Grinding of Stumps, Logging Residues and Small Diameter Wood Using a CBI 5800 Grinder with a Truck as a Base Machine (*Brief report*)

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Abstract

This study defined the productivity levels of a CBI 5800 grinder using a truck as a base machine for processing stumps, logging residues and whole trees at a roadside landing. For defining the solid content of the truck loads, the weight of each load was recorded. Furthermore, samples from each load were collected in order to define the moisture content, dry green density, green mass, particle size distribution and ash content of processed raw material. The solid content of the chip loads was based on the relation of the recorded dry masses, dry green densities and frame volumes of each load. The time study was conducted using a hand-held field computer by means of continuous timing, where the clock is running continuously and the different work elements are separated from each other. The effective hourly productivity (E_0h) of the operation was presented per solid and loose volumes (m^3), green and dry mass (kg), and the energy content (MWh) of the forest chips. Furthermore, the noise and vibration of the grinding operation were measured.

The effective hourly productivity of grinding was highest for logging residues (loose volume, 224 m^3/E_0h & solid volume, 81 m^3/E_0h). The productivity of whole tree grinding was second highest (loose volume, 198 m^3/E_0h & solid volume, 60 m^3/E_0h) and the lowest productivity (loose volume, 131 m^3/E_0h & solid volume, 36 m^3/E_0h) was in stump grinding. Based on dry masses the productivity of grinding logging residues was 29,022 kg/E_0h. The productivities of grinding whole trees and stumps were 24,958 kg/E_0h and 17,315 kg/E_0h. The effective hourly productivity of grinding logging residues based on energy content was 135 MWh/E_0h and respectively for whole trees 119 MWh/E_0h. For stumps free of mineral soil, the productivity was 85 MWh/E_0h and for stumps of the time study experiments with mineral soil 72 MWh/E_0h, respectively.

Based on the results of this study, it can be concluded that the CBI 5800 grinder (power 462 kW/620 hp) works well for grinding logging residues, split stumps and whole trees at a roadside landing. Moreover, the grinder was consistent in terms of interruptions caused by impurities in the raw material. The bulk density of chips based on grinding was lower than the bulk density of conventional chips. The productivity of the studied grinder was significantly better compared to conventional drum chippers at the same size category when comminuting logging residues at the roadside landing. The grinding productivity of whole trees was slightly lower or at the same level than when performed by drum chippers with a truck as a base machine. The productivity of the CBI 5800 grinder was significantly lower when compared to large grinders used in terminals and end use facilities. However, the productivity was three times higher compared to the pre-grinding of stumps with slow-running grinders at the roadside landing.

Key words: stumps, logging residues, small diameter wood, comminution, chip dimension, noise, vibration, heating value

Introduction

Forest chips procurement chains

The forest chips procurement chains can be categorised into centralised and decentralised comminuting methods (Asikainen et al. 2001, Yoshika et al. 2006, Stampfer and Kanzian 2006, Rinne 2010, Laitila et al. 2011, Routa et al. 2013). In the centralised method, the raw material is chipped or ground in a terminal or at an end use facility. This enables bigger annual production, a higher utilisation rate for machines, lower labour force and thereby lower total productions costs (Asikainen et al. 2001, Rinne 2010, Laitila 2011). By using the centralised method, the payload is often unutilised when transporting the unprocessed raw materials (e.g. whole trees, logging residues and stumps) which increase the costs of long-distance transportation. In the centralised method, the investment costs are extensive and due to that the method is profitable only in relatively large power and heating plants with large comminuting volumes. Furthermore, comminuting spreads dust particles and noise in surrounding settlements and it requires a relatively large area which limits the launch of the system in urban environments (Rinne 2010). The terminal enables a regular supply of fuel for power and heating plants, even during seasons of frost heave and in the wintertime, when the energy consumption is at its highest (Asikainen et al. 2001, Kanzian et al. 2009, Laitila et al. 2011). Comminuting in terminals requires large storages and the handling of unprocessed and processed raw material produces extra costs. Moreover, the investment cost of asphalted terminals is high.

In the decentralised method, the raw material is comminuted at a roadside landing or in stands and thereafter the chips are transported to the end use facility or terminal (Asikainen et al. 2001, Rinne 2010, Laitila et al. 2011, Routa et al. 2013). At the roadside landing, the raw material is comminuted directly into the the truck's load space. During the work the chipper/grinder and truck are dependent on each other. This means that there is always idle time for the truck and the chipper/grinder, depending on the length of the long-distance transport and comminuting productivity. When comminuting at the roadside landing, the payload of the truck-trailer unit is fully utilised, which means that the method is also cost-effective for long transporting distances (Asikainen et al. 2001, Rinne 2010, Laitila et al. 2011, Routa et al. 2013). Comminuting at the roadside landings is a feasible method both for small and large heating and power plants. Large chippers are usually mounted on trucks or trailers and small chippers are powered by a tractor (e.g. Rottensteiner et al. 2013). Furthermore, an integrated concept of chipper-truck-container unit is available (Rinne 2010, Routa et al. 2013). Grinders, which are used in roadside operations, are usually mounted on semitrailers (Rinne 2010).

The raw material of forest fuel for heat and power plants is comminuted up into dimensions which are suitable for the demands of conveyors, storage hopper and boilers. The two main comminuting methods are chipping and grinding (Rinne 1998, Yoshika et al. 2006, Asikainen et al. 2001, Rinne 2010, Spinelli et al. 2012). The advantage of chipping is the homogeneous dimensions of the particles and low fuel consumption of the operation per produced cubic metre. The blades of the chippers are sensitive to impurities, which accordingly lowers the productivity and the quality of the chips (Rinne 1998, Stampfer and Kanzian 2006, Rinne 2010, Nati et al. 2011, Spinelli et al. 2011, Spinelli et al. 2012, Spinelli et al. 2013). The grinders are more consistent against interruptions caused by impurities. However, grinding consumes more fuel than chippers. Moreover, the quality of ground fuel chips (particle size distribution) is lower, which limits the applicability for the smaller power plants (Rinne 1998, Strelher 2000, Asikainen et al. 2001, Aman et al. 2011, Spinelli et al. 2012). The grinders are heavy and large machines, which is a challenge, especially for the operations on roadside landings and terminals (Rinne 2010). In Finland, the stumps are ground, whereas logging residues and whole trees and stem wood are usually chipped.

