased by 30% and 39%, respectively, when working with dull blades compared to working with sharp blades. The best product quality was obtained when applying the disc chipper to pulpwood material. However, the same machine produced more fines when fed with forest residues.

Keywords: chipping, disc, drum, fuel consumption

1. Introduction

Nordic countries are innovators in the use of wood biomass for energy purposes. In Sweden, the utilization of forest residues started in the early 70s after the first oil crisis and increased dramatically since the late 90s (Mälkki and Virtanen 2003). In 2009 bioenergy accounted for 28.4% of the Swedish energy use (110.3 TWh) (Anon. 2010) and most of this came from woody biomass. Swedish heating and CHP plants generated 26.6 TWh of heat and electricity from wood chips and 5.8 TWh from wood pellets and briquettes in 2009, which increased to 30.0 and 6.6 TWh, respectively, in 2010 (Anon. 2011). Further amounts were used by the forest industry itself, to generate process heat (Björheden 2011).

Chips are obtained from sawmill residues (mostly saw dust and bark) and from forest operations. Final cuts generate large amounts of logging residues, while pre commercial thinning operations offer small trees, unsuitable for other uses (Ranta 2005). Both sources of biomass explain the strong connection between the energy sector, forestry and forest products industry (Hillring 2006). Since most biomass used in Sweden originates from the forests, forestry and forest industry represent key sectors for the Swedish biofuel market (Ericsson and Nilsson 2004).

An increasing demand for solid biofuels requires increased efficiency in the supply chain, in order to avoid increased fuel costs (Björheden 2011). The cost of the whole chipping or comminution system represents a significant component of the overall supply chain expense. In particular, fuel costs account for a large share of the overall cost incurred by chipping contractors (Granlund 2011). Comminution also represents about 30% of the total sulfur dioxide, total suspended particles and carbon monoxide (SO_2, TSP and CO) emissions generated by the forest energy supply chain (Mälkki and Virtanen 2003). In order to reduce emissions and contain supply cost, it is crucial to increase the productivity or reduce the fuel consumption of chipping operations. This can be done by manipulating several variables, and especially machine selection, feedstock type and knife sharpness (Nati et al. 2010).

Chipping is the most efficient when performed at the plant or at a terminal using a large stationary machine, which explains the keen interest towards terminal based logistics (Kärha 2011). However, chipping increases the density and homogeneity of forest residues, which justifies its application early in the supply chain (Björheden 2008). Chip trucks have a higher payload than trucks for loose residues, which allows substantial savings on transportation cost. Thus, chipping at the roadside landing results in the lowest total costs of chipping and transportation, when the chips are moved over medium and long distances. That is well known to Swedish fuel suppliers, who in 2009 chipped 80% of the logging residues at roadside landings, 15% at plants or terminals after transportation in loose form, and only 5% at plants or at terminals after transportation as bundles (Brunberg 2011). Currently, roadside chipping is the dominant chipping technique in Sweden as well as in other European countries. That also accounts for Italy, where terrain and roadside chipping are prevalent because of increased efficiency of transportation to the plant (Spinelli and Hartsough 2001). That explains the large popularity of mobile chippers, despite the superior chipping performance of stationary units (Spinelli and Magagnotti 2010a).

2. Materials and Methods

The study tested two different chippers used for roadside chipping. The drum chipper used was a Jenz HEM 561, powered by a 246 kW Claas Xerion, equipped with a crane and a grapple for grabbing the material to be chipped. The drum was equipped with 20 disposable micro knives. A 80 x 80 mm screen was placed between the drum and the evacuation system, in order to reduce the amount of oversize particles (slivers). The produced chips were blown directly into 40 m^3 containers that were set out on the landing by the container truck or a tractor. Trials with this chipper were carried out at two different locations in south western Sweden. Logging residues of mainly birch and spruce from a final felling were chipped at Skultorp (N 58 20.268 E 13 51.267), and thinning material was chipped near Tibro (N 58 25.216 E 14 04.980). The thinning material consisted of 5 m long tree sections of mainly deciduous tree species (aspen, alder and birch). As the availability of residues was good, chipping of logging residues were run with used blades in good conditions (henceforth called »good«) and artificially dulled blades in order to test the effect of blade wear. The procedure was realized by the chipper operator by means of an angle grinder, in order to reproduce the effect of several working hours. During the tests, carried out in October 2010, 14 full 40 m^3 containers were produced – 5 using logging residues and sharp knives, 3 using logging residues and blunt knives, and 6 using tree sections from thinning. These corresponded to 84 and 58 green tons of chips (40% m. c.), respectively.

