

Effect of chipper knives sharpening on the forest chips quality

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Abstract: *Effect of chipper knives sharpening on the forest chips quality.* Power plants make adequate demands concerning the forest chips quality. The basic parameters include: moisture content, size and calorific value. The carried out investigations aimed at determination of size and fraction distribution of forest chips produced with the chipper BRUKS 805 CT at various sharpening of knives as well as determination of moisture content. The obtained results enable to find, that to decrease material moisture content to the level that meets the demands of power plants it is recommended to store the cutting residues on forest site for several months. Significant effect of cutting knives sharpening on the share of particular chips fractions and their size was found. Cutting with blunt knives increases share of fine fractions of mean size particles 35.78 mm and lower; there is significant difference in mean size of chips cut with the sharp or blunt knife.

Key words: forest biomass, quality of chips, fraction, chipper, forest chips

INTRODUCTION

According to Decree of National Economy Minister (Rozporządzenie Ministra Gospodarki) [2012], the forest biomass designed for energy purposes is the timber of not full value, consisted mainly of cutting residues that include branches, tree-tops, off-dimension-fragments of round wood. These residues are made and transported to intermediate or final consumer in the form of packs or chips (more common). Characteristic feature of this biomass form is the substantial

content of green parts (leaves, litter of conifer needles), bark and mineral impurities. This material is also quite diversified in respect of dimensions.

Production of forest chips is based on utilization of assortment that is not widely used in industry. Application of chips is determined mainly by such parameters as: wood species, fraction, shape, moisture content and level of impurities [Bąkowski 1975, Glazar 2006, Glazar et al. 2010].

Various technologies are applied in the process of forest chips harvesting; they are affected by, among others, different conditions during timber harvesting and kind of operations, e.g. late cleaning or final cutting [Patalas 1968]. The quantity of biomass available at various stages of tree stand growth. The cutting itself is most important operation in every technology of forest chips harvesting.

Variety of materials used in production of chips significantly affects their quality and destination. Characteristic features of forest chips are determined in Polish Standard PN-91/D-95009, where there are specified parameters concerning kind of wood raw material, its dimensions, its moisture content and the storage and transport requirements. According to the mentioned standard, quality of chips is assessed in consideration of the following criteria: percent share of particular fractions, correctness of

right fraction, share of bark, mechanism of surface upset. However, the quality of chips is most often associated with their physical properties – size, moisture content, calorific value. However, size parameters of forest chips are not unequivocally described in Polish Standard PN-91/D-95009, which classifies forest chips only in respect of industrial utilization.

At present the basic standard is PN-EN 14961-1:2010 that classifies biomass designed for energy purposes and the main forms of solid biomass. The standard EN 14961-4:2011 determines main parameters to be considered in assessment of forest chips.

Basing on the mentioned standards and other legal acts, the final consumers of biomass utility commercial form make most often strictly specified demands in respect of chips parameters (dimensions, calorific value, moisture content, content of impurities). There are often specified demands as to delivery size, method of unloading, transport means used in realization of delivery to the thermal power plant [Zawistowski 2003]. Both the production process itself and also subsequent links of logistic chain connected with biomass processing must meet conditions of the final consumer.

Compliance with specified quality demands connected with wood chips is essential for the proper course of combustion, both in individual heating systems and industrial ones. The modern and automated systems call for precisely specified physico-chemical and geometrical properties. The size of fuel fractions, determined as size distribution, is mostly responsible for continuous and reliable operation of equipment. Particles of too large dimensions may lead to blocking boilers and suspension of fuel in the machines. Current legal regulations concerning the forest chips and the requirements used in professional power engineering determine only the maximal length of chips, that should not exceed 40 mm; particular plants apply some deviations from this rule and introduce their own dimensions. Exemplary requirements of selected Polish power plants in respect of forest chips are presented in Table 1.

