Selected properties of agricultural biomass

V. Kažimírová[1], T. Brestovič[2], R. Opáth[1]

[1]Department of Production Engineering, Faculty of Engineering, Slovak University of Agriculture in Nitra, Nitra, Slovak Republic
[2]Department of Power Engineering, Faculty of Mechanical Engineering, Technical University of Košice, Košice, Slovak Republic

Abstract

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The presented contribution deals with the quantification of moisture, combustible matter content, ash content and higher heating value of the selected types of biomass used for the heat production by direct combustion. The moisture, combustible matter, and ash contents were determined by gravimetric analysis in accordance with the established standards. The average moisture of the materials examined varied from 4.35 to 9.17%; the combustible matter content in the original samples ranged from 79.46 to 93.51%; the ash content ranged from 2.14 to 11.28%. Higher heating values of the examined types of biomass varied from 14,996 to 17,641 kJ/kg. The main contribution of the thesis is the acquisition of values usable in subsequent theoretical and practical efforts to increase the efficiency of the heat production by direct combustion of biomass. The results are useable in biomass boiler design and in identifying suitable conditions for combustion, including the service parameters of biomass boilers.

Keywords: gravimetry; dry mass; combustible matter; ash; higher heating value

Combustion is one of the possible biomass uses, resulting in the production of heat utilisable for the household heating, heating of industrial and agricultural structures, and as processing heat. The products of combustion are combustion gases, solid combustion products, and heat.

The goal of this paper is to determine the proportions of combustible matter and ash in the dry mass and the higher heating value of several materials produced in agriculture and landscape design that could be used as biofuels utilised in energy production by their direct combustion.

The dry mass of solid fuels consists of ash and combustible matter. The energy content of a fuel is not characterised by the content of combustible matter in that fuel because each fuel has a different higher heating value depending on its chemical composition. The amount of ash produced by combustion of a certain type of fuel can be estimated by means of the known composition of the dry mass of this fuel.

MATERIAL AND METHODS

Fuel samples that were subjected to analysis (wheat screenings, hay, cane, Japanese knotweed, and poppy screenings) belong to a wide group of the agricultural waste biomass and biomass obtained from the landscape maintenance. The other examined sample was wheat not used for feeding purposes.

Measuring of moisture and percentages of combustible matter, and ash. A muffle furnace Nabetherm L9/11/SW (Nabertherm GmbH, Lilienthal, Germany) (Fig. 1) with the heating device

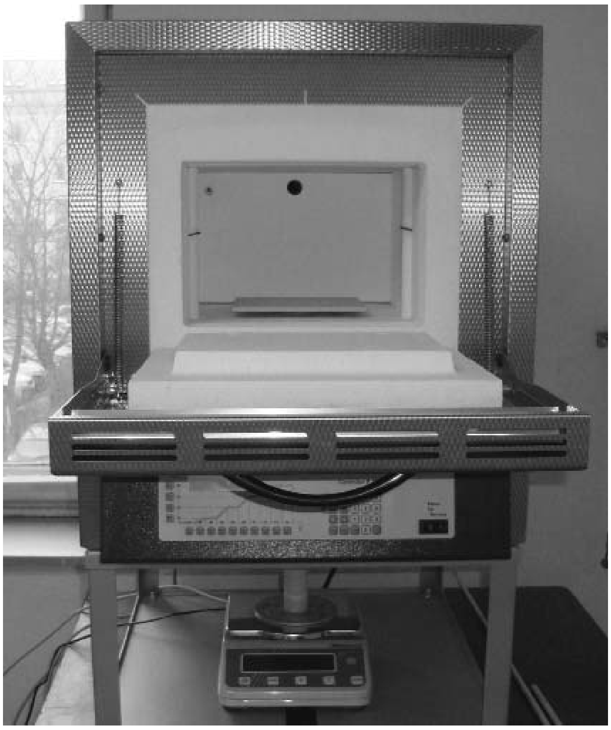

Fig. 1. Muffle furnace Nabetherm L9/11/SW

power of 3.0 kW was used in the measuring of moisture, combustible matter, and ash contents. The muffle furnace was equipped with a Controller P 320 (Nabertherm GmbH, Lilienthal, Germany) control unit and digital scales Kern EW 420-3NM (Kern & Sohn GmBb, Balingen, Germany) with the accuracy of ±0.001 g. The furnace enables the heating of the samples examined up to 1,100°C while recording the weight of the sample.