The disc chipper was a TS 1200 powered by a 147 kW independent engine and mounted on a John Deere 810D forwarder. The forwarder also carried a dumping bin, with a capacity of 13 m^3 loose. This set-up gives the machine an increased off road mobility and the contractor used it to some extent for chipping in the forest stands. The disc chipper comminuted mixed hardwood and spruce logging residues at a landing near Mariestad (N 58 35.873 E 13 42.658), and mixed birch/pine pulpwood from a thinning at the biomass terminal in Götene (N 58 31.351 E 13 29.071). During the tests 6 containers of chips were produced, 3 using forest residues from a final felling and 3 using pulpwood from thinning. These corresponded to 23 and 22 green tons of chips (40% m. c.), respectively. As 36 m^3 containers were used, only 2 bins were dumped in each container. During transport between the chipping site for logging residues and the place where the containers could be set out, the chipper engine was turned off. The tests were run with sharp blades and, for organizational reasons, no artificially wore blades were used. There was no significant difference in the moisture content of different material types, since all had been left to dry over the summer, which is common practice in Nordic countries (Suadicani and Gamborg 1999). The material was all in reach of the feeding boom, and the machine was sitting at a single location until the container was filled up.

Time studies were carried out at the cycle level in order to measure time consumption and calculate productivity. Both productive and delay time were measured, but the analysis was conducted on productive time only. This was partly done to avoid the confounding effect of delay time, which is typically erratic (Spinelli and Visser 2009), but also as the studies were far too short to record representative delay times. Time was recorded with Allegro hand held computers, equipped with Skogforsk SDI software. Both chippers discharged chips into containers, and a full chip container was then assumed as a single cycle, and considered as a replicate. Due to the amount of available material and a somewhat limited machine availability for the disc chipper, the number of containers produced differs between the trials.

Chip output was measured by taking all containers to a certified weighbridge, where both the filled and empty weight of each container was recorded. Each container was identified with appropriate labels, in order to match its weight to the chipping time. A 10 dm^3 sample of chips was taken from each container for determining moisture content and particle size distribution. Moisture content determination was conducted on subsamples, collected in sealed bags and weighed fresh and after drying at 105° C to constant mass (i.e. according to SS-EN 14774-2). Moreover, wood chip quality was assessed by sieving the wood chips according to the SIS-CEN/TS 15149-1 standard. Five sieves were used to separate the six following chip length classes: > 63 mm (oversize particles), ≤ 63 – 45 mm (large-size chips), ≤ 45 – 16 mm (medium size chips), ≤ 16 – 8 and ≤ 8 – 3 mm (small size chips), < 3 mm (fines). Each fraction was then weighed with a precision scale.

Chipper fuel consumption was measured for each container, by starting with a full diesel tank and refilling it every time a cycle had been completed and a container load had been produced. To this end, the filling pump was equipped with a fuel reader, with an accuracy of 0.01 dm^3. The evaluation of fuel consumption concerned the motive power for both of the chipping systems, the Claas Xerion on one hand and the independent engine of TS1200 on the other hand.

The studies were conducted on commercial operations and not under controlled conditions. The analysis was divided in two parts. The first part consisted of comparing the two machines equipped with new and good blades on two different feedstock types, namely: residues and thinning material. The second part consisted of an analysis of the effect of different levels of blade wear on chipper productivity and fuel consumption. Material availability was limited to the landing were the Jenz chipper worked on logging residues.

Data were analyzed with the SAS advanced statistics software, in order to check the statistical significance of the possible differences between treatments (SAS 1999). In particular, analysis of variance was used to determine the effect of machine type, feedstock type and blade wear levels on specific time and fuel consumption. χ^2 tests were used in the comparisons of particle size distribution. The assumed significance level was 5%.

3. Results

Table 1 shows the effects of machine and feedstock type on specific time consumption in minutes per oven dry ton (odt). These figures refer to actual chipping time, excluding the time taken by other activities, such as accessory work (moving of the loads, load transfer, etc.) and delays. In particular, chipping time accounted for 46.1% and 30.6% of total worksite time for the drum and disc chipper, respectively.

Table 1 Total effective chipping time indicated as cmin odt^{-1} for different machines and materials (standard deviation in parenthesis)

Machine	Material	
	Residues	Thinning
Jenz 561	336.9 (19.5)	300.9 (17.5)*
Jenz 561, dull knives	390.3 (2.3)	–
TS1200	701.1 (167.8)	466.3 (24.4)**

* Chipping of tree sections

** Chipping of small diameter pulpwood

All the analyzed factors had a significant effect on the specific time consumption absorbed by chipping (Table 2). The specific time consumption per odt was 83% higher for the less powerful TS chipper, and chipping forest residues from final cuts resulted in a 35% increase in specific time consumption compared to chipping small trees from thinning material. What is more, the statistical significance of the interaction factor shows that there is a significantly larger difference between the two chippers when chipping logging residues than when chipping thinning material (Table 2).

