Annals of Warsaw University of Life Sciences – SGGW
Agriculture No 63 (Agricultural and Forest Engineering) 2014: 65–72
(Ann. Warsaw Univ. Life Sci. – SGGW, Agricult. 63, 2014)

Investigations on the calorific value of forest chips

ARKADIUSZ GENDEK, WITOLD ZYCHOWICZ
Department of Agricultural and Forest Engineering, Warsaw University of Life Sciences – SGGW

Abstract: *Investigations on the calorific value of forest chips.* Forest biomass designed for energetic purposes and directed – first of all – to power plants comes mainly from the felling residues that are directly disintegrated in the forest or at the customer. The composition of the produced chips depends to great extent on type of initial material stand. The authors of this paper presented results of investigations on the gross calorific value and heating value of forest chips produced in various technologies from: large-sized and medium-sized round wood and from small-sized wood in the form of loose branches and bundles. The material was obtained directly on a forest site, where the felling residues were disintegrated with the use of a mobile chipper equipped with container or on the site of chip producer, where the round wood and spruce bundles were disintegrated with the use of electric stationary chipper. The calorific value of investigated forest chips was determined; it varied from 14.64 (spruce bundle) to 19.53 MJ per 1 kg (pine with shrub layer).

Key words: forest biomass, biofuels, heating value, calorific value, forest chips

INTRODUCTION

Management of rational forest economy that meets the requirements of equalized forest development calls for undertaking many practical activities and introducing the new and more and more efficient machines and technologies. The used techniques and technologies of wood harvesting for energy purposes should consider not only economic aspects, but also maximal adaptation to specific requirement of the forest environment [Moskalik 2004]. In connection with the increasing demand for forest biomass and meeting the EU directives with standards of green energy production and the ban on co-combustion of biomass and coal, it seems that in Polish forestry there occurs a perspective of application of dedicated technologies for forest biomass harvesting for energetic purposes. These technologies can involve intentional harvesting and disintegration of the entire trees in younger stands and designing of this biomass for combustion in the boilers, in contrast with hitherto routine of biomass harvesting together with the main assortments harvesting (round timber).

Since introduction of the wood of full value definition [Decree of National Economy Ministry from 2012 – Rozporządzenie...], there has been changed the structure of forest biomass that is bundled and disintegrated for the power plants. If the decree is followed strictly, the buyers and producers of chips have only the felling residues in the form of small-sized wood – M1 and M2. These residues are characterized by large share of green particles and by small diameter of branches; this is not always profitable from the viewpoint of the supplier and buyer of chips. Power plants are not interested in chips of substantial share of green particles, high moisture content and low calorific value [Sadowski 2013]. From the view point of combustion technology and raw material feeding, too high share of the fine or coarse fractions is unfavourable also.

In the process of forest chip production one can distinguish the quality in geometric sense (shape and dimensions of chips) and energetic one. The first quality is connected with production process with the use of a chipper, thus, with type of chopping mechanism, sharpness of cutting knives, effectiveness of sifting, durability of device; the second quality is connected with calorific value of wood subjected to processing, moisture content of wood and cleanness of raw material. Problems connected with moisture content in the forest chips, their drying, storage and changes in their temperature were investigated by, among others, Barwicki and Gach [2010], Gendek and Głowacki [2009, 2011].

In account settlements of power plants with the supplier there are several parameters connected with forest chip quality that affects the price. Two basic parameters are: maximal moisture content and minimal calorific value. The calorific value of selected wood species and mineral fuels given in references are presented in Table 1 [Monkielewicz and Pflaum 1967; Krzysik 1974; Haufa and Wojciechowska 1986; Rembowski 2007; Komorowicz et al. 2009; Björn et al. 2012; Reva et al. 2012; So and Eberhardt 2013].

The carried out investigations aimed at presenting changes in the forest chip calorific value, depending on their species composition and technology of their production.

