Original scientific paper

Effects of Sieve Size on Chipper Productivity, Fuel Consumption and Chip Size Distribution for Open Drum Chippers

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Abstract

Chip size distribution is an important quality variable not only for buyers of forest fuels, but also for chipping contractors as it influences both fuel consumption and productivity of chippers. Studies of disc chippers and of drum chippers with closed drums have shown that increased chip target length increases chipper productivity and decreases fuel consumption per ton of chips produced. For open drum chippers, chip length is partly controlled by the mesh size in the sieve. In order to evaluate how this sieve affects productivity and fuel consumption of chippers, two open drum machines for professional chipping of forest fuels were studied. Small chippers were represented by a Kesla 645, and larger ones by an Eschlböck Biber 92. The Kesla 645 was studied with 25, 50, and 100 mm sieves and the Biber 92 with 35, 50, and 100 mm sieves. With the 100 mm sieve the Kesla chipper produced 14.5 oven dry ton (odt) of chips per effective hour and the Biber 30.0 odt per effective hour. Fuel consumption per odt was 3.0 l for the Kesla and 2.1 l for the Biber. A reduction of sieve mesh size decreased productivity and increased fuel consumption for both machines. Reducing the mesh size decreased the size of produced chips for the Kesla, but not for the Biber. The sieve on the Biber seems to be a safety measure against oversized pieces whereas chip size is, as on a closed drum chipper, mainly controlled by the cut length of the knives.

Keywords: biomass, forest fuel, chip quality

1. Introduction

In Sweden, 90% of logging residue biomass is chipped on or adjacent to the landing (Brunberg 2013) in order to reduce road transport costs. Terrain chipping, i.e. chipping of small piles on the cut, is not used anymore as it is too expensive (Eliasson 2011). Mainly truck mounted and forwarder mounted chippers are used for chipping of forest biomass that is stored in piles on landings or on the side of the road. If the material is stored some distance from the road, e.g. in a large pile on the cut, forwarder mounted chippers are the preferred choice. In central Europe, one of the dominating chipper types for both these conditions are farm tractor towed machines powered by the tractor power take off (PTO). The advantages with a towed chipper is that they are faster and easier to move between setups than forwarder mounted chippers as they do not require flatbed trailers for the relocation and that it is possible to utilise the farm tractor for other purposes while there is no chipping work. On the other hand they are less mobile off-road, and are not able to transport the chips to/on the landing by themselves like a forwarder mounted chipper.

Forwarder mounted chippers that are equipped with a chip bin, e.g. Erjo 9/93 and Bruks 806STC, usually transport the chips to a reloading spot where the chips either are dumped in containers or on a tarpaulin on the ground (cf. Eliasson et al. 2011, Lombardini et al. 2013). Towed chippers, and some forwarder mounted chippers, usually chip directly into containers (cf. Eliasson et al. 2011, Eliasson et al. 2013, Grönlund and Eliasson 2013) or trucks. In the former case the contractor often have a second tractor or a forwarder equipped with a hook loader to shunt the containers to a suitable reloading place.

An increased target length for the produced chips has proven to increase chipper productivity, as well as reduce the fuel consumption per produced oven dry tonne of chips both for disc chippers (Eliasson et al. 2012, Facello et al. 2013) and drum chippers with a closed drum (Johannesson et al. 2012, Spinelli and Magagnotti 2012). For both these chipper types, target length is mainly a function of the distance between the knife edge and the drum or disc surface. For drum chippers with an open drum, it is a bit more complex to control the target chip length, i.e. to control the chip size distribution, as it is influenced by the feeding speed, the amount of self-feed, distance between the knife edge and the imaginary drum surface (were there can be a stopping device to prevent overfeeding), and the mesh size in the bottom sieve that acts as a barrier to stop oversized chips leaving the drum casing. Contractors operating open drum chippers claim that by changing feeding speed and sieve they can produce chips according to the customers' preferred chip size distribution. There are studies of open drum chippers that show that an increased sieve mesh size increases chipper productivity and reduces fuel consumption (Nati et al. 2010, Röser et al. 2012).