The forest chips are produced by shredding the cutting residues in the machines called chippers, equipped with wood cutting knives as working elements. Both the knives and the bed knives included in working elements of the forest chipper are made most often of alloy steel of high chromium content (about 7%) with addition, among others,

TABLE 1. Required parameters of forest chips for selected thermal power plants

Thermal power plant	Calorific value (Q_{ir})			Moisture content (W_{ir})			Size of chips (L)
	min.	max.	expected	min.	max.	expected	
	MJ/kg			%			
A	7.0	18.0	≥ 10.5	5.0	65.0	≤ 40.0	≤ 35.0
B	7.0	18.0	≥ 17.0	10.0	20.0	≤ 10.0	≤ 48.0
C	7.1	10.3	≥ 8.7	38.0	50.0	–	$38 \leq L \leq 63$
D	7.0	–	–	–	50.0	–	$10 \leq L \leq 55$

of silicon or vanadium, that enable to obtain appropriate hardness of the knife and substantial abrasion resistance. Angle of knives' sharpening amounts most often to 30–45°, while their thickness is included in the 6–20 mm. The angle of knife clearance varies usually from 5 to 8°. Fitting in the given limits allows for better pressing down of wood by the cutting knives [Lisowski 2009]. Independently of the way of mounting the knives, an appropriate arrangements of blades against the bed knives should be assured. Distance between the knife blade and the bed knife blade amounts most often to 0.5–1.0 mm. As the knife blade gets worn and blunt, and knife clearance increases beyond admissible range, the blade should be replaced with a new one.

Sharpening of knives affects considerably energy consumption in the wood cutting process. Energy needed for cutting material with the use of knife with blunt edge could be even 4.4 times higher than energy needed for cutting with the sharp knife [O'Dogherty 1982]. Mounting of suitable sensors in wood cutting machines to control the knives' sharpening and the resulted energy consumption would be a beneficial solution [Nati et al. 2010]. Dullness of knife disadvantageously affects its ability for cutting material. The forces needed in further utilization of the blunt blade increase very rapidly up to the critical value [Lisowski – Ed. 2010].

Degree of knives' dullness affects very much the chips quality, diversification of their dimensions and degree of fibres upset [Chandrasekaran 2013]. Uniformity of chips dimensions mainly depends on the knife sharpening angle throughout its

length [Barontini et al. 2014]. If variability of this angle is chosen properly, dimensions of chips can be similar. Then, no additional sorting of chips is needed. However, designing of such angle is not easy, due to diversified wood feeding of the chipper. Therefore, the chippers had to cooperate very often with chip sorting machines [Kawka and Reczulski 2011]. A decrease in blade angle of the knife results in its sooner dullness and the increased amount of the fine fraction (by 3–4 times). The knives dullness worsens the chips structure and increases energy consumption. According to Spinelli, the wear of chipper's knives results from a series of complex mechanical, thermal, electrical and chemical processes [Spinelli et al. 2014].

However, deformation of chips produced during wood cutting does not depend exclusively on the chipper parameters, but also on physical properties of wood, among others on wood resistance to compression and bending. In the moment of chip separation, its shape is similar to a trapezoid. However, it results from deformation under the influence of the knife action, since in initial phase the material had the shape of a parallelogram. Therefore, permanent deformation of chips results from compression of wood along the length of fibres [Reczulski 2013].

Replacement of knives in the chipper is based on individual decision of operator. However, according to Facello [2013], in no case one should allow for situation, when the knives are not able to produce chips of good quality. The cutting knives' parameters should be selected in a way to maximize the period of their utilization; however, along with

savings of longer exploitation of a single knife the additional fuel costs may occur, together with the expenses resulted from lower machine productivity [Facello et al. 2013].

This paper aimed at determination of forest chips quality, depending on the chipper knives sharpening related to consumers' demands. The two parameters were considered in the investigations – moisture content and size of the chips.