Moisture is measured in accordance with the standard STN 44 1377 (1978). The sample is heated up to a temperature of 105–110°C and is dried until the difference between the subsequently measured weights (measurements are made in 30 min intervals) is less than 0.1% of the sample weight determined in the previous measurement.

The ash content was determined according to the standard STN ISO 1171 (2003). The samples were annealed at the temperature of 815°C.

The combustible content can be either established from the gravimetric analysis or calculated using the known values of humidity and ash contents.

The sample of the analysed fuel kept in a ceramic bowl was placed in the muffle furnace. The temperatures and time periods of the application (Fig. 2, Table 1) were adjusted on the control unit.

The moisture, ash, and combustible matter contents in the original samples of the examined fuels were determined according to the following equations:

– moisture content:

$$W = \frac{m_1 - m_2}{m_1} \quad (–) \qquad (1)$$

– ash content:

$$A = \frac{m_3}{m_1} \quad (–) \qquad (2)$$

– combustible content:

$$h = \frac{m_2 - m_3}{m_1} \quad (–) \qquad (3)$$

or

$$h = 1 - (A + W) \quad (–) \qquad (4)$$

where:
m_1 – original weight of sample (g)
m_2 – weight of dry mass (g)
m_3 – weight of ash (g)

For better comparability of the fuels, ash and combustible matter contents in the dry mass of the individual fuels were calculated using the gathered results:
– ash content in dry mass:

$$A_s = \frac{m_3}{m_2} \quad (–) \qquad (5)$$

– combustible matter content in dry mass:

$$h_s = \frac{m_4}{m_2} \quad (–) \qquad (6)$$

where:

$$m_4 = m_2 - m_3 \quad (\mathrm{g}) \qquad (7)$$

where:
m_4 – weight of combustible matter (g)

Estimation of higher heating value. The higher heating value is estimated by the combustion of a small fuel sample in the calorimeter in accordance with the standard STN ISO 1928 (2003). The higher

Table 1. Temperatures used in gravimetric measurements

Period	Time of temperature application (min)	Temperature (°C)
1	60	20–107
2	120	107
3	60	107–500
4	60	500
5	60	500–815
6	60	815

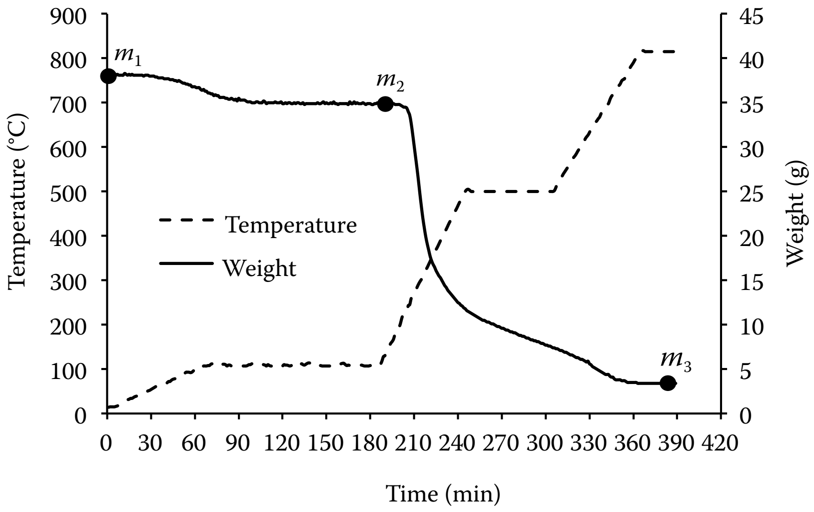

Fig. 2. Gravimetric record showing the used temperatures and periods of their application

m_1 – original weight of sample, m_2 – weight of dry mass, m_3 – weight of ash

heating value was determined on the basis of heating the water into which the pressure tank of the calorimeter with the fuel sample was immersed.