Based on the feeding method, chippers and grinders can be divided into two main categories: horizontal feeding and vertical feeding (Rinne 2010). For the slow-running grinders, the frequency of the rotation of the rotors is under 100 per minute. For the fast-running grinders and chippers, the value is over 600 rotations per minute (Rinne 2010). Chippers and hammer grinders are fed horizontally and are fast-running. The dimensions of the feeding hopper of the vertical grinders do not usually limit the size of the feeding bunch (Asikainen and Pulkkinen 1998, Yoshioka et al. 2006). However, the vertical grinder is unable to process long material such as whole trees and stem wood (Rinne 2010). In addition it is possible to crush large or dirty material in two stages: 1) firstly, pre-grinding to a dimension of 100-500 mm by slow-running grinder and thereafter, 2) grinding the material to final fuel using fast rotation grinders. The productivity of stump grinding in particular is highly dependent on the piece size of the stumps (Rinne 2010, Kärhä et al. 2011a).

In Finland, in the 2000s, the use of forest chips has increased significantly (Ylitalo 2012). In 2011, 7.5 million m^3 (15 TWh) of forest chips were used for energy generation, from which 90.7% was for heat and power plants and 9.3% domestic houses. The raw material of forest chips in heat and power plants are divided into the following materials: small diameter wood (whole trees, delimbed stems, pulp wood) 45%, logging residues (tops and branches) 33%, stumps 14% and large sized or rotten stem wood 8% (Ylitalo 2012). The proportion of procurement methods including all raw materials was as follows: comminuting at roadside landings 61%, comminuting in terminals 21% and comminuting at the end use facilities 18% (Strandström 2012). The chipping in the terrain method is not in use in Finland (Strandström 2012).

In Finland, the most common forest chips procurement chain from small diameter wood with a proportion of 72% is based on comminuting at roadside landings. The second procurement chain in priority based on terminal comminuting accounted for 12%, while the share of comminuting at the end use facility was 10% (Strandström 2012). Comminuting at roadside landings also dominated the forest chips production from logging residues, with the proportion of 74%. Comminuting at the end use facility accounted for 15%, and comminuting in a terminal was 11% (Strandström 2012). The stumps are most often transported by trucks to power plants or terminals where they are comminuted using stationary grinders or by mobile grinders placed on semitrailers. In 2011, in the production of stump chips, the proportion of grinding in end use facilities was 45% and grinding in terminals 44% (Strandström 2012). The novel method is the pre-grinding of stumps at the roadside landing where the hog wood is transported to the terminal or plant for secondary grinding (Kärhä et al. 20011a). The advantages of pre- and final grinding of stumps at roadside landings are better utilisation rate of the load space (compared to unprocessed stumps) and the option to use standard trailer units for transport (Asikainen 2010). In 2011, 11% of the total amount of produced stump chips was ground at roadside landings and thereafter transported to the end use facility (Strandström 2012).

Objectives and implementation of the study

This study defined the productivity levels of the CBI 5800 fast-running grinder for processing three different raw materials – stumps, logging residues and whole trees at roadside landings. The grinder used in the experiment was mounted on a heavy truck. Additional aims of the study were to define the compactness of the produced chips in the truck loads of different raw materials (solid-%), to compare the quality of the stump chips to chips produced from whole trees and logging residues, and to measure the noise and vibration of the grinding operation. The effective hourly productivity (E_0h) of the operation was presented per solid and loose volumes (m^3), green and dry mass (kg), and the energy content (MWh) of the forest chips.

The time studies were conducted in cooperation with the carrier Vaahterinen PLC and Stora Enso Forest in November 2012 in the municipalities of Varkaus, Heinävesi and Liperi. The Finnish Forest Research Institute Metla was responsible for collecting the time study data and chip samples, and the further analysis and reporting of these. The Finnish Institute of Occupational Health measured the noise and vibration of the grinder. The produced raw materials of the experiments were transported to the power plants of Stora Enso in Varkaus and Fortum heat and Power PLC in Joensuu.

Materials and Methods

Truck mounted CBI-5800 fast-running grinder

The study was conducted using a CBI 5800 fast-running grinder with horizontal feeding constructed using a Scania R620 truck with four axles as a base machine (Figure 1). The weight of the grinder concept was 31,740 kg (Eliasson et al. 2012) and the raw material was fed into the feeding table by an Epsilon M120Z truck-crane with a cabin. The reach of the crane was 9.7 metres. The whole concept was powered by the engine of the Scania R620 truck (power 462 kW/620 hp). Using the ReCoDrive function, the whole concept was relocated and steered in the crane cabin at landing areas. The belt conveyor line was located in the back of concept, the maximum rotation motion of the line was 110 degrees and loading level from the ground surface was 5 m. The feeding table was located on right side of the grinder (Figure 1) and the maximum feeding width was 1.22 metres. The diameter of the feed roller was 762 mm and the spikes of the feed roller were made from beaten carbide. The diameter of the grinder's rotor was 1000 mm, and it included 16 incorporated hammers. The grinder unit included an MDS function (Metal Detecting System). The sound-based sensor of the system detected pernicious materials during the operation (e.g. stones, metal) and in such cases it stopped the grinder automatically. The holes of the curved grinder sieve were alternately 2 * 6 inches (50%), and 3 * 6 inches (50%).

The operator of the CBI 5800 grinder was very experienced and skillful: he had over five years' constant experience of comminuting work as a contractor. Moreover, his former duties included the forwarding of logging residues. He had been operating the

Figure 1. CBI 5800 grinder using a Scania R620 truck as a base machine (Photo J. Laitila, Metla)

grinder in the present study for three months at the time of the study.

During the experiments, the chips were loaded directly by conveyor line into the load space of a truck container or a trailer. With the exception of one load, the loading was conducted from the back of the load space. All loads were considered to be 100% full. In the experiments, two different types of trucks were used:

1) Chip truck with an interchangeable container (load volume 50 m^3). The container had a tipping device which enabled the container to be in a slanted position during the operation. This truck type was always used without a trailer.

