Comminution of logging residues with a tub grinder: Calculation of productivity and procurement cost of wood chips

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Abstract – Nacrtak

An experiment on comminution of logging residues with a tub grinder was carried out in order to calculate the productivity and procurement cost of wood chips. At the investigated site, the tub grinder had a hammer mill crusher at the bottom of the tub, and a grapple loader and a bucket loader worked as auxiliary machines for the grinder. As a result, the productivity of the tub grinder was 60.0 loose m^3/PMH$_0$, and the total comminuting cost was calculated as 5.637 US$/m^3, indicating that the comminuting cost of a large-sized crusher was lower than that of a small-sized chipper. The percentage of the cost of loaders, that of carrying in, installing, and carrying out the machines, and that of constructing a landing was 53% of the total comminuting cost. When a truck with the capacity of 40 m^3 transported wood chips three times a day, the costs of comminution and transportation were 71.2 US$/t (DM[1]), which is almost on a par with those of European countries in which the energy utilization of logging residues is making steady progress. As a result of the discussion about the balance between the processing capacity of the tub grinder and that of other machines, it seemed reasonable for Japanese forestry to consider the use of one tub grinder at several logging sites.

***Keywords:** biomass, logging residues, tub grinder, productivity, cost of comminution and transportation*

1. Introduction – *Uvod*

As one of the major woody biomass resources, logging residues, *i.e.*, tree tops and branches which are generated during limbing and bucking, are expected to be a source of energy and an alternative to fossil fuels. The annual available amount of logging residues in Japan is currently estimated to be 3 million t/y on a dry-weight basis (Yoshioka et al. 2005), with a calorific value of 60 PJ (16.7 TWh). With respect to a harvest of logging residues, for instance, an experiment on hauling them with a forwarder was carried out by the authors of this paper (Yoshioka et al. 2000). In order to utilize logging residues for energy, however, it is necessary to comminute them so that their forwarding and transporting efficiency can be enhanced. In addition, for pretreatment in an energy-conversion plant, residues should be chipped or crushed before being converted into usable energy, *e.g.*, heat, electricity, liquid fuel.

Logging residues can be comminuted in a forest, at a landing of the roadside, or at an energy-conversion plant. Various kinds of chippers and crushers for logging residues have been developed and examined worldwide under field conditions (Asikainen and Pulkkinen 1998, Delgado and Giraldo 1995, Desrochers et al. 1993, Hall et al. 2001). In several countries, the technique has been already finalized, and

[1] Dry matter (DM); refers to biomass that has been dried
Suha tvar (ST); odnosi se na biomasu u suhom stanju

operating manuals have been published (Alakangas et al. 1999, FAO 1976, Folkema 1989). On the other hand, chippers and crushers for comminuting logging residues and unmerchantable thinned trees have been diffused in recent Japanese forestry. The increasing nationwide interest in bioenergy utilization is one reason, and some small-sized and medium-sized chippers have been tested at the local government level in order to define the productivity of these machines and the quality of the chips obtained.

When a large-sized chipper or crusher is introduced, economies of scale will be achieved, *i.e.*, the comminuting cost of a large-sized chipper or crusher is expected to be lower than that of a small-sized one. However, few trials on comminuting logging residues by a large-sized chipper or crusher with an engine output higher than ca. 150 kW have been carried out in Japan. The previous study by the authors of this paper, which discussed the appropriate site for comminuting logging residues from the viewpoint of the total procurement cost of wood chips, showed that the comminuting cost of a large-sized crusher was lower than that of a small-sized chipper (Yoshioka et al. 2002). As for comminution by the large-sized crusher, the study in which the performance of a tub grinder (TG400A, Vermeer Manufacturing Company, United States) was investigated at a grading site was referred to. Concerning the cost calculation of the tub grinder, however, only the labour cost, the machine cost (expenses for depreciation and supplies), and the fuel cost incurred by the operation of the tub grinder itself were considered in the study. On the other hand, Moriguchi et al. (2004), in a study about comminution by a medium-sized chipper with an engine output of 60.3 kW, showed that the cost of a grapple loader related to feeding logging residues into the chipper, cost of carrying in, installing, and carrying out the chipper and the loader, and that of constructing a landing for the operation accounted for a considerably high proportion of the total chipping cost (Moriguchi et al. 2004), suggesting that those additional costs should be considered, essentially, in the case of calculating the cost of comminuting logging residues with a large-sized crusher such as a tub grinder.