TABLE 1. Calorific value of selected species dry wood and mineral fuels

Species	Calorific value [$MJ \cdot kg^{-1}$]
Pine	19.2–21.2
Spruce	18.8–20.5
Alder	18.1–22.0
Oak	17.5–18.5
Chips (not cleaned)	6–16
Hard coal	21–29
Petroleum	38–49

MATERIAL AND METHODS

Research material in the form of chips was collected in the enterprise that harvested the felling residues for energetic purposes. The enterprise operates in many regions of Olsztyn, Białystok and Wyszków. The chips are most often supplied to thermal power plant in Białystok and Łódź.

Forest biomass is harvested as residues in the form of bundles and is disintegrated on the woodyard with the use of a stationary chipper; the felling residues are disintegrated with the use of a mobile chipper directly on forest site [Gendek and Zychowicz 2006; Zychowicz and Gendek 2009; Nurek and Gendek 2012; Moskalik 2013] and supplied to power plants. If supplying process is stopped by power plants, the chips and bundles with residues can be directed to one of the store places.

The chips were produced of various material and in various technologies; this affected their size, fractional composition and moisture content. The subsequent technologies involved [Gendek and Zychowicz 2006; Zychowicz and Gendek 2009; Moskalik 2013]:

– bundling of felling residues on forest site, transport to a store place and storing for several months, then chopping of bundles with the use of stationary electric chipper and storing of chips in flitches on the store place, then transport to power plant;
– chopping of felling residues with the use of mobile chipper directly on forest site and transport to power plants or the store place and storing in flitches;
– chopping of round wood of medium size and large size of poor quality on store place with the use of stationary electric chipper, as well as sawmill waste, storing of chips in flitches.

Chips made of the round wood, because of their better parameters, were added and mixed with the chips made of felling residues; their specification is presented in Table 2.

The measurements on heat of combustion and calculation of calorific value were made by calorific method according to PN-ISO 1928:2002 Standard. The obtained material was disintegrated to get particles of dimensions below 1 mm with the use of a mill, and then dried in a laboratory drier SLW 115 TOP to get the dry mass. The material moisture content was determined according to PN-77/D--04100 Standard, with the use of electric drier with elementary graduation 1°C, analytical balance with elementary scale 0.01 g and laboratory containers.

The investigations consisted in completed combustion of 1 g samples in oxygen atmosphere under pressure 2.8 MPa and determination of water temperature increment in a calorimetric container. Combustion was executed in a calorimetric bomb placed in this container and immersed in water of volume 2.7 dm^3 [kalorymeter KL10]. The sample was ignited by a resistance wire. The calorimeter operates by principle of measurements on characteristic temperatures of heat balance of the system: calorimetric bomb with fuel subjected to combustion – calorimetric container with water. The weighed quantity of sample for analysis of 1 g were measured with accuracy up

TABLE 2. Specification of material designed for chopping

Name	Composition	Place of chopping	Chipper
Spruce bundle	spruce small-sized wood, felling residues (M1, M2) bundled on forest site, seasoned at producer for 2–4 months	on buyer's place	stationary – electric
Pine with shrub layer	pine small-sized wood, felling residues (M1, M2) deciduous shrub layer of different kinds	on forest site	self-propelled with container
Oak	round medium-sized wood (S)	on buyer's place	stationary – electric
Mixture	alder – round medium-sized and large-sized wood (S, W) spruce – felling residues (M1, M2) after disintegration, chips were mixed on the yard in unknown ratio	alder – on buyer's place spruce – on forest site	stationary – electric self-propelled with container

to 0.001 g with the use of balance WSP 210S. The measurement was repeated five times for each kind of material.

The calorimeter used in research determined automatically the value of combustion heat (Q_s) of investigated substance with the use of internal program according to dependence:

$$Q_s = K \cdot (T3 - T2 - k) \ [\text{kJ} \cdot \text{kg}^{-1}] \quad (1)$$

where:
K – constant of calorimeter [kJ·kg^{-1}];
$T2$, $T3$ – characteristic temperatures of balance [K];
k – correction for heat exchange of calorimeter with environment.