The calorimeter is characterised by its heat capacity, that is, the amount of heat that must be provided in order to increase the temperature of the system (pressure tank, calorimetric bucket, stirrer, thermometer, and water) by 1°C.

An isoperibolic calorimeter IKA C200 (IKA®-Werke GmbH & Co. KG, Staufen, Germany) (Fig. 3) was used to determine the higher heating value. The temperature of water in the casing must be adjusted to the temperature of the room (±0.5°C) before the measurements. After the preparation of the sample weighing 0.8–1.5 g, the temperature is recorded every 60 s until reaching the max. value and then for another five min. of the final stage.

The characteristic course of a temperature change is shown in Fig. 4. The course of temperature before ignition is called the initial stage, the course of temperature during combustion and temperature adjustment is called the main stage, and the course of temperature past max. is called the final stage.

The higher heating value Q_s^a of a sample is calculated from the equation:

$$Q_s^a = \frac{C(D_t - K) - c}{m} \quad \text{(J/g)} \qquad (8)$$

where:

C – heat capacity of the system (J/°C)

D_t – total increase of temperature during the main stage (°C)

K – correction covering heat exchange with surroundings (°C)

c – sum of corrections (J)

m – weight of sample (g)

Correction K is calculated from the equation:

$$K = 0.5\,(d_H + d_K) + (n - 1)\,d_K \qquad (9)$$

where:

d_H – average temperature change/min in the initial stage (°C/min)

d_K – average temperature change/min in the final stage (°C/min)

n – time of the main stage (min)

The sum of corrections is the sum of the types of heat that cause an increase in temperature in the calorimeter besides the heat released by the sample combustion. This includes the heat released by combustion of the iron wire, calorimetric paper or fastening stitch used, as well as the heat released by nitric acid and sulphuric acid generation. For this reason, all supplementary combustible materials must be accurately weighed before the measurements and their weights or weight losses (iron wire does not have to burn completely) is to be multiplied by their combustion heat in the corrections calculation.

RESULTS AND DISCUSSION

Measuring of moisture, percentage of combustible matter, and ash

The weights of the examined samples determined by the gravimetric analysis are presented in Table 2. The processed results of the gravimetric analysis of the samples are presented in Table 3.

The gravimetric analysis has shown that the moisture contents, of the materials examined were relatively low, with the highest one being 9.17%; these

Fig. 3. Calorimeter IKA C200

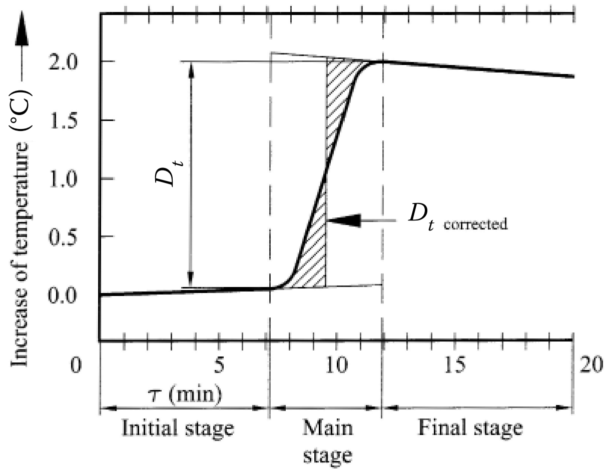

Fig. 4. Course of temperature in the calorimeter
D_t – total increase of temperature during the main stage (°C); τ – time of the initial stage (min)

materials were not modified in any way before the analysis and were stored in regular atmospheric conditions. The results show that poppy screenings had the lowest combustible matter content (87.57%) while wheat grain had the highest one (97.76%).