Therefore, the objective of this study was to investigate the following items by experimenting on comminution of logging residues with a tub grinder:

⇒ Productivity of a large-sized crusher;

⇒ Proportion of the cost of auxiliary machines, *e.g.*, a grapple loader, that of carrying in, installing, and carrying out the crusher and auxiliary machines, and that of constructing a landing to the total cost;

⇒ Calculation of the cost of comminuting logging residues collected at a landing and transporting wood chips;

⇒ Balance of the processing capacity between the large-sized crusher and other machines, *e.g.*, a yarding machine and auxiliary ones.

2. Materials and methods – *Materijal i metode*

2.1 Experimental site – *Mjesto istraživanja*

The experiment was conducted at a site where pulpwood was extracted from scrap trees generated in the course of building a dam and residual material was comminuted by a tub grinder. In other words, the residual material was regarded as logging residues in this study. This was the building site of the Fukashiro Dam of Yamanashi Prefecture, which is to the west of Tokyo. The site is located at the upper reaches of the Kazuno River, which belongs to the system of the Sagami River. The scrap trees, which had to be disposed of properly according to local government regulations, were collected from an area of 18 ha of stands of Japanese cedar (*Cryptomeria japonica* D. Don) and broad-leaved trees, which were to be submerged.

2.2 System description – *Opis sustava*

The Operation was divided into two systems, that is, a 'COLLECT and SORT' system and a 'COMMINUTE and TRANSPORT' one. After a certain amount of logging, residues were collected and comminuting operation was carried out.

In the 'COLLECT and SORT' system, felling was carried out with chain saws, extraction with a yarder (cable yarding system: endless Tyler system; maximum yarding distance: 460 m), bucking with chain saws, and sorting with a grapple loader. Pulpwood and logging residues were sorted, and a pile of pulpwood and a heap of residues were made. Logging residues, in this study, were considered as by-products of pulpwood production. In this sense, all the costs associated with this system are attributed to produced pulpwood. Time study of a yarder was carried out, and the balance of the processing capacity between this system and the 'COMMINUTE and TRANSPORT' one was discussed.

In the 'COMMINUTE and TRANSPORT' system, a grapple loader fed logging residues into a tub grinder, a tub grinder comminuted the logging residues (the screen size opening of a tub grinder was set at 5.0 cm), a bucket loader (a digging bucket of an excavator was replaced with a larger-sized bucket

Fig. 1 Tub grinder
Slika 1. *Bubnjasti iverač*

for the purpose of loading wood chips) loaded wood chips onto a truck, and a truck transported the wood chips. Therefore, these two loaders were regarded as auxiliary machines for the tub grinder in this system. The tub grinder was equipped with a conveyor to take wood chips directly into a truck. However, a bucket loader for loading chips was introduced because interest was focused on the truck mobility. Time studies were conducted of the tub grinder and two loaders, and the volume of the processed chips and fuel (light oil) consumption of each machine was measured. A bin (0.60 meters long, 0.50 m wide, 0.60 m high, and 3.6 kg weight) was filled with chips, and the weight of the bin was also measured (scales: MODEL DS–261, Teraokaseiko Co., Ltd., Japan). Consequently, the green weight of the chips per unit volume could be calculated. In order to define the moisture content of the chips, ten chip samples were taken. The green mass of each sample was measured, and the samples were then dried at 103 degrees Celsius for more than 24 hours. The moisture content was determined by dividing the mass of water contained within the sample by the dry mass of the sample.

2.3 Machine description – *Opis strojeva*

The tub grinder (HD–9 Industrial Tub Grinder, DuraTech Industries International, Inc., United States, Figure 1) is 7.72 m long, 2.49 m wide, and 2.62 m high and weighs 8,760 kg. Its engine (275 HP John Deere) has an output of 205.1 kW. The tub is 1.02 m deep, and its diameter at the top and at the bottom is 2.91 m and 2.29 m, respectively. It has a hammer mill crusher at the bottom of the tub.

The grapple loader (base machine: EX120–5, Hitachi Construction Machinery Co., Ltd., Japan; grapple: GS90LHV, Iwafuji Industrial Co., Ltd., Japan, Figure 2) is 7.58 m long, 2.50 m wide, and 2.72 m high and weighs 11,800 kg. Its engine output is 67.1 kW.