MATERIAL AND METHODS

A research material were the chips produced by shredding of fine-dimension assortments harvested from the two different forest areas. The chips of fine-dimension wood (cutting residues, assortments M1 and M2) were produced directly on the cutting site with the use of chipper BRUKS 805 CT equipped with a drum shredding unit with two knives [Zychowicz and Gendek 2009]. The drum diameter amounted to 800 mm, clearance between the knife and the bed knife was equal to 1 mm. Pine stands on the sites were similar in respect of age, species composition and habitat (site index III). The pine stand of 115 years with addition of birch of 80 years was

removed from Area 1 by clear cutting, while from Area 2 there was removed the pine stand of 110 years with addition of spruce of 105 and 85 years. In the period from cutting execution till cutting time, the cutting residues were stored on forest site for 7 and 5 months, respectively. The cutting operation was carried out in June.

To obtain a representative sample, the chips were taken at random from different places of chipper container, and then mixed. Chips for the blunt knife were collected just before replacement of knives (the knife of maximal bluntness), while for the sharp knife they were collected just after replacement of knives (the knife of maximal sharpness). The moment of knife replacement was determined by machine operator and was based on his own experience. Volume of collected material was contained in the range 60–80 l for every material batch. The state of knife cutting edge sharpening is presented on Figure 1.

In determination of material moisture content a weighing-drying method was applied. Ten samples were taken for every kind of material; the samples were placed in laboratory glass-ware and weighed with accuracy of 0.01 g. The weighted samples were placed in

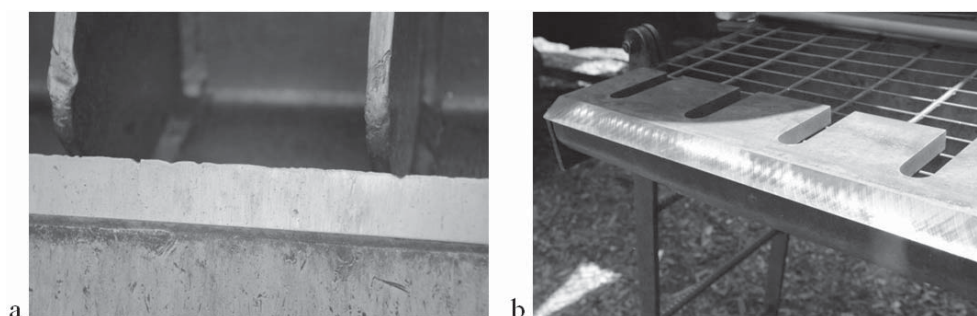


FIGURE 1. Cutting edge of chipper knife: a – blunt knife, b – sharp knife (photo A. Gendek)

a laboratory dryer equipped with thermo regulator that maintained the required temperature $\pm 1^\circ\text{C}$. Drying of samples was executed at temperature 104°C and lasted till the samples reached constant mass. Using the obtained masses of wet and dry samples, the relative and absolute humidity were determined [PN EN-13183-1:2004]. It was determined for an original material – the initial material were the collected chips containing wood, litter of conifer needles bark and other impurities.

In determination of size distribution of chips there was used the sieve separator developed in Department of Agricultural and Forest Engineering WULS in Warsaw [Lisowski et al. 2008a, Lisowski et al. 2008b]. The collected material of about 10 l was screened through a set of sieves of openings diameters 60, 50, 40, 32 and 6 mm. Particles of size lower than 6 mm were accumulated on the bottom of the separator. The given size of openings corresponded to the mean geometric size of particle on the sieve determined by dependence (3), that amounted to 94.87, 54.77, 44.72, 35.78, 13.86, 3.00 mm, respectively. Upon completing separation the material remaining on every sieve and the bottom was weighed with accuracy of 0.1 g. For each material five repetitions were realized and the mean values of them were calculated. After sieve separation the mass share of impurities in chips was determined. The stand was fabricated and measurements were executed according to standard ANSI/ASAE S421.1 [Lisowski et al. 2008a, Lisowski et al. 2008b, Lisowski et al. 2009].

