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Analysis of woodchip heating capacity calculated according to technical standards and measurements of calorific value

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ABSTRACT: Woodchip sampling may be done according to two methodologies, based on the volume or calorific value of the fuel. The paper compares heating values obtained through relative humidity measurements according to Slovak technical standards and through determination of calorific value according to the ISO 1928:2003 Standard. The aim is to compare values obtained by both methods from a selection set and to determine possible reasons in case various values are obtained. Based on the results obtained it may be confirmed that differences between the heating value calculated according to the ISO 1928:2003 Standard and according to the STN 48 0057 (2004) and STN 48 0058 (2004) Standards are statistically significant. The average difference in heating value is 0.629 MJ·kg^{-1}.

Keywords: wood chips; heat capacity; caloric value; relative moisture

The Czech Republic, Slovakia and Poland are among countries which do not use their full potential in the sphere of renewable energy resources utilization. The annual biomass potential in Slovakia is over 35 PJ, while the existing share of biomass in total primary energy consumption is approx. 9 PJ. This means that only approx. 25% of the total technical biomass potential is used annually. Biomass contributes approx. 4% to Slovakia's total energy mix (Suchomel, Gejdoš 2012). In 2010, the Czech Republic potential of biomass suitable for energy production (dendromass, straw) was estimated at 62 PJ (Váňa 2003), although its actual utilizability was 49 PJ in 2006 (Vlk 2009). Dendromass from logging residues, which is unsuitable for industrial processing and which represents 15–25% of all dendromass produced in forests, has the highest potential for biomass energy production (Simanov 1993; Chytrý 2008).

Political objectives promoting the use of renewable energy expect a rise in domestic resource utilization (Jandačka, Malcho 2007; Anonymous 2006), whereby biomass and dendromass produced by forest management and grown for energy purposes such as for example, the energy willow will respectively represent a major share (Fijałkowska, Styszko 2011; Sztyma-Horvat, Styszko 2011). The method of energy wood sampling plays a key role in setting timber prices for energy production purposes. The existing methods of energy wood sampling are conditioned by the size and technical equipment of the given biomass processor. Generally, energy woodchips sampling may be divided into two groups, according to the supplied timber volume and according to the fuel energy value. The FINBIO (1998) sampling influences the accuracy of the monitored solid biofuel testing to the greatest extent. Biofuel evaluation and definition of the heating value energy parameters was the subject of research by Curvers and Gigler (1993), Puttkamer (2005), Geffertova and Geffert (2011).

The paper aims to compare heating values obtained through a simplified method based on determina-

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tion of relative moisture content described in technical standards STN 48 0057:2004, STN 48 0058:2004 and determination of calorific value according to 48 0057:2004, STN 48 0058:2004 Solid fuels: Determination of calorific value in a bomb calorimeter using the calorimetric method and calculation of heating value (in the Czech Republic and in Poland, standards ČSN EN 14961-4:2011 and PN-EN 14961-4:2011 Solid biofuels-Specifications and Fuel Classes – Part 4: Woodchips for Retailers are applied for the same purpose). The key issue in the woodchip producer-customer relationship is determination of the volume of delivered woodchips and their energy value expressed by the heating value. The aim is to compare values obtained from a sampling set using both methods and to determine possible causes upon finding different values.

MATERIAL AND METHODS

Laboratory determination of calorific value using the calorimetric method operates with the terms calorific value (Q_s) and heating capacity (Q_n) determined according to relevant standards (ČSN 44 1352:1980, STN ISO 1928:2003).

Methods of energy woodchip sampling. Volume is frequently used as a standard unit measuring energy wood. This measurement method is quick and not costly. Its downside is insufficient accuracy in determining the storage volume, e.g. with respect to unevenly loaded truck. Woodchip size, the ratio of fraction sizes, transport distance and the vehicle used all significantly affect the determination of volume in spatial units.

Water content significantly affects fuel's heating capacity, due to the decreased dry matter and the energy required for vaporization. As a result, fuel sale must take moisture into consideration (Jandačka, Malcho 2007). In accordance with the Slovak standard STN 48 00 58: 2004 or according to the Ministry of Agriculture of the Czech Republic, delivery and reception of broadleaf woodchips and sawdust favours weight measurement to volume measurement due to its higher accuracy – Atro-method. The measuring unit upon weight-based takeover is tonne. Weight is determined as a difference between a loaded and empty transport vehicle and from dry matter content.