2) The conventional chip truck-trailer unit (total load volume 48 m^3 + 97 m^3 = 145 m^3). This truck type was used either with or without a trailer.

The grinding places and raw materials

The grinding experiments for broadleaved dominant whole trees from thinnings were conducted on 21.11.2012 in the city of Varkaus. The experiments were conducted in the daylight with the exception of one load which was conducted after dark. The one-year-old piles (constructed in November 2011) were located at the roadside in three different places. The piles were covered by paper sheet and the trees in the piles were cut in lengths of 5-8 metres. The diameter of the butt of the whole trees varied in the range of 6-26 cm and the average diameter of the butt was between 8 and 12 cm. The measured height of the piles was 4 metres. The piles included pieces of iron pipes, wire and iron chains, which caused delays in the operation. During the experiments a total of 291 m^3 = 89 solid m^3 = 61,560 kg (green mass) raw material was ground, which corresponded to four loads of chip trucks with a container and one load of the chip truck with a trailer. The weather during the experiments was cloudy but fair and the temperature was +8 °C. There was no snow.

The grinding experiments for logging residues were conducted in Heinävesi on 22.11.2012. During the experiments a total of 585 m^3 = 212 solid m^3 = 16,0140 kg (green mass) raw material was ground, which corresponded to three loads of the chip truck with a container and three loads of the chip truck with a trailer. With the exception of the first load, the experiment was conducted in daylight. This experiment consisted of four separate piles at a roadside landing. The logging residues of the experiment were pre-piled during timber harvesting on 6.10.2011 and were forwarded to the roadside landing on 14.6.2012. The height of the piles was approximately 4 metres and they were covered by paper sheet. During the experiments the weather was cloudy but fair and the temperature was +5 °C. There was no snow.

The grinding experiments of spruce stumps were conducted in Liperi on 26.11.2012 in the daylight. During the experiments, a total of 342 m^3 = 94 solid m^3 = 71,300 kg (green mass) raw material was ground, which corresponded to seven loads of the chip truck with a container. The stumps were lifted on 2.8.2011 and forwarded to the roadside landing on 4.11.2011. The diameter of the harvested stumps was in the range of 30-40 cm. During the lifting operations the stumps were split in 2-4 pieces and the harvested stumps contained no stones. The height of the pile was 5 metres and it was left uncovered. During the experiment, the weather was cloudy but fair and the temperature was +2 °C. There was no snow.

Implementation of the time study

The time study material was collected by means of continuous timing (Magagnotti and Spinelli 2012) and the work elements were recorded using a Rufco-901 hand-held field computer (Nuutinen et al. 2008, Nuutinen 2013). The division of work elements was the same as in the study of the CBI 5800 grinder conducted by Skogforsk (Eliasson et al. 2012). During the experiment the researcher observed the work performance outside of the risk zone so that he was not disturbing the work of the operator. Furthermore, the observer had all the work safety equipment according to industrial safety legislation: an orange safety vest and safety helmet with hearing protectors.

The operation time of the studied grinder was recorded, and the working time was divided into work elements as follows:

- Swinging the boom towards a raw material stack (crane out)
- Grasping the grapple bunch
- Transferring the grapple bunch to the grinder (crane in)
- Feeding the grapple bunch into the grinder
- Additional feeding of the raw material
- Grinding
- Arrangement of the pile
- Starting the grinder concept, increasing the RPM (Revolutions Per Minute) and warming the engine
- Preparation for grinding: landing the outriggers, lifting the crane in work position, etc.
- Preparing for moving in the working location
- Moving the grinder in the working location/pile
- Stopping the engine and decreasing the RPM
- Clearing the machine concept (e.g. conveyor belt)
- Moving of the truck in the storage
- Delays under 15 minutes
- Grinder concept's service

In this study, to the effective working time (E_0h) were included the following work elements: swinging the boom towards a raw material stack (crane out), grasping the grapple bunch, transferring the grapple bunch to the grinder (crane in), feeding the grapple bunch into the grinder, additional feeding work of the raw material, grinding and arrangement the pile (Eliasson 2012). The division of the effective work time elements in this form was necessary to compare the influence of the raw material to the grinding productivity. The remaining work elements that were recorded did not fit with the productivity-analysis because the working environments of the roadside landings were not equal (e.g. the number of piles, the amount of impurities in the raw material and extra traffic in the landing area).

Collection and analysis of the chip samples

Each load was measured with a certified weight scale at the plant, and both filled and empty weights of the load were recorded. Furthermore, samples were collected from each load of ground raw material to analyse the degree of moisture content, basic density, the particle size distribution of the chips, the content of ash and the heating value (SFS-EN 14774-2, SFS-EN14774-3, SCAN-CM 43:95, SFS-EN 15149-1, SFS-EN 14775, SFS-EN 14918). The chip samples from truck loads were analysed by the Finnish Forest Research Institute's laboratory. During each grinding experiment the loading was conducted so that each load was considered to be full. However, the upper surfaces of the full chip loads were not adjusted to horizontal and the compaction degree during transport was not determined.

The samples for analysis were collected in the power plants' storage area immediately after unloading. Four samples – one sample bag measured 35 cm * 35 cm (volume 8 litres) – were collected from each load. The sample for moisture content was packed in double sample bag to prevent the evaporation of water. Each sample was collected systematically from four different points of the pile: two sub-samples from both sides from a depth of 0.5 m. The same person collected all the samples and he had approved training and several years' work experience in environment sampling. During the field study, the chip samples were stored in a cool outbuilding at temperatures of +5 to +1 ºC.

Measurements of noise and vibratory during grinding

The noise A-levels in the grinder's cabin were recorded using a Larson-Davis 706 volume meter in one-minute periods ($L_{Aeq.\ 1\ min}$). The recording produced a noise profile which describes the chronological variance of the noise level and the average volume during the registered time period. Moreover, the noise level was recorded using a B&K 2250 volume meter in four separate directions at a 20 m distance from the grinder: front and behind, to the left and the right-front side. The noise level was registered at the height of 1.5 m. The measurements were done according to the standard of Finnish Institute of Occupational Health.