The bucket loader (312B, Shin Caterpillar Mitsubishi Ltd., Japan, Figure 3) is 7.57 m long, 2.89 m wide, and 2.83 m high and weighs 12,300 kg. Its bucket capacity and its engine output are 0.5 m^3 and 66.9 kW, respectively. The maximum load volume of the truck was 40 m^3. The operators of the machines shown above had a significant amount of relevant work experience, and the landing was large enough for the operators to maneuver the machines at will.

Fig. 2 Grapple loader
Slika 2. *Utovarivač s hvatalom*

Fig. 3 Buchet loader
Slika 3. *Utovarivač s korpom*

2.4 Cost calculation – *Kalkulacija troška*

The total comminuting cost per m^3 of the processed wood chips, *TC* (US$/m^3), is expressed as:

$$\mathrm{TC} = \sum_i \left(\frac{LA_i + M_i + F_i}{P_i} + \frac{CA_i}{W} \right) + \frac{CO}{W} \quad (1)$$

where LA_i (US$/PMH), M_i (US$/PMH), and F_i (US$/PMH) are the labour, machine, and fuel costs per PMH of each machine, respectively (*i* represents each machine, *i.e.*, a tub grinder, a grapple loader, and a bucket loader); P_i (m^3/PMH) is the productivity of each machine; CA_i (US$) is the cost of carrying in, installing, and carrying out each machine; *W* (m^3) is the whole amount of wood chips processed at the investigated site; *CO* (US$) is the cost of constructing a landing. The machine cost (expenses for depreciation and supplies), M_i, and the fuel cost, F_i, are calculated on the basis of the following two equations:

$$M_i = \frac{MP_i \times 0.9}{H_i \times D_i \times LI_i} + S_i \quad (2)$$

$$F_i = FC_i \times 0.76 \quad (3)$$

where MP_i (US$), H_i (h/d), D_i (d/y), and LI_i (y) are the machine price, hours of operation a day, days of operation a year, and life of each machine, respectively; S_i (US$/PMH) is the expense for supplies; FC_i (dm^3/h) is the fuel (light oil) consumption; 0.76 (US$/dm^3) is the unit fuel price. P_i and FC_i were calculated based on the results of the field experiment. LA_i, CA_i, *W*, *CO*, H_i, and S_i were gathered by means of a questionnaire (the expense for supplies of a tub grinder, essentially, should have been investigated in detail, for instance, the frequency of replacing old worn-out hammers with new ones; concerning this, further discussion is required).

3. Results – *Rezultati*

The time study finished when the tub grinder had comminuted almost all of the logging residues collected at the landing and the truck had transported three full loads of wood chips. Therefore, every quantity processed by the tub grinder and the two loaders during the time study was considered to be 120 m^3 in terms of the loose volume of chips (the volume of chips is expressed in loose measures in this study).

During the time study, the effective working time of the tub grinder was 119.93 minutes; thus, the productivity of the grinder was calculated as 60.0 m^3/PMH$_0$. On the other hand, the effective working time of the grapple loader and that of the bucket loader were 112.98 minutes and 118.78 minutes, respectively. Consequently, the performances were calculated to be 63.7 m^3/PMH$_0$ for the grapple loader and 60.6 m^3/PMH$_0$ for the bucket one. Details about the calculation of the total comminuting cost are listed in Table 1 (the exchange rate is roughly 105 yen to the U.S. dollar). The cost of constructing the landing per m^3 of chips in Table 1, 0.732 US$/m^3, was calculated by dividing the cost of constructing the landing, 2,857 US$, by the whole amount of wood chips processed at the investigated site, 3,903 m^3. However, 361.8 m^3 of pulpwood was also produced at the site, so the cost of constructing the landing, essentially, should have been distributed between those of pulpwood and wood chips according to their economic values. In order to collect materials for the time study of the tub grinder and the two loaders, the yarder was in operation for 657.07 minutes, and the amount of the collected materials was equivalent to 40 m^3 of pulpwood in addition to 120 loose m^3 of wood chips.

The bin filled with the processed wood chips (Figure 4) weighed 61.4 kg at the experimental site. The bin was 0.18 m^3 volume and 3.6 kg weight, so the green weight of the chips per unit volume was calculated as 321 kg/m^3. Finally, the average moisture content of chips was 120.4% (on a dry-mass basis, with a standard deviation of 12.6%), and the dry weight of chips per unit volume was estimated to be 146 kg/m^3 (DM).

