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PRODUCTION OF WOOD ENERGY BY CHIPPING

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Abstract: Increasing demand for using renewable energy resources is strongly emphasized during the last decades. On the international level it is recognized through a series of conventions, conclusions and recommendations. Forests are energy source through conversion of wood biomass into solid, fluent and gaseous fuels for industrial and household use. Wood chips is a form of biomass, size of 5-50 mm, which is obtained by chipping of lower quality logs, trees, brushwood and wood residues. Some investigation showed that choosing the right chipper is crucial in a projection of chipping system. In this study, chipping at the landing site was compared with the Jenz HEM 700 and Pezzolato PTH 1300/1500 chippers. The subject of chipping was beech long fuelwood and stacked fuelwood. The investigation was done with the time and work-study method. Cost calculation was performed according to FAO methodology, slightly modified for local conditions. Also, in simulations, Jenz HEM 561 DQ was included in order to cover a wider range of chippers by the capacity, but data for this chipper were undertaken from other research. Unit costs of chipping were calculated on the basis of raw material input and chipper output. Unit costs were expressed for factory projected chippers productivity also, in order to compare obtained unit costs with costs when chippers are working below full capacity. Results of the productivity and cost calculation of chippers showed that bigger chippers had lower unit costs, but because of inability to achieve full capacity at the forest landing site and because of their dimensions which hinder the manipulation, it can be recommended using of chippers of smaller capacity like Jenz HEM 561 DQ or even smaller.

Keywords: wood energy, chipping, productivity, cost.

1. INTRODUCTION

The forest harvesting methods in Bosnia and Herzegovina (BIH) refer mostly to the motor-manual cut-to-length method. The half-tree length and tree length method are rarely practiced, while the whole tree method and chipping itself are not practiced at all. The contemporary harvesting technology in forestry of BIH is felling and processing trees at the stump using chainsaws and skidders for roundwood extraction. Sometimes, when terrain and stand conditions require, animals and cable yarders are in use. Roundwood is skidded to the forest road (landing site) with forest skidders or adapted agricultural tractors. Stacked wood (traditional fuelwood) is extracted by animals in the traditional way. As a consequence of current methods, forest harvesting is low in utilization of total tree biomass, i.e. significant amount of wood biomass remains unused in the forest. Residue and stacked wood that occur during wood processing in the cut-to-length method remain in the forest. In the tree length or the half-tree length method where wood processing is at the landing site, there is a presumption that wood residue remains on the forest road and can be used for chipping (wood energy).

Increasing demand for using of renewable energy resources is strongly emphasized during last decades. On the international level it is recognized through series of conventions, conclusions and recommendations [1]. Forests are an energy source through conversion of wood biomass into solid, fluent and gaseous fuels for industrial and domestic use. Bioenergy systems can use wood biomass

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which would, in other cases, remain unused because of a low market price and high utilization costs. In conventional forestry, biomass is utilized as a co-product of roundwood production [1]. Almost all operations in forestry leave residues (tops, branches, needles, bark) which can be used for energy if there is a suitable technological solution. There are estimations that 25-45% of volume of harvested trees remain in the forest [2]. This residue is usually dispersed on the large area, which makes transport costs per energy unit very high [3, 4]. Biomass is unfossilized plant material, which originates from photosynthesis with creation of oxygen and consumption of CO_2 from atmosphere. Such composition of biomass has an advantage in relation to other renewable energy sources, because it is very similar to classical fuels (oil and coal) and technology for biomass does not require such large changes in relation to the existing energy technology [5]. Forest biomass potential can be divided into theoretic and effective. The theoretic potential is present in the forest and the effective potential can be realized on the basis of management systems, harvesting technology, wood market and socio-economic situation of forest owners [6].

Chipping of wood is defined as a procedure of forest biomass processing into a form suitable for use in power generators, and the need for forest biomass chipping is based on enabling the automation handling of wood chips, economical transport and easier drying and combustion [7]. Räisänen and Nurmi [8] examined the amount of wood residues remaining after felling in the stand and dependence on the place of slicing on the thinner side of the tree. Westbrook et al. [9] examined the addition of a small chipper to a conventional harvesting operation in Georgia (USA). They found that the logging residues could be produced for about the same price as the chipper operating costs. Wood biomass, in the form of slash or loose stems, has a solid volume factor (ratio of solid wood volume to total volume) of 0.15 to 0.25. Comminuted biomass in the form of chips or chunks has a solid volume factor of 0.35 to 0.45, more than double the density of loose slash [10]. In investigations of Bjorheden and Eriksson [11], Hakkila [12] and Talbot and Suadicani [13] three different chipping methods were compared. They were classified on the basis of place of comminution and chipping where a chipper characteristic is very important. Chipping systems are grouped in literature as a terrain chipping method, chipping at the forest road, chipping at the landing site and chipping at the terminal [14, 15, 16, 17].

