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PROPERTIES OF SOLID BIOFUELS OBTAINED FROM RESIDUES OF WOOD-BASED MATERIALS

Processing of wood and composite wood materials contributes to the creation of considerable amounts of production residues. These materials are potential energy sources. However, the content of synthetic substances (including binding and finishing agents) may cause the emission of harmful substances during the thermal destruction of such materials. Therefore, to derive benefit from waste from wood-based materials, it is necessary to obtain information on its physical and chemical properties (especially its fuel properties). Hitherto, literature reports say little of those properties. The aim of this study was to determine the basic fuel properties of residues from the industrial processing of composite wood materials (such as particleboards, fibreboards and plywood) and to assess their suitability for biofuel production. Four groups of wood-based materials were tested:. particleboards (standard boards and OSBs), fibreboards (MDF, HDF, CDF and SB), layer materials (plywood and LVL), and wood materials being a combination of the other groups (double T-bars). The total moisture content, ash content, elementary composition (C, H, N, S, Cl), trace element content (As, Cd, Cr, Cu, Hg, Ni, Pb, Zn) and gross calorific value were determined, and the net calorific value was calculated. The results showed that the tested wood materials had favourable fuel properties and could be used in place of raw wood as an energy source.

Keywords: solid biofuels, wood-based panels, wood residues, wood waste, fuel properties of chemically treated wood biomass

Introduction

The rapid development of the wood industry in Poland in the last thirty years has brought about an increase in demand for wood materials used for the manufacture of final products such as furniture, furnishing elements, builder's carpentry and joinery elements, and others. This, in turn, has resulted in

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increased demand for such wood materials as particleboards, fibreboards and layer materials (e.g. plywood).

Because of the considerable market share represented by these goods (11% of European manufacture of wood materials in 2014) [European Panel Federation 2015] together with the increasingly common use of such materials in Poland, considerable amounts of wood residues are created during their production and use. These residues, characterised by different properties due to the various binders and finishing agents used in the production process, have to be managed; however, it should be mentioned that while the content of binding agents in wood materials is approximately 10%, the content of finishing agents is many times lower.

Economic practice suggests that the majority of such wood residues are used as energy sources and consumed by manufacturers for technological and material purposes. Therefore, both the International Organization for Standardization (ISO) and the European Committee for Standardization (CEN) deem by-products and residues created during the processing of wood materials a source of biomass for the production of solid biofuels (chemically processed wood biomass), as is recorded in the definition of wood biomass contained in the EN ISO 17225-1:2014 standard.

Economically viable management of by-products and residues of wood--based materials requires information on their physicochemical properties (especially fuel properties), and such information is scarce in the literature. Available data concerning the fuel properties of waste from wood material created by Polish manufacturers are many years old [Cichy and Prądzyński 1995]. Information on selected types of waste can be found in more recent reports [Cichy 2013]. None of those publications, however, presents comprehensive information on the fuel properties of waste from wood materials – that is to say, none encompasses the majority of the products available on the Polish market.

According to data published by the European Panel Federation (EPF), European particleboard production increased by 1.5%, to 29.1 million m^3, in 2015. OSB production was up by 3.9% compared with 2014, and amounted to 5 million m^3. MDF production increased by 2.7% to 11.8 million m^3, while hardboard and softboard production rose by 9% and 10% respectively, to reach 0.6 million m^3 and 4.4 million m^3. Plywood production also showed an upward trend, increasing by 1% in 2015, to reach a total of 2.8 million m^3 [European Panel Federation 2015].

According to the same source, in 2014 production and consumption of particleboards in Poland amounted to 2.8 million m^3 and 3.3 million m^3 respectively, up by 8.3% and 8.8% compared with the previous year. This high production volume made Poland the third largest particleboard producer in Europe (with approximately 11% of European production). Compared with 2013, Polish imports of particleboards increased by 4.8%, while exports fell by

2.7%. As regards MDFs, in 2014 production capacity in Poland was 2.6 million m^3 and was similar to the previous year, while consumption increased by 9.5% and amounted to 1.15 million m^3. The EPF report also lists OSB production capacity, which amounted to 0.4 million m^3 in the same period, and hardboard and softboard production capacity, which totalled 1.8 million m^3 [European Panel Federation 2015].

The above information concerns the production of wood-based panels, which are merely a raw material for the manufacture of other goods: furniture, wooden accessories, and builder's carpentry and joinery products. This manufacture is responsible for the creation of considerable amounts of wood waste, which in the majority of European countries is commonly burnt for energy recovery. Hence, there is a need to determine the basic fuel properties of these waste materials.

The aim of the study was to determine the basic fuel properties of residues from the industrial processing of composite wood materials (such as particleboards, fibreboards, and plywood), and to assess the suitability of the obtained materials for the production of solid biofuels.

Materials and methods

Materials

Samples of wood-based panels and wood materials for testing were obtained from several different Polish manufacturers. The samples were so chosen to represent the wide assortment of manufactured and marketed wood-based materials (particleboards, fibreboards, layer materials, and other wood materials), and reflect the diversity of applications of wood materials in furniture-making and construction (e.g. floor panels, wall panels, kitchen tops, insulating materials) as well as the properties of those materials (e.g. non--flammable panels, panels with high resistance to moisture). The tested materials were divided into groups and assigned appropriate codes to be used in the assessment of their properties (table 1).

Analytical work

Analytical work was carried out based on the guidelines contained in the standards for the characterisation of solid biofuels. The following analytical procedures were used:

- preparation for further analyses by the procedures described in EN 14780:2011;
- determination of total moisture content according to EN 14774-1:2010;
- determination of ash content according to EN 14775:2010;
- determination of the content of carbon, hydrogen and nitrogen according to EN ISO 16948:2015, using gas chromatography (GC-TCD);

Table 1. Description of test samples by group

Wood materials	Sample no.	Description
Particleboards	PW1	Raw particleboard
	PW2	Laminated particleboard
	PW3	E-LE type particleboard
	PW4	Raw particleboard with increased fire-resistance
	PW5	Laminated particleboard with increased fire-resistance
	PW6	Laminated particleboard – kitchen countertop
	POSB1	Raw OSB
	POSB2	Non-flammable OSB
Fiberboards	PP1	Raw MDF
	PP2	MDF with increased resistance
	PP3	MDF with increased density
	PP4	Non-flammable MDF
	PP5	Raw HDF
	PP6	Lacquered HDF
	PP7	HDF – floor panel
	PP8	HDF – AC5 floor panel
	PP9	HDF – AC3 floor panel
	PP10	HDF – wall panel
	PP11	Raw CDF
	PP12	Laminated CDF
	PP13	Porous insulation softboard
	PP14	Four-layer porous softboard
Layer wood materials	S1	UF 1 plywood
	S2	PF 1 plywood
	S3	UF 2 plywood
	S4	PF 2 plywood
	S5	LVL
Other wood materials	B1	Double T-bar 1
	B2	Double T-bar 2

- determination of total content of sulphur and chlorine according to EN ISO 16994:2015, using ionic chromatography (IC);
- determination of the content of trace elements according to EN ISO 16968:2015, using atomic absorption spectrometry (AAS) techniques: F-AAS, GF-AAS, CV-AAS;

– determination of gross calorific value according to EN 14918:2010.