Although the moisture content of logging residues to be comminuted and the screen size opening of a tub grinder would influence the productivity of the tub grinder, only one instance (120.4% of mois-

Fig. 4 Processed wood chips

Slika 4. *Izrađena drvna sječka*

Table 1 Details about the calculation of the total comminuting cost
Tablica 1. *Pojedinosti kalkulacije ukupnoga troška usitnjavanja*

Item *Opis*		Tub grinder *Bubnjasti iverač*	Grapple loader *Utovarivač s hvatalom*	Bucket loader *Utovarivač s korpom*	Note *Napomena*
Productivity – *Proizvodnost*, m^3/PMH	[1]	60.0	63.7	60.6	Results of the field experiment – *Rezultat terenskoga istraživanja*
Labour costs – *Trošak radnika*, US$/PMH	[2]	23.8	23.8	23.8	From personal communication – *Iz osobnih kontakata*
Machine cost – *Trošak stroja*, US$/PMH	[3]	74.8	29.2	26.2	[3] = [4] + [9]
Expence for depreciation – *Izdatak za amort.*, US$/PMH	[4]	61.2	21.6	18.6	[4] = {[5] x 0.9} / {[6] x [7] x [8]}
Machine price – *Cijena stroja*, US$	[5]	476,190	192,381	165,714	
Hours of operation per day – *Sati rada na dan*, h/d	[6]	7	8	8	From personal communication – *Iz osobnih kontakata*
Days of operation per year – *Radnih dana godišnje*, d/y	[7]	200	200	200	
Useful life, y – *Normalno vrijeme uporabe, god.*	[8]	5	5	5	
Expence for supplies – *Izdatak za rez. dijelove*, US$/PMH	[9]	20.4	0.7	0.7	From personal communication – *Iz osobnih kontakata*
Fuel cost – *Trošak goriva*, US$/PMH	[10]	54.4	7.6	7.6	[10] = [11] x 0.76, 0.76: unit fuel price – *jedinična cijena goriva*, US$/$dm^3$
Fuel (light oil) consumption – *Potrošnja goriva*, dm^3/h	[11]	71.4	10.0	10.0	Results of the field experiment – *Rezultat terenskoga istraživanja*
Subtotal of the costs of labor, machine and fuel – *Zbroj troškova radnika, stroja i goriva*, US$/PMH	[12]	159.8	53.7	50.7	[12] = [2] + [3] + [10]
per m^3 of the chips - *po m^3 ivera*, US$/$m^3$	[13]	2.663	0.843	0.837	[13] = [12] / [1]
Whole amount of the chipss processed at the site – *Ukupna količina sječke izrađene na radilištu*, m^3	[14]	3,903	3,903	3,903	From personal communication – *Iz osobnih kontakata*
Cost of carrying, installing and carrying out – *Trošak dopreme, postavljanja i otpreme*, US$	[15]	952	619	619	From personal communication – *Iz osobnih kontakata*
per m^3 of the chips – *po m^3 sječke*, US$/$m^3$	[16]	0.244	0.159	0.159	[16] = [15] / [14]

Item *Opis*		Value *Vrijednost*	Note *Napomena*
Cost of constructing a landing – *Trošak izgradnje stovarišta*, US$	[17]	2,857	From personal communication – *Iz osobnih kontakata*
per m^3 of the chips – *po m^3 sječke*, US$/$m^3$	[18]	0.732	[18] = [17] / [14]
Total comminuting cost – *Ukupni trošak usitnjavanja*, US$/$m^3$	[19]	5.637	[19] = [13] + [16] + [18]

ture content and 5.0 cm of screen size opening) was examined in this study. Moreover, from the viewpoint of the quality of wood chips, the issue of whether the processed wood chips in this study shown in Figure 4 are suitable for energy or not must be discussed further.