The aim of the study was to infer the effects of sieve mesh size on chipper performance and fuel consumption and on chip size distribution for the produced chips. In order to do this, two open drum machines for professional chipping of forest fuels were studied when chipping tree sections. Both machines were powered by farm tractors. The small chippers were represented by a Kesla 645, and the larger ones by an Eschlböck Biber 92.

2. Material and methods

The study was carried out on June 1 and 2 adjacent to Åre Östersund airport in northern Sweden (63°12'9.3"N 14°28'51.8"E). Two open drum chippers owned by the same contractor were studied, a Kesla 645 powered by a 270 kW John Deere 8345R farm tractor and a Eschlböck Biber 92 powered by a 358 kW Claas Xerion 5000 farm tractor. The contractor operates a chipper together with two farm tractors, where each tractor pulls two 42.5 m^3 chip trailers. During chipping, the chips are blown directly into the trailers and when both trailers are filled, the tractors travel to the customer.

The Kesla 645 chipper has 6 angled blades that are positioned in a spiral around the drum and the Eschlböck Biber 92 was used with 10 knives positioned on 4 positions around the drum. The cut length for the Bieber was 24 mm and approximately 25 mm for the Kesla. The chip extraction is done in a similar way for the two chippers. In both cases there are augers beneath the open drum that feed the chips to a fan that throw the chips out through the chip tube. A square mesh sieve is placed between the drum and the auger to avoid that oversized chips leave the drum casing. Both chippers were studied with 3 different sieves; Coarse (100 mm mesh size), medium (50 mm mesh size), and fine (25 mm mesh size for the Kesla 645, and 35 mm mesh size for the Biber 92 chipper). The reason for the different mesh sizes in the fine sieves is that they were the sizes available to the contractor.

During the study, newly harvested (i.e. in late May) tree sections from a first thinning were chipped and transported to the CHP plant in Östersund. The tree sections in chipped piles consisted of a random mix of pine, spruce, aspen, and birch. The average moisture content in the chipped material was 41.7%. For each chipper and sieve combination, it was intended to fill with chips three tractor trailers, each with a gross volume of approximately 42.5 m^3. After filling three trailers, the sieve was shifted and the chipper fitted with a new set of sharp knives to avoid that knifewear should affect the results. The tractor trailers were taken to the measurement station at the CHP plant in Östersund, where the volume and weight of the chips was measured, and samples were taken for determination of moisture content and chip size distributions. For each trailer, a 10 l sieving sample and at least 3 smaller samples for moisture content determination were taken. For the combination of the Kesla chipper and fine sieve 3 sieving samples were taken from the same trailer. The moisture content samples were scaled when sampled and after drying at 105°C for 24 hours. The sieving samples were sieved according to SIS-CEN/TS 15149–1:2006.

The fuel consumption of the tractors that powered the chippers and their hydraulic loaders were measured by topping up the fuel tank after each filled chip trailer using an accurate fuel gauge. To compensate for differences between trailer loads, fuel consumption per produced amount of chips (odt) were used in the analyses.

The time study of the chipping work was done as a comparative time study with snap back timing (Bergstrand 1987). Time recording was made with Allegro hand-held computers equipped with Skogforsk SDI software. Chipping work was split into 8 elements (Table 1). All measured times for each trailer load have been summarized per work element and divided by the oven dry mass of the load to get times in centiminutes per oven dry ton (odt). In some of the analyses the elements »Boom out«, »Grip«, »Boom in & feeding«, »Release & adjustment«, »Chipping«, »Move and Other« have been summarized in the main work

Table 1 Work elements used in the study

Element	Definition
»Boom out«	Boom movement from the chipper to the piled material
»Grip«	Gripping of material
»Boom in & Feeding«	Boom movement from the pile to the machine and using the boom to assist feeding the chipper before the grapple load is released
»Release & adjustment«	Releasing the grapple load and possible adjustments of the material on the feeding table
»Chipping«	Chipping while the loader is idle
»Move«	Repositioning of the machine alongside the piled material
»Other«	Other work time – works not covered above that is needed to complete the work task
»Delays«	All that is not productive work

element efficient chipping time. Only effective times have been included in the analysis and no delays have been reported. The reason for not reporting any delays are that all delays either were caused by this study or by the establishment of a storage trial at the heating plant in Östersund. The storage trial substantially increased unloading times for the transport tractors, thus causing waiting times for the chippers.

