ASSESSMENT OF COMBUSTION PARAMETERS OF BIOMASS MIXTURES

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Abstract. Herbaceous energy crops would be the main basis for solid biofuel production in agricultural ecosystem in future. Reed canary grass is grown in recent years and is recommended for solid biofuel production. Besides that, there is a possibility to utilize for bioenergy production natural biomass of common reeds overgrowing the shorelines of Latvian more than 2000 lakes. Growing of hemp can be a good alternative source for energy producing. Peat can be used as the best additive for manufacturing of solid biofuel, because it improves the density, durability of stalk material briquettes (pellets) and avoids corrosion of boilers. Given that the peat calorific value is greater than the calorific value of straw biomass, the total calorific value of the mixture increases. In the study the experimentally obtained calorific values for different biomass mixtures are given, as well as the method of calculation for higher calorific value of biomass mixtures.

Keywords: calorific value, hemp, reed, reed canary grass.

Introduction

According to Eurostat the renewables covered 18.3 % of the gross inland consumption in the EU 27 countries in 2009. Biomass gave almost two thirds of renewables-based energy (67.7 %). In almost all of the Baltic Sea countries the share of biomass in the gross inland energy consumption is higher than the EU average. The share of biomass as a fuel in Latvia is 29.2 %, which is the highest percentage in the enlarged EU [1]. Latvia has a target in 2020 for renewable energy resources to be 40 % in gross final consumption of energy [2]. Biomass has relatively low costs, less dependence on short-term weather changes and it is a possible alternative source of income for farmers.

The available modern biofuel production and combustion technologies enable effective utilization of practically all type wood and also herbaceous biomass including different types of cereals, hemp, common reeds etc. Also herbaceous biomass, for example, straw has found increasingly wider implementation as a fuel. The main resources for solid biofuel in rural areas of Latvia are wood, residues of cereal crops, peat and emergent vegetation in lakes as common reeds (*Phragmites australis*). By its characteristics as an energy plant, Common Reed can be compared with Reed Canary Grass, which is a field-grown grass. Reed Canary Grass has proven to be both a winter-hardy and a high-yielding energy plant (in spring harvest, 6-8 tons per hectare), which stays productive for 10-12 years. Reed Canary Grass is deemed for the energy plants best suited for Northern European conditions [3].

Growing of hemp, which is a good fibre, oil and biofuel resource, can be a good alternative source for energy producing [4].

Peat can be used as the best additive for manufacturing of solid biofuel, because it improves the density, durability of stalk material briquettes (pellets) and avoids corrosion of boilers. Previous studies showed that the addition of peat in stalk biomass increases the strength and the calorific value of fuel briquettes.

The study aims to find out how the peat content affects the net calorific value, ash content and ash melting point of biomass fuels.

Materials and methods

Using biomass and their mixtures for energy production, it is important to get as much as possible the amount of heat of fuel in the combustion process. In order to compare the different fuels the following parameters are used: fuel moisture content, calorific value of the fuel, ash content, ash melting point. Biomass pellet and briquette combustion parameters are governed by several standards. These standards were investigated, and parameters of biomass mixture were determined in accordance with these standards (Table 1).

Experimentally the burning properties of peat, reed, reed canary grass and hemp stalks were tested. The main burning properties were stated also for the mixtures from the mentioned biomass with

peat in different proportions. Gross and net calorific values were determined according to the standard EN 14918. Measurement uncertainty was ± 3 %.

Table 1

Standards of pellet combustion parameters

ID	Year	Name	Type
LVS EN 15103	2010	Solid biofuels. Determination of bulk density.	**Normative**
LVS EN 14774-2	2010	Solid biofuels. Determination of moisture content. Drying oven method. Part 2: Total moisture.	**Normative**
LVS EN 14775	2010	Solid biofuels. The ash content.	**Normative**
LVS EN 14918	2010	Solid biofuels. Determination of calorific value.	**Normative**
LVS EN 15370-1	2007	Ash melting behaviour oxidizing atmosphere	**Normative**
LVS EN 15150	2012	Solid biofuels. Particle density determination methods.	Informative

Biomass is a hygroscopic material and it contains a certain amount of water. The moisture content during storage varies and depends on the relative humidity. By incineration of fuels the existing water is evaporated using a certain amount of heat, reducing the fuel efficiency. Moisture content in the fuel can be characterized by the absolute moisture content and relative humidity. Assessing the quality of fuels it is more convenient to use the relative humidity expressed as a percentage of the moisture content of the fuel mass.

The relative humidity of fuels can be determined in two ways [5]:

- by calculation to wet-weight basis
- by calculation to dry-weight basis.

Relative humidity calculation to wet mass basis W is calculated by the formula (1):

$$W = \frac{[m - m_d] \cdot 100}{m}, \tag{1}$$

where m – wet sample mass, g;
        m_d – dry sample mass, g.

In this case, the moisture content is located within the limits of 0 to 100 %. The moisture content of biomass fuels is determined according to the standard BS EN 14774-1, by drying the mass in 105 ºC temperature till the weight of the sample does not change. Relative humidity to dry-weight basis $u\%$ was determined by the formula (2):

$$u = \frac{[m - m_d] \cdot 100}{m_d}. \tag{2}$$

In this case, the moisture content may exceed 100 %. For example, if the relative humidity for fuel W is 80 %, the appropriate moisture content to dry-weight basis is $u = 400$ %. In this way the moisture content is often presented to the wood fuels.

Calorific value of fuel is one of the most important parameters that directly characterize the amount of energy produced by the combustion of one unit mass of fuel. Any fuel, including biomass pellets, calorific value can be determined:

- theoretically – by calculating the amount of energy acquired by the chemical composition of biomass,
- experimentally – a certain amount of fuel burning oxygen in the atmosphere and determining the obtained heat.

Any major fuel burning substances are carbon C and hydrogen H. In the combustion process also oxygen O, sulfur S and partially nitrogen N take part. Combustion of various elements impacts the obtained heat in different ways - burning of carbon C, hydrogen H and sulfur S excreted the heat, while burning of nitrogen N and oxygen O reduces the amount of the obtained heat. Ash also reduces

the amount of the obtained heat. As the heats of chemical reactions are known, then the fuel calorific value can be calculated from the well-known Mendeleev's formula [6]:

$$Q_{as} = 0.34 X_C + 1.26 X_H + 0.1 \left(X_S - X_O \right) - 0.02 \left(X_N + X_p \right),$$ (3)

where X_C – carbon content in the fuel, %;
X_H – hydrogen content in the fuel, %;
X_S – sulphur content in the fuel, %;
X_O – oxygen content in the fuel, %;
X_N – nitrogen content in the fuel, %;
X_p – ash content in the fuel, %.

The coefficients at the quantities indicate combustion gain or loss of heat. The calculation of the gross calorific value of fuel is obtained in MJ·kg⁻¹ at constant volume relative to the amount of dry matter. This means that it is assumed that the entire combustion process is totally finished and water is completely evaporated and condensed. Normally, the test sample is a fuel with certain moisture content. The gross calorific value usually is determined by the calorimeter, where during combustion the gas volume remains unchanged (standard LVS EN14918). In that case the fuel calorific value is derived as received at constant volume $Q_{V,\ gr.ar}$. Gross calorific value as received to the dry-weight $Q_{V,gr,dr}$ is calculated by the formula:

$$Q_{V,gr,dr} = Q_{V,gr,ar} \cdot \frac{100}{100 - W},$$ (4)

where W – fuel humidity, %.

The moisture content significantly affects the lower calorific value of the fuel. Regarding biomass fuels it is particularly important because during the storage process the material humidity can increase and, as the result, the calorific value of the fuel can decrease. The reduction of the calorific value depending on the moisture is calculated using the formula 5 (standard LVS EN14918):

$$Q_{V,net,dr} = \left(Q_{V,gr,dr} - 206 \cdot X_{Hd} \right) - 23.0 \cdot W,$$ (5)

where $Q_{V,gr,dr}$ – gross calorific value, kJ·kg⁻¹;
W – moisture content in the sample, %.

The above mentioned calorific values are defined for the combustion process that occurs at constant volume. In practice, when fuels are burned in the furnace, combustion products freely expand and the process happens almost at constant pressure. To get the actual heat output recalculation using the formula given in the standard LVS EN 14918 will be carried out:

$$Q_{p,net,dr} = Q_{V,gr,dr} - 212.2 \cdot X_{Hd} - 0.8 \cdot \left(X_{Od} + X_{Nd} \right),$$ (6)

where $Q_{p,net,dr}$ – net calorific value at the constant pressure calculated to the dry-weight basis, kJ·kg⁻¹;
X_{Hd} – hydrogen content in the dry matter, %;
X_{Od} – oxygen content in the dry matter, %;
X_{Nd} – nitrogen content in the dry matter, %.

The net calorific value at the constant pressure for fuel with the certain humidity is determined by the formula 7:

$$Q_{p,net,ar} = Q_{p,net,dr} \cdot \left(1 - 0.01 \cdot W \right) - 24.43 \cdot W.$$ (7)

The calculated calorific value shows the actual amount of heat obtained in the furnace by incineration 1 kg of fuel with a humidity W.

Increased ash reduces the calorific value of fuel and complicates the operation of the heating system. Biomass fuel ash in most cases is a valuable fertilizer. Ash content is determined according to the standard LVS EN 14775. Ash-melting and sintering temperature is an important quality of boiler operation. Low ash melting temperature leads to ash sintering and troubles the boiler ash disposal

system operation. Ash melting temperature is to be carried out using a number of recommendations for the standards: ASTM D1857, ISO540 and DIN51730. Melting temperature was determined using the standard ash cone shape change by heating the ash with oxygen-enriched environment.

The experimental samples were prepared by mixing the finely chopped biomass together with peat. The samples were held long in a room with constant humidity and the moisture content was appropriate given the equilibrium moisture content of biomass. The combustion characteristics of the samples were tested in the company "Virsma" Ltd. in accordance with the above mentioned standards.

Results and discussion

Experimentally biomass mixtures of reed, red canary grass and hemp with peat were tested. In previous experiments, it was found that 50 % is the recommended maximum amount of peat in the biomass mixtures [7]. Increasing the peat content of over 50 % peat briquettes or pellets with straw biomass additives will be acquired. As it can be seen from Table 2, with increasing the peat content in the mixture the gross calorific value increases.

Table 2

Parameters of the biomass mixtures

Material	Moisture, %	Gross calorific value, $Q_{V,gr,dr}$, MJ·kg^{-1}	Net calorific value, $Q_{V,net,dr}$, MJ·kg^{-1}	Ash,%
Hemp	8.75	18.29	15.54	2.97
Hemp+ peat 15 %	9.08	18.43	15.52	2.60
Hemp+ peat 30 %	10.30	19.03	15.79	2.92
Hemp+ peat 50 %	11.53	19.43	16.25	2.88
Straw	8.40	17.64	16.02	2.10
Reed	9.16	19.00	15.94	2.76
Reed+ peat 15 %	10.33	19.18	15.84	3.20
Reed+ peat 30 %	10.53	19.03	15.68	2.83
Reed+ peat 50 %	14.10	18.95	14.89	2.50
Reed canary grass (RCG)	15.68	19.40	15.12	5.13
RCG + peat 15 %	16.13	18.80	15.16	4.33
RCG + peat 30 %	15.00	19.56	15.39	4.15
RCG + peat 50 %	14.85	19.77	15.60	3.63
Peat	18.4-22.6	20.8	14.32-15.03	2.6

This can be explained by the fact that the peat calorific value is greater than the reed calorific value. The experimentally stated peat gross calorific value is 20.8 MJ·kg^{-1}. This result coincides with the data found in the literature [3]. It should be noted that in different peat fields its composition will be different, so the higher calorific value of peat in a particular case should be determined experimentally.The net calorific value significantly affects the moisture content. The change of the net calorific value at constant pressure was calculated according to formula (7). Experimentally it was found that compared with straw, the reed gross calorific value is about 12 % greater.

The net calorific value of fuel decreases in proportion to the moisture content and, where the biomass humidity is around 40 %, the calorific value is only half of the higher calorific value (Fig. 1). In practice, this means that in order to obtain the required amount of heat twice as much fuel will be burned. The net calorific value is indicated for the samples with the appropriate moisture content.

The highest gross calorific value 20.8 MJ·kg^{-1} (dry weight) was determined to peat, but the smallest 18.29 MJ·kg^{-1} was found of the hemp straw.

Using biomass mixtures of various components it is important to determine the calorific value of the mixture, where the calorific value of each mixture component is known. During the experiments it was found that the calorific value of the mixture depends on higher calorific values for each component and their percentage in the mixture. Total calorific value of the mixture was determined by the linear regression equation, which describes the change of the mixture calorific value depending on

the quantity of the additives in the mixture. The gross calorific value of the mixture is calculated using the formula:

$$Q_{am} = \frac{Q_{a1} \cdot x_1 + Q_{a2} \cdot x_2}{100},$$ (8)

where Q_{a1} and Q_{a2} – gross calorific values of the components, MJ·kg^{-1};
            x_1 and x_2 – percentage of the components in the mixture, %.

The resulting formula is valid when dry matter higher calorific values of the components in a mixture are used (Fig. 2).
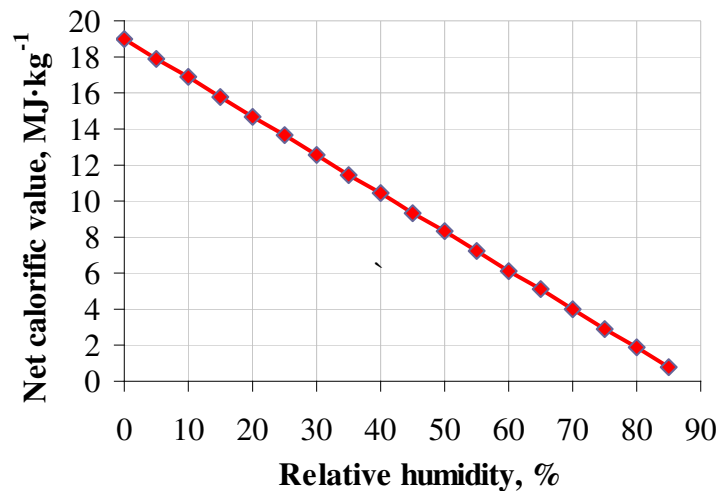

