

Comparison of heat of combustion and calorific value of the cones and wood of selected forest trees species

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Abstract. Every year, scaling plants buy (up to tens of tons) cones which needs to be peeled. After the process of scaling, the cones themselves are waste, which is partly sold. The problem of waste disposal is especially severe in plants where the processing is performed by electrically-powered scaling cabinets, but the problem does not apply to facilities where pellets are burned to produce heat.

We examined the heat of combustion and calorific value of the residues from scaling plants that can be used in the production of refined wood fuels. The residues consist of the empty cones of pine, spruce, larch as well as husks and stems of silver fir. Additionally, we conducted measurements of the heat of combustion for wood and cones of each species and compared them to their respective calorific values.

The results revealed that the average calorific value of the cones is in the range 17.81–19.86 MJ/kg. Our work showed that empty cones have a significantly higher calorific value and heat of combustion than the wood of spruce, larch and fir. In the case of pine, cones and wood did not differ significantly.

These results led us to the conclusions that empty de-scaled cones can be utilised as a valuable primary solid fuel or fuel additive for the production of refined products for the local market.

Due to the low annual production of cones in comparison to other materials such as sawdust and wood chips, pine cones should be used as a supplement, to enrich fuels of inferior quality by enhancing their energetic properties.

Key words: cone, wood, biomass, heat of combustion, calorific value

1. Introduction

After joining European Union in 2004, Poland undertook to adapt to a system functioning in member countries. One of this system's elements was a directive introduced in March 2007 by European council, in which written was inter alia that up to year 2020, 20% of energy used in all countries entering European Union should be from renewable sources. It is underlined in the document that greenhouse gases emission should be reduced by 20%, and energy efficiency should increase to 20%.

Those conditions caused an intensive development of research over renewable sources of energy.

In Poland, energy obtained from wind, water and biomass is considered as the basic source of renewable primary energy. Wood biomass obtained is inter alia from small-sized wood or wood waste after chipping (Zychowicz, Gendek 2009), which was obtained from forest or, for example, from willow, poplar, alder or false acacia plantation. Created chips may be combusted or processed into enriched fuels (pellets and briquettes), commonly used for burning in cauldrons. In dependence

on technology and used material, pellets and briquettes may be produced from one tree species or from mix of many species. Which fuel is better and what should it consist of? Such researches are being conducted by different scientific units.

The authors of article conducted a research on combustion heat and calorific value of waste from kiln, which may be used for enriched wood fuel production. Every year, several dozens of cones were bought for seed kilns and after extraction, they face the problem of waste disposal. Cones that were included to peeling waste are put on sale as a standard value minor product (open cones are used as decorative element in wreaths, headdresses and bouquets), but due to its high price they do not have many buyers. Other way of using empty cones is their fragmentation and addition to substratum used in seedlings production in plastic greenhouses. Those interventions require, however, significant energy and financial effort, so therefore they are not used too often.

Discussed problem of waste disposal concern only those kilns, in which cabinet kilns powered by electric energy are used in cones peeling process (Suszka 2000). This problem does not concern objects, in which cones are being peeled in cabinet kilns powered by firewood. In those kilns for production of thermal energy, often instead of wood empty cones are used. Such kilns are not numerous, however (Aniszewska 2012).

Nowadays in Poland, there are 16 kilns, in which every year cones are peeled for obtaining seeds and the size of purchase depends on the size of harvest. In years of coniferous trees' seeds harvest, for kilns tens of tones of various species cones are bought— for example, kiln in Jarocin peels almost 200 tons per year. After seed peeling process, mass of cones decreases but their volume increases (Aniszewska 2013). The number of remaining empty cones may constitute an excellent base for enriched fuels production and meet the local market demand for thermal energy.

The basic advantage of kiln waste, which are cones, stems, empty seeds and wings, is their low humidity, which does not exceed 10% (e.g. fresh wood consists of 30–70% of water). In this case, facilities producing pellets and briquettes will not have to bear additional costs connected with reducing humidity to level allowing pressure agglomeration to pellet form (Gendek, Głowacki 2010; Głowacki, Gendek 2011), but humidification to around 15% may still be required for briquetting. The disadvantage of cones is their low bulk

density, which affects significantly transport costs, especially for greater distance. The authors plan to describe those issues in next publication.

The aim of this research is a definition of combustion heat and calorific value of four basic coniferous tree species' cones and definition of their usefulness as a material for energy production. Heat of combustion or calorific value defined on its base are two most important parameters needed for kiln's waste energy utilization evaluation, for its future use as a component of enriched fuel in the form of pellets and briquettes. Obtained results will be compared with calorific values for wood of appropriate species.