The same was not verified for specific fuel consumption, where the only significant difference could

Table 2 Relationship between machine and material on total effective chipping time expressed as cmin odt^{-1}

Source	DF	Type III SS	Mean Square	*F* value	Pr > *F*
Machine	1	271 382.0715	271 382.0715	58.23	<.0001
Material	1	70 989.1853	70 989.1853	15.23	0.0018
Machine * Material	1	38 271.7114	38 271.7114	8.21	0.0133

be attributed to machine type (Table 4). The less powerful TS chipper used 28% less fuel per oven dry ton, compared to the more powerful Jenz (Table 3).

In the second part of the test, analysis of the Jenz results when chipping logging residues showed that time consumption increased by 30% (p = 0.004) and fuel consumption by 39% (p = 0.001) when working with dull blades, compared to working with sharp blades.

When chipping thinning material (pulpwood), the disc chipper produced significantly more chips in the 16 – 45 mm category and significantly less fines (< 3 mm) and oversized chips (> 100 mm) than was produced with any other chipper and material combination. However, the same machine gave significantly higher amounts of oversized material than any other combination when fed with logging residues (Fig. 1) resulting in a product unsuitable for non-industrial biomass systems. Also for the drum chipper the thinning material produced significantly more chips in the 16 – 45 mm category and significantly less fines (< 3 mm) and oversized chips (> 100 mm) than when logging residues were chipped.

Table 3 Fuel consumption expressed as $dm^3\ odt^{-1}$ for different chippers and materials (standard deviation in parenthesis). Thinning material is tree sections for Jenz 561 and small diameter pulpwood for TS1200

Machine	Material	
	Residues	Thinning
Jenz 561	2.43 (0.12)	2.26 (0.17)*
Jenz 561, dull knives	3.12 (0.15)	–
TS1200	1.68 (0.23)	1.66 (0.17)**

* Chipping of tree sections
** Chipping of small diameter pulpwood

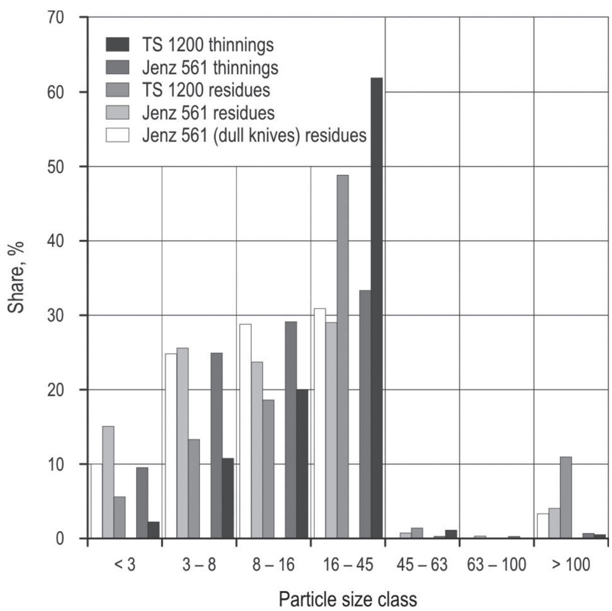

Fig. 1 Classification of woodchip according to standard

4. Discussion

The first part of the study confirms previous knowledge and offers interesting hints at new aspects, which should receive specific attention in the future. Other studies have already shown that specific time (Spinelli and Magagnotti 2010b) and fuel (Van Belle 2006) consumption are inversely proportional to machine power and piece size. In the present study there was no significant effect of material type on fuel consumption per odt and however the effect of the chipper used was significant. This confirms that disc chippers are more fuel efficient than drum chippers (Spinelli et al 2013) and that the fuel consumption per hour is proportional to the productivity. Furthermore, not all studies agree on the effect of piece size on specific fuel consumption (Spinelli et al. 2011a). Spinelli also reports of a higher fuel consumption at around 3.2 l odt^{-1} than the one in this study. Such difference is likely related to different data collection methods, since the study by Spinelli et al. (2011a) refers to pure chipping time, excluding all time when the chipping unit was not working. In that case, fuel consumption was recorded with a flow meter, and only when the drum was engaging the wood and the engine was un-

Table 4 Relationship between machine and material on fuel consumption (l odt^{-1})

Source	DF	Type III SS	Mean Square	*F* Value	*Pr* > *F*
Machine	1	1.65462675	1.65462675	55.97	<.0001
Material	1	0.03543882	0.03543882	1.20	0.2950
Machine * Material	1	0.02269759	0.02269759	0.77	0.3981

der a workload. In the current study, fuel consumption was recorded by refilling the tank after each container load, so that the average fuel consumption figures accounted also for all inevitable short reductions of engine load, such as when the loader was handling wood and the chipper was running idle, waiting for new material to be fed. Each cycle lasted at least half an hour, so that the accumulated micro pauses were likely to have a significant impact on fuel consumption, and produce a different figure from those reported by Spinelli et al. (2011a).