The calorific value (Q_{op}) was calculated with dependence [PN-ISO 1928:2002]:

$$Q_{op} = (Q_s - 206 \cdot H) \cdot (1 - 0.01 \cdot W_w) - 23.0 \cdot W_w \ [\text{kJ} \cdot \text{kg}^{-1}] \quad (2)$$

where:
H – hydrogen content [%];
W_w – relative humidity [%].

According to information in objective references, the hydrogen content for various kinds of biomass varies from 5.5 to 7% [Świeca 2007; Komorowicz et al. 2009; Głodek 2010; Reva et al. 2012]. In respect of kind, species and origin of material, in calculation of calorific value there was assumed a constant hydrogen content equal to 6.3%, given in references for the common coniferous and deciduous species as 6.2–6.3%.

Statistical analysis of the results was carried out with the use of Statistica program [StatSoft 2011]. Mean values and standard deviation values were calculated and there were performed the analyses and variance homogeneity tests as well as the multiple comparison test.

RESULTS AND DISCUSSION

The obtained means of combustion heat and calorific value together with significant statistical value are presented in Table 3 and Figure 1. The mean combustion heat for the chips of various origin ranged from 16.09 to 21.03 MJ·kg^{-1}, while the calculated calorific value from 14.64 to 19.53 MJ·kg^{-1}.

Since the heat of combustion in dry state is higher than calorific value by the heat needed to vaporize water produced in combustion of hydrogen [Krzysik 1974], in all analyzed cases calorific value of dry mass of various chips was lower than the heat of combustion. In further part of studies there was analyzed only the calorific value of chips of higher practical meaning.

Comparing the obtained results of calorific value with the value given in references (Table 1) one can find, that the chips made of oak wood and felling residues of pine with addition of deciduous shrub layer contain in the range reported by other authors for the oak and pine wood, respectively.

Mean calorific value of the chips made of bundled spruce residues amounts to 14.64 MJ·kg^{-1}; it is lower by 4.16 MJ·kg^{-1} than the minimal calorific value reported for spruce wood. One should consider, that the bundles contain not only wood but also bark, litter of conifer needles and various impurities taken up during bundling of felling residues.

TABLE 3. Sections of basic statistics for heat of combustion and calorific value of chips

Material	Heat of combustion [MJ·kg^{-1}]								Calorific value [MJ·kg^{-1}]							
	Mean	Confidence –95.000%	Confidence +95.000%	Standard deviation	Variance	Standard error	Minimum	Maximum	Mean	Confidence –95.000%	Confidence +95.000%	Standard deviation	Variance	Standard error	Minimum	Maximum
Mixture	18.07	17.63	18.51	0.35	0.12	0.16	17.71	18.53	16.60	16.17	17.04	0.35	0.12	0.16	16.25	17.06
Spruce bundle	16.09	14.06	18.12	1.63	2.67	0.73	14.45	18.48	14.64	12.63	16.66	1.62	2.63	0.72	13.02	17.01
Pine with shrub layer	21.03	20.31	21.74	0.58	0.33	0.26	20.09	21.49	19.53	18.83	20.24	0.57	0.32	0.25	18.61	19.99
Oak	19.73	19.42	20.05	0.25	0.06	0.11	19.42	20.10	18.25	17.94	18.56	0.25	0.06	0.11	17.94	18.61

A dependence similar to chips of spruce residues occurs for the chips made of the mixture of alder wood with spruce residues. The obtained calorific value 16.60 MJ·kg^{-1} is lower than the alder wood calorific value (by min. 1.50 MJ·kg^{-1}) and lower than the spruce wood ones (by min. 2.20 MJ·kg^{-1}).