4. Discussions – *Rasprava*

4.1. Total comminuting cost – *Ukupni trošak usitnjavanja drva*

When only the labour cost, machine cost, and fuel cost of the tub grinder were considered on the basis of the previous study by the authors of this paper (Yoshioka et al. 2002), the comminuting cost per m^3 of the processed wood chips was calculated as 2.663 US$/$m^3$ (Table 1). This value corresponds to 18.2 US$/t (DM) (= 2.663 (US$/m^3) × 1,000 (kg/t)/146 (kg/m^3 DM); 1,000 kg/t is the conversion coefficient) in terms of the cost per dry mass of chips, showing a lower comminuting cost than that of the previous study, *i.e.*, 22.7–45.5 US$/t (DM) (Yoshioka et al. 2002). The moisture content observed in this study, 120.4%, was quite similar than that in the previous study by the authors of this paper, 119.3% (Yoshioka et al. 2002), and typical of green logging residues (Asikainen and Pulkkinen 1998). On the other hand, the bulk density, 146 kgDM/m^3 (DM), was higher than that in the previous study, 113.9 kg/m^3 (DM) (Yoshioka et al. 2002). This is because the processed wood chips included coniferous and broad-leaved species, while the chips in the previous study included only Japanese cedar. In general, a broad-leaved tree is heavier than a coniferous one from the viewpoint of the weight per unit volume. Consequently, the higher bulk density is supposed to be one of the reasons why the comminuting cost in this study was lower than that of the previous study in terms of cost per dry mass of chips.

The cost of the two loaders, that of carrying in, installing, and carrying out the machines, and that of constructing the landing are also listed in Table 1 and the breakdown of total comminuting cost is shown in Figure 5. The percentage of the cost of loaders, that of carrying in, installing, and carrying out the machines, and that of constructing the landing is 53% of the total comminuting cost. These costs have to be reduced in order to improve the total comminuting cost. The cost of the two loaders makes up 30% of the total cost (Figure 5). Instead of the operational system examined in this study, however, other operation patterns such as different combination of machines could have been adopted at the experimental site. With respect to this, it is necessary

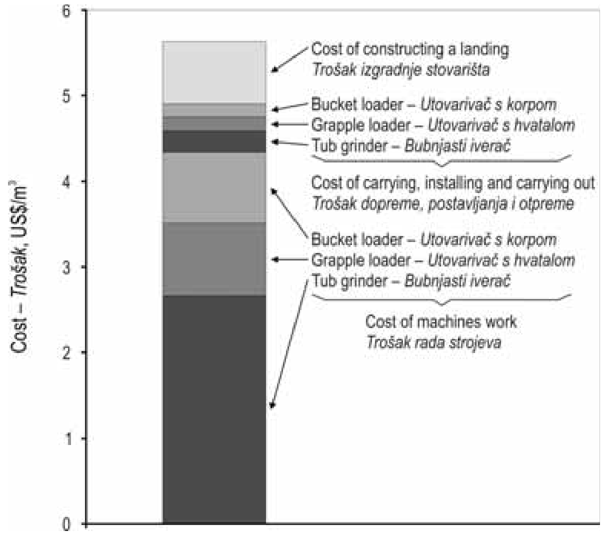

Fig. 5 Breakdown of the total comminuting cost

Slika 5. *Raščlamba ukupnoga troška usitnjavanja*

to make a comparison between total cost of this study and the cost of the cases described below:

⇒ Case One: Instead of a grapple loader, the operator of a tub grinder manipulates a grapple by installing it in the tub grinder or introducing another chipper or crusher equipped with a grapple;

⇒ Case Two: Instead of a bucket loader, a tub grinder takes wood chips directly into a truck with its conveyor;

⇒ Case Three: Instead of two loaders (and a truck), a chipper truck, which can comminute logging residues and transport chips, is introduced. When only one machine works at the landing, there is no interaction between machines. Therefore, the operator of the chipper truck can control the entire 'COMMINUTE and TRANSPORT' system. Although the operation rates of both of the chipping and transporting functions of the chipper truck will be lower than those of a tub grinder and a truck, it is easier to plan and carry out the operation of one machine than those of two or three machines from the point of view of management.

The cost of carrying in, installing, and carrying out the machines (10%) and that of constructing the landing (13%) shown in Figure 5 are calculated by dividing their original cost by the whole amount of wood chips processed at the investigated site. In order to reduce these two costs, therefore, it is necessary to produce as many wood chips as possible at one landing, in other words, as many logging