Results and discussion

The results of the analyses carried out for the selected wood materials are presented in figures 1-16. Tables 2-4 contain literature data [Cichy and Prądzyński 1995; Cichy 2013; EN ISO 17225-1:2014] concerning the fuel properties of various wood waste and solid biofuels obtained from wood that has not been chemically treated.

With regard to the fact that moisture content is of importance in practical terms and is one of the major indices in biofuel assessment, figure 1 presents the results of determinations of moisture content in tested samples. The data indicate the low proportion of water in the tested materials, this being a result of the technologies used for the production of those materials. Determined moisture contents ranged from 4.6% for lacquered HDF to 8.6% for double T-bar 2.

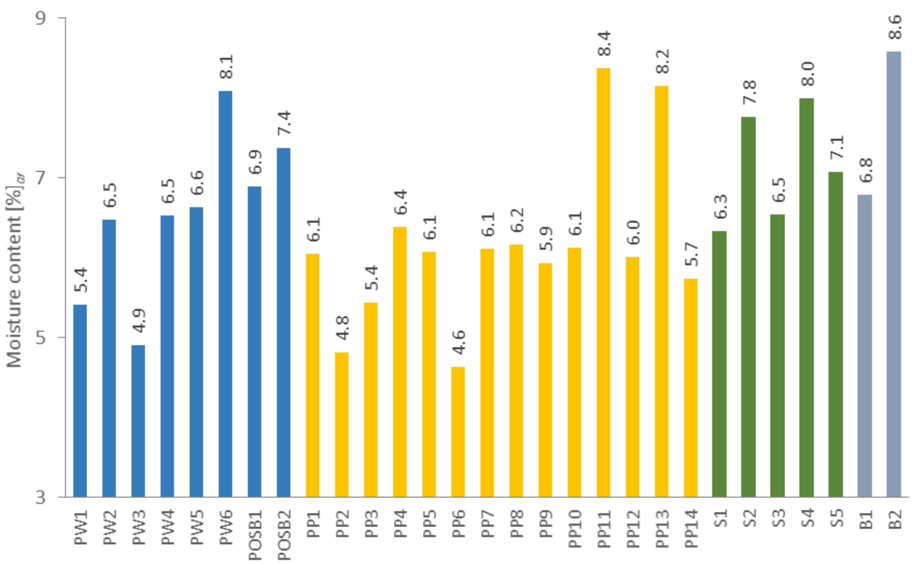

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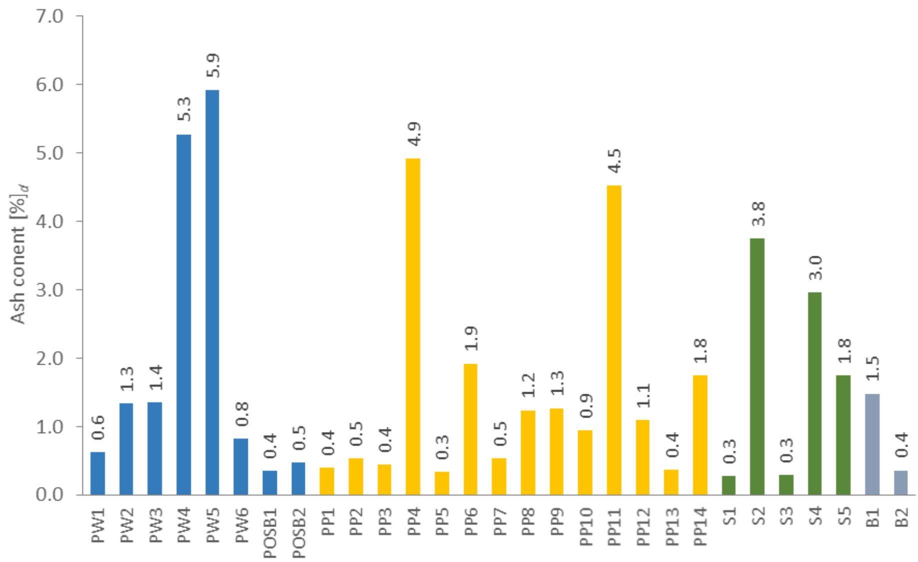
Fig. 1. Total moisture content in the analysed wood materials

The ash content in solid biofuels is of importance for the selection of a suitable combustion technology and gas purification technology. When plant biomass is burnt, both volatile and sedimentary forms of ash are created. The determinations show that the ash content was diverse, even within the respective groups of tested materials (fig. 2). The highest values were determined for laminated particleboard with increased fire-resistance (5.9%) and for raw particleboard with increased fire-resistance (5.3%). Slightly lower proportions of mineral substances were found in the case of non-flammable MDFs (4.9%), raw CDFs (4.5%), and PF plywood (3.8% and 3.0%). In the case of particleboards and MDFs with increased fire-resistance, CDFs and PF plywood, the higher content of mineral substances resulted from the applied protective agents and fillers. For the other materials the determined values of ash content ranged from 0.3% (UF plywood and raw HDF) to 1.9% (lacquered HDF). These results correlate with the literature data for particleboard (4.8%), MDF (0.7-2.3%) and plywood (0.3-2.4%) given in table 2. However, the majority of them are higher than typical ash content values determined for various types of virgin wood materials (0.1-1%; table 3).



d – dry.