Although calorific value of the spruce bundles and the alder-spruce mixture was lower than the respective values for particular species, it is contained in the range for not cleaned chips. The chips made of oak wood and pine residues with addition of shrub layer had a higher value than that reported in references for not cleaned chips by 2.25 MJ·kg^{-1} for oak chips and 3.53 MJ·kg^{-1} for chips of pine branches with addition of shrub layer. Therefore, one can conclude that they are the product of higher quality from the viewpoint of energy.

To check if calorific value of chips in particular groups varies depending on the material they were made of, there were performed the analysis of variance and the variance homogeneity tests of Levene and Brown-Forsyth (results in Table 4). The carried out tests showed that variance in the groups is not homogeneous and there are differences between the results.

Since the variance values are not homogeneous, there was performed the Duncan test of multiple comparisons to find significance of differences between the group means in the variance analysis system (results in Table 5). Basing on the obtained results one can find, that in all cases the mean calorific values of chips differ significantly depending on the material they were made of and the groups are not homogeneous.

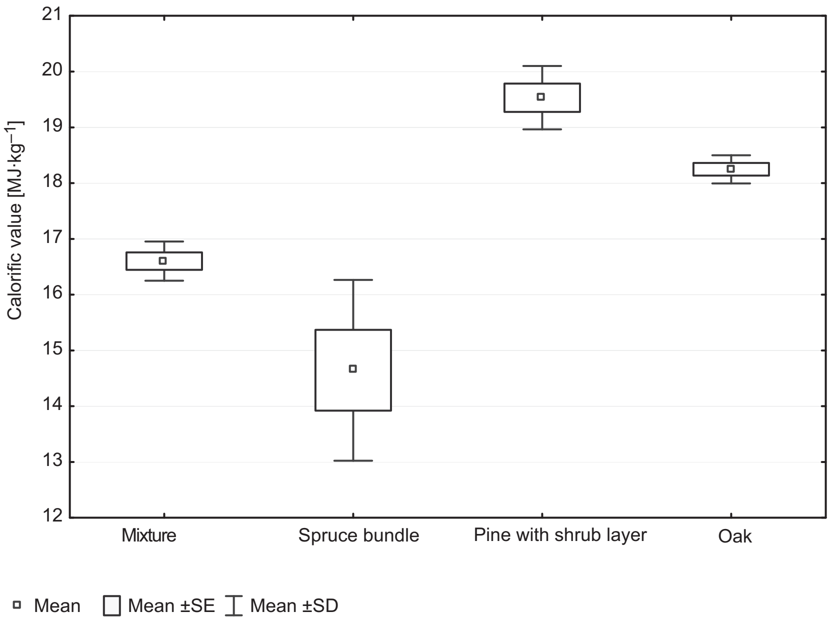

FIGURE 1. Mean value and scatter of chip calorific value

TABLE 4. Analysis of variance and variance homogeneity tests of Levene and Brown-Forsyth (effects significant for $p < 0.05$)

Calorific value [MJ·kg^{-1}]	SS – Effect	df – Effect	MS – Effect	SS – Error	df – Error	MS – Error	F	p
Variance comparison in groups	67.072	3	22.357	12.536	16	0.783	28.535	0.000001
Levene Test	3.340	3	1.113	3.416	16	0.213	5.215	0.010569
Brown-Forsyth Test	3.356	3	1.118	4.786	16	0.299	3.739	0.032847

TABELA 5. Duncan test of multiple comparisons (differences significant for $p < 0.05$)

Material	Mixture	Spruce bundle	Pine with shrub layer	Oak
Mixture	–	0.0031	0.0002	0.0098
Spruce bundle	0.0031	–	0.0001	0.0001
Pine with shrub layer	0.0002	0.0001	–	0.0358
Oak	0.0098	0.0001	0.0358	–

RECAPITULATION AND CONCLUSIONS

The obtained calorific value of chips made of round wood (without impurities) are high (for pine with shrub layer – 19.53 MJ·kg^{-1}, for oak 18.25 MJ·kg^{-1}) and are contained in the range reported in references.