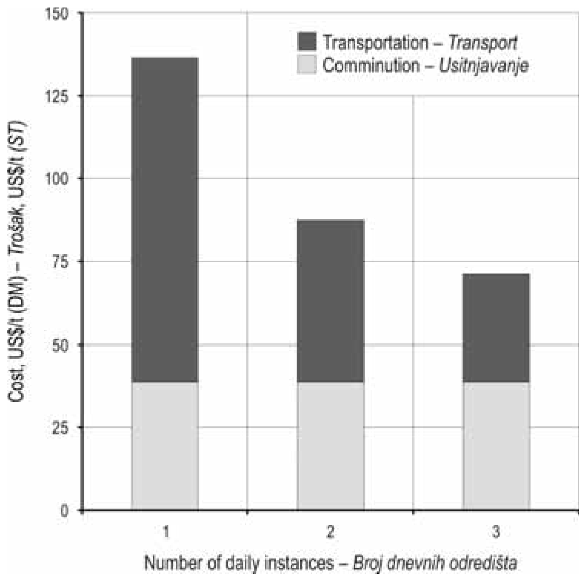

Fig. 6 Dependance of comminution and transportation costs per dry mass of chips vs. number of daily instances

Slika 6. *Ovisnost troškova usitnjavanja i prijevoza drvne sječke o broju dnevnih odredišta kamiona*

residues as possible should be collected at one landing. For instance, when a 10% more amount of wood chips was produced at the landing, the percentage of the two costs to the total cost would decrease to 21.3% and the total cost would decrease by 2.1%. Moreover, if 10,000 m^3 of wood chips was produced, the percentage of the two costs would decrease to 11.2% and the total cost would decrease by 13.3%.

The total comminuting cost is calculated as 5.637 US$/$m^3$ (Table 1). In a Finnish case study, the cost of comminution with a tub grinder was 1.7 US$/$m^3$ although its productivity was similar to that of this study (Asikainen and Pulkkinen 1998). The reason for this seems to be that there was only one machine in the Finnish system. The tub grinder was equipped with both a grapple and a conveyor. The grapple put logging residues into the tub, and the conveyor took wood chips directly into a truck; in other words, the tub grinder required no auxiliary machines. On the other hand, the mobility of a truck for transportation was probably restricted. This study and the Finnish one should have been compared from the standpoint of the sum of costs of comminution and transportation. Incidentally, the total comminuting cost in this study, 5.637 US$/$m^3$, corresponds to 38.6 US$/t (DM) in terms of the cost per dry mass of chips. The cost of a small-sized chipper, which would be suitable for tree tops and branches with a maximum diameter of 15 cm, was calculated as 66.5 US$/t (DM) in the previous study by the authors of this paper (Yoshioka et al. 2002). Therefore, the comminuting cost of a large-sized crusher is lower than that of a small-sized chipper.

From personal communication, the cost of a truck was shown to be 571 US$ per day at the investigated site. Figure 6 shows the relationship between the number of daily instances of truck transportation and the costs of comminution and transportation per dry mass of chips. The sums of the costs of comminution and transportation were 136.4 US$/t (DM), 87.5 US$/t (DM), and 71.2 US$/t (DM) when the truck transported wood chips once a day, twice a day, and three times a day, respectively (a truck will transport three times a day when its running speed, hours of operation a day, operation time of loading and unloading per cycle, and one-way running distance is 30 km/h, 6 h/d, 40 minutes per cycle, and 20 km, respectively). The cost of 71.2 US$/t (DM), for instance, corresponds to 3.56 US$/GJ or 12.8 US$/MWh in terms of the cost per calorific value of chips, and it is almost on a par with those of European countries in which the energy utilization of logging residues is making steady progress (Yoshioka et al. 2002). For the energy utilization of logging residues, Figure 6 may also be used in designing the arrangement of landings around an energy-conversion plant and the order of truck transportation, while the cost of a truck must be investigated and analyzed in detail.

4.2. Balance of the processing capacity between a tub grinder and other machines – *Ravnoteža proizvodnih kapaciteta bubnjastoga iverača i ostalih strojeva*

The productivity of a tub grinder ranges from 14–24 to 100–150 m^3/PMH in the existing studies (Asikainen and Pulkkinen 1998). The difference in the results is said to be due to difficulties in feeding logging residues into the tub grinder. The productivity of the tub grinder during the time study, 60.0 m^3/PMH_0, is quite similar to that of the Finnish case study, 60–70 m^3/PMH (Asikainen and Pulkkinen 1998), showing high performance of the tub grinder investigated in this study.