During the work performance the operator may be exposed to vibration in the grinder's cabin, which was recorded using a Larson & Davis HVM100 meter and a PCP 356B41 body vibration sensor according to the ISO 2631-1:1997 standard. During the experiment, the body vibration sensor was placed on the operator's seat.

Results

Distribution of work time

The proportion of the effective grinding time (E_0h) of the gross effective grinding time (E_{15}h) was 39% for whole trees, 67% for logging residues and 84% for stumps (Figure 2). The whole tree piles contained metal, which caused numerous delays during the experiments. However, the MDS function and the robust structure of the machine prevented expensive and time-consuming repairs. The proportions of time spent starting the grinder and preparing for the grinding work elements of the gross effective time (E_{15}h) were significantly higher for grinding whole trees than for logging residues and stumps due to the impurities in the whole tree piles.

The piles of logging residues were located in four different points beside the road, which significantly increased the proportions of the moving of the grinder in the working location/storage and moving the truck in the storage work elements (Figure 2). Moreover, the grinding area was located 52 km away from the power plant and therefore the transport capacity of the two trucks did not fulfil the capacity of the grinder: the grinder had to wait occasionally for the trucks (Figure 2). Furthermore, the trucks occasionally queued for weighing and for unloading at the CHP plant.

The operational utilisation rate of the grinder was at its highest when grinding stumps because the stumps were located in one big pile at the roadside landing and there were no stones or metal in the pile. Moreover, the grinder did not have to wait for the trucks (Figure 2). Furthermore, when stumps are grinding, the trucks did not have to wait at the power plant for weighing and unloading.

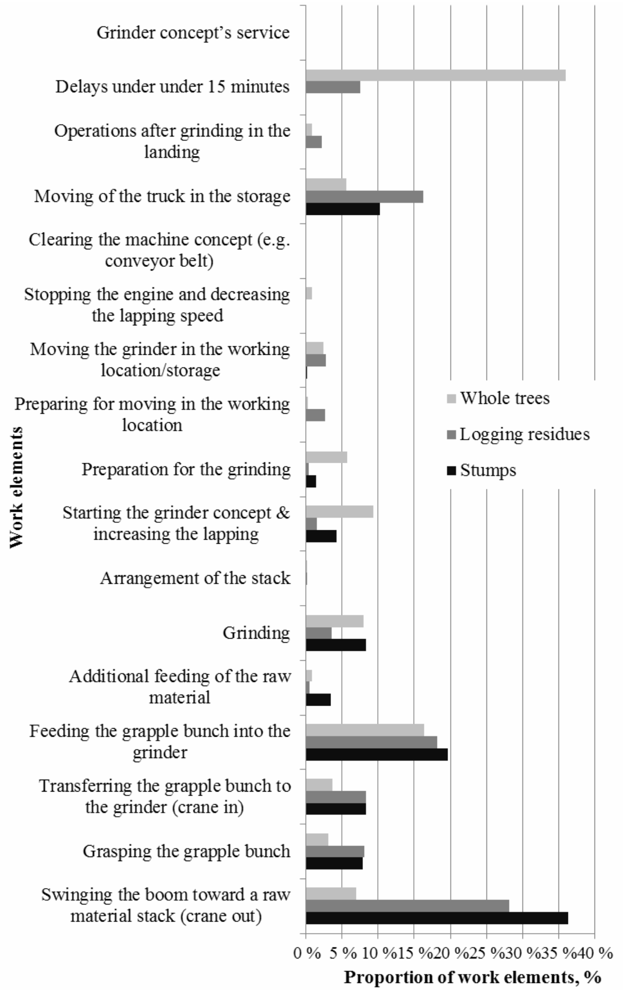

Figure 2. The relative time consumption for the work elements of the gross effective time (E$_{15}$h) for grinding whole trees, logging residues and stumps at the roadside landing

Productivity of grinding

To ensure the comparability of the results, the effective hourly productivity (E$_0$h) of grinding was presented as per forest chips' solid (m^3) and loose (l-m^3) volume, green and dry mass (kg) and energy content (MWh). The productivity of grinding based on green mass was highest for logging residues. The average effective hourly productivity for grinding logging residues was 61,312 kg/E$_0$h and the average weight of grapple load was 237 kg. The productivity of grinding the whole trees averaged 41,897 kg/E$_0$h and the average weight of a grapple load of whole trees was 260 kg. The productivity of grinding stumps averaged 27,282 kg/E$_0$h wherein the average weight of a grapple load was 119 kg.

The effective hourly productivity of grinding based on loose volume of forest chips (Figure 3) was highest for logging residues (224 m^3/E$_0$h). The productivity of whole tree grinding was second highest (198 m^3/E$_0$h) and the lowest productivity of 131 m^3/E$_0$h was in stump grinding, respectively. The productivity based on solid volume for grinding logging residues was 81 m^3/E$_0$h (Figure 4). The respective values for grinding whole trees and stumps were 60 m^3/E$_0$h and 36 m^3/E$_0$h (Figure 4). The conversion coefficient of basic density for logging residues (359 kg/m^3) was smaller than for whole trees (413 kg/m^3) and for stumps (479 kg/m^3) (Table 1).