Geometrical mean of particles distribution and geometrical standard de-

viation were calculated with the following dependence [Lisowski et al. 2008b, Lisowski – Ed. 2010]:

$$x_g = \log^{-1} \frac{\sum (m_i \log x_{si})}{\sum m_i} \quad (1)$$

$$s_g = \log^{-1} \sqrt{\frac{\sum m_i (\log x_{si} - \log x_g)^2}{\sum m_i}} \quad (2)$$

$$x_{si} = \sqrt{x_i x_{i-1}} \quad (3)$$

where:

x_g – geometrical mean of distribution;

s_g – geometrical standard deviation;

m_i – mass on i -sieve [g];

x_{si} – mean length of particles on i -sieve [mm];

x_i – diameter/diagonal of i -sieve opening [mm];

x_{i-1} – diameter/diagonal of opening of sieve above i -sieve [mm].

RESULTS AND DISCUSSION

The obtained results of material moisture content were subjected to statistical analysis and presented in Table 2. Since in the case of biomass used for energy purposes the relative humidity (W_w) is applied, this parameter will be subjected to further analysis.

Mean relative humidity of chips for Area 1 amounts to 32.55%, while for Area 2 amounts to 22.96%. The carried out analysis of variance and statistical tests showed, that material moisture content between two areas differs statistically from each other. Comparing the obtained results and the material one can find that the factor differentiating

TABLE 2. Sections of descriptive statistics for material moisture content [%]

Moisture content	Area	Mean values	Confidence -95.000%	Confidence +95.000%	Valid	Standard deviation	Variance	Standard error	Minimum	Maximum
Relative humidity	Area 1	32.55	30.75	34.34	40	5.61	31.50	0.89	22.22	39.30
	Area 2	22.96	22.42	23.50	35	1.58	2.49	0.27	20.19	27.30
	mean	28.07	26.60	29.54	75	6.40	40.93	0.74	20.19	39.30
Absolute humidity	Area 1	49.21	45.41	53.01	40	11.88	141.25	1.88	28.56	64.75
	Area 2	29.85	28.93	30.78	35	2.70	7.29	0.46	25.29	37.56
	mean	40.18	37.16	43.20	75	13.13	172.33	1.52	25.29	64.75

material moisture content between areas might be different period of timber harvesting, species composition of biomass (additive species) and the period of cutting residues storage on forest site. The material collected for several months on forest site was subjected to natural drying process; it resulted in a decrease in its moisture content in relation to the wood just after cutting, which could amount to 60–90% [Rimár 2013, Tonerio et al. 2014]. This process does not call for additional energy inputs to dry the material [Gendek and Głowacki 2009, Głowacki and Gendek 2011].

Referring to demands of power plants presented in Table, 1 one can find that in respect of moisture content the chips of both areas meet the demands of plants A, C, D. However, they do not meet the very rigorous criteria of plant B, where maximal moisture content should not exceed 20%.

The research material harvested on forest area was subjected to sieve separation in order to determine, whether the dullness of knives affects the share

of particular fractions and the quality of chips. The obtained results are presented in Table 3.

The highest share of fraction for both Areas 1 and 2 and the sharp and blunt knives was found for fraction of average size of particles 13.85 mm. The mean share of fraction depends on the area and the knives dullness and varies from 65.7 to 76.9%. The average particle size of 3.00 mm is the second in respect of share. The Area 2 makes an exception, where in cutting with the sharp knife, the second subsequent share is taken by particles of 35.78 mm.

For the obtained data of fraction shares on particular areas and for the sharp and blunt knives the analysis of fitting variables to natural distribution was carried out. Basing on carried out analysis one can find the normal distribution for the results.

To determine the effect of knives dullness on the share of particular fractions the Duncan test of multiple comparisons was executed. It enabled to find that on Area 1 in all cases there as a statistically

TABLE 3. Sections of descriptive statistics – share of fractions for research areas and degree of cutting knives sharpening