Determination of heating capacity from calorific value is conducted in accordance with STN ISO 1928: 2003. To calculate the heating capacity, calorific value needed to be determined from the sampled material. Calorimeter IKA C200 (IKA Werke GmbH & Co.Kg, Staufen, German) was used to determine the calorific value. When determining calorific value, the analytic sample is mixed thoroughly and a sample of 0.8 to 1.5 g with 0.0002 g accuracy is weighed. Its weight should facilitate a water temperature increase of 2–3°C in the calorimeter. The prepared sample is placed in a loop holder. A cotton fuse is attached to the fuse wire (a standard fixed part of the bomb calorimeter). If the sample material does not burn fully, it must be briquetted. Pressure which ensures the briquette's compactness is sufficient. If the measured material has very low calorific value, the sample is mixed with benzoic acid. The ratio of individual components corresponds to the expected calorific value of the tested material. The oxygen bomb calorimeter is sealed with a screw cap and filled with oxygen to an overpressure of 2.5–3.5 MPa – the required pressure being pre-set at the filling station. Then the ignition adaptor is put on the bomb head and the bomb is lowered into the calorimeter in a defined position. The temperature of water in the calorimeter jacket should not differ from the lab air temperature by more than ± 0.5°C – but need not be checked. Two liters of water was added in the calorimeter bucket prior to conducted measurement. The calorimeter measures out an exact amount of water automatically at the onset of measuring session. After the calorimeter is set and filled with water, the apparatus is sealed with a lid.

Water temperature data are updated in one minute intervals. The main measuring stage, in the course of which data logging continues, starts after ignition. The temperature rises rapidly at the beginning, then the changes become slower and after 7–8 min the temperature approaches a maximum (end of the main stage). In the following five minutes (the final measuring stage) the temperature drops slowly. The last temperature reading recording a decrease concludes the measuring session. The resulting value shown on the calorimeter display represents the calorific value of the analyzed sample in pre-set units. Calorific value is calculated according to the following equation (1):

$$Q_S = \frac{C(D_t - K) - c}{m} \quad (\mathrm{J{\cdot}g^{-1}}) \qquad (1)$$

where:

C – heat capacity of the calorimetric system ($\mathrm{J{\cdot}°C^{-1}}$),

D_t – total temperature rise in the main stage (°C),

K – correction for heat exchange with the surrounding atmosphere (°C),

c – sum of corrections (J), where $c = c_1 + c_2 + c_3 + c_4$ (c_2, c_3 and c_4 are not taken into account),

c_1 – correction for combustion of heat released by burning of the cotton fuse – 50 J,

m – weight of the analytical fuel sample (g).

Calculation of heating capacity according to equation (2) in accordance with standard STN ISO 1928:2003:

$$q_{v,net,m} = [q_{v,gr,d} - 206w(H)_d] \times (1 - 0.01M_T) - 23.5M_T \quad (2)$$

where:

$q_{v,net,m}$ – heating capacity upon constant volume and water content M_T (kJ·kg^{-1}),

$q_{v,gr,d}$ – calorific value upon constant volume and waterless state (kJ·kg^{-1}),

$w(H)_d$ – hydrogen percentage representation (value used for wood – 6.0) (%)

M_T – total water content in the fuel which is required for conversion – relative moisture content (%).

Methodology for heating capacity calculation based on standards STN 48 0057:2004 and STN 48 0058:2004. Dry wood heating capacity values are approx. 18.7 MJ·kg^{-1} for conifers and 18.4 MJ.kg^{-1} for broadleaf species. These data allow us to assume that it is moisture content, not the respective tree species, which will affect the heating capacity of energy woodchips most significantly. The difference in heating capacities of individual dendromass components or tree species respectively, is to a major extent caused by the existing moisture content in wood. According to the authors of the STN standard, these facts were adopted from relevant literature and a comparison of individual values reveals similarities with the Austrian standard ÖNORM M 7132 Energiewirtschaftliche Nutzung von Holz und Rinde als Brennstoff – Begriffsbestimmungen und Merkmale (ONORM M7132 1:1998).