In comparison with spruce chip pellets with 3.02% ash content (Malaťák, Vaculík 2008), a lower ash content was observed in wheat grain and Japanese knotweed. This topic was dealt with by other authors as well, for instance, Pepich (2009) states that Japanese knotweed contains 4.1% of ash and wheat grain contains 1.6% of ash. The same amount of ash in wheat grain was observed by Maga et al. (2008). These values are comparable to the results obtained in this research. The combustible matter content in all of the examined materials, except for poppy screenings, is comparable to that in beech chip, which contains 95.41% of combustible matter in its dry mass (Kažimírová et al. 2011).

Estimation of higher heating value

The calculation of the higher heating value of the selected types of biomass was based on the observed values, gathered from the combustion of samples in the calorimeter. The calculated results are presented in Table 4.

Higher heating values of the examined fuel samples varied from 14,996 to 17,641 kJ/kg. The lowest higher heating value was observed in poppy screenings and the highest one in Japanese knotweed. Higher heating values of the analysed materials are comparable to those of other types of biomass which are used for energy production; for instance, the higher heating value of poplar is 17,556 kJ/kg (Brestovič 2006).

CONCLUSION

The aim of the performed analyses resided in gathering the values of the selected attributes of several types of agricultural biomass, which can be obtained from the agricultural activity, agricultural produce processing, and pharmaceutical industry. According to the results of this research, the examined types of biomass are comparable in their attributes, to the biomass commonly used for energy production by means of direct combustion. The combustible matter content in the dry mass of the examined types of agri-

Table 2. Weight of samples determined by gravimetric analysis

Weight (g)	Wheat grain	Wheat screenings	Hay	Cane	Japanese knotweed	Poppy screenings
Original sample	28.021	25.444	38.194	30.729	13.050	12.962
Dry mass	26.802	23.111	34.794	28.329	12.150	11.762
Ash	0.600	1.333	3.094	1.329	0.350	1.462

Table 3. Gravimetric analysis of the samples

Parameter	Wheat grain	Wheat screenings	Hay	Cane	Japanese knotweed	Poppy screenings
Moisture ratio in original sample	0.0435	0.0917	0.0890	0.0781	0.0690	0.0898
Ash content in original sample	0.0214	0.0524	0.0810	0.0433	0.0268	0.1128
Combustible matter content in original sample	0.9351	0.8559	0.8300	0.8786	0.9042	0.7946
Weight of combustible matter (g)	26.202	21.778	31.700	27.000	11.800	10.300
Ash content in dry mass	0.0224	0.0577	0.0889	0.0469	0.0288	0.1243
Combustible matter content in dry mass	0.9776	0.9423	0.9111	0.9531	0.9712	0.8757

Table 4. Higher heating values of the samples

Sample	(kJ/kg)
Wheat grain	15,650
Wheat screenings	16,421
Hay	16,720
Cane	17,587
Japanese knotweed	17,641
Poppy screenings	14,996

cultural biomass varied from 87.57 to 97.76%, which also indicates a low amount of ash in the dry mass.

The ash contents in the examined materials approximate to the results obtained by other authors. The differences between the results can be explained by different varieties of the examined plants, different agricultural technologies used, and different macroclimatic conditions in which the plants were grown.

The results of the measurements of higher heating values of the samples vary from 14,996 to 17,641 kJ/kg and suggest that all of the examined types of agricultural biomass can be used in energy production by direct combustion.

The benefit of using agricultural biomass as a solid fuel resides in its energy value and a low amount of incombustible components.

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Corresponding author:

Ing. Viera Kažimírová, Ph.D., Slovak University of Agriculture in Nitra, Faculty of Engineering, Department of Production Engineering, Tr. A. Hlinku 2, 949 76 Nitra, Slovak Republic
phone: + 421 376 414 403, e-mail: viera.kazimirova@uniag.sk