In order to collect data for the experiment, the yarder was in operation for about 11 hours (657.07 minutes), while the tub grinder comminuted the sorted logging residues for almost 2 h (119.93 minutes). During the whole period (361.8 m^3 of pulpwood and 3,903 m^3 of wood chips were processed), the yarder and tub grinder operated for 105 days and 21 days, respectively. All operating hours of the yarder were not only used for wood chips because the yarder collected pulpwood material at the same time by whole-tree yarding. However, the yarder had to work for a much longer time than the tub grinder to cope with the relatively higher productivity of the grinder.

The percentages of idling time of the grapple loader and bucket loader were 6.2% and 4.6% of the total observed time, respectively. There was little time for both machines to idle, so it is supposed that the two loaders were running almost non-stop to cope with the high performance of the tub grinder.

From personal communication, the net productivity of the tub grinder during the whole period was 26.6 m^3/PMH_0, which is 44% of the productivity based on the time study, 60.0 m^3/PMH_0. It can be interpreted that the rate of operation of the tub grinder was below 50% even when the grinder worked at the site. This should be due to a relatively higher productivity of the tub grinder than that of the yarder. As a result, the rate of operation of the tub grinder will not be enhanced unless large amounts of logging residues are collected for comminution. Accordingly, a comparison of the costs of comminution and transportation between the two cases described below should be made and further discussion is required:

⇒ Case One: A large amount of logging residues is collected to counterbalance the high productivity of the tub grinder. The total comminuting cost will be reduced because a larger amount of wood chips will be produced at one landing and the cost of carrying in, installing, and carrying out the machines and that of constructing a landing will be reduced. However, a landing that is large enough to operate the auxiliary machines for the tub grinder and accommodate large amounts of collected logging residues and processed wood chips must be constructed. Moreover, it would be necessary to build a network of high-grade forest roads on which large-sized trucks that can carry loads of as much as 40 m^3 of wood chips can travel directly to the landing;

⇒ Case Two: Another smaller-sized tub grinder is introduced. In order to keep the rate of operation of the tub grinder high, the size of the grinder should be determined in accordance with the amount of logging residues that can be collected at one landing, the processing capacity of a yarding (or skidding) machine and auxiliary ones, and the degree of preparation of the network of high-grade forest roads.

In both cases presented above, the productivity of a tub grinder is expected to be still higher, so it would be reasonable for Japanese forestry to consider the use of one tub grinder at several logging sites. In this case, planning and management of an operational system at each site considering the transfer of machines from one site to another will influence the total comminuting cost, since it has been clarified in this study that the proportion of the sum of the cost of carrying in, installing, and carrying out machines and that of constructing a landing in the total cost is not small.

5. Conclusions – *Zaključak*

In this study, an experiment on the comminution of logging residues with a tub grinder was carried out in order to calculate the productivity and procurement cost of wood chips, and the following conclusions have been drawn from the results and discussions:

⇒ The productivity of the tub grinder was 60.0 m^3/PMH_0, and the total comminuting cost was calculated as 5.637 US$/$m^3$, indicating that the comminuting cost of a large-sized crusher was lower than that of a small-sized chipper;

⇒ The percentage of the sum of the cost of a grapple loader and a bucket loader, that of carrying in, installing, and carrying out the machines, and that of constructing a landing was 53% of the total comminuting cost. Concerning the cost of the loaders, there seemed to be room for improvement, from the point of view of operational efficiency in comminution, in the combination of the tub grinder and loaders, so three alternatives were proposed (on the other hand, as many wood chips as possible should be produced at one landing in order to reduce the cost of carrying in, installing, and carrying out the machines and that of constructing the landing);

⇒ When a truck with a capacity of 40 m^3 transported wood chips three times a day, the sum of the costs of comminution and transportation was 71.2 US$/t (DM), which is almost on a par with those of European countries in which the energy utilization of logging residues is making steady progress;

⇒ As a result of the discussion about the balance between the processing capacity of the tub grinder and that of other machines, it seemed to be reasonable for Japanese forestry to consider the use of one tub grinder at several logging sites.

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Sažetak

Usitnjavanje otpada pri sječi i izradbi drva bubnjastim iveračem: kalkulacija proizvodnosti i trošak pridobivanja drvne sječke

Šumski ostatak, tj. otpad pri sječi i izradbi drva (grane i ovršine), jedan je od glavnih izvora biomase od koje se očekuje da bude izvor energije, odnosno zamjena uporabi fosilnih goriva. Godišnja dostupna količina šumskoga ostatka u Japanu trenutačno se procjenjuje na 3×10^6 t/god. (ST), s kalorijskom vrijednošću od 60 PJ (16,7 TWh).