Wood biomass is used in various forms for energy purposes. Technology depends on biomass characteristic; such as size, size distribution, moisture content, ash content and contaminants (stones, earth and sand). The biomass energy content is shown as the energy value which depends on the physicochemical characteristics, primarily from feedstock moisture content. The calorific value is expressed as an upper (gross calorific value - GCV) or as a lower value of firewood (net calorific value - NCV). Upper calorific value represents the energy content of the biomass without free water while in the case of lower calorific value, the energy required to evaporate the water is taken into account. Calorific value of wood also depends on the wood species respectively of its density. On average, gross calorific value of wood is about 19.5 MJ/kg. Moisture content of wood biomass is usually expressed with regard to wet basis, as well as with regard to dry basis. The average wood moisture content is about 50% (wet basis), while after drying period it is about 18% (wet basis), which largely depends on the method and duration of storage after harvest. Natural ash content in needles and leaves exceeds 5%, in brushwood and crust it is about 3%, while in logs it is about 0.6%. Also, different pretreatment techniques of raw material are currently used to increase density which achieves higher energy value relative to the volume, which reduces transportation costs and facilitates handling of raw material. Thus, the density of biomass can vary from 150 kg/m^3 to over 600 kg/m^3. Technologies related to the pre-treatment of raw materials include well-known mechanical technologies, such as logging and production of wood chips, but also little less known and used thermo-mechanical and thermo-chemical technologies to increase the density of raw materials, such as production of pellets or torrefaction which produces product similar to coal which increases energy value, energy density and the ability to crush raw materials.

Wood chips are a form of biomass, size of 5-50 mm, which are obtained by chipping of lower quality logs, trees, brushwood and wood residues. For the automatic use of the wood chips it is good to be evenly sized. Moisture of wood chips obtained by chipping just harvested wood is about 50%, but after the summer drying in period of 3-6 months, the moisture is lowered to 30-40%. Further drying with hot air can lower moisture to 20%. Ash content in the wood chips depends on the type of wood and leaves, brushwood and logs. Wood chips, depending on the method of manufacture and storage, can be contaminated with stones, earth and sand which increase the ash content. Calorific value of wood chips depends on the moisture and the raw materials from which they were obtained. Moisture content depends on the season of harvesting, type of biomass, time after harvesting etc. Moisture content of the raw wood chips is over 40% and even over 50%, the forest dry wood 20-40% (depending on the time spent in the forest), up to 20% (air dry wood) and technical dry wood with a moisture content of 6-15% [18]. Raw wood with the water content of 50-60% has a calorific value of about 7.1 MJ/kg, wood with the water content of 25-35% has a calorific value of about 12.2 MJ/kg, and stored through the summer wood with the water content of 15-25% has a calorific value of about 14.4 MJ/kg [18].

The aim of this research is to compare the productivity and costs of producing wood chips with different wood chippers, and to investigate what amount of wood chipping at the forest road is rational, in given conditions.

2. MATERIAL AND METHOD

Data were collected by performing a time and work study. Time study is one of most common practices of work measurements. It is used worldwide, in many types of work analysis in order to determine the input of time in the work performance [19]. Empirical performance models are generally developed by collecting field data and testing the statistical significance of any relationships [20]. This technique is used to calculate an equation capable of representing the relationship between a dependent variable (typically time consumption or productivity) and one or more independent variables [21].

