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HOW BLADE WEAR OF CHIPPERS CAN AFFECT FUEL CONSUMPTION AND WOOD CHIP SIZE DISTRIBUTION

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Abstract: *This paper presents the results of a research conducted on the effect of wearing chipper knives on machine performance - in terms of productivity and fuel consumption - and particles size distribution. Blade wear causes a significant reduction of chipping productivity and a remarkable increase of fuel consumption. For the same screen type and knife wear level, productivity and fuel consumption are the same for the two species analyzed, poplar and pine. The use of a narrower screen has a similar effect, further decreasing productivity and increasing fuel consumption. Concerning chip size distribution, chips produced from logs always contain a smaller proportion of oversize particles and a higher proportion of accepts. For the same large mesh screen, poplar chips tend to be larger than pine chips and to restrain a higher proportion of oversize particles. Conversely, pine chips tend to be smaller and to contain a higher proportion of fines.*

1. Introduction

Wood chips characteristics, as moisture content, ash content, percentage of fine particles, and particle-size distribution, are essential when wood is used as fuel or for industrial purposes (Asikainen and Pulkkinen, 1998). For solid bio-fuels particle size distribution is a crucial parameter for an efficient combustion at heating plants (Hartmann et al., 2006) and is also important during storage, as it affects caloric value (Kofman and Spinelli, 1997) and durability (Nellist, 1995).

A European standard (EN, 2010) defines quality parameters and classification of solid bio-fuels, also for the purpose of increasing the opportunities for international trade. So oversize particles (sticks), should be avoided, because they tend to stick together, hindering the boilers feeding. For different considerations, fines under 3 mm of length (wood dust) should be excluded because they can be a health hazard due to the limitation of air flow during storage, supporting bacteria diffusion, with an increased risk of combustion (Garstang et al., 2002). As stated by some Authors (Spinelli et al., 2005), wood chips size depends on chipper type, besides on tree part (branches, stems or logs), tree species, knife setting and screen type (Alakangas, 2005).

This paper shows the results of a study carried out with the aim to analyze the potential influence of blade wear and screen type on wood particle size for two tree species, different feedstock and screen types. Moreover a time study was conducted on the chipper in order to estimate how productivity and fuel consumption change as a consequence to increased knife wearing.

2. Materials e method

The study was conducted on a drum chipper, powered by a 420 Hp independent engine, fitted with two different screen types, a medium one (60 x 40 mm rectangular holes) and a larger one (60 x 240 mm rectangular holes).

Chipping operations were carried out on two tree species, a broadleaved and a conifer: hybrid poplar (Populus x euramericana Guiner), on which only the larger screen was used, and Eastern White pine (Pinus strobus L.), on which both the screen were tested. In both cases raw material consisted of residues – branches, tops – and logs, that were comminuted separately. Three batches of tests were carried out, each beginning when a new set ok knives was mounted on the drum and finishing when the operator resolved to install a new one (Table 1).

Table 1. Experimental layout: every test begins with a new set of knives and lasts until knives need replacement

Species	N. test	Screen type (mm)	Raw material
Hybrid Poplar	1	60 x 240	Tops and branches
			Stems
White Pine	2	60 x 240	Tops and branches
			Stems
	3	60 x 40	Tops and branches
			Stems

For each cycle, corresponding to the time required to fill up a standard truck container (app. 10 tonnes), the authors performed a time-motion study, measuring time and fuel consumption, as well as load weight (Table 2).

Table 2. Tests data

	Large screen (60 x 240 mm)		Medium screen (60x40 mm)
Place (Province)	Savigliano (CN)	Biella (BI)	Voghera (PV)
Number of loads	11	8	4
Tree species	Poplar	Pine	Pine
Average Moisture content (%)	46.8	59.1	59.0
Biomass produced (green tonnes)	285	249	116
Average productivity (t h-1)	28.4	29.2	23.5
Average fuel consumption (l t-1)	0.72	1.09	1.22

The time study was conducted according to the continuous-timing method (Bergstrand, 1991) and collected by means of a stopwatch. Load weights were measured by taking the trucks to a certified weighbridge. Fuel consumption was determined by starting with the chipper fully tanked and recording the decrease in the tank level at the end of each cycle with a graduated stick.

Particle size distribution and moisture content were determined on wood chip: four samples were collected when starting to fill a truck container and four when the container was half full. Each four-sample batch consisted of two samples of branches and two samples of logs. Wood chips, which were sealed in polyethylene bags to avoid drying, were tagged and weighed with a precision balance, then placed in aluminum trays and put in a ventilated oven at 103 ± 2°C.

Particle size distribution was determined according to the National Recommendation CTI SC09 R03/01, because at the time of this study the European technical specification (CEN/TS, 2006), improving some criteria of classification, had not been issued yet.

Data were analyzed with multiple regression techniques using the Statview advanced statistics software (SAS, 1999). Indicator (dummy) variables were created in order to test the significance of any effects attributed to non-numeric variables, such as: tree species (pine or polar), tree part (branches or logs) and screen type (large or medium). This technique is often used in forest engineering studies, and is considered a simple and reliable way to check the effect of these variables (Olsen et al., 1998).