Area	Knives	Sieve opening [mm]	Mean particle length on sieve [mm]	Share of fractions [%]					
				Mean	Confidence -95.00%	Confidence +95.00%	Standard deviation	Variance	Standard error
1	sharp	60	94.87	3.00	1.77	4.22	2.30	5.30	0.58
		50	54.77	2.92	1.96	3.87	1.78	3.18	0.45
		40	44.72	5.37	4.06	6.68	2.46	6.04	0.61
		32	35.78	9.27	8.25	10.30	1.93	3.72	0.48
		6	13.85	69.19	67.36	71.02	3.43	11.78	0.86
		bottom	3.00	10.26	8.18	12.33	3.89	15.14	0.97
	blunt	60	94.87	0.23	0.08	0.37	0.31	0.10	0.07
		50	54.77	0.55	0.32	0.78	0.49	0.24	0.11
		40	44.72	0.99	0.69	1.30	0.65	0.42	0.14
		32	35.78	1.94	1.41	2.47	1.12	1.26	0.25
		6	13.85	76.95	74.90	79.00	4.38	19.19	0.98
		bottom	3.00	19.34	17.30	21.38	4.36	19.05	0.98
2	sharp	60	94.87	4.04	2.80	5.27	2.31	5.36	0.58
		50	54.77	3.02	1.93	4.10	2.04	4.16	0.51
		40	44.72	7.41	6.22	8.59	2.22	4.92	0.55
		32	35.78	11.32	9.94	12.70	2.58	6.66	0.65
		6	13.85	67.89	65.55	70.22	4.38	19.21	1.10
		bottom	3.00	6.34	4.58	8.09	3.29	10.80	0.82
	blunt	60	94.87	2.64	1.53	3.75	2.08	4.34	0.52
		50	54.77	3.32	2.18	4.46	2.14	4.57	0.53
		40	44.72	5.78	4.79	6.78	1.87	3.49	0.47
		32	35.78	8.65	7.62	9.68	1.94	3.77	0.49
		6	13.85	65.72	63.84	67.61	3.54	12.53	0.88
		bottom	3.00	13.89	12.08	15.70	3.40	11.53	0.85

significant difference between the same fractions depending on degree of knives sharpening. In cutting with the sharp knife the share of size 35.78 mm and above was higher than in cutting with the blunt knife. Opposite situation was

found, when the mean particular sizes of 13.85 and 3.00 mm were compared; a higher share was found for the blunt knife.

Statistical analysis for Area 2 showed that shares of particles of size 94.87,

54.77 and 44.72 mm did not differ from each other depending on the cutting knife dullness. The significant difference and the effect of knife sharpening occurred for particles of mean size 35.78 mm and smaller.

Basing on carried out analyses, one can find significant effect of cutting knife dullness on the share of particular fractions of chips; application of the blunt knife results in more chips of smaller size. Referring to demands of consumers (Table 1), the chips share of mean size 35.57 mm and smaller amounted to 88.72% for the sharp knife and 98.23% for the blunt knife on Area 1 and to 85.55% for the sharp knife and 88.26% for the blunt knife on Area 2.

Basing on dependences (1)–(3) there was calculated the mean geometric size of particles for particular areas and the states of knife sharpening. In Table 4 there are presented parameters of descriptive statistics section for geometric mean of particles, namely x_g – geometric mean and s_g – geometric standard deviation. Calculation were carried out for each sample, then, the result was averaged.

Basing on data in Table 4, one can find that the bigger values of mean geometric size of particles had chips cut with the sharp knives – 15.29 mm for Area 1 and 17.30 mm for Area 2; it corresponds to the share of particular fractions. Mean size of chips produced by shredding of cutting residues with the use of blunt knives amounts to 10.77 mm on Area 1 and 14.42 mm on Area 2.

The carried out analysis of variance showed differences in mean geometric for considered size of particles. To determine more accurately the effect of knives

TABLE 4. Sections of descriptive statistics for geometric mean size of particle

Area	Knives		Standard deviation – SD (s_g)																	
	sharp	dull	Mean [mm]	Confidence –95.000%	Confidence +95.000%	Valid	SD	variance	Standard error	Minimum	Maximum	Mean [mm]	Confidence –95.000%	Confidence +95.000%	Valid	SD	variance	Standard error	Minimum	Maximum
1	sharp		15.29	14.29	16.28	16.00	1.87	3.50	0.47	12.40	18.75	2.08	2.02	2.15	16.00	0.13	0.02	0.03	1.82	2.26
	dull		10.77	10.40	11.15	20.00	0.80	0.63	0.18	9.49	12.10	1.93	1.88	1.98	20.00	0.11	0.01	0.02	1.71	2.09
2	sharp		17.30	16.25	18.36	16.00	1.98	3.93	0.50	13.09	21.46	2.03	1.97	2.08	16.00	0.11	0.01	0.03	1.84	2.24
	dull		14.42	13.48	15.36	16.00	1.76	3.08	0.44	12.40	18.69	2.21	2.14	2.28	16.00	0.13	0.02	0.03	1.99	2.46