Investigation was conducted in the northern part of the Republic of Srpska in the area of municipality of Ribnik, in two compartments, 98 (A) *section a*, M.U. "Potoci-Resanovača" and 65 (B), *section a*, M.U. "Šiša-Palež". Chipping was done at the landing site on the forest road. Subject of chipping was long and stacked beech fuelwood and residue which was left after timber processing. During time study, the time consumption data were collected and wood input and chips output were measured. The way of measuring the fuel consumption of chipper was filling the chipper fuel tank to the top at the beginning of chipping, and refilling it again after the chipping was done. The amount of refilled fuel was measured. Water content in logs was measured with the PCE-WMH 3 hygrometer at the moment of chipping. Several measurements were done on each log and an average value was calculated. Water content of the input wood was implied as water content of the chips. It was assumed that the chipping process had no influence on water content. Wood input was measured before chipping and wood chips were measured in the transport container after chipping. The conversion coefficient from solid wood volume into loose chips volume was calculated in that way. For comparison of some machine suitability in different working conditions or for different technologies in similar working conditions, it is useful to compare productivity expressed in measuring units. Beside productivity it is necessary to compare costs too. Direct machine work cost is determined by cost calculation using some calculation method and on the base of the input data. Most used calculation methods in forestry are based on Miyata [22] and FAO [23]. These methods are often modified in dependence of the input data availability and target precision of calculation. For calculation of direct machine work costs in this study modified FAO methodology was used [23] according to calculation scheme used in the Public Company “Šume Republike Srpske”.

Wood chipping was done with the Jenz HEM 700 and Pezzolato PTH 1300/1500 chippers. In calculation Jenz HEM 561 DQ was included also, in order to cover a wider range of chippers by the capacity (Table 1) (Figure 1 and 2). Truck used for feeding of chippers was Mercedes Actros 2654 with Palfinger Epsilon 120Z plus crane.

Table 1. Characteristics of chippers

Chipper	Jenz HEM 700	Jenz HEM 561 DQ	Pezzolato PTH 1300/1500
Max. input diameter (cm)	70	56	90
Woodchips output (loose m/h)	160	120	260
Engine power (kW/hp)	522/700	360/482	858/1150
Fuel consumption (l/h)	60	45	80
Feed width (mm)	1000	1000	1200
Feed height (mm)	700	650	900
Rotor diameter (mm)	1040	820	1500
Number of blades	10	10	2
Total weight (kg)	17500	13300	33000

Figure 1. Jenz HEM 700 (Photo D. Marčeta)

Figure 2. Pezzolato PTH 1300/1500 (Photo D. Marčeta)

3. RESULTS

3.1. Productivity

Wood chips were thrown directly into the truck with the container for transport. The container volume was 30 loose m^3. Established conversion coefficient was 2.7 i.e. 1 m^3 of wood was equal to 2.7 loose m^3 of wood chips. Water content of chips was 33%.

Productivity of chipper was calculated on the basis of productive machine hours. Calculated productivity for JENZ HEM 700 was 51 m^3/h of roundwood with average diameter of 18.6 cm and an average length of pieces was 6.6 m. Expressed in chips amount productivity was 137.7 loose m^3/h. When chipping of stacked fuelwood productivity was 36m^3/h, so 29.5% lower, compared to roundwood chipping. The reason for this was the fact that crane could not achieve full efficiency when manipulating with the stacked wood, especially when stacked wood was not piled. This was highly dependable on the operator skills. Measured fuel consumption was 56 l/h.

Chipper Pezzolato PTH 1300/1500 belongs to the group of big capacity chippers. It has its own motor and needs a truck for transport and loading of raw material. Because of its capacity and dimensions, this chipper is suitable for big central landing sites. The chipper was fed by the crane mounted on the truck. Produced wood chips were piled on the ground. For that reason, there was no opportunity for estimation of conversion factors from solid wood volume into loose volume. Granulation (dimension) of chips was the same as in chipping with the JENZ HEM 700, so presumption was that the same conversion factor can be used, 2.7. Average water content of chips was 35%. Productivity of chipper was calculated on the basis of productive machine hour too. Calculated productivity was 60 m^3/h of roundwood with average diameter of 20.5 cm and average length of pieces 7.6 m. Productivity of chips was 162.0 loose m^3/h of chips. Fuel consumption was 72 l/h.

3.2. Cost calculation

Cost calculation for chippers and trucks was done on the basis of combination of collected data during time study, data from chipper owners and from other sources like other studies and manufacturer's data (Table 2). Jenz HEM 700 and Pezzolato PTH 1300/1500 were included in time study, but Jenz HEM 561 DQ was also included in cost calculation. Some data for this chipper were taken from other sources [24; 25]. The chipper and truck lifetime is 8 years. Yearly working hours for chippers are 1600 hours. Remained value was calculated as 10% of purchase value.