Fig. 2. Ash content in the analysed wood materials

The graphs in figures 3-7 show the results of determination of the contents of basic elements constituting the chemical structure of the tested materials. Figure 3 shows the results for carbon content. The highest carbon contents were determined for OSB (non-flammable – 52.1%, raw – 50.9%), double T-bars (51.3% and 50.7%), and for four-layer porous softboard and LVL (51.1%). The lowest values of carbon content were obtained in the case of laminated particleboard with increased fire-resistance (44.6%), raw CDF (44.8%), raw particleboard with increased resistance (45.5%), and non-flammable MDF (45.6%). The low carbon content was a consequence of the high content of

Table 2. Fuel properties of by-products and residues from the wood material industry [Cichy and Prądzyński 1995; Cichy 2013]

Parameter	Unit	Glued wood elements	MDF	MDF residues	Particle-board residues	UF plywood	PF plywood
Moisture	%	24.5	5.7	10-50	15.0	5.7	11.4
Ash	%	23.0	0.70	2.3	4.8	0.3	2.4
Gross calorific value	MJ/kg_d	19.8	20.1	–	–	–	19.5
Net calorific value	MJ/kg_{ar}	13.6	17.5	8.1-16.5	14.8	16.8	15.9
Carbon	%	47.5	49.0	48.9	48.0	45.4	49.7
Hydrogen	%	4.4	6.1	6.5	6.5	6.2	6.1
Nitrogen	%	0.8	5.5	5.0	2.0	6.8	0.4
Sulphur	%	< 0.01	< 0.01	–	0.03	0.04	0.02
Chlorine	%	0.04	0.011	0.0004	0.004	0.03	0.017
Arsenic	mg/kg	7.6	< 0.01	–	–	–	< 0.01
Cadmium	mg/kg	0.3	0.4	–	0.6	0.7	0.2
Chromium	mg/kg	10.0	0.8	–	–	–	0.7
Copper	mg/kg	4.7	1.8	0.8	3.8	19.6	1.1
Mercury	mg/kg	0.003	0.02	–	–	–	0.02
Nickel	mg/kg	8.7	0.4	–	–	–	0.4
Lead	mg/kg	9.0	0.5	–	9.3	21	2.0
Zinc	mg/kg	23.8	12.0	6.3	19.8	23.1	17.1

d – dry; *ar* – as received.

mineral substances in those materials. In the other materials, carbon content was in the range 47.2-49.8% (for laminated CDF and raw MDF respectively). Compared with biofuels obtained from virgin wood, whose typical carbon content is 49-51% (table 3), most of the determined carbon content values were considerably lower.

Figure 4 shows the hydrogen content of the tested materials. The data indicate that the proportions of hydrogen in the evaluated wood materials were similar, ranging from 5.8% (raw CDF) to 6.5% (non-flammable OSB). These figures lie within the range of typical hydrogen content in wood biofuels (table 3).

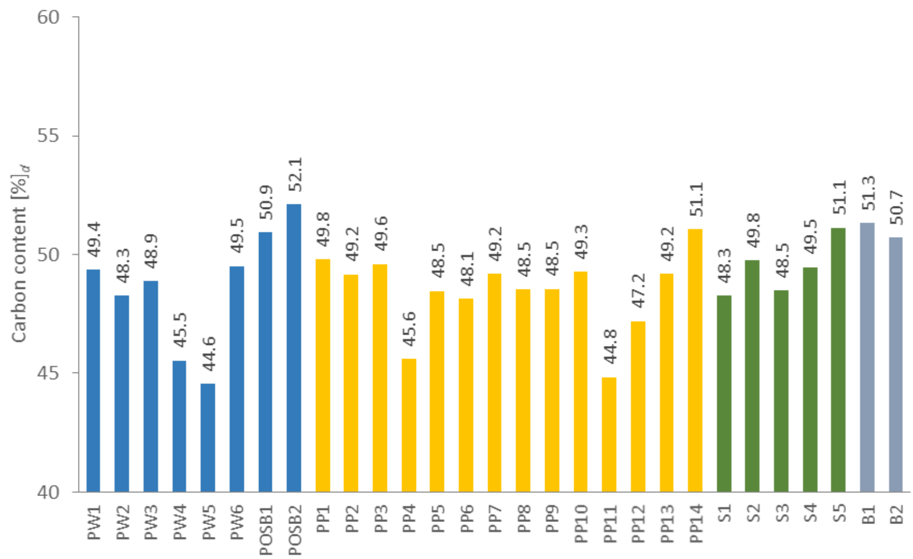


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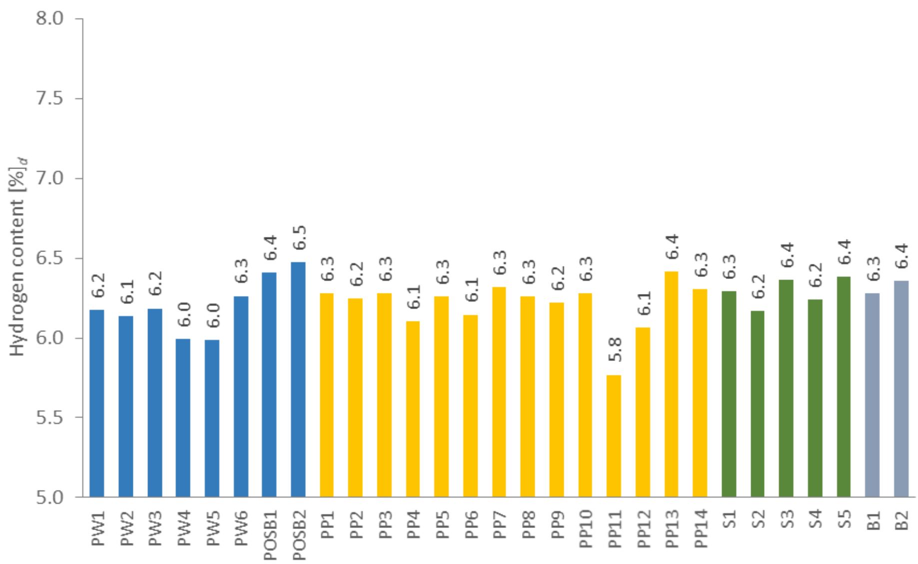
Fig. 3. Carbon content in the analysed wood materials



d – dry.