The study was designed as a factorial experiment with the factors »Chipper« in two nominal levels (Kesla 645 and Biber 92), »Sieve_size« in three ordinal levels (coarse, normal and fine), and »Size_class« in eight ordinal levels (<3.15, 3.15–8, 8–16, 16–31, 31–45, 45–63, 63–100, >100). All analyses of productivity and fuel consumption have been made using analysis of variance, and difference between means have been tested post hoc using *t*-tests and Tukey *t*-tests.

Chip size distribution has been analysed using a general linear model (GLM) on logit transformed shares (S) using the factors »Chipper«, »Sieve_size«, and »Size_class«. The logit transformation was necessary since it transforms the primary range of shares $S \in [0, 1]$ onto the interval $[-\infty, \infty]$ assumed by the normal distribution (Olsson 2002). The test criteria were the respective interactions of »Size_class« within »Chipper« (Chipper × Size_class) and »Size_class« within »Sieve_size« (Sieve_class × Size_class). If the effect of »Size_class« (on Logit S) was found to be independent of the respective interactive factors »Chipper« and »Sive_size«, no effect on chip size distribution may be assumed. The model used can be expressed as:

$$Logit\ S = Log\ (\frac{S}{1-S}) = \\ = Chipper + Sieve\ size + Size\ class + Chipper \times Size\ class + \\ + Sieve\ size \times Size\ class + \varepsilon \quad (1)$$

The two-way interaction Chipper × Sieve_size and the 3 way interaction Chipper × Sive_size × Size_class were not included in the model since they lack plausible interpretation. Restricted maximum likelihood methodology was used for the GLM analysis, and Type V sum of squares as implemented in the STATISTICA version 12 statistical software package.

3. Results

Both the performance and fuel consumption per produced odt of chips were significantly dependent on the choice of sieve (Tables 2–4). With the 100 mm sieve, the Kesla 645 chipper produced 14.5 oven dry ton (odt) of chips per effective hour and the Biber 92 30.0 odt per effective hour.

Table 2 Chipper performance and fuel consumption depending on sieve mesh size. Fuel consumptions followed by different letters within a machine are significantly different ($p < 0.05$)

Chipper	Sieve	Performance	Fuel consumption
		Odt/Eff.hour	Liter/TTV
Biber 92	100	30.0	2.1*a*
Biber 92	50	25.8	2.8*b*
Biber 92	35	23.0	3.2*c*
Kesla 645	100	14.5	3.0α
Kesla 645	50	13.1	3.4β
Kesla 645	25	6.7	7.0γ

Decreasing sieve size to 50 mm decreased productivity by 10% for the Kesla and 14% for the Biber

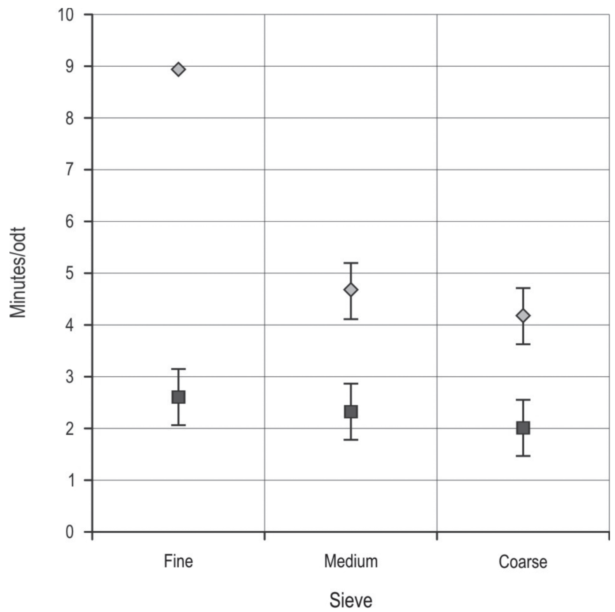

Fig. 1 Time consumption for efficient chipping work in minutes per odt of chips separated on sieve size and machine. Biber 92 denoted by black squares and Kesla 645 by blue rhombs. Bars denote 95% confidence intervals