Based on data from the STN 48 0057:2004 and STN 48 0058:2004 the following equations were set to calculate the heating capacity (Table 1). Equation (3) for calculation of coniferous woodchip heating capacity according to STN 48 0057:2004:

$$Q_y^r = 18.708 - 0.2132w_r \text{ (MJ·kg}^{-1}\text{)} \quad (3)$$

Equation (4) for calculation of broadleaf woodchip heating capacity according to STN 48 0058:2004:

$$Q_y^r = 18.705 - 0.231w_r \text{ (MJ·kg}^{-1}\text{)} \quad (4)$$

Equation (5) for calculation of mixed broadleaf (70%) and coniferous (30%) woodchip heating capacity according to STN 48 0057:2004 and STN 48 0058:2004:

$$Q_y^r = 18.706 - 0.2256w_r \text{ (MJ·kg}^{-1}\text{)} \quad (5)$$

where:

Q_y^r – heating capacity (MJ·kg^{-1})

w_r – relative moisture (%)

All samples were collected in a single heating plant. The woodchip producer comes from the Banská Bystrica self-governing region and based on experience from previous years, the ratio between broadleaf and coniferous wood mass was set at 70:30%. This ratio was specified in supplier contracts with respect to records of energy wood chips receipts in the previous three years. Actual checks of the conifer-broadleaf wood ratio were not conducted in the said plant. A total of 81 samples were processed for the purposes of continuous control.

RESULTS

Based on the values of heating capacity obtained through methods according to ISO 1928:2003 and according to STN 48 0057:2004 and STN 48 0058:2004, differences in heating capacity were calculated, as shown in Fig. 1.

The average difference in heating capacity is 0.629 MJ·kg^{-1}. A negative difference was calculated in four samples and 77 samples showed a positive difference in favour of calculations according to ISO 1928:2003. Based on the obtained data, the monitored values were subjected to variance analysis with the objective to find out whether the differences in heating capacity obtained through the two methods were statistically significant. Results of the analysis are depicted in Fig. 2. Scatter plot of correlation between norms STN and ISO see Fig. 2.

The null hypothesis on agreement of parameters (means) of two basic data sets was tested (Table 2). The tested parameters are dependent and the basic data sets have equal number $n = 81$ of measurements (calculations). Testing criterion $T = 14.17495$ was cal-

Table 1. Woodchip heating capacity of woodchips (GJ·t^{-1}) in relation to relative moisture (STN 48 00 57:2004 and STN 48 0058:2004)

Tree species	Relative moisture (%)								
	15	20	25	30	35	40	45	50	55
Coniferous	115.5	114.4	113.4	112.3	111.3	110.2	99.1	88.0	77.0
Broadleaf	115.5	114.1	112.9	111.7	110.5	99.4	88.3	77.2	66.2

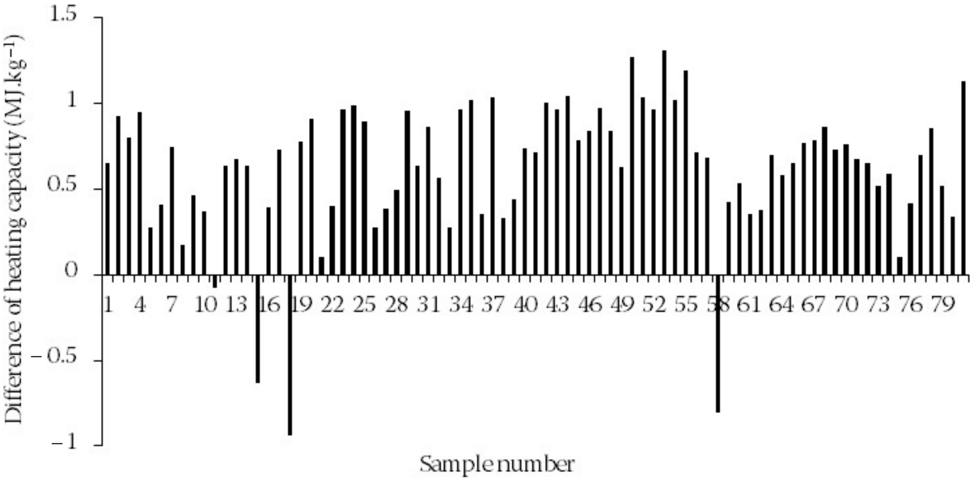

Fig. 1. Differences in heating capacity

Table 2. Statistical parameters calculated from the basic data sets

	Mean	SD	n	R	R^2			$s_{(xA-xB)}$	T	$T_{\alpha/2}$
ISO	7.972579	1.784410	81	0.97923	0.958891	Sx^2_A	0.039801	0.044356	14.1749	1.645
STN	7.343837	1.910132	81			Sx^2_B	0.045608			