Fig. 4. Hydrogen content in the analysed wood materials

Table 3. Typical properties* of solid biofuels obtained from woody biomass [EN ISO 17225-1:2014]

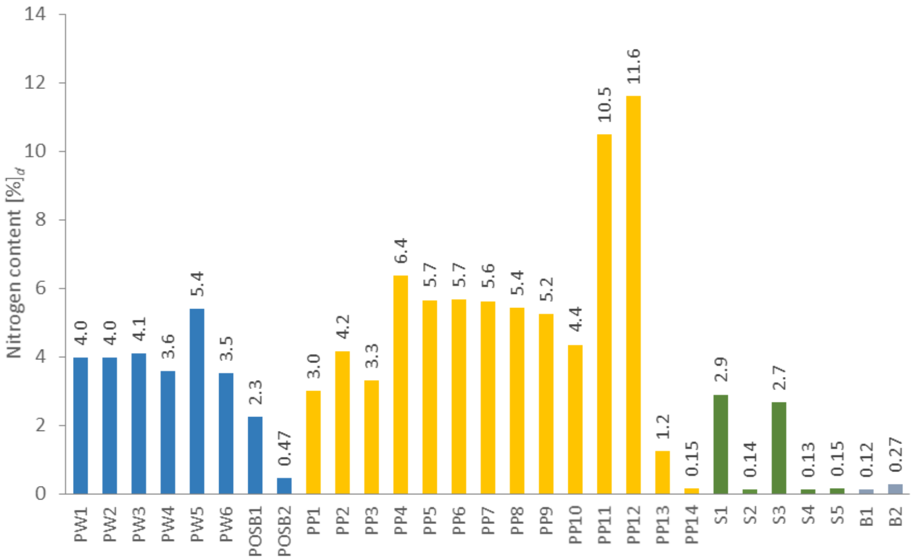
Parameter	Unit	Coniferous wood	Deciduous wood
Ash	%	0.1-1.0	0.2-1.0
Gross calorific value	MJ/kg_d	20.0-20.8	19.4-20.4
Carbon	%	47.0-54.0	48.0-52.0
Hydrogen	%	5.6-7.0	5.9-6.5
Nitrogen	%	< 0.1-0.5	< 0.1-0.5
Sulphur	%	< 0.01-0.02	< 0.01-0.05
Chlorine	%	< 0.01-0.03	< 0.01-0.03

d – dry.
*Data are obtained from a combination of mainly Swedish, Finnish, Danish, Dutch, Spanish and German research.

The results of C and H determinations in the tested wood-based materials are in agreement with available literature data concerning the content of those elements in wood-based materials [Cichy and Prądzyński 1995; Cichy 2013] as given in table 2 (C: 45.4-49.7%; H: 4.4-6.5%).

As has been previously mentioned, the percentage of nitrogen, sulphur and chlorine reflects the possibility of danger from nitrogen oxides (NO_x), sulphur oxides (SO_x), dioxins and difurans (PCDD/F), and hydrogen chloride (HCl). Moreover, high contents of sulphur and chlorine in biofuels lead to corrosion of boiler installations. Much of the chlorine condenses in the form of salt on the surface of boiler elements or reacts with the formed ash. The main effects of the action of chlorine and sulphur are high-temperature corrosion and cindering [Makles et al. 2001; Ściążko and Zieliński 2003; Obernberger et al. 2006; Król et al. 2010].

Nitrogen content varied significantly between the evaluated materials. The lowest content was found in PF plywood (0.14% and 0.13%), LVL (0.15%) and double T-bars (0.12% and 0.27%) (fig. 5), while the highest content was determined for CDFs: 11.6% in laminated board and 10.5% in raw board. The other materials contained from 0.47% (non-flammable OSB) to 6.4% (non-flammable MDF) of nitrogen. In each case the nitrogen content is linked to synthetic additives present in the wood materials, such as amine adhesives. According to available literature data, nitrogen content in various wood-based materials lies within the range 0.4–6.8% (table 2), while in wood it is much lower (<0.1-0.5%; table 3).

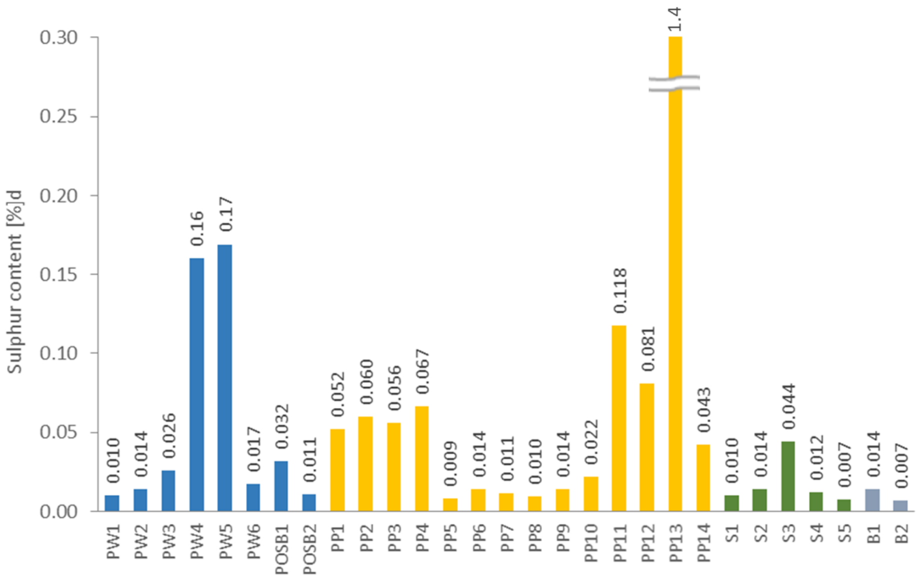


d – dry.

Fig. 5. Nitrogen content in the analysed wood materials

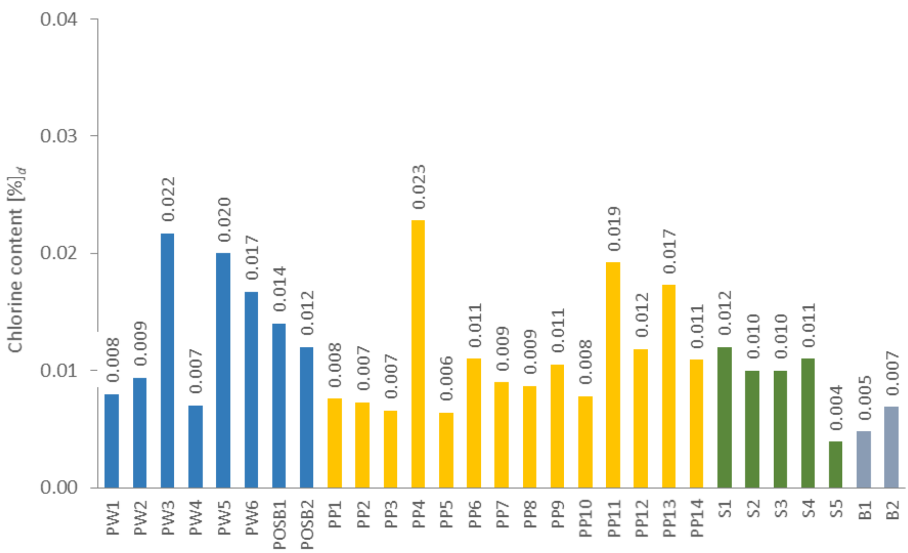
The determined values of total sulphur content, similarly to the case of nitrogen, were very diverse (fig. 6). The high content of sulphur in porous insulation softboard (1.4%) deserves attention. The high proportion of this element was probably connected with the method of processing the fibres used for the production of this type of panels. In the other materials total sulphur lay within a broad range, from 0.007% in double T-bar 2 and LVL to 0.16-0.17% in particleboards with increased fire-resistance (raw and laminated). According to literature data, sulphur content in wood-based materials is within the range <0.01-0.04% (table 2), while typical sulphur content in wood biofuels that have not been chemically treated is in the range <0.01-0.05% (table 3).