sharpening on the mean geometric size of particle the Duncan test was executed; its results are presented in Table 5. The analysis showed significant difference between mean geometric size of particles for the sharp and blunt knives.

One can find that sharpening of knife affects the size of particles, however,

TABLE 5. Duncan test of multiple comparisons for mean geometric size of particle (x_g) – differences significant at $p < 0.05$

×	Area 1, blunt knife	Area 1, sharp knife	Area 2, blunt knife	Area 2, sharp knife
Area 1, blunt knife	–	0.00	0.00	0.00
Area 1, sharp knife	0.00	–	0.13	0.00
Area 2, blunt knife	0.00	0.13	–	0.00
Area 2, sharp knife	0.00	0.00	0.00	–

since investigations were carried out on the two different areas, the species composition of cutting residues may be important.

SUMMARY

Basing on the obtained results, one can find that degree of chipper knife sharpening significantly affects the share of particular fractions of chips and their size. During cutting with the blunt knife there are produced chips of smaller size, and the share of finer fractions of particle size 35.78 mm and smaller increases.

The mean size of chips obtained in cutting with the blunt knife was smaller by 29.5 (Area 1) and by 16.6% (Area 2)

in relation to cutting with the sharp knife. Mean geometric size of chips produced of cutting residues on investigated forest sites amounts to 10.77–17.30 mm; it meets general demands of power plants in respect of forest chips size.

To achieve moisture content required by power plants it is advisable to store the cutting residues on a forest site for several months. After 5–7 months the relative humidity amounts on the average to about 28%.

The forest chips harvested from research sites and prepared with the use of chipper BRUKS 805 CT meet general demands of power plants both in respect of maximal moisture content and size. It should be underlined, that the size demands of power plants are met in greater part by chips produced with the blunt knives. Therefore, the question arises: is sharpening of shredding knives rational? Answer to this question calls for further investigations on energy inputs of the chipping process.

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Streszczenie: *Wpływ zaostrenia noży rębarki na jakość zrębków leśnych.* Zakłady energetyczne stawiają odpowiednie wymagania dotyczące jakości zrębków leśnych. Podstawowymi parametrami są wilgotność, wielkość oraz wartość opałowa. Przeprowadzone badania miały na celu określenie wielkości i rozkładu frakcji zrębków leśnych pozyskiwanych rębarką BRUKS 805 CT z różnym stopniem zaostrenia noży oraz określenie wilgotności zrębków

przeznaczonych do produkcji energii w dużych zakładach energetycznych. Zrębkowanie prowadzono rębarką mobilną na dwóch powierzchniach leśnych o podobnym składzie gatunkowym. Uzyskane wyniki pozwalają stwierdzić, że dla zmniejszenia wilgotności materiału odpowiadającej wymaganiom zakładów energetycznych wskazane jest przechowywanie pozostałości zrębowych na powierzchni leśnej przez okres kilku miesięcy. Stwierdzono istotny wpływ zaostrenia noży rozdabiających na udział poszczególnych frakcji zrębków i ich rozmiar. Zrębkowanie nożami tępymi zwiększa udział frakcji drobnych o cząstkach średniej wielkości 35,78 mm i mniejszych oraz istnieje istotna różnica między średnią wielkością zrębków wytworzonych ostrym lub tępym nożem. Pozyskane na powierzchniach badawczych zrębki leśne przygotowane za pomocą rębarki BRUKS 805 CT spełniają ogólne wymagania zakładów energetycznych zarówno pod kątem maksymalnej wilgotności, jak również pod kątem wielkości.

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