3. Results and Discussion

The average duration of a set of blades was 216 tonnes, corresponding to about 7 truck loads. Chipper productivity was significantly influenced by blade wear and screen size, as shown in Figure 1.

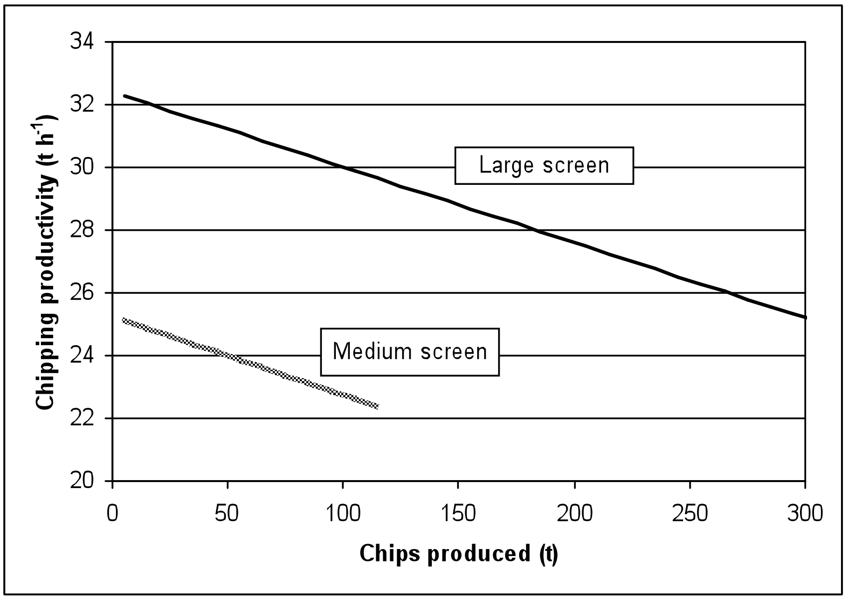

Figure 1. Chipping productivity related to screen size and amount of chips processed with the same knives

These parameters could explicate 70 % of the variation recorded for chipper productivity, and they were all statistically significant. Conversely, the effect of species, had no statistical significance. After chipping 215 tons of wood the net productivity reached 5 green tons per hour, with a decrease in net productivity of 15 %. Only net chipping productivity was considered, because delays can embody a significant proportion of a chipper's scheduled work time (Spinelli and Visser, 2009), thus reducing the actual productivity and potentially evening out differences, at least in part.

As represented in the graph in Figure 2, it exists a positive correlation between fuel consumption, blade wear and screen type.

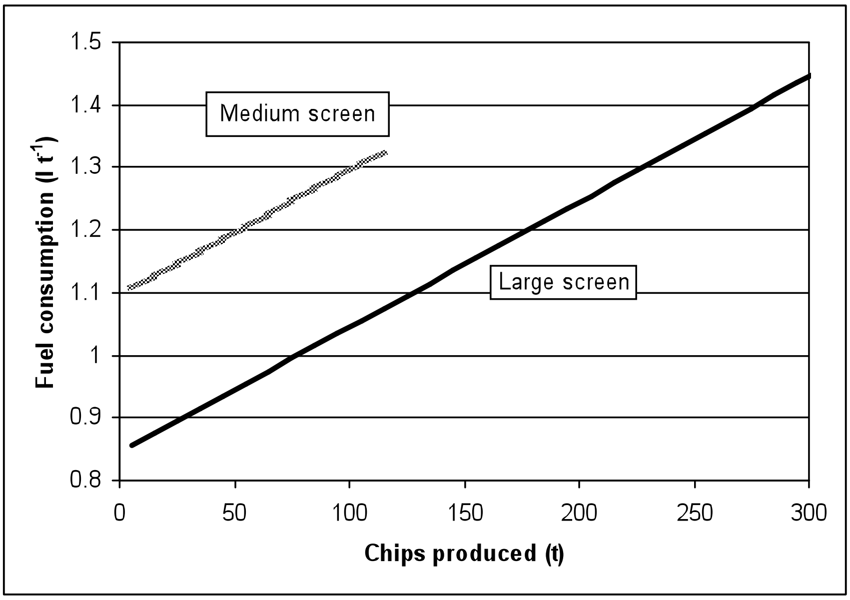

Figure 2. Fuel consumption related to screen size and amount of chips processed with the same knives

Again, these variables could explain the 60 % of the variation in fuel consumption, and their effects were proven statistically significant by regression analysis. Fuel consumption increased by 49 % of the initial value - surveyed with new knives - after chipping 215 tons of wood. No significant effect could be detected for tree species, so that the specific fuel consumption can be expected to be the same for pine and poplar.

In Table 3 are reported the results of the particle size analysis. All treatments generated on average a significant quantity of accepts (particles within commercial size specifications), which varied from 88 to 95 %, in weight.