The highest values of chlorine content were determined for non-flammable MDF (0.023%), E-LE type particleboard (0.022%), laminated particleboard with increased fire-resistance (0.020%) and raw CDF (0.019%). The lowest chlorine content was found in the case of LVL (0.004%) and double T-bar 1 (0.005%). The results of chlorine determination (fig. 7) are in agreement with literature data (table 2), which indicate that chlorine content in wood materials lie within the range 0.0004-0.04%. Typical contents of this element in wood biofuels that have not been chemically treated are in the range <0.01-0.03% (table 3).



d – dry.

Fig. 6. Total sulphur content in the analysed wood materials



d – dry.

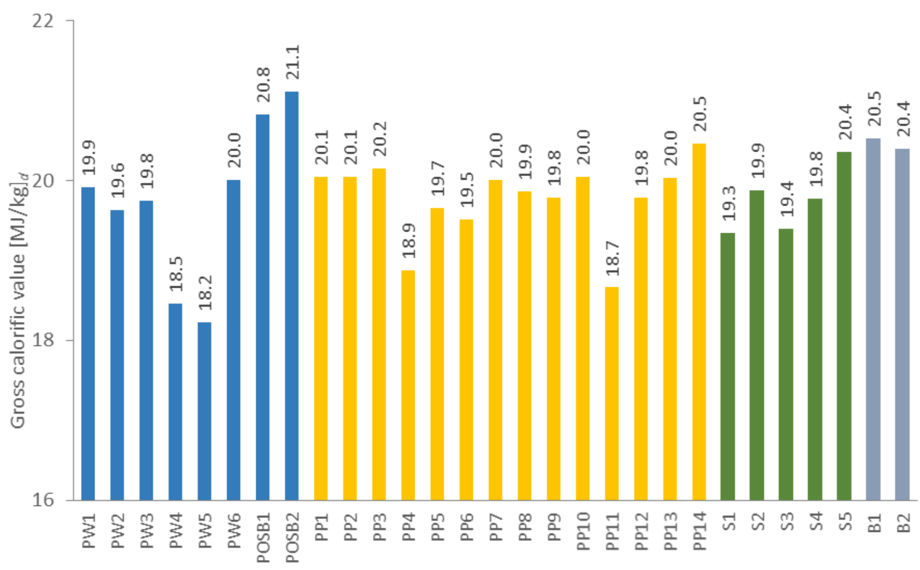
Fig. 7. Chlorine content in the analysed wood materials

A basic characteristic determining the quality of a fuel is its calorific value, which may be calculated on the basis of previously determined heat of combustion, moisture content, and ash content. Apart from these factors, one must also consider other factors affecting the amount of energy generated per unit mass: the heat of water evaporation, of nitric acid formation and of sulphuric acid formation (from the nitrogen and sulphur contained in the material structures).

Figures 8 and 9 illustrate gross calorific value (dry basis) as a starting point for further calculations of caloricity and net calorific value (on an "as received" basis), i.e. taking account of the actual content of ballast factors (moisture, ash).

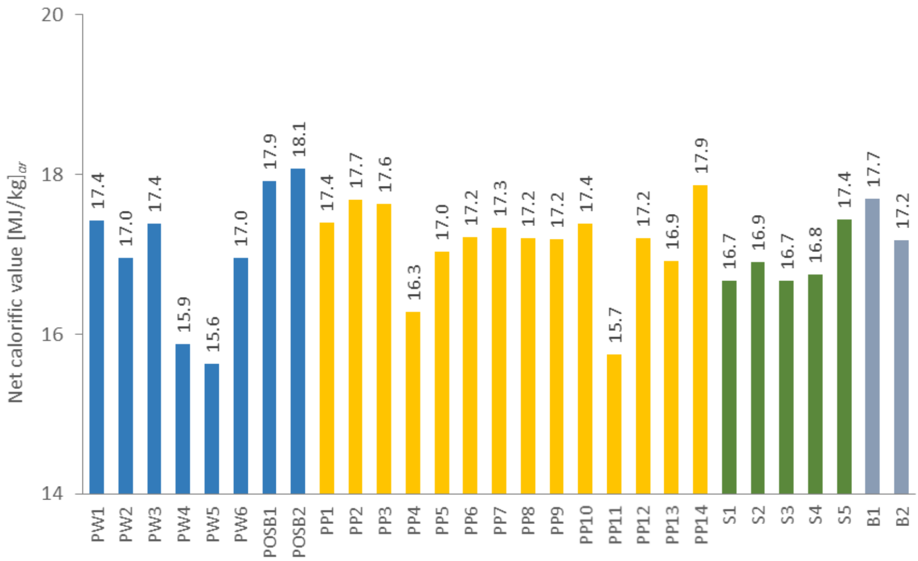
The gross calorific value of the tested samples of wood materials ranged from 18.2 MJ/kg to 21.1 MJ/kg, these being the values for laminated particleboard with increased fire-resistance and non-flammable OSB respectively. The results obtained are similar to typical gross calorific values obtained for wood free of chemical components, which lie in the range 19.4-20.8 MJ/kg (table 3).

Determinations of net calorific value were subject to wide variation, linked to the chemical composition of the tested materials. The highest net calorific values were found for OSBs (17.9 MJ/kg and 18.1 MJ/kg) and four-layer porous softboard (17.9 MJ/kg), and the lowest for particleboards with increased fire-resistance (raw – 15.9 MJ/kg, laminated – 15.6 MJ/kg) and for raw CDF (15.7 MJ/kg).



d – dry.