The lower calorific value of chips made of spruce bundles and the mixture results from the fact that the investigated material contained impurities other than wood. The obtained calorific values (for spruce bundles – 14.64 MJ·kg^{-1}, for alder-spruce mixture 16.60 MJ·kg^{-1}) are contained in the range reported in references for this kind of chips. It means that such raw material harvested for energy purposes may need cleaning or adding the chips of pure wood.

REFERENCES

BARWICKI J., GACH S. 2010: Some aspects of biomass utilization concerning energy shortage. Annals of Warsaw University of Life Sciences – SGGW. Agriculture (Agricultural and Forest Engineering) 56: 39–44.

BJÖRN G., GEBAUER K., BARKOWSKI R., ROSENTHAL M., BUES C.T. 2012: Calorific value of selected wood species and wood products. Eur. J. Wood Prod. 70: 755–757.

GENDEK A., GŁOWACKI S. 2009: Convectional drying of chips for energy purposes. Annals of Warsaw University of Life Sciences – SGGW. Agriculture (Agricultural and Forest Engineering) 53: 67–72.

GENDEK A., ZYCHOWICZ W. 2006: Pozyskiwanie odpadów zrębowych na cele energetyczne w postaci pakietów. Technika Rolnicza Ogrodnicza Leśna 11: 19–21.

GŁODEK E. 2010: Spalanie i współspalanie biomasy. Instytut Ceramiki i Materiałów Budowlanych, Opole.

GŁOWACKI S., GENDEK A. 2011: Application of forced dryling methods in preparation of forest chips for energy purposes. Annals of Warsaw University of Life Sciences. Agriculture (Agriculture and Forest Engineering) 58: 29–34.

HAUFA T., WOJCIECHOWSKA D. 1986: Leśne sortymenty opałowe – jako potencjalne źródło energii cieplnej. Las Polski 20: 12–14.

Kalorymetr KL-10 automatyczny. Dokumentacja technczno-ruchowa. Producent PPHU Precyzja.

KOMOROWICZ M., WRÓBLEWSKA H., PAWŁOWSKI J. 2009: Skład chemiczny i właściwości energetyczne biomasy z wybranych surowców odnawialnych. Ochrona Środowiska i Zasobów Naturalnych 40: 402–410.

KRZYSIK F. 1974: Nauka o drewnie. PWN, Warszawa.

MONKIELEWICZ L., PFLAUM H. 1967: Użytkowanie lasu. PWRiL, Warszawa.

MOSKALIK T. 2004: Model maszynowego pozyskiwania drewna w zrównoważonym leśnictwie polskim. Wydawnictwo SGGW, Warszawa.

MOSKALIK T. 2013: Techniczne, technologiczne i organizacyjne uwarunkowania pozyskania i transportu drewna energetycznego. Biomasa leśna na cele energetyczne. Wyd. IBL, Warszawa: 107–118.

NUREK T., GENDEK A. 2012: Wykorzystanie pakietu Witness do modelowania przebiegu procesów produkcyjnych w leśnictwie. Technika Rolnicza Ogrodnicza Leśna 2: 17–20.

PN-77/D-04100. Drewno. Oznaczenie wilgotności.

PN-ISO1928:2002. Paliwa stałe. Oznaczanie ciepła spalania metoda spalania w bombie kalorymetrycznej i obliczanie wartości opałowej.

REMBOWSKI Ł. 2007: Wartość opałowa drewna. [electronic resource http://agroenergetyka.pl/?a=article&id=146].

REVA V., FONSECA L., LOUSADA J., ABRANTES I., VIEGAS D. 2012: Impact of the pinewood nematode, *Bursaphelenchus xylophilus*, on gross calorific value and chemical composition of *Pinus pinaster* woody biomass. Eur. J. Forest Res. 131: 1025–1033.