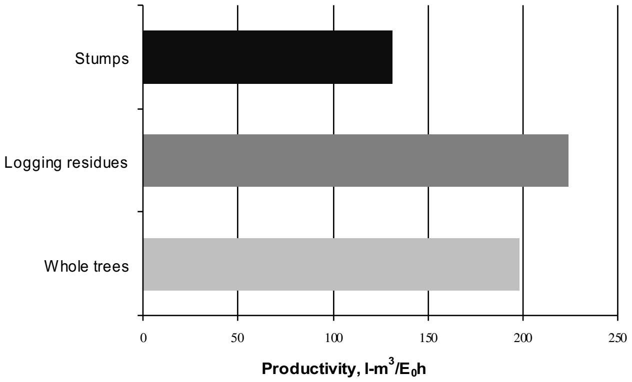

Figure 3. Effective hourly grinding productivity per forest chips' loose volume (m^3/E$_0$h) for stumps, logging residues and whole trees. The solid percentage of the stump, logging residue and whole tree loads were 28%, 30% and 36% (Figure 9)

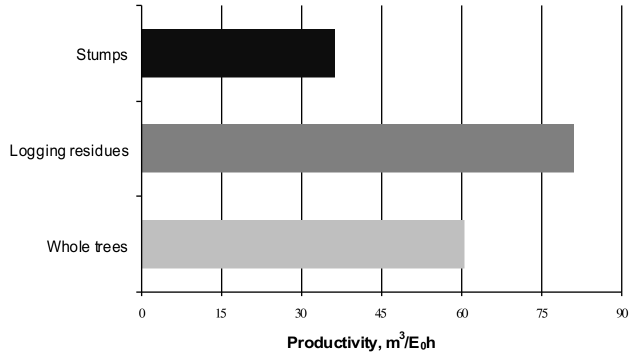

Figure 4. Effective hourly grinding productivity per forest chips' solid volume (m^3/E$_0$h) for stumps, logging residues and whole trees

Based on dry masses, the productivity of grinding logging residues was 29,022 kg/E$_0$h. The productivities of grinding whole trees and stumps were 24,958 kg/E$_0$h and 17,315 kg/E$_0$h, respectively (Figure 5). Figure 6 presents the grinding productivity determined by means of effective heating value (MWh/E$_0$h). The results presented in Figure 6 were computed using the parameter values of Table 1 for moisture content (%) and effective heating value (MJ/kg). For stumps that

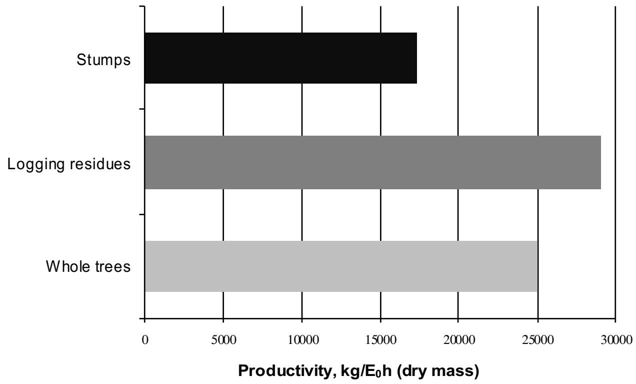

Figure 5. Effective hourly grinding productivity per forest chips' dry mass (kg/E_0h) for stumps, logging residues and whole trees

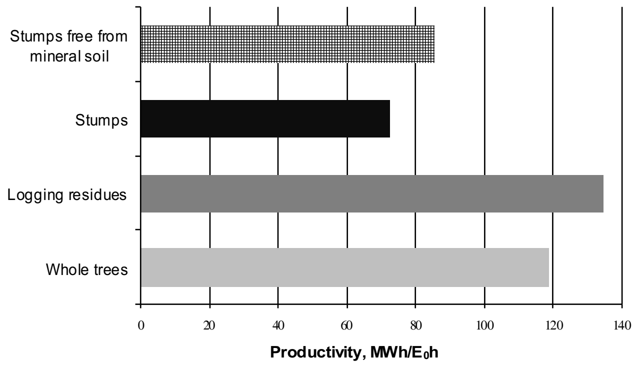

Figure 6. Effective hourly grinding productivity per forest chips' energy content (MWh/E_0h) for stumps, logging residues and whole trees. For stumps the energy content is computed both for the ash content and the stumps free from mineral soil (Hakkila 1978)

were considered to be free from mineral soil, the heating value and productivity were computed using the parameters of Hakkila (1978): *Picea abies* = 19.1 MJ/kg. The effective hourly productivity of grinding logging residues based on energy content was 135 MWh/E_0h and respectively for whole trees 119 MWh/E_0h (Figure 6). For stumps free from mineral soil, the productivity was 85 MWh/E_0h and for stumps of the time study experiments with mineral soil 72 MWh/E_0h, respectively (Figure 6).

Properties of fuel chips

The proportion of the chip diameter under 31 mm from the dry mass of whole tree, logging residue and stump chips was over 90%. Rough chips with a diameter of over 100 mm were not found in any samples (Figure 7). The proportion of fines with a diameter under 3.15 mm from the dry mass of the chips was 36% for logging residue chips, 12% for whole tree chips, and 13% for stump chips (Figure 7). Some 86% of the dry mass of the whole tree chips was in the diameter range of 3.15-31.5 mm and for stump chips this accounted for 80% (Figure 7). The proportion of the diameter class 1-16 mm was 84% for the dry mass of logging residues (Figure 7).

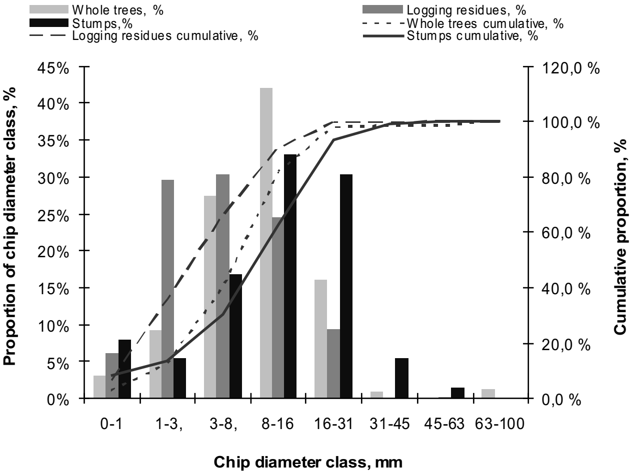

Figure 7. The particle size distribution of whole tree, logging residue and stump chips according to the SFS-EN 15149-1 standard

The effective heating value for the dry mass of whole tree chips was 18.8 MJ/kg, for logging residue chips 19.4 MJ/kg and for stump chips 16.4 MJ/kg (Table 1). The results of the chip sample analysis indicated that the basic density were highest for stump chips and lowest for logging residues (Table 1). The ash content of 12.9% for stump chips was by far the highest, which reduced the heating value of the stump chips (Table 1). The diameter class under 1 mm of stump chips had the lowest heating value of 7.6 MJ/kg, wherein the fines consisted mostly of mineral soils or bark (Figure 8).