Fig. 8. Gross calorific value of the analysed wood materials



ar – as received.

Fig. 9. Net calorific value of the analysed wood materials

Most of the trace elements are present in the ash remaining after combustion of the evaluated materials. These elements influence the fusibility of the ash and the formation of sediments, volatile forms of ash and aerosols, as well as high--temperature corrosion of boiler installations (in combination with Cl and S). During the combustion process some of the ash-constituting compounds volatilise and becomes gaseous. The formation of this fraction depends on the chemical composition of the fuel, the surrounding atmosphere, the temperature, and the combustion technology used [Obernberger et al. 2006].

Of many trace elements, eight were selected for analysis: arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), mercury (Hg), nickel (Ni), lead (Pb) and zinc (Zn). These elements are the basis for the classification of processed solid biofuels such as pellets and briquettes [EN ISO 17225-2:2014; EN ISO 17225-3:2014].

The contents of trace elements in the tested wood materials are presented in Figures 10-17.

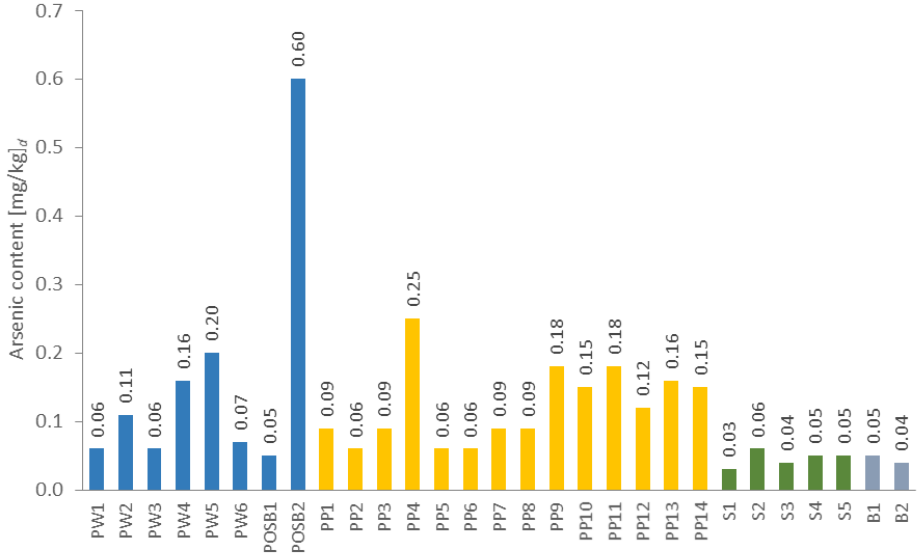
The determined contents of arsenic, copper and mercury in the tested materials (fig. 10, 13, and 14) correspond to the values typical for wood which has not been chemically treated (table 4) and to literature data [Cichy and Prądzyński 1995; Cichy 2013]. In the case of most of the tested samples, the content of the other determined elements, namely cadmium, chromium, nickel, lead and zinc (figs. 11-12 and 15-17), was higher than in natural wood (table 4) and corresponded to literature data (table 2). The highest values of trace elements were observed in the following samples: As – non-flammable OSB (0.60 mg/kg), Cd – laminated particleboard with increased fire-resistance (0.89 mg/kg), Cr – laminated particleboard with increased fire-resistance (66.6 mg/kg), Cu – laminated particleboard with increased fire-resistance (6.5 mg/kg), Hg – LVL (0.012 mg/kg), Ni – HDF, AC5 class floor panel (22.0 mg/kg), Pb – E-LE type particleboard (20.5 mg/kg), and Zn – E-LE type particleboard (65.8 mg/kg).

The high values of chromium, nickel and lead in certain of the tested wood materials (laminated particleboard with increased fire-resistance: Cr 66.6 mg/kg, Ni 20.6 mg/kg; HDF AC5 class floor panel: Cr 55.0 mg/kg, Ni 22.0 mg/kg; E-LE type particleboard: Pb 20.5 mg/kg) were probably connected with the chemical treatment of those materials, that is, the use of substances such as fungicides and/or fireproofing agents in their production.

Table 4. Typical content of* trace elements in solid biofuels obtained from wood [EN ISO 17225-1:2014]

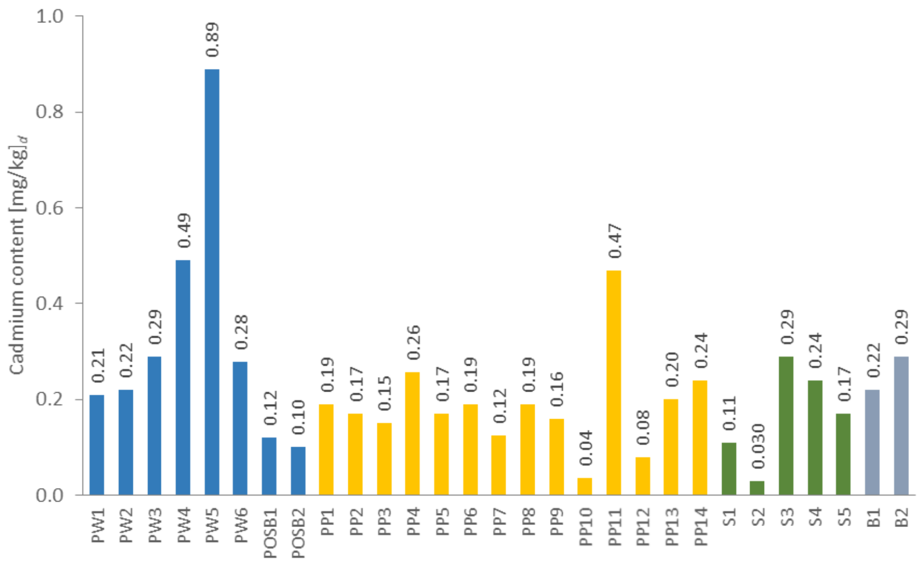
Element	Typical variation	Typical value
	mg/kg	
Arsenic	< 0.1 – 1.0	< 0.1
Cadmium	< 0.05 – 0.5	0.1
Chromium	0.2 – 10	1.0
Copper	0.5 – 10	2.0
Mercury	< 0.02 – 0.05	0.02
Nickel	< 0.1 – 10	0.5
Lead	< 0.5 – 10	2.0
Zinc	5 – 50	10

d – dry.
*Data are obtained from a combination of mainly Swedish, Finnish, Danish, Dutch, Spanish and German research.



d – dry.