(Table 2) and a further decrease in sieve size caused further reductions in chipper performance. There were significant effects on the effective chipping time per odt of chips by both machine and sieve, and a significant interaction between the two was observed (Table 4, Fig. 1).

Table 3 Anova for the fuel consumption per odt. $n = 16$

Source	*DF*	Type III SS	Mean Square	*F* Value	*Pr* > *F*
»Machine«	1	10.53	10.53	122.84	<.0001
»Sieve«	2	13.28	6.64	77.44	<.0001
»Machine * Sieve«	2	5.62	2.81	32.80	<.0001

The interaction is caused by the slow chipping work that occurred when the Kesla 645 was used with the fine sieve (Fig. 1). Only one trailer of chips was produced with the Kesla and the fine sieve, as the contractor was not keen to continue to operate the machine in this setting. For the Biber 92 chipper, the choice of sieve had significant effects on the time consumption per odt for the individual work elements »Boom in & feeding« and »Chipping« (Table 5). For the Kesla 645, observed time consumptions are higher for the fine sieve, but in the statistical comparison between the medium and coarse sieve no differences can be found.

Table 4 Anova for the efficient chipping time per odt. $n = 16$

Source	*DF*	Type III SS	Mean Square	*F* Value	*Pr* > *F*
»Machine«	1	442 101.4	44 101.4	246.86	<.0001
»Sieve«	2	151 648.6	75 824.3	42.34	<.0001
»Machine * Sieve«	2	99 519.2	49 759.6	27.78	<.0001