Table 1. The averages of the moisture, dry green density, effective heating value and ash content for the chip samples of each ground material

	Effective heating value, MJ/kg (dry mass)	Moisture, %	Dry green density, kg/m^3	Ash content, %
Whole trees	18.8	40	413	1.35
Logging residues	19.4	53	359	4.35
Stumps	16.4	37	479	12.90

The solid percentage of the whole tree, logging residue and stump chip loads was computed by dividing the solid volume of the loads by the respective loose volumes (Figure 9). The loads of logging residue chips had the highest solid percentage of 36%. The respective values were for 30% and 28% for whole trees and stumps (Figure 9).

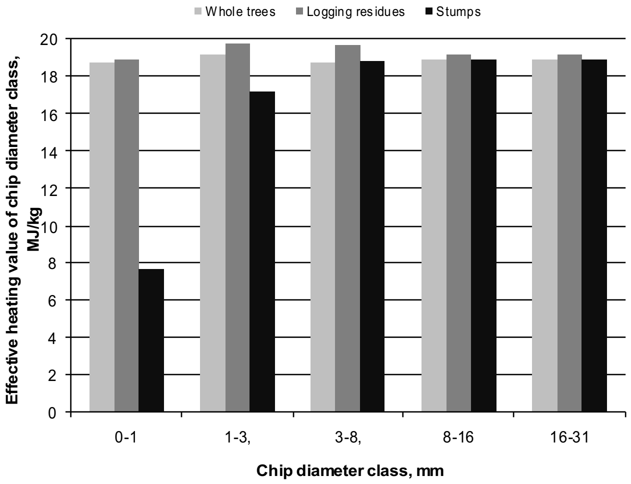

Figure 8. The effective heating value for whole tree, logging residue and stump chips in each particle size class (MJ/kg)

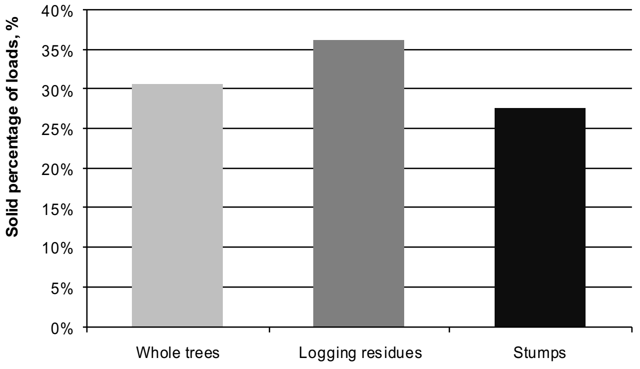

Figure 9. The solid percentage of the whole tree, logging residue and stump chip loads

Figure 10 presents the payload of 50 m^3 truck container according to its energy content (MWh), solid volume (m^3) and dry mass (kg). The dry mass of the load were computed using the recorded payload weights and moisture contents of the collected chip samples. The heating values (MWh) and the solid volumes of the loads were computed using the values presented in Table 1. The effective heating value for stumps without mineral soil was 19.1 MJ/kg (Hakkila 1978).

The dry mass of the container was 6200 kg for whole tree chips, 7500 kg for logging residue chips and 7000 kg for stump chips (Figure 10). The payload for logging residue chips was 21 m^3 and for stump chips and for whole tree chips the payload were 15 m^3 (Figure 10). The payload based on the energy content for stump chips without mineral soil was 37 MWh while the payload for the stump chips in the time study experiments was only 29 MWh (Figure 10). The payload for logging residue chips was 35 MWh and 30 MWh for whole tree chips (Figure 10).

The noise impact and the vibration that the operator was exposed to during the grinding

The noise level of the grinding was recorded during the experiments of two loads wherein the average noise level was 82 dB (Figure 11). This is more than the lowest lawful action level of 80 dB(A) set by the Council of State. The noise level in the cabin varies in the range of 77-78 dB(A). Between the experiments (loads) the noise exposure was stronger (Figure 11), when cabin door was opened, which increases the total noise exposure for the operator.

The noise regulation 85/2006 set by the Council of State specifies the limiting values for the noise exposure that corresponds to an eight-hour work day as follows:

The worker is entitled to personal hearing protectors if the noise exposure level runs over the lower operation value 80 Db(A) during the work day. Moreover, the worker has the right to preventive audiometric control if the recorded noise level during the work indicates a risk to health. If the noise exposure level

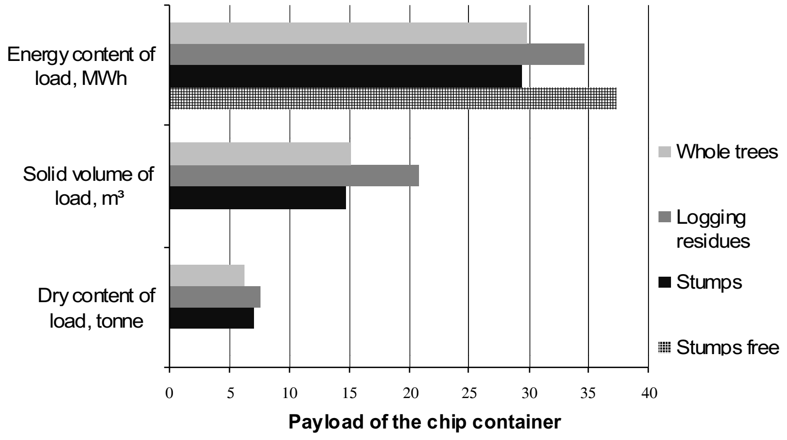

Figure 10. The payload of 50 m^3 container for stump, logging residue and whole tree chips according to the energy content (MWh), solid volume (m^3) and dry mass (tonnes)

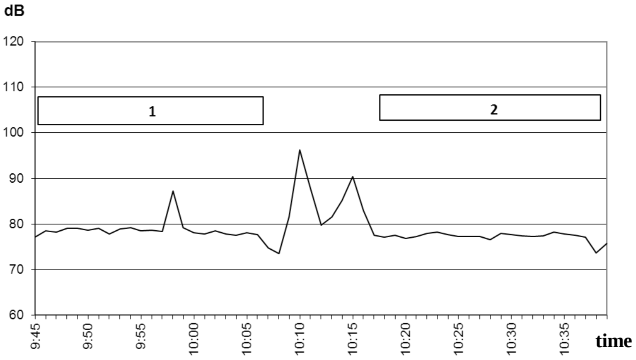

Figure 11. The variation of the noise level presented as averages of one-minute time intervals during two stump grinding experiments of the study

runs over the upper operation value 85 dB(A), the employer must prepare and implement a noise reduction plan, and the worker is obliged to use hearing protectors.