Uporaba šumskoga ostatka u energetske svrhe zahtijeva njegovo usitnjavanje i transport prije nego što se pretvori u korisnu energiju – toplinu, struju ili tekuće gorivo. Šumski se ostatak može usitnjavati na mjestu sječe stabala (sastojini), pomoćnom stovarištu uz šumsku cestu ili na stovarištu energane. Širom svijeta razvijene su i u terenskim uvjetima istražene razne vrste strojeva (sječkalice, iveralice) za usitnjavanje šumskoga ostatka, čija je djelotvornost (proizvodnost i troškovi rada) veoma važna za uporabu u operativnom šumarstvu.

Cilj je ovoga rada istražiti značajke usitnjavanja šumskoga ostatka bubnjastim iveračem kroz:

⇒ *proizvodnost velikoga iverača*

⇒ *izradu kalkulacije troškova usitnjavanja šumskoga ostatka na pomoćnom stovarištu i prijevoza drvne sječke krajnjemu korisniku*

⇒ *strukturu troškova pomoćnih strojeva (utovarivači), troškova gradnje stovarišta te troškova dopreme, postavljanja i otpreme strojeva na stovarište u ukupnom trošku pridobivanja drvne sječke*

⇒ utvrđivanje ravnoteže proizvodnih kapaciteta bubnjastoga iverača i ostalih strojeva u sustavu usitnjavanja šumskoga ostatka.

Istraživanje usitnjavanja šumskoga ostatka bubnjastim iveračem provedeno je na pomoćnom stovarištu sječine japanske kriptomerije (Cryptomeria japonica D. Don.) i primiješanih listača.

Bubnjasti je iverač (HD–9 Industrial Tub Grinder, DuraTech Industries International Inc.) konstrukcijski postavljen na prikolicu (priključno, vučeno vozilo) duljine 7,72 m, širine 2,49 m i visine 2,62 m. Snaga pogonskoga motora iznosi 205,1 kW, a ukupna masa agregata 8,76 t. Bubanj je dubine 1,2 m, s gornjim promjerom 2,91 m, odnosno donjim 2,29 m. Na dnu bubnja nalaze se čekići kojima se usitnjava šumski ostatak. Iverač je opremljen i konvejerom za dobavu sječke u tovarni prostor kamiona.

Sustav pridobivanja drvne sječke na pomoćnom stovarištu čine utovarivač s hvatalom za utovar šumskoga ostatka u bubanj iverača i utovarivač s korpom za utovar drvnoga ivera s tla u kamion. Unatoč opremljenosti bubnjastoga iverača konvejerom razlog uključivanja utovarivača s korpom u sustav pridobivanja drvne sječke jest postavljanje zahtjeva kretnosti kamiona za prijevoz sječke krajnjemu korisniku kao prioriteta.

Gustoća sječke u svježem stanju iznosila je 321 kg/m^3, uz prosječnu vlažnost 120,4 ± 12,6% mase sječke u suhom stanju. Gustoća je suhe tvari usitnjenoga šumskoga ostatka iznosila 146 kg/m^3.

Rezultati istraživanja pokazuju da:

⇒ proizvodnost bubnjastoga iverača iznosi 60 m^3 rasute sječke po efektivnom satu rada uz ukupni trošak iveranja od 5,637 US$/$m^3$, što upućuje na troškovnu pogodnost usitnjavanja drva većim iveračima u odnosu na manje iverače

⇒ udio troškova rada utovarivača, gradnje stovarišta te dopreme, postavljanja i otpreme strojeva na stovarište iznosi 53% od ukupnoga troška usitnjavanja šumskoga ostatka

⇒ u slučaju prijevoza drvne sječke kamionima kapaciteta 40 m^3 tri puta dnevno, ukupni trošak usitnjavanja i prijevoza iznosi 71,2 US$/t (ST), što je približno podjednako kao i u europskim zemljama koje u korištenju energije iz šumskoga ostatka ostvaruju značajan napredak

⇒ analizom proizvodnih mogućnosti bubnjastoga iverača i ostalih strojeva, u sustavu pridobivanja drvne sječke, može se realno očekivati da se bubnjasti iverač izmjenjuje na više radilišta.

Ključne riječi: *biomasa, otpad pri sječi i izradbi drva, bubnjasti iverač, proizvodnost, trošak usitnjavanja i prijevoza*

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