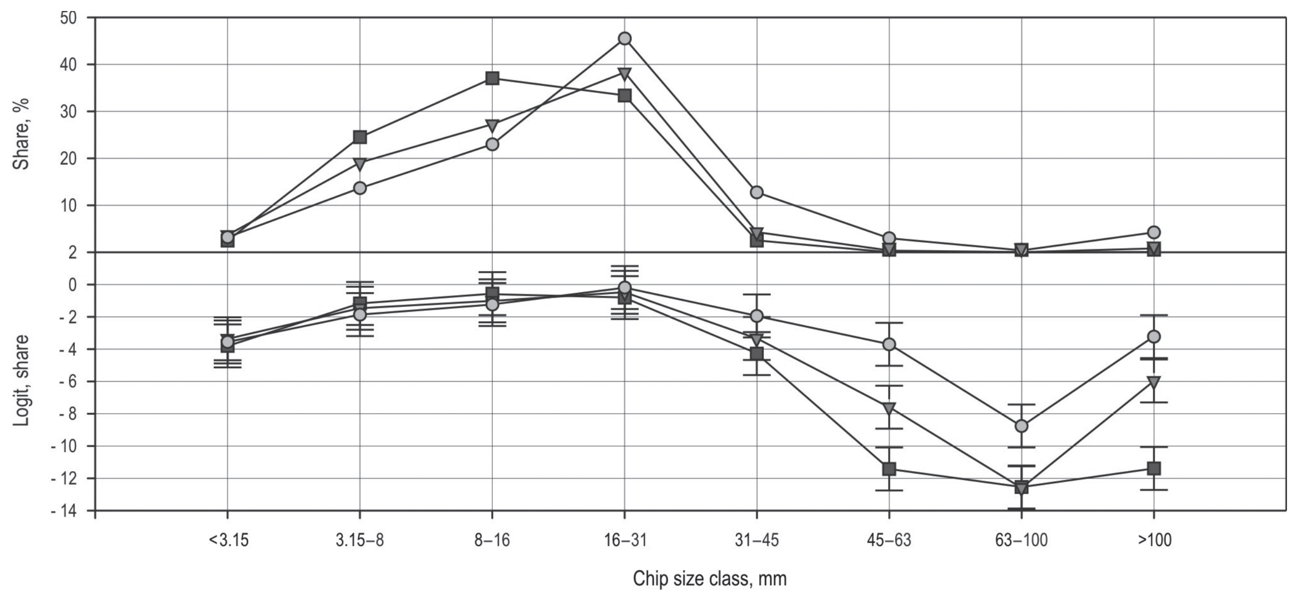

Fig. 2 Chip size distribution as an effect of sieve size, upper part of the figure actual shares in per cent per class, lower part of the figure logit transformed data with 95 % confidence intervals. Coarse sieve denoted by black dots, medium sieve by triangles and fine sieve by squares

Table 5 Time consumption per odt for the individual work elements separated on chipper and sieve. Time consumptions followed by different letters within a machine are significantly different ($p < 0.05$)

Work element Sieve size	Kesla 645			Biber 92		
	Fine	Medium	Coarse	Fine	Medium	Coarse
»Boom out«	103.6	74.3α	68.8α	44.4*a*	42.4*a*	37.9*a*
»Grip«	50.2	29.0α	29.0α	13.8*a*	14.2*a*	12.2*a*
»Boom in & Feeding«	328.5	219.5α	182.8α	73.0*a*	71.2*a*	58.4*b*
»Release & adjustment«	19.2	18.4α	24.5α	3.4*a*	5.5*a*	7.3*a*
»Chipping«	392.2	126.9α	113.1α	125.9*a*	99.0*b*	85.3*c*
»Other«	0.0	0.0	0.0	0.0	0.0	0.0
»Move«	0.0	0.0	0.0	0.3	0.3	0.0
»Efficient chipping time«	893.7	468.0	418.2	260.6	232.4	201.1

Fuel consumption increased by approximately 50% for the Biber 92, and 130% for the Kesla 645 when the coarse sieve was replaced by the fine sieve (Table 2).

The chip size distributions of the produced chips were quite uniform, and only the share of particles in size classes larger than 31 mm was significantly affected by sieve size (i.e. the significant Sieve_size × Size_class interaction in Table 5, Fig. 2).

The coarse sieve produced significantly more chips in these size classes than the fine sieve. No significant differences between chippers, i.e. in the Chipper × Size_class interaction, could be found (Table 5).

A visual inspection of the chips showed that the chips produced by the Kesla 645 with the fine sieve were not cut but rather ground, and were more like a hog fuel in structure than normal chips. This is probably an effect of the mesh size that was smaller than the cut length of the knives.

Table 6 Anova table from the test of chip size distribution

Source	DF	Type III SS	Mean Square	*F* Value	$Pr > F$
»Chipper«	1	1.58	1.58	0.53	0.4679
»Sieve«	2	126.83	63.41	21.26	<.0001
»Size class«	7	1498.99	214.14	71.80	<.0001
»Chipper * Size class«	7	14.85	2.12	0.71	0.6625
»Sieve * Size class«	14	218.83	15.63	5.24	<.0001

4. Discussion

As the studied chippers represented two different size classes for professional chipping on landings, it was expected that there should be a productivity difference between them. The observed difference in productivity and fuel consumption, when the chippers used the fine sieve, is misleading for two different reasons: the sieves used did not have the same mesh size and the area of a 35 mm square hole is actually 96% larger than that of a 25 mm square hole, so the »fine« sieve in the Kesla caused more resistance to the chips than the »fine« sieve in the Biber. The operator was not able to adjust the feeding speed of the Kesla chipper, so that the cut length of the chips became smaller than the sieve size. This caused the chipper to almost grind the cut chips as it forced them through the sieve. To perform as intended with the fine sieve the operator should have needed to adjust the knife and counter blade settings on the Kesla.