Rozporządzenie Ministra Gospodarki z dnia 18.10.2012 r. w sprawie szczegółowego zakresu obowiązków uzyskania i przedstawienia do umorzenia świadectw pochodzenia, uiszczenia opłaty zastępczej, zakupu energii elektrycznej i ciepła wytworzonych w odnawialnych źródłach energii oraz obowiązku potwierdzania danych dotyczących ilości energii elektrycznej wytworzonej w odnawialnym źródle energii. Dz.U. 2012, poz. 1229.

SADOWSKI K. 2013: Problematyka użytkowania biomasy leśnej na przykładzie rozwiązań w Elektrociepłowni Białystok S.A. Biomasa leśna na cele energetyczne. Wyd. IBL, Warszawa: 225–245.

SO C.-L., EBERHARDT T. 2013: A mid-IR multivariate analysis study on the gross calorific value in longleaf pine: impact on correlations with lignin and extractive contents. Wood Sci. Technol. 47: 993–1003.

StatSoft, Inc. 2011. STATISTICA (data analysis software system), version 10. www.statsoft.com.

ŚWIECA G. 2007: Zawartość wodoru w różnych rodzajach biomasy. Instytut Chemiczny Przeróbki Węgla. Zabrze. [electronic resource www.ichpw.zabrze.pl/cms.php?getfile=607].

ZYCHOWICZ W., GENDEK A. 2009: Efektywność stosowania samobieżnej rębarki z zasobnikiem do pozyskiwania zrębków na cele energetyczne. Zeszyty Problemowe Postępów Nauk Rolniczych 543: 417–425.

Streszczenie: *Badania wartości opałowej zrębków leśnych.* Biomasa leśna przeznaczona na cele energetyczne i kierowana przede wszystkim do zakładów energetycznych, pochodzi głównie z pozostałości zrębowych rozdrabnianych bezpośrednio w lesie lub u odbiorcy. Skład produkowanych zrębków zależy w dużej mierze od rodzaju drzewostanu, z jakiego pochodził materiał początkowy. W publikacji autorzy przedstawili wyniki badań ciepła spalania i wartości opałowej zrębków leśnych wytworzonych w różnych technologiach zarówno z drewna okrągłego wielko- i średniowymiarowego, jak i z drewna małowymiarowego w postaci gałęzi luzem i pakietów. Materiał pozyskano bezpośrednio na powierzchni leśnej, gdzie rozdrabniane były pozostałości zrębowe rębarką mobilną z zasobnikiem lub na placu u producenta zrębków, gdzie za pomocą elektrycznej rębarki stacjonarnej rozdrabniano drewno okrągłe i pakiety świerkowe. W zależności od technologii pozyskiwania oraz miejsca rozdrabniania, zrębki przeznaczane na cele energetyczne zostały wytworzone z rozdrobnionego okrągłego drewna dębowego, rozdrobnionych pakietów świerkowych, rozdrobnionych gałęzi i wierzchołków sosnowych z podszytem. Ostatnią grupę stanowiła mieszanka z rozdrobnionych gałęzi i wierzchołków świerkowych oraz rozdrobnionego okrągłego drewna olchowego. Dla badanych rodzajów zrębków leśnych określono ich wartości opałowe, które wahały się od 14,64 (świerk z pakietu) do 19,53 $MJ \cdot kg^{-1}$ (sosna z podszytem). We wszystkich przypadkach – po wykonaniu analiz statystycznych – wartość opałowa poszczególnych grup zrębków w zależności od ich pochodzenia różniła się istotnie od siebie.

MS. received March 2014

Authors' address:
Arkadiusz Gendek, Witold Zychowicz
Wydział Inżynierii Produkcji SGGW
Katedra Maszyn Rolniczych i Leśnych
02-787 Warszawa
ul. Nowoursynowska 164, Poland
e-mail: arkadiusz_gendek@sggw.pl
witold_zychowicz@sggw.pl