Fig. 10. Arsenic content in the analysed wood materials



d – dry.

Fig. 11. Cadmium content in the analysed wood materials

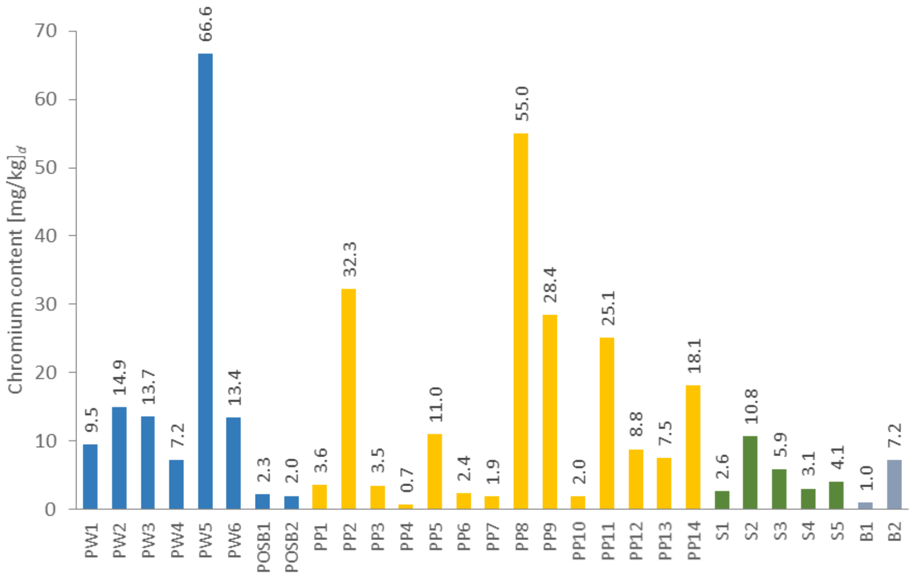


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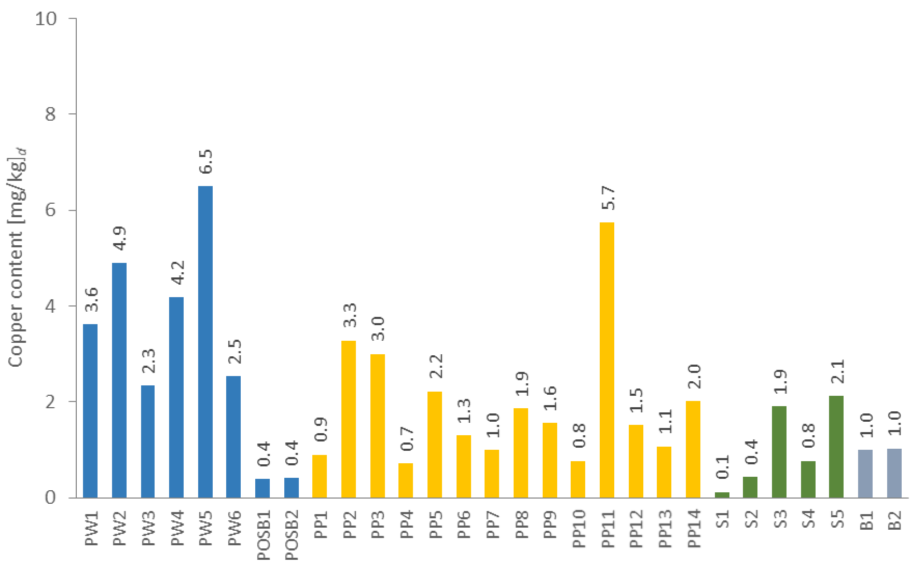
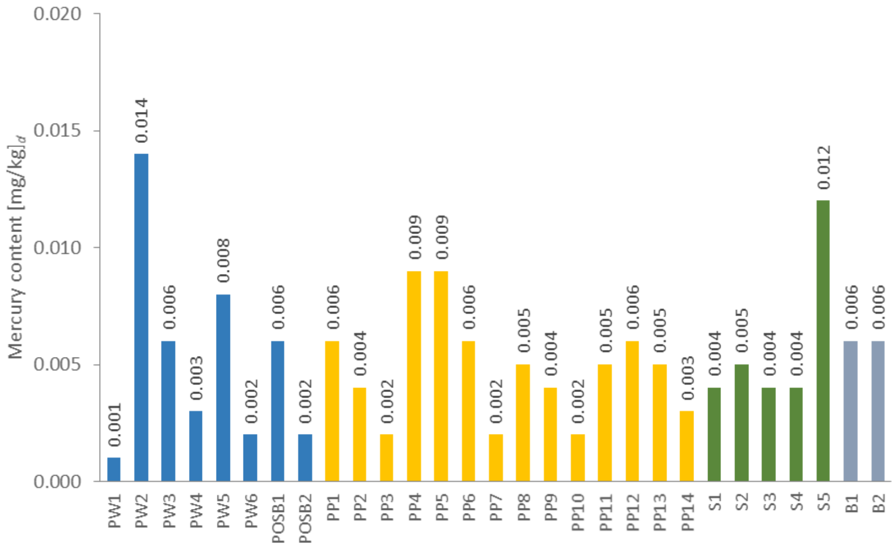
Fig. 12. Chromium content in the analysed wood materials



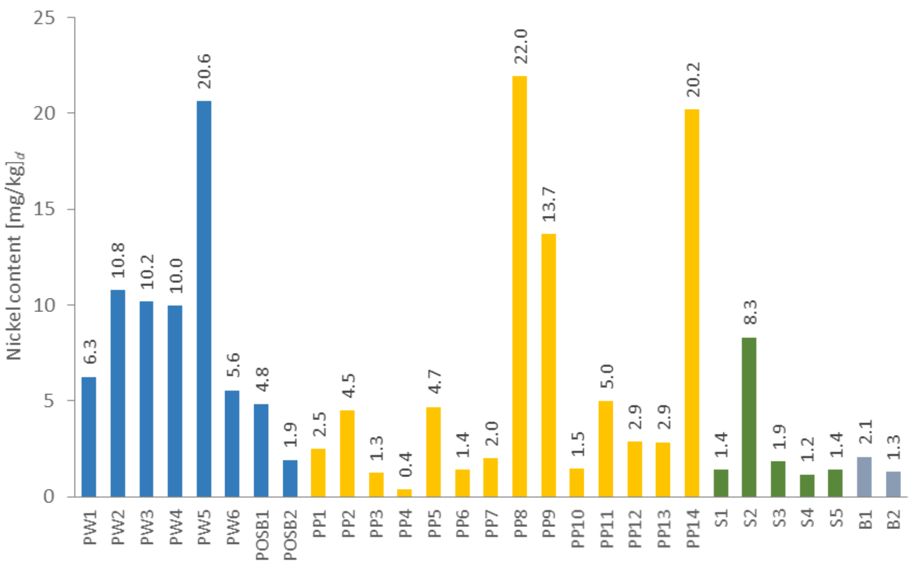
d – dry.