Unit costs of chipping were calculated on the basis of raw material input and chipper output (Table 3). Roundwood (m^3) was taken as an input and chips volume (loose m^3) as an output. In chipping of stacked wood unit costs were about 30% higher. Unit costs were expressed for factory projected chippers productivity also, in order to compare obtained unit costs with costs when chippers are working under full capacity.

Table 2. Cost calculation for chippers and truck

	Jenz HEM 700	Jenz HEM 561 DQ	Pezzolato PTH 1300/1500	Mercedes ACTROS 2654
Lifetime (year)	8	8	8	8
Working hours per year	1600	1600	1600	1640
Purchase price (€)	350000.00	265356.00	500000.00	98280.00
Remained value (€)	35000.00	26535.60	50000.00	9828.00
Depreciation(€/year)	43750.00	33169.50	62500.00	12285.00
Investment (€/year)	13781.25	10448.39	19687.50	3869.78
Insurance(€/year)	0.00	0.00	0.00	1730.32
Fixed costs(€/year)	57531.25	43617.89	82187.50	17885.10
Cost of spare parts and maintenance (€/year)	21875.00	16584.75	31250.00	6142.50
Cost of additional wear parts(€/year)	448.50	448.50	448.50	2691.00
Fuel costs(€/year)	112404.13	84303.10	149872.18	25203.11
Lubricant costs(€/year)	11240.41	8430.31	14987.22	2520.31
Variable costs(€/year)	145968.04	109766.66	196557.89	33161.49
Fixed costs (€/year)	**57531.25**	**43617.89**	**82187.50**	**17885.10**
Variable costs (€/year)	**145968.04**	**109766.66**	**196557.89**	**33161.49**
Workers costs(€/year)	**10226.00**	**10226.00**	**10226.00**	**10226.00**
Total costs (€/year)	**213725.29**	**163610.55**	**288971.39**	**61272.59**

Table 3. Unit costs of chipping

	Jenz HEM 700	Jenz HEM 561 DQ	Pezzolato PTH 1300/1500	Mercedes ACTROS 2654
	Unit costs of chipping based on the calculated productivity			
m³/h (roundwood)	51.00	31.00	60.00	-
Loose m³/h (woodchips)	137.70	83.70	162.00	.
€/h	133.58	102.26	180.61	37.36
€/m³ (roundwood)	2.62	3.30	3.01	-
€/ loose m³ (woodchips)	0.97	1.22	1.11	-
	Unit costs of chipping based on the factory predicted productivity			
m³/h (roundwood)	60.00	45.00	100.00	-
loose m³/h (woodchips)	162.00	121.50	270.00	
€/h	133.58	102.26	180.61	37.36
€/m³ (roundwood)	2.23	2.27	1.81	-
€/ loose m³ (woodchips)	0.82	0.84	0.67	

4. DISCUSSION AND CONCLUSIONS

Investigated chippers achieved less productivity than was predicted by the manufacturer. At the landing site manipulating with the chippers crane and feeding did not go smoothly because of limited space. Cost calculation of chippers showed that bigger chippers had lower unit costs, but because of inability to achieve full capacity at forest landing site and because of their dimensions which hinder the manipulation, use of smaller chippers can be recommended, such as Jenz HEM 561 DQ or even smaller. When it comes to transportation, it is noticeable that there should be enough chips containers if we want chippers to work under full capacity. Spinelli et al. [3] also found that chipping at the landing site is technically a very effective method but requires close coordination of the transportation fleet.

Selling price of the fuelwood at the landing site was 30.26 €/m^3. At the moment of investigating, the average price of wood chips was about 19

€/loose m^3. Since it was established that from 1 m^3 of roundwood it was possible to get 2.7 loose m^3 of chips, what is close to the investigations of Johnson [10] and that chipping cost with chipper Jenz HEM 700 was 2.62 €/m^3 of roundwood fuelwood it was obvious that from 1 m^3 of roundwood fuelwood with value of 30.26 €, 2.7 loose m^3 of chips with value of 48.68 € can be produced. The value was increased for 18.42 €.