The noise level during grinding the stumps at a distance of 20 metres from the grinder was 78 dB(A) in front of the base truck, 81 dB(A) to the left side, 81 dB(A) to the rear and 82 dB(A) at the right-front side (the same side as the feeding table).

During the grinding, the vibration of the crane cabin seat was 0.5 m/s^2, which is at the same level as the regulation for the body vibration operating value of 0.5 m/s^2 set by the Council of State. In actual work the recorded value means that if the operator grinds the stumps for over 8 hours per day, the body vibration operating value will be exceeded. However, during normal work days – maximum 8 hours per day – the vibration for the body adheres to the regulations.

Discussion and conclusions

The productivity of the CBI 5800 grinder was good compared to the recent results of similar work studies on chipping and grinding in Finland and Sweden (Karttunen et al. 2008, Föhr et al. 2010, Kärhä et al. 2010, Kärhä et al. 2011abcd, Laitila and Väätäinen 2011, Eliasson et al. 2012). The effective hourly productivity (m^3/E$_0$h) of the studied fast-running grinder was significantly better compared to conventional truck mounted drum chippers of the same size category when comminuting logging residues at roadside landings (Karttunen et al. 2008, Kärhä et al. 2011bd). The grinding productivity of whole trees was slightly lower or at the same level than when performed by drum chippers (Karttunen et al. 2008, Föhr et al. 2010, Kärhä et al. 2010, Kärhä et al. 2011bd, Laitila and Väätäinen 2011).

The effective hourly productivity of the CBI 5800 grinder was three times higher compared to pre-grinding of stumps with slow rotation grinder (Kärhä 2011a) when using the 120*90 mm sieve and at the same level when using the sieve 500*320 mm. In the secondary grinding of hog wood, the productivity of the slow rotation grinder were 52 m^3/E$_0$h and 33 m^3/E$_0$h (Kärhä 2011a). Compared to heavy terminal and end use grinders (Kärhä et al. 2010, Aman et al. 2011, Kärhä et al. 2011c), the productivity of the CBI 5800 grinder was significantly lower.

In Sweden, Skogforsk studied a similar CBI 5800 grinder when grinding stumps, and logging residues at a roadside landing (Eliasson et al. 2012). In the Skogforsk study, the effective hourly productivity for logging residues was 23.8 dry tonnes/E$_0$h and for stumps 16.8 dry tonnes/E$_0$h. In the present study, the respective productivities of 29.0 dry tonnes/E$_0$h and 17.3 dry tonnes/E$_0$h are slightly higher (Figure 5). In the Skogforsk study, the oversized dimensions of the harvested stump wood occasionally complicated the feeding and grinding of stumps. In the present study the preliminary splitting of the stumps was conducted entirely during harvesting and therefore the raw material fit without difficulties into the feeding table. For a fluent grinding process it is important that the stumps are preliminary cut into three or four pieces. In our study, fuel consumption was not recorded. However, in Skogforsk's study, the fuel consumption of grinding logging residues was 3.05 litre per dry tonne and for stump grinding 4.08 litre per dry tonne (Eliasson et al. 2012).

In this study, the solid content of the truck loads was lower than the average compactness of loads of whole tree and logging residue chips. The lower compactness is due to the conveyor line of the CBI 5800 grinder which was not able to compress the chips during loading as well as the chippers equipped with a blower or thrower (e.g. Uusvaara and Verkasalo 1987, Kärhä and Mutikainen 2011). The low compactness of the truck loads decreased the payloads, especially when grinding dry raw materials (e.g. delimbed trees and whole trees). This results in lower productivity and higher costs in long-distance transport. However, with moist raw materials (e.g. logging residues) the maximum total weight of 60 tonnes is almost invariably fully utilised.

The solid percentages of this study cannot be generalised for measuring the fuel chip loads. The study material was rather limited, the upper level of the loads was not balanced when the load space was full, the compactness of the load during transport was not defined and with the exception of one load, all were loaded from behind the load space. However, the values can be used for approximate estimations. For defining accurate compactness of fuel chip loads, more extensive follow-up studies should be conducted.

In the study of a Jenz HEM581 DQ drum chipper conducted by Metsäteho, the compactness of the loads for logging residue chips ranged from 45% to 58% and for small diameter whole trees in the range was 42% to 48% (Kärhä et al. 2011b). Uusvaara and Verkasalo (1987) studied the Lokomo MS 9 hammer grinder for comminuting logging residues and the grinder was equipped with a conveyor line for loading the chips. In the study, the compactness of the logging residue chips averaged 38.3% within the range of 35.8% to 46.9%. In the study of Ala-Fossi et al. (2007) the compactness of the stump wood chips that were transported to the power plant from the terminal varied from 31% to 34%. In our study, the grinding of stumps at the roadside landing increased the payload compared to the transport of split stumps. In the previous studies, the compactness of the stump loads using biomass truck-trailer units ranged from 18.5% to 25% (Ranta and Rinne 2006, Ala-Fossi et al. 2007, Kärhä et al.2011c). Moreover, with roadside landing grinding, the productivity of loading increased compared to loading of split stumps. Salonen (2008) and Palander et al. (2011) found the productivity of loading the split stumps using a traditional timber crane to be 19.7 green tonnes/E_0h. In the present study, the productivity of grinding/loading the chips was 27.4 green tonne/E_0h or in other words 17.3 dry tonnes/ E_0h.