2. Materials and methods

For research, waste from kiln was used from Grotniki Forest Inspectorate (Łódź Regional Directorate of State Forest) in the form of peeled Scots pine cones (*Pinus sylvestris* L.), Norway spruce (*Picea abies* L.) and European larch (*Larix deciduas* Mill.) and scales and stems of Silver fir (*Abies Alba* Mill.).

Measurement of combustion heat and calculation of calorific value were made using calorimetric method according to PN-ISO 1928:2002 standard. Obtained cones and wood were grinded with the use of mill for particles below 1 mm, and fragmented material was dried in laboratory dryer SLW 115 TOP for 24 h at temperature $104\pm 1^\circ\text{C}$ until the dry mass was obtained.

The research was based on complete combustion of 1 g samples in oxygen atmosphere, under 2.8 MPa pressure and determination of water temperature increase in calorimetric vessel. Combustion took place in calorimeter bomb placed in this vessel and submerged in water of volume 2.7 dm^3 (KL-10 calorimeter). For sample ignition, kanthal resisting wire was used.

Calorimeter measures characteristic temperature of system's heat balance: calorimetric bomb with combusted fuel and calorimetric vessel with water.

Calorimeter works in five stages:

0 – inclusion of calorimeter on and stabilize calorimeter's internal temperature.

1 – temperature T_1 registration and measurement of five measuring periods.

2 – temperature T_2 registration and combustion of fuel sample in calorimetric bomb (duration – in minutes – until reaching maximum temperature).

3 – maximum temperature T_3 registration and measurement of next measuring periods.

4 – temperature T_4 registration, calculations made by internal program and end of work.

Analytical samples weighing 1 g were measured with 0.001 g accuracy with the use of WSP 210S scale. Samples prepared this way were combusted in KL-10 calorimeter. For each material type, the measurement was done 5–6 times. During measurement with the use of Rotnik Hygro-Palm hygrometer, temperature in the room was registered with an accuracy of $\pm 0.1\%$.

Calorimeter used for research determined the value of combustion heat Q_s of the examined substance automatically with the use of internal program according to dependence:

$$Q_s = K \cdot (T_3 - T_2 - k) \quad [\text{kJ} \cdot \text{kg}^{-1}] \quad (1)$$

where

K – is the calorimetric's constant, $\text{kJ} \cdot \text{kg}^{-1}$,

T_2 and T_3 – are the characteristic temperatures of heat balance, K , and

k – is the correction for calorimetric heat exchange with surrounding,

$$k = 0,5 \cdot [0,2 \cdot (T_2 - T_1) + 0,2 \cdot (T_4 - T_3)] + 0,2(n - 1) \cdot (T_4 - T_3) \quad (2)$$

where

n – is the number of minutes in second stage (until reaching maximum temperature), and T_1 and T_4 – are the characteristic temperatures of heat balance, K .

Calorific value Q_{op} was calculated on the basis of the formula (PN-ISO 1928:2002):

$$Q_{op} = (Q_s - 206 H) \cdot (1 - 0,01 \cdot W_w) - 23,0 \cdot W_w \quad [\text{kJ} \cdot \text{kg}^{-1}] \quad (3)$$

where

W_w – is the relative humidity (%) and

H – the hydride content (%).

According to information in literature on the subject, for different types of biomass, hydride content (H) ranges from 5.5% to 7.0% (Głodek 2010; Skrifvars and oth. 1988; Świeca 2007; Werther and oth.. 2000). For calculating wood and cones calorific values, hydride content in percent was adopted on permanent level for coniferous wood – 6.3%.

Average values and standard deviation were calculated, and Student's t -test was performed for few samples. With t -test combustion heat and calorific value of individual cones' species and wood were compared. Tests of fitting to normal distribution were also performed. Statistical analysis of results was conducted with the use of the program Statistica 10 (StatSoft 2011).

3. Results

Combustion heat. Measurements' results, average values and standard deviation of combustion heat values are given in Table 1. The highest average combustion heat 21.16 MJ/kg was registered for fir's cones, and the lowest 19.11 MJ/kg for larch's wood. In turn, the lowest combustion heat values among cones had pine's cones – 19.4 MJ/kg.

Combustion heat of all species is characterised with normal distribution. Comparison with the use of Student's t results obtained for cones and wood within the same species showed that in the case of spruce, larch and fir, cones' combustion heat differs significantly from wood combustion heat (Table 2). In those cases, average value of cones combustion heat was higher. The biggest difference was in case of larch – cones combustion heat was by 7.96% higher than wood combustion heat (Table 2).