It was very hard to achieve full capacity of chipper when chipping at the forest landing site; especially during chipping with large chippers. The reason was that chipper often should change the place from one to another landing site, waiting for containers, trucks, etc. This was increasing delays time and costs consequently. For calculating the utilization rate of each chipper in given conditions, long observations are necessary. With choosing the chipper with optimal capacity, work could be more or less optimized. Level of optimization, in addition to chipper characteristic, depends on availability of wood amount at one place and frequency and distance of chipper moving. In this experiment the investigation was done on chippers who only were available at the labor market in the area. The chipper must be engaged with enough number of special trucks with containers for chips transport. Transport should be done at the same time as chipping. Transport costs of chips are very uncertain and depend on many factors, like transport distance, road condition, wood chips price, etc. Spinelli and Hartsough [26] suggested that disc chippers have dominated the industry, but drum chippers are making inroads, especially in fuel supply operations.

Chipping and using of wood chips in general is relatively new on the local market and this investigation only opens this problem for discussion and for further investigations. State-of-art intentions in using of wood as a green energy are coming with delays in Republic of Srpska, but in recent years, this process has been visibly accelerating. There are several plants for briquette and pellet production, and several district heating plants converted from fossil fuels to the wood biomass (Banja Luka, Prijedor, Gradiška). Pellet plants export their products to Italy and other EU countries. As a raw material they use sawmill residue mostly. As the sawmill residue has limiting potential and pellet production has intention for expansion, there will be need for other raw material sources. Some pellet plants managers are already buying the lower quality wood (fuelwood and pulpwood). So far, fuelwood is used mostly for household heating of local people and a certain amount of fuelwood is exported. Local people still use traditional furnaces where energy efficiency is very low. They can allow to have such low efficiency because fuelwood is still relatively cheaper than other energy sources. As demand for fuelwood form side of pellet plants would arise, competitiveness between local people and pellet plants will arise also. This could have influence on the price of fuelwood and local people will have to transfer toward the more efficient technology of heating, like district heating on wood chips, or small pellet furnace. Wood chips, which are producing now, are used for an industrial purpose and for heating of several biomass-heating systems.

Using of biomass of branches, twigs and other parts of a tree, which are left in the forest after felling, is still not common and lack of adequate machinery and technical solutions is evident. This should be the subject of further investigations. Forest managers must follow wood and wood energy market and adjust harvesting technology in order to be economically viable and to meet market needs. Purchase and inclusion of mobile chippers and container transportation trucks in the production chain is an opportunity and investigations in this area should be encouraged.

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ПРОИЗВОДЊА ДРВНЕ ЕНЕРГИЈЕ ИВЕРАЊЕМ

Сажетак: Растућа потреба за обновљивим енергетским изворима снажно је наглашена посљедњих деценија. На интернационалном нивоу та потреба је препозната кроз серије конвенција, закључака и препорука. Шуме су извор енергије кроз конверзију дрвне биомасе у чврста, течна и гасовита горива за употребу у индустрији и домаћинствима. Дрвни ивер је форма биомасе, величине 5-50 mm, која се добија иверањем трупаца, обично слабијег квалитета, стабала, грмља и дрвних остатака. Нека истраживања су показала да је избор оптималног иверача круцијалан у пројектовању система за иверање. У овом истраживању упоређивано је иверање на стоваришту иверачима Jenz HEM 700 и Pezzolato PTH 1300/1500. Предмет иверања је било буково обло и просторно огревно дрво. Провођен је метод студија рада и времена, а калкулација трошкова је урађена према ФАО методологији, благо модификованој према локалним условима. У симулацију система укључен је и иверач Jenz HEM 561 DQ у сврху да се покрије шири дијапазон иверача по капацитету, али сви подаци за овај иверач нису снимани већ су преузети из других истраживања. Јединични трошкови израчунати су на бази сировог улазног материјала и излазног ивера. Изражени су и фабрички пројектовани јединични трошкови и упоређени са израчунатим, у сврху поређења трошкова кад иверачи раде у пуном капацитету са израчунатим трошковима при раду иверача испод фабрички пројектованих капацитета. Резултати продуктивности и калкулација трошкова иверања су показали да иверачи већих капацитета имају мање јединичне трошкове, али због немогућности да постигну пун капацитет на шумском стоваришту и због својих димензија које им лимитирају покретљивост може се препоручити коришћење иверача мањег капацитета, као што је Jenz HEM 561 DQ, или чак још мањег.

Кључне ријечи: дрвна енергија, иверање, продуктивност, трошак.

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