Table 3. Chips size distribution for different tree species and tree parts (%)

	Poplar logs			Poplar branches		
Fraction	Avg.	min	max	Avg.	min	max
>100	2.1	0.0	17.9	7.4	0.0	34.5
100-63	1.5	0.0	8.7	2.3	0.0	9.8
63-45	1.0	0.0	8.1	1.7	0.0	13.3
45-16	65.1	41.0	85.1	53.2	36.9	66.9
16-3	29.0	7.9	49.2	33.4	18.8	50.7
<3	1.2	0.1	4.6	1.9	0.6	5.0
Accepts	*95.1*	*79.5*	*99.6*	*88.3*	*64.5*	*98.9*

	Pine logs			Pine branches		
Fraction	Avg.	min	max	Avg.	min	max
>100	0.0	0.0	1.1	0.3	0.0	6.1
100-63	0.3	0.0	6.5	0.2	0.0	3.9
63-45	0.6	0.0	6.8	0.9	0.0	9.0
45-16	48.4	11.6	83.6	40.7	14.7	66.9
16-3	45.1	10.6	82.4	47.6	26.5	65.9
<3	5.6	0.3	23.8	10.3	2.0	22.1
Accepts	*94.1*	*76.2*	*99.5*	*89.2*	*77.9*	*95.5*

The regression analyses conducted to this end took account only variables with a significance level of $p \leq 0.05$ (Table 4). Particles longer than 63 mm (oversize particles) augmented rapidly with the amount of chips processed (about 0.5 % per 25 t trucks) and were significantly more frequent in the chips produced from branch material and from poplar.

Table 4. Regression equations relating the percent proportion of a given particle size class to blade wear, tree species, tree part and screen type.

Class	R^2	F-Value	Intercept	t	Branches	Poplar	Screen
>63	0.506	116.512	-1.925	0.022	3.454	3.749	no effect
45-16	0.486	80.263	51.385	-0.037	-10.027	18.014	-3.749
16-3	0.477	77.604	42.963	0.018	3.518	-16.108	5.596
<3	0.612	179.203	6.749	-0.004	2.528	-5.858	no effect
Accepts	*0.361*	*64.28*	*95.176*	*-0.002*	*-5.982*	*2.109*	*no effect*

Legenda: t = fresh tonnes processed by the current set of knives; Branches = indicator variable for branch material, equals 1 if tree part is branches, 0 if logs; Poplar = indicator variable for poplar material, equals 1 if tree species is poplar, 0 if pine; Screen = indicator variable for medium size screen, equals 1 if screen size is medium, 0 if large

Contrary to expectation, the size of the screen did not have any significant additional effect. The amount of dust was significantly higher in chips produced from branch material and from pine, maybe related to the presence of needles. Pine chips tended to be smaller than poplar ones and they also included very little oversize particles. On the other hand, poplar produced larger chips and a significantly higher proportion of oversize particles, which might be related to different wood properties.

The chips produced from branches had a significantly lower proportion (- 6%) of accepts, which were also lower in pine material (2%). Overall, the medium size screen had the effect of reducing the size of commercial chips, so as to produce a higher proportion of small chips (16-3 mm; + 5%) and a comparably lower proportion of medium chips (45-16 mm; -4%). However, since the test conducted with the medium size screen was the shortest and produced a smaller amount of samples than the other tests and no trials were conducted with the medium-size screen on poplar wood, the data were also analyzed after removing the observations obtained from medium size screen and the results did not change significantly.

So, it can be affirm that: pine produces smaller chips and less oversize particles than poplar, regardless of screen type; branch material produces less accepts, more fines and more oversize particles than log material, regardless of species; a finer screen does not produce significant benefits when used with pine.

4. Conclusions

In chipping process knife wear causes a significant reduction of machine productivity and a remarkable increase of fuel consumption. By replacing the standard wide mesh screen with a narrower screen has a similar effect, further decreasing productivity and increasing fuel consumption. Given the same screen type and knife wear level, productivity and fuel consumption are the same for poplar and pine.

The tendency to produce oversize particles may depend on wood characteristics and on the flexible twigs in the material to be chipped. This is peculiar to broadleaves and would explain the rapidly increasing proportion of “sticks” in poplar as the work proceeds and the knives wear out. After processing approximately 80 tonnes of fresh poplar, the proportion of oversize particles shows a marked increase.

Such trend does not appear for Eastern White Pine, where the use of a finer mesh screen does not seem to entail any significant quality benefits, except for the reduction in size of already acceptable chips. In fact, the installation of a medium screen causes a significant reduction of chipping productivity and a comparable increase of fuel consumption. Pine on the other hand, tends to produce a high proportion of fines, especially when branches are chipped, which it might be related to the presence of needles on conifer branches.

Chip producers can manage raw material type in order to obtain a given target quality, as a higher rate of logs to process in order to obtain a smaller proportion of oversize particles and a higher proportion of accepts. If the scope is to obtain high grade chips, producers should consider replacing the knives of their chippers more often: future research may try to determine the break-even point between the additional cost entailed by a more frequent maintenance and the additional gains.

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