In case of pine, no significant difference of cones and wood combustion heat was stated. Cones combustion heat was smaller by 1.01% from wood combustion heat.

Combustion heat of particular species cones (pine, spruce, larch, fir) was evaluated with the use of F -test (variance analysis). According to this test, significant differences occur between pine's and fir's cones combustion heat, but no differences between combustion heat of remaining species were stated.

Calorific value. On the basis of determined calorific value, from relation (3) cones calorific value was calculated and for comparison – wood calorific value – of particular species. Detailed list of measurements results, average value and standard deviation of cones' dry mass calorific value and wood calorific value of discussed tree species are given in Table 1. Calorific value changes with the change of material humidity (Fig. 1).

With humidity 0% (dry mass), the highest calorific value had fir cones. With humidity 20%, this value decreased by 4.43 MJ/kg, i.e. by 22.3%, and with humidity 70% – by 15.51 MJ/kg in relation to initial level (by 78.1%).

The lowest calorific value with humidity 0% had pine's cones. With humidity 20%, this value decreased by 4.08 MJ/kg, i.e. by 22.5%, and with humidity 70% a drop occurred in relation to initial level by 14.29 MJ/kg (by 78.9%).

Calorific value of cones and wood of all species is characterised with normal distribution. Comparison of results obtained from samples for given species from Student's t -test showed that in case of spruce, larch and fir, cone's calorific value differs significantly from wood calorific value, whereas in case of pine no differences were stated.

Table 1. The heat of combustion and calorific value of the dry weight of the cones and wood tested samples

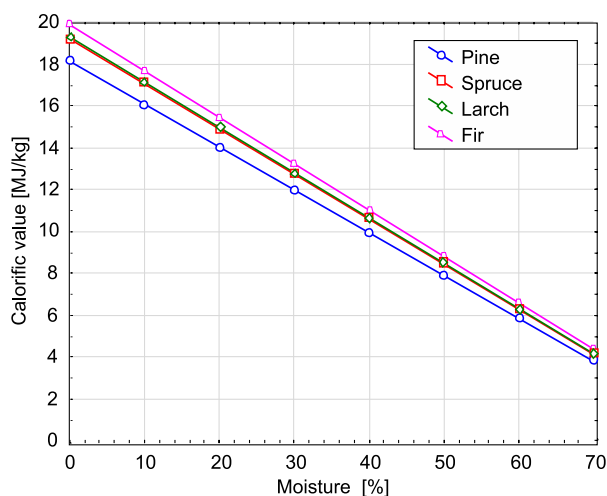
Material	Trial number	Heat of combustion			Calorific value			
		measurement	average	std. dev.	measurement	average	std. dev.	
MJ/kg								
Scots pine	cone	1	19.18	19.40	0.36	17.89	18.11	0.36
		2	19.00			17.70		
		3	19.29			17.99		
		4	19.69			18.39		
		5	19.86			18.56		
	wood	1	19.37	19.61	0.45	18.07	18.32	0.45
		2	20.16			18.86		
		3	19.23			17.94		
		4	20.16			18.86		
		5	19.62			18.32		
		6	19.14			17.85		
	Norway spruce	cone	1	20.303	20.55	0.47	19.01	19.25
2			19.99	18.69				
3			21.05	19.75				
4			20.39	19.09				
5			21.02	19.73				
wood		1	20.24	19.96	0.19	18.94	18.66	0.19
		2	19.92			18.62		
		3	19.99			18.69		
		4	19.69			18.40		
		5	19.95			18.65		
European larch	cone	1	20.59	20.58	0.28	19.29	19.28	0.28
		2	20.96			19.66		
		3	20.59			19.29		
		4	20.17			18.87		
		5	20.57			19.28		
	wood	1	19.96	19.11	0.55	18.66	17.81	0.55
		2	19.06			17.76		
		3	18.97			17.68		
		4	19.10			17.80		
		5	18.44			17.14		
Silver fir	cone	1	21.42	21.16	0.34	20.12	19.86	0.34
		2	20.70			19.41		
		3	21.25			19.95		
		4	21.52			20.22		
		5	20.91			19.61		
	wood	1	20.99	20.59	0.30	19.70	19.29	0.30
		2	20.73			19.43		
		3	20.43			19.13		
		4	20.68			19.38		
		5	20.11			18.81		
		6	20.59			19.29		

Calorific value of particular species cones' dry mass (pine, spruce, larch and fir) was evaluated with the use of *F*-test (variance analysis). The results confirmed that

differences between calorific value of examined species cones are significant. Multiple comparison test confirmed that calorific value of pine cones differs signif-

Table 2. *T*-test comparison of the heat of combustion of cones and wood for independent samples (differences significant at $p < 0.05$) and the variance ratio of *F*-test

Species	The difference of heat of combustion of cones and wood	<i>t</i> -test		<i>F</i> -test	
		<i>t</i>	<i>p</i>	<i>F</i>	<i>p</i>
Scots pine	-0.21	-0.83	0.43	1.61	0.67
Norway spruce	+0.59	2.61	0.03	5.94	0.11
European larch	+1.47	5.36	0.00	3.81	0.22
Silver fir	+0.57	2.97	0.02	1.32	0.75

**Figure 1.** Variation of the cones calorific value depending on moisture

icantly from fir's cones calorific value. This test did not show differences in case of remaining species. Similar situation occurred in case of cones combustion heat.

Comparison of cones dry mass calorific value and wood calorific value within the same species showed that in case of spruce, larch and fir, cones had higher calorific value, whereas in case of pine by 1.59% smaller. The highest cones calorific value in relation to wood calorific value was in case of larch (bigger by 5.36%).

4. Discussion

In literature, the results of combustion heat and calorific value of wood are given, whereas authors did not find publications concerning cones of particular species. Results concerning cones were compared therefore with literature data concerning wood. An exception is Fonta et al. publication (2009) in which the combustion heat value for pine's cones (18.7 MJ/kg) was given, lower than that obtained in this study.

Obtained average values of cones and wood combustion heat range from 19.11 to 21.16 MJ/kg (Table 1) and in majority they are higher from the values given in literature for combustion heat of wood of the same species. Combustion heat of pine's cones and wood defined in the following thesis is lower – respectively by 1.79 and 1.59 MJ/kg – from combustion heat values given in literature inter alia by Głodek (2010) and Font et al. (2009) (21.2 MJ/kg – concerns Scot's pine wood). In case of Norway spruce, cones combustion heat was higher from the one given in literature by 0.05 MJ/kg, and wood combustion heat lower by 0.39 MJ/kg. In case of larch cones and wood, differences in comparison to values from literature (19.5 MJ/kg – for wood) are 1.08 and 0.39 MJ/kg. On the other hand, Silver fir's cones and wood combustion heat values obtained in this study are higher from those quoted in literature for wood (Krzysika 1974; Björn and oth. 2012; Wąsik, Michalec 2012), which is 20.15–20.4 MJ/kg, respectively, by 1.20 and 0.19 MJ/kg.

Average calorific value of cones' dry mass and wood of examined species ranges from 17.81 to 19.86 MJ/kg (Table 3). Comparison of obtained results with results from literature can allow to notice that calorific value of pine's and larch's cones can be found within ranges defined for pine's wood (16–19 MJ/kg) and larch wood (17.6–19.9 MJ/kg) (Głodek 2010; Monkielewicz, Pflaum 1967). According to literature data (Monkielewicz, Pflaum 1967; Rembowski 2007; Głodek 2010; Björn and oth. 2012), calorific value of spruce's wood is 17.2–18.6 MJ/kg, and fir's 18.0 MJ/kg. Determined in this study, spruce's cones calorific value is therefore higher by 3.5–11.9%, and fir's cones – by 10.3%.

5. Results

The highest combustion heat value had fir cones – 21.16 MJ/kg, and the lowest pines cones – 19.41 MJ/kg (smaller by 8.27%).

The highest calorific value of dry mass had fir's cones – 19.86 MJ/kg, and the lowest pines cones – 18.11 MJ/kg (lower by 8.81%).

Waste material from kiln (empty cones) has average calorific value higher than wood of the same species in case of spruce, larch and fir, whereas lower in case of pine.

Comparison of calorific value and combustion heat for cones and wood allows to state that cones are valuable energetic material and can be used for direct burning or for production of enriched fuel, which is used in local energetics. Due to relatively small annual cone production in comparison to other materials (sawdust, shavings), out of which produced are briquettes or pellets, cones should be an addition to initial product of lower quality in order to increase the calorific value of final product. Still cones' percentage amount as an addition should be further examined. In further studies, authors will attempt to evaluate energy value and cones usefulness as an addition to sawdust, shavings or biomass in the form of needles, straws or energy crops at the production of briquettes and pellets.

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Authors' contribution

M. A. and A. G. – Concept and design studies, conduct research, data analysis, literature review, preparation of text publication.