In this respect, it should be taken into consideration that the figures in this study refer to chipping time only, excluding all accessory work time and delays (Björheden et al. 1995). These figures are ideally suited for comparisons of different chippers and work methods, but do not reflect long term productivity levels per scheduled work hour. In particular, delays represent a significant proportion of a chipper's scheduled work time, and may occupy up to 50% of the total worksite time (Spinelli and Visser 2009). In actual operations, the effect of delays may blur the eventual differences related to the characteristics of machine, material and blade conditions.

The comparison between chipper types shows that the disc chipper offers excellent results with thinning material, but is not well suited to handle forest residues as it produces far too much oversized chips for a non-industrial use (UNI EN 14961-4:2001). This is something that many practitioners have stated but it has not been confirmed in earlier studies (cf. Spinelli et al. 2013). It may be argued that the thinning material was not exactly the same for both machines, since the Jenz handled tree sections while the TS was fed with delimbed pulpwood. However, lengths and diameters were almost the same, and the amount of branches on the tree sections was limited, so that this difference was unlikely to introduce a significant bias.

The data on fuel consumption indicate that the smaller disc chipper used significantly less fuel per oven dry ton, compared to the larger drum chipper. That goes against the basic tenets of scale economy, which seem to be verified also for the specific fuel consumption of disc chippers (Marchi et al. 2011), but confirms the results of Spinelli et al. (2013) that disc chippers are more fuel efficient than drum chippers. The lower specific fuel consumption of the disc chipper was at least partly related to a different power transmission and to a different use of the available engine power. The drum chipper was powered by a tractor PTO and through a belt transmission and may have suffered higher power train losses than the disc chipper, which was powered directly through a belt transmission. More importantly, the engine powering the drum chipper was also used to run the loader while the independent engine mounted on the disc chipper powered the chipper only. On the disc chipper, the loader was powered by the engine of the forwarder. The fuel consumption of the forwarder was not recorded, because the forwarder was also used for moving the loads to the load transfer site, and for lifting and tilting the chip container during the load dumping phase. Hence, the recording of forwarder consumption while using the loader would have been rather complicated, due to the need for separating the consumption incurred during the load transfer phases. For this reason it was excluded from the measurements. Hence, it is not possible to state that the lower specific fuel consumption of the disc chipper was caused by the disc chipping mechanism only.

While the results of the current comparison between disc and drum chipper cannot be assumed as conclusive due to the above-mentioned limitations, they certainly hint at very interesting trends, which is worth exploring with further research on the different performance of disc and drum chippers.

The data obtained in the second part of the study closely match the results presented by Nati et al. (2010), who conducted a similar research with a drum chipper. Their study reported increases in specific time and fuel consumption of 50% and 22%, respectively. The corresponding figures in this study are 39% and 30%, instead. The difference is indeed minor, considering the variability of differences of material chipped, different chipper models and operator work techniques. In particular, the chipper studied by Nati et al. (2010) was equipped with two large re-usable single piece knives, whereas the chipper used for the present study used multiple disposable micro knives. The two different types of knives and knife set-ups may have had different wear patterns, so that one type may have lost its efficiency faster and steeper than the other. Operator effect could also be a main source of variability (Purfürst and Erler 2006), since it may account for productivity differences up to 77% in harvester work (Harstela 1988). Feeding a chipper is a simpler job than felling and processing trees with a harvester, and therefore differences may not be as large as reported in harvester studies. Nevertheless, operator technique may well explain part of the differences found between the two studies. What is more, none of the studies included a quantitative measure of knife wear, as it could be indicated by measuring the sharpness angle of the knives or other similar parameters. Blades were considered dull when the respective operators reputed they could not effectively work much longer. Such a subjective criterion is likely to introduce substantial differences between the studies, hence the importance of their general agreement on a common order of magnitude. These figures can be used to calculate a rough breakeven point, beyond which the savings inherent to the extended use of worn chipper blades are lower than the additional cost caused by blade wear. Knives should be replaced when this point is reached. This study only provides the starting (new blades) and arrival (dull blades) points for blade wear, and does not allow this calculation to be conducted. Further research should address this point, as well as the actual difference between the drum and disc chipping mechanisms in terms of productivity, fuel consumption and product quality.

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