Fig. 13. Copper content in the analysed wood materials



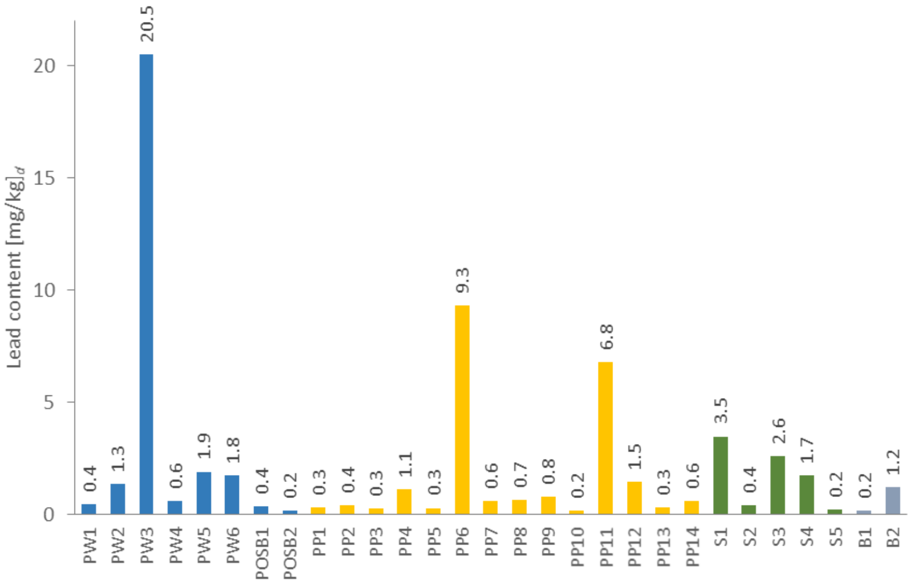
d – dry.

Fig. 14. Mercury content in the analysed wood materials



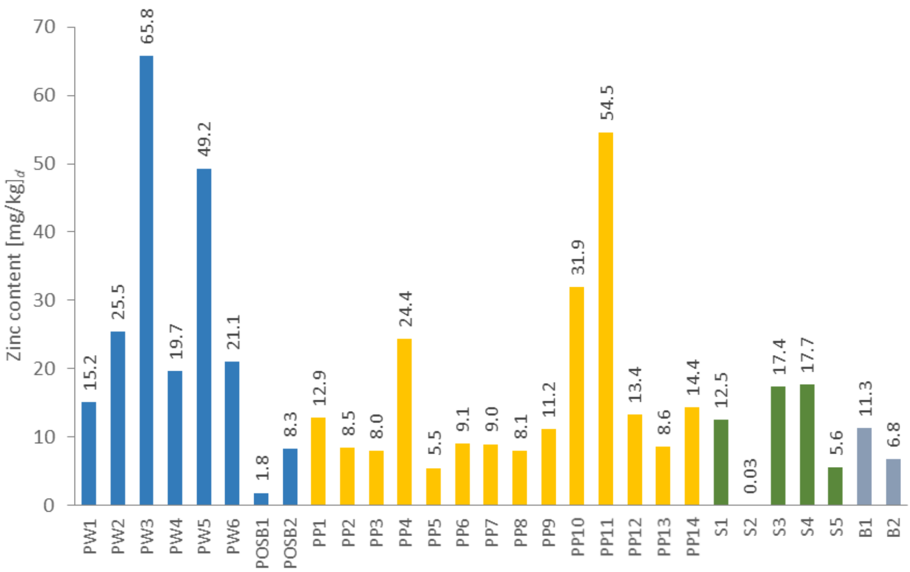
d – dry.

Fig. 15. Nickel content in the analysed wood materials



d – dry.

Fig. 16. Lead content in the analysed wood materials



d – dry.

Fig. 17. Zinc content in the analysed wood materials

Conclusions

The results of the tests of different types of wood materials have shown that production residues of those materials may serve as raw material for the production of solid biofuels.

The energy properties of the evaluated materials confirm that such raw materials can be substituted for forest raw material used for energy purposes. The heat of combustion of tested samples of wood materials ranged from 18.2 MJ/kg to 21.1 MJ/kg. The results are similar to the typical gross calorific values of wood free from chemical components, i.e. 19.4-20.8 MJ/kg.

The fuel properties of solid biofuels obtained from production residues of wood materials did not vary significantly from the typical properties of solid biofuels from wood biomass that has not been chemically treated. The only exception was the nitrogen content determined in the tested materials (0.13-11.6%). The elevated content of nitrogen stemmed from the presence of synthetic substances (amine resins).

The content of mineral components, determined as ash in the tested samples, ranged from 0.3% to 5.9%, which directly influenced the fuel properties of the materials (as the proportion of ash in the evaluated samples increased, their net calorific value decreased).

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List of standards

EN 14774-1:2010 Solid biofuels – Determination of moisture content – Oven dry method – Part 1: Total moisture – Reference method
EN 14775:2010 Solid biofuels – Determination of ash content
EN 14780:2011 Solid biofuels – Sample preparation
EN 14918:2010 Solid biofuels – Determination of calorific value
EN ISO 16948:2015 Solid biofuels – Determination of total content of carbon, hydrogen and nitrogen
EN ISO 16968:2015 Solid biofuels – Determination of minor elements
EN ISO 16994:2015 Solid biofuels – Determination of total content of sulphur and chlorine
EN ISO 17225-1:2014 Solid biofuels – Fuel specifications and classes – Part 1: General requirements
EN ISO 17225-2:2014 Solid biofuels – Fuel specifications and classes – Part 2: Graded wood pellets
EN ISO 17225-3:2014 Solid biofuels – Fuel specifications and classes – Part 3: Graded wood briquettes

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