The productivity of the Kesla 645 was somewhat lower and the fuel consumption was higher compared to studies of the similarly sized Bruks 605 chipper (Johannesson et al. 2012, Grönlund and Eliasson 2013), which to a large extent may be caused by the material chipped, the tractors powering the chippers and the operators. The Biber 92/Claas Xerion 5000 is comparable in size and power to forwarder mounted Biber 84 and Bruks 806 chippers that were studied in the spring of 2013 (Eliasson et al. 2013, Lombardini et al. 2013) and both performance and fuel consumption were on par with those machines.

Previous studies of chippers with a bottom sieve have shown that a larger mesh size gives increased productivity and improved fuel efficiency compared to a smaller mesh size (Nati et al. 2010, Röser et al. 2012). This is confirmed for both chippers in the current study. Furthermore, both productivity and fuel efficiency will decrease radically if the cut length of the chipper exceeds the mesh size as for the Kesla chipper with 25 mm sieve. The use of a sieve between the drum and the auger that extracts the chips from the drum casing introduces a resistance in the chip extraction. This resistance is dependent on the total sieve area, the area of the individual holes in the sieve and the amount of chips that passes the sieve per minute. If the amount of chips per time unit is large, all chips smaller than the mesh size will not be able to leave the drum casing but will start to tumble around in the drum casing. In this process, oversized chips and some chips that are of acceptable size will be chipped further. However, the tumbling of material is energy demanding and time consuming. As an example of the chip samples produced with the Biber chipper and the coarse sieve, approximately 80% passed the 31 mm sieve in the fraction analysis and since the 35 mm square meshes in the fine sieve on the Biber chipper is substantially larger, most chips should in theory be able to pass it. Even if those last 20% of the material are needed to be chipped again, and this will take as long time as chipping the same amount of unchipped material, the total chipping time would only increase by 20% and not by 30%, which is the difference noted between the coarse and fine sieve.

As expected, a decreasing sieve size decreased the share of coarser chips. However, the ability of the chippers to produce coarser chips and less fines by using a sieve with larger mesh size seems to be limited. For the Eschlböck Biber 92 the cut length is probably the factor that is most important to the chip length, while the effect of feeding speed and sieve seems to be of minor importance. In other words, it behaved almost as a closed drum chipper. For the Kesla 645, it may be possible for the operators to increase the chip size by changing feeding speed and sieve mesh size without changing the cut length, as long as the mesh size exceeds the cut length. On the other hand, to operate acceptably with the fine sieve, in this study the operators should have decreased the cut length of the Kesla chipper. A decrease in cut length decreases productivity and fuel efficiency for the chipper (Spinelli and Magagnotti 2012), but probably not as much as the »grinding« process observed in this study when the chips were forced through an undersized sieve.

Regardless of the sieve used, both chippers produced chips that are considered on the fine side for the large CHP plants in Sweden. Many of these plants prefer chips with the highest possible proportions of chips in the 31–45 mm size class and a low amount of chips smaller than 8 mm. On the other hand, the chips are well adapted to the demands of smaller heating plants. If the contractors are interested in increasing the chip size to adhere to demands from the larger plants, the cut length of the chippers must be increased. However, it is not possible to increase the chip size that much by simply changing the sieve and increasing the infeed speed.

In the past, statistical analyses regarding the effects of different chip-size distributions have often been done separately for each chip size class (e.g. Spinelli et al 2013). These analyses usually use Anova or *t*-tests on transformed shares, most often using arcsin transformations. The drawback with this method is that each of the eight tests needed introduce standard type 1 and 2 errors that combine into an accumulated error when hypotheses are repeatedly tested across chip-size classes. The method used in this paper increases the power of the test and avoids the multiple testing that occurs when each size class is analysed separately.

The study shows that there is a potential to increase chipper productivity by 10–20% and to reduce the fuel consumption as much by increasing the sieve mesh size from the normal 50 mm mesh size to 100 mm, if the customer can accept that 5% of the chips are longer than 100 mm.

Acknowledgement

This research is a part of the INFRES project which has received funding from EU 7th framework programme under grant agreement n°311881, and it is also a part of the »Efficient Forest Fuel« programme funded by the Swedish forest sector and the Swedish energy agency.

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Received: April 28, 2014
Accepted: September 23, 2014

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