ISO, STN – type of standards, Sx^2_A, Sx^2_B – variance of the diference of the heating capacity, $s_{(xA-xB)}$ – standard deviation of the diference of the heating capacity, T – test criterion, $T_{\alpha/2}$ – critical value

culated and based on the f number of degrees of freedom = $n_A + n_B - 1 = 161$, the critical value ($T_\alpha/2$) = 1.645 was established. Based on a comparison of test criterion (T) and critical value ($T_\alpha/2$), i.e. 14.17495 ≥ 1.645, the null hypothesis H_0 was rejected. The tested difference was therefore statistically significant with 95% reliability level and 5 % error probability. The obtained test parameters allow us to formulate a statement that the difference between heating capacity defined by the given standards and that calculated according an equation are statistically significant.

The conducted statistical analysis reveals that differences in calorific values as determined by calculations according to ISO 1928:2003 and STN standards are statistically significant. Higher heating capacity values are obtained from calculations of calorific values according to ISO 1928:2003, while lower values are provided by calculations according to the STN 48 0057:2004 and STN 48 0058:2004 standards. The average difference in heating capacity is 0.629 MJ·kg^{-1}.

Analysis of possible causes of the heating capacity differences

The following causes of resulting differences in heating capacity determination may be listed:

- a deviation in determining calorific value using calorimeter (based on information obtained, the IKA C 200 calorimeter used in laboratory analyses was

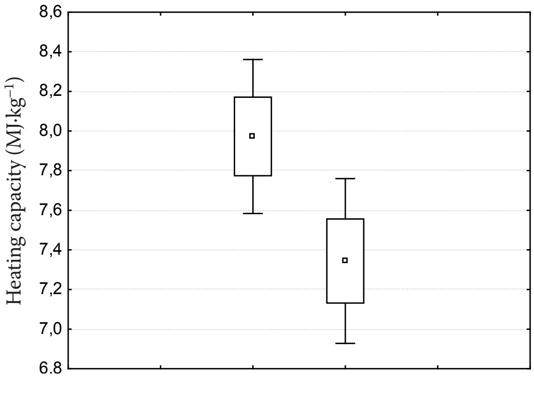

Fig. 2. Determination of statistically significant differences in heating capacity according to (left) ISO 1928:2003 and (right) STN 48 0057:2004/ STN 48 0058:2004 upon a given conifer: broadleaf ratio (70:30)

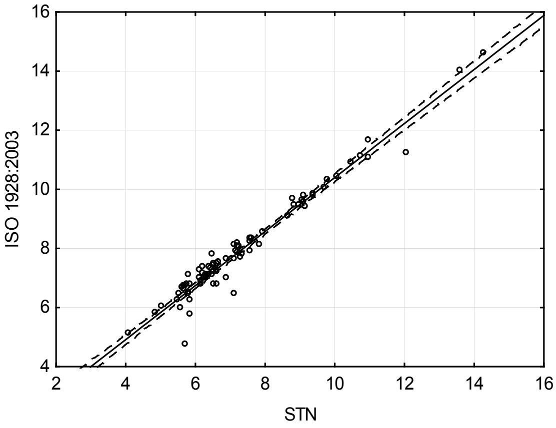

Fig. 3. Scatter plot of correlation between STN 48 0057: 2004, STN 48 0058:2004 and ISO 1928:2003 (r = 0.97915)

calibrated by benzoic acid (1.2.2012). A calibration performed outside standard calibration terms did not reveal a deviation from the prescribed limits. The deviation recorded was 0.002 MJ·kg^{-1},

- specification of mean values of H, O and N upon simplifying equation 2 in ISO 1928:2003,
- fundamentally different methodologies of determining heating capacity – as a result, heating capacity according Austrian or German technical standards differs as well. A unified calculation is recommended by STN EN 14961-1: determination of precise heating capacity requires weight ratios of H, O, N in individual samples.

CONCLUSION

Based on the established facts it may be said that heating capacity values obtained using both studied methodologies differ significantly in the sample set. By using Equation (3) to calculate heating capacity of coniferous species with regard to their relative moisture, the average differences in heating capacity values of STN and ISO in the sample set may be decreased from 0.629 MJ·kg^{-1} to 0.002 MJ·kg^{-1}. However, such a change does not correspond to the actual tree species composition and as such may not be considered a proper solution despite the more closely corresponding values. Based on the established facts a follow-up study of heating capacity using both methods may be suggested. Upon expanding the sample set the key cause enabling elimination of the differences found between the tested methods may be detected.

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