The proportion of the fines from logging residue chips, consisting of needles and dust of branch bark, was over 30% from the dry mass (Figure 7). Previous studies have also found the significant proportion of fines from the logging residue chips (Kärhä et al. 2010, Kärhä et al. 2011bd). The high ash content of stump chips (12.9%) lowered its heating value. The effective heating value per dry mass of stump chips (16.4 MJ/kg) was significantly lower than for clean stump wood chips (19.1 MJ/kg) (Hakkila 1978).

In the study of Laurila and Lauhanen (2010), the effective heating value of spruce (*Picea abies*) stumps after three years of storage was 18.9 MJ/kg. According to Anerud and Jirjis (2011), the effective heating value of spruce stumps per dry mass varied from 17.8 to 18.5 MJ/kg, depending on the working method. After one year of storage, the heating value was increased to 18.8 MJ/kg, respectively. Jahkonen et al. (2012) found the effective heating value of stumps to be 18.7 MJ/kg. Based on the results of the previous studies, it can be assumed that careful lifting and sufficiently long storage time have an influence on the ash content and heating value. Moreover, the numbers of different work phases of the stump processing chain have the same influence. In the studies of Anerud and Jirjis (2011) and Jahkonen et al. (2012), the stumps were first transported by biomass truck-trailer unit to the terminal and after that they were ground in the terminal. During this work process, the raw material was exposed to vibration during transport, loading and unloading much more than in the case of grinding the raw material at the roadside landing. If grinding includes screening and the removal of fines, the quality of fuel chips gets significantly better (e.g. Anerud 2012, Laitila and Nuutinen 2014).

Based in the results of our study, it can be concluded that the CBI 5800 grinder works well for grinding the following raw materials: logging residues, split stumps, whole trees from thinnings. In actual work, in addition to an experienced operator and an efficient machine, the working environment and the delivery and reception logistics must also work efficiently (Spinelli and Hartsough 2001, Stampfer and Kanzian et al. 2006, Yoshioka 2006, Kanzian et al. 2009, Spinelli and Visser 2009, Asikainen 2010, Holzleitner et al. 2013). This ensures that efficient work time is not lost as a result of unnecessary moving between the piles and landings, machine delays or waiting for the trucks.

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ИЗМЕЛЬЧЕНИЕ ПНЕЙ, БИОМАССЫ КРОНЫ ДЕРЕВЬЕВ И ТОНКОМЕРНОЙ ДРЕВЕСИНЫ НА ПОГРУЗОЧНОЙ ПЛОЩАДКЕ С ПОМОЩЬЮ ДРОБИЛКИ МОДЕЛИ CBI 5800 НА БАЗЕ ГРУЗОВОГО АВТОМОБИЛЯ

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Резюме

В исследовании изучалась производительность измельчения пней, биомассы кроны деревьев и тонкомерной древесины на погрузочной площадке у дороги с помощью дробилки модели CBI 5800 установленная на шассе грузового автомобиля. Для измерения объема измельченной древесины и ее плотности взвешивание перевозимого машиной груза производили на месте погрузки мостовым краном, из груза брали пробы, по которым определяли показатели влажности, зольности, плотности и размеров измельченной древесины. Для определения плотности перевозимого груза использовали данные взвешивания груза, показатели образцов частиц и расчеты объема штабеля на грузовой платформе щеповоза. В ходе исследований вели непрерывный фотохронометраж, по ключевым точкам измерений документировались на мобильный компьютер различные стадии рабочего процесса (подъем груза, его подача в дробилку, ожидание, перемещение дробилки, автомобиля и щеповоза между рабочими площадками и т.д.). Производительность измельчения в эффективный час (E_0h) определялась по показателям плотного и насыпного объема (куб. м), сырой и сухой массы (кг), а также энергоемкости измельченной древесины. Дополнительно измерялся уровень шума и вибраций, испытываемых оператором дробилки, а также общий уровень шума, производимого при измельчении пней.

Наивысшая производительность измельчения биомассы кроны деревьев составила в час (насыпной – 224 куб. м., плотной – 81 куб м.). Второй по величине показатель производительности в час был достигнут в процессе измельчения целого дерева (198 куб. м и 60 куб. м), при измельчении пней производительность была еще меньше (131 куб. м и 36 куб. м). Когда измерялась производительность измельчения сухой массы кроны деревьев, то показатель составил 29 022 кг/час, сухого целого дерева 24 958 кг/час, а сухих пней 17 315 кг/час. Учитывая содержание энергии производительность эффективного часа измельчения биомассы кроны деревьев составила 135 МВт-ч/час, а в измельчения целых деревьев - 119 МВт-ч/час. Расчетная производительность очищенных от почвы пней составило 85 МВт-ч/час, а полученной дроблением пней в ходе исследования, из-за зольности этот показатель был несколько ниже, 72 МВт-ч/час.

Результаты показывают, что скоростная дробилка CBI 5800 хорошо подходит для измельчения пней, биомассы кроны деревьев и тонкомерной древесины на погрузочной площадке у дороги. Кроме того, дробилка CBI 5800 не чувствительна к примесям, загрязняющим измельчаемую древесину. Плотность перевозимого груза для измельченной древесины меньше, чем для обычной щепы. По сравнению с рубительной машиной дробилка CBI 5800 более эффективна при измельчении биомассы кроны деревьев. Производительность измельчения тонкомерной древесины с помощью дробилки CBI 5800 была либо немного меньше, либо на одном уровне барабанными рубительными машинами на автоплатформах, которые рассматривались в более ранних исследованиях. По сравнению с тяжелыми стационарными (терминальными либо работающими на месте заготовок) измельчителями дробилка CBI 5800 обладает значительно меньшей производительностью при переработке пней, однако ее эффективность в три раза выше, чем у тихоходных дробилок предыдущих поколений, предназначенных для переработки древесины на погрузочных площадках у дороги.

Ключевые слова: пни, биомасса кроны деревьев, тонкомерная древесина, производство щепы у дороги, измельчение, размер частиц, шум, вибрации, теплопроизводительность.

Ключевые слова: пни, порубочные остатки, тонкомерная древесина, измельчение, размер щепы, шум, вибрация, теплопроизводительность