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Combustion heat and calorific value of the mix of sawdust and cones of common pine (*Pinus sylvestris* L.)

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Abstract: *Combustion heat and calorific value of the mix of sawdust and cones of common pine (Pinus sylvestris L.).* The research conducted was aimed at specification of the combustion heat and calorific value for the mix of sawdust and crushed cones. The research material consisted of sawdust obtained from processing of pine wood and crushed common pine cones, obtained from the husking mill after the seed husking process. The measurements and calculations were conducted in accordance with PN-ISO 1928:2002 and PN-ISO 1928:2002 standards. The obtained calorific value results range between 17.98 (±0.63) MJ·kg^{-1} for pure pine sawdust and 18.32 (±0.34) MJ·kg^{-1} for crushed pine cones and are within the limits quoted in literature. It can be stated, however, that an addition of pine cones up to 50% of share to sawdust does not result in significant increasing of the mix calorific value. Nevertheless, there is a statistically significant difference between the calorific value of the sawdust mix with the addition of pine cones up to 30% of share in relation to calorific value of pines only. Further research associated with adding of cones to sawdust of other species may indicate, which mix will give positive effects in terms of energy efficiency, manifested by reduction of initial moisture content of the mix and increasing of its calorific value

Key words: forest biomass, combustion heat, calorific value

INTRODUCTION

In the opinion of specialists, wood biomass is dominant among the sources of energy in Poland, classified as solid biomass; it is estimated that it represents about 80% of consumption [Gajewski 2010, Flakowicz 2011]. As the wood-working industry plants are the natural source of solid biomass in various forms, they may, like forests, generate supply on the market of wood biomass. Apart from these plants and forests, a large part of biomass for energy production purposes comes from plantations, which are popular not only in Poland, but also abroad [Heneman and Červinka 2007]. Depending on the type of production activity of enterprises associated with the woodworking sector, the structure of by-products resulting from wood processing varies. These may be pieces (e.g. edgings) or crushed bits of varying size (chips, sawdust, shavings, wood dust) [Komorowicz et al. 2009].

Sawdust is produced mainly by sawmills and plywood production plants. In the structure of wood byproducts from the woodworking sector, in year 2010, it constituted about 25 and 4%, respectively [Ratajczak et al. 2011, Szostak 2013]. According to Szostak et al. [2015], the calculated supply of wood byproducts from sawmills in 2010 amounted to 2.32 million m^3. According to Ratajczak et al. [2012], own consumption for power generation purposes in the sawmill industry amounted to 930 thousand m^3, while about 1.39 million m^3 could have been sold to customers outside the sector. Sawdust is thus a serious source of biomass for energy production purposes and a popular material for production of pellet as a refined fuel.

Apart from sawdust, cones of forest trees are also a good material for energy production. In seed production, several dozen tons of cones are sold to husking plants each year; after husking, the cones are treated as waste. Due to low humidity (about 7–8%), these cones can be used for heating of husking cabinets or for production of refined fuel in form of pellets or briquettes. The cones can be used mainly on the local market, as the main problem is their seasonal availability in the mast years and in the growing months, as well as their mass and low bulk density [Aniszewska 2013, Aniszewska and Gendek 2014]. Their advantages, however, include low moisture content, which does not require additional energy expenditures for drying of the material [Gendek and Głowacki 2010, Zawistowski et al. 2010, Głowacki and Gendek 2011, Aniszewska 2013].

During production of refined fuel, addition of crushed pine cones to sawdust may thus reduce the moisture content in the material, which exerts negative impact e.g. on storage of wood products [Barwicki and Gach 2010], and it may increase the calorific value of pellet or briquettes, which will exert positive impact on improvement of the conditions of combustion in furnaces [Polak 2008]. The best effects will be achieved with a great difference in calorific value between a cone and sawdust of the proper kind.

The objective of research undertaken was to specify the combustion heat and to determine the calorific value of pine sawdust as the main, widely available type of biomass, and crushed cones of common pine (*Pinus silvestris*) and to determine whether addition of pine cones will exert positive impact on calorific value of such material.

MATERIAL AND METHODOS

The research material consisted of pure sawdust and crushed pine cones and their mix in an appropriate proportion, where the base consisted of sawdust, while the cones were an addition. Sawdust was obtained from a company dealing with wood processing. Pine cones were obtained from a husking plant after the seed husking process. Prior to preparation of mix, the cones were crushed in a hammer crusher with a sieve with mesh size of 6 mm. The test samples were prepared by making and marking the mix of sawdust (*T*) and crushed cones (*S*) in the proportions presented in Table 1.

The samples prepared in this manner were dried for 24 h in the temperature of 104 ±1°C, until achieving dry substance. A laboratory drier SLW 115 TOP was used.

TABLE 1. Designation of share of sawdust and cones in the samples examined

Designation	Sawdust share	Cone share
	%	
T100S0	100	0
T90S10	90	10
T80S20	80	20
T70S30	70	30
T60S40	60	40
T50S50	50	50
T0S100	0	100

Measurement of the combustion heat was performed in accordance with the standard PN-ISO 1928:2002. Analytical samples of mass of 1 g were measured with accuracy of 0.001 g using scales WSP 210S. The study consisted of complete combustion of the samples weighing 1 g in the atmosphere of oxygen under pressure of 2.8 MPa and determination of water temperature increase in the calorimetric dish. The measurement was conducted at a workstation equipped with calorimeter KL-10, which automatically made the measurement and calculated the combustion heat result using an internal program. For the purpose of accurate analysis and interpretation of the results, the measurement was repeated 20 times for each mix type.

During the measurement, using an electronic hygrometer, room temperature was recorded with accuracy of ±0.1°C and humidity was recorded with accuracy of ±0.1%.

On the basis of the combustion heat results obtained, the calorific value was determined on the basis of the following equation [PN-ISO 1928:2002]:

$$Q_{op} = (Q_s - 206 \cdot H) \cdot (1 - 0.01 \cdot W_w) - 23 \cdot W_w \quad (1)$$

where:
Q_{op} – calorific value [kJ·kg^{-1}];
Q_s – combustion heat [kJ·kg^{-1}]
H – hydrogen content [%],
W_w – relative humidity [%].

Hydrogen content (H) for various types of biomass was within the range of 5.5–7.0% [Skrifvars et al. 1988, Werther et al. 2000, Świeca 2007, Font et al. 2009, Głodek 2010]. For all mix types, the constant value of 6.3% was assumed, which is quoted in literature on the subject for coniferous wood. Statistical analyses of results were conducted using Statistica 12 software [StatSoft 2014].

RESULTS AND DISCUSSION

The basic statistics for results obtained from measurement of combustion heat of individual mixes of sawdust and pine cones and the calculated calorific value have been presented in Table 2. Due to the fact that calorific value is a variable used in power engineering for settlement and determination of quality of fuel from biomass, combustion heat will be disregarded in the analysis.

The average calorific value of milled cones (T0S100) was 18.32 (±0.34) MJ·kg^{-1}, falling within the range of 17.42–18.94 MJ·kg^{-1}. It was higher by 1.89% than the average calorific value of pine sawdust (T100S0) without the addition of cones – 17.98 (±0.63) MJ·kg^{-1} ranging between 17.06–19.43 MJ·kg^{-1}.

TABLE 2. Combustion heat and calorific value of the mix of pine sawdust and cones [Statistica 12]

Designation	Additional of cones [%]	Average	Confidence −95.00%	Confidence +95.00%	Minimum	Maximum	Variance	Standard deviation	Coefficient of variation	Standard error	Skewness	Kurtosis
Combustion heat [MJ·kg^{-1}]												
T100S0	0	19.27	18.98	19.57	18.36	20.73	0.40	0.63	3.28	0.14	0.37	–0.16
T90S10	10	19.28	19.11	19.45	18.48	19.79	0.13	0.36	1.89	0.08	–0.54	–0.05
T80S20	20	19.28	19.04	19.51	18.61	20.44	0.25	0.50	2.57	0.11	0.56	–0.12
T70S30	30	19.32	19.12	19.53	18.57	19.99	0.19	0.44	2.25	0.10	0.15	–0.86
T60S40	40	19.43	19.21	19.65	18.69	20.51	0.22	0.47	2.42	0.11	0.51	0.24
T50S50	50	19.51	19.35	19.67	18.81	20.15	0.12	0.35	1.78	0.08	–0.05	–0.68
T0S100	100	19.62	19.46	19.78	18.71	20.24	0.12	0.34	1.73	0.08	–0.82	1.75
Calorific value [MJ·kg^{-1}]												
T100S0	0	17.98	17.68	18.27	17.06	19.43	0.40	0.63	3.51	0.14	0.37	–0.15
T90S10	10	17.99	17.82	18.16	17.19	18.50	0.13	0.36	2.03	0.08	–0.52	–0.10
T80S20	20	17.98	17.75	18.21	17.31	19.14	0.25	0.50	2.75	0.11	0.56	–0.12
T70S30	30	18.03	17.82	18.23	17.27	18.69	0.19	0.43	2.41	0.10	0.14	–0.83
T60S40	40	18.13	17.91	18.35	17.40	19.21	0.22	0.47	2.59	0.10	0.53	0.24
T50S50	50	18.21	18.05	18.38	17.51	18.85	0.12	0.35	1.90	0.08	–0.06	–0.65
T0S100	100	18.32	18.16	18.48	17.42	18.94	0.11	0.34	1.84	0.08	–0.82	1.72

Comparing the results obtained with research studies conducted by other authors, it can be noted that the calculated average calorific value of sawdust and cones is within the limits or similar to calorific value of pine wood quoted in literature – 16–19 MJ·kg^{-1} [Monkielewicz and Pflaum 1967, Krzysik 1974, Rembowski 2007, Björn et al. 2012, Głodek 2010] and to the calorific value of pine cones – 18.11 (±0.36) MJ·kg^{-1} [Aniszewska and Gendek 2014].

Analyzing distribution of the results obtained for calorific value and comparing it with the normal distribution, on the basis of skewness (Table 2), it can be stated that in three cases, that is, in samples with addition of cone of 10, 50 and 100% the distribution is skewed negatively, while in the remaining cases it is skewed positively. The results that are closest to normal distribution have been obtained for a mix containing 50% of sawdust and cones.

Considering on the basis of kurtosis (Table 2) the concentration of the obtained calorific value results around the average value, it can be stated that the highest concentration was obtained for the material consisting in 100% of crushed cones and for material with the cone share amounting to 40%. In the remaining five cases, where kurtosis was negative, the spread of results was greater and more extreme results could be observed in the set of data.

The impact of addition of crushed sawdust on calorific value of the mix has been presented by a figure. Initially, adding of crushed cones to pine sawdust does not result in increasing of the calorific value. Until the share of cones in the mix exceeds the level of 0–30%, the average calorific value of the mix remains similar. A gradual increase in the calorific value is observed when the share of cones is increased to the level of 40% and more.

In order to find out whether significant differences occur between the obtained results of calorific value of individual mixes of sawdust and cones, at the significance level of $\alpha = 0.05$, Levene and Brown-Forsythe homogeneity of variance tests were conducted (Table 3), which showed that there are differences between the average values.

In order to specify, which mix groups differ at a statistically significant level, a multiple comparison test NIR was conducted (Table 4). On the basis of the results obtained, it can be stated that adding of crushed cones to pine sawdust until their share reaches 50% and a slight increasing of the calorific value from the level of 17.98 (±0.63) to 18.21 (±0.35) $MJ \cdot kg^{-1}$ did not indicate a statistically significant difference of the results, and thus the values can be considered to be homogeneous.

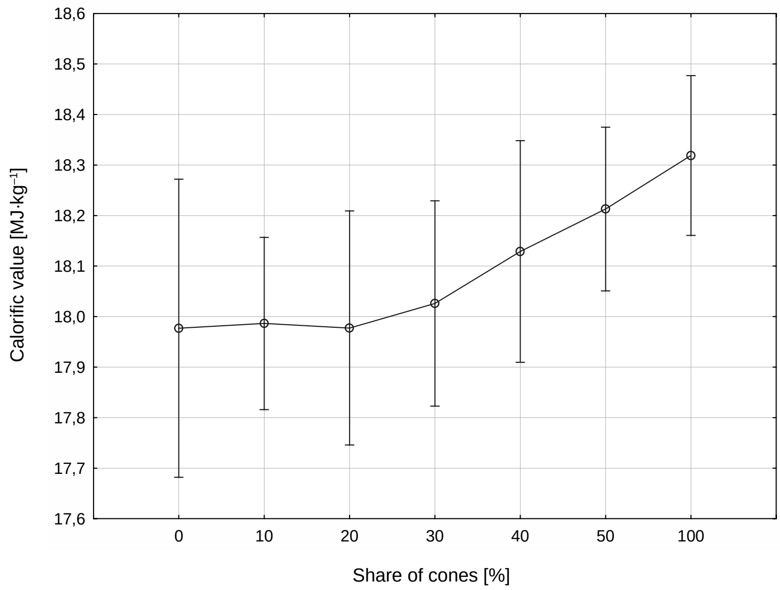

FIGURE. A chart of interaction between the calorific value of the mix – average values and confidence intervals (±95.00%)

TABLE 3. Levene and Brown-Forsythe homogeneity of variance tests for calorific value of mixes (differences are significant for p <0.05)

Test type	*SS*	*df*	*MS*	*SS*	*df*	*MS*	*F*	*p*
	effect			error				
Levene	0.9450	6	0.1575	8.8392	133	0.0665	2.3697	0.0331
Brown-Forsythe	0.9393	6	0.1566	9.3286	133	0.0701	2.2320	0.0438

TABLE 4. A multiple comparison test NIR for calorific value of mixes (the differences are significant for p <0.05)

Mix	T100S0	T90S10	T80S20	T70S30	T60S40	T50S50	T0S100
T100S0	–	0.9469	0.9972	0.7311	0.2873	0.0995	0.0176
T90S10	0.9469	–	0.9497	0.7817	0.3184	0.1138	0.0209
T80S20	0.9972	0.9497	–	0.7337	0.2889	0.1003	0.0178
T70S30	0.7311	0.7817	0.7337	–	0.4704	0.1910	0.0414
T60S40	0.2873	0.3184	0.2889	0.4704	–	0.5560	0.1840
T50S50	0.0995	0.1138	0.1003	0.1910	0.5560	–	0.4576
T0S100	0.0176	0.0209	0.0178	0.0414	0.1840	0.4576	–

Statistical analyses have shown, however, that the average calorific value of cones without additions (18.21 ±0.34 MJ·kg^{-1}) is statistically significantly different from calorific value of sawdust without additions and of sawdust with the addition of up to 30% cones. Increasing of the share of cones in the mix to 40 and 50% resulted in the calorific value of such mix 18.13 (±0.47) and 18.21 (±0.35) MJ·kg^{-1} – which is not statistically significantly different from the calorific value of pine cones of 18.32 (±0.34) MJ·kg^{-1}.

CONCLUSIONS

Calorific value of the examined material ranged between 17.98 (±0.63) MJ·kg^{-1} for pure pine sawdust and 18.32 (±0.34) MJ·kg^{-1} for crushed pine cones. Research was conducted using sawdust and cones of the same species (common pine), and their calorific value differed slightly, that is, by 1.98%; however, the difference was statistically significant.

The obtained results of calorific value of sawdust, cones of the common pine and their mixes are within the range quoted in literature on the subject (16–19 MJ·kg^{-1}).

On the basis of the results obtained, it can be said that addition of cones to pine sawdust up to 50% of share does not lead to a significant increase in the calorific value of the mix. However, there is a statistically significant difference in calorific value of the sawdust mix with the addition of cones up to 30% of share in relation to the calorific value of cones.

Due to the fact that the quantity of cones used for husking on the national scale, which can be potentially used for energy production, is rather small (about 30 Mg per year per husking mill), to enhance the energy efficiency, they can be mixed for combustion with pine sawdust.

The research conducted was focused on one species. Further research on addition of crushed cones to sawdust of other species of trees or other forms of biomass of varying origin may indicate whether this material will give a positive effect by enhancing the quality of the mix for combustion (lower moisture content, higher calorific value) or for production of refined fuel (cones used as a binding agent for pellet production).

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Streszczenie: *Ciepło spalania i wartość opałowa mieszanki trocin i szyszek sosny zwyczajnej (Pinus sylvestris L.).* Przeprowadzone badania miały na celu określenie wartości ciepła spalania i wartości opałowej dla mieszanki trocin i rozdrobnionych szyszek. Materiał badawczy stanowiły trociny pozyskane w wyniku przerobu drewna sosnowego oraz rozdrobnione szyszki sosny zwyczajnej pozyskane w wyłuszczarni po procesie pozyskania nasion. Otrzymane wyniki wartości opałowej zawierają się w granicach od 17,98 (±0,63) $MJ \cdot kg^{-1}$ dla czystych trocin sosnowych do 18,32 (±0,34) $MJ \cdot kg^{-1}$ dla rozdrobnionych szyszek sosnowych i mieszczą się w granicach podawanych w literaturze. Można jednak stwierdzić, że domieszka szyszek do trocin sosnowych w zakresie do 50% udziału nie zwiększa istotnie wartości opałowej mieszanki. Istnieje jednak statystycznie istotna różnica w wartości opałowej mieszanki trocin z dodatkiem szyszek do 30% udziału w stosunku do wartości opałowej samych szyszek. Prowadzenie dalszych badań związanych z dodawaniem szyszek do trocin innych gatunków może wskazać, która mieszanka będzie dawała korzystne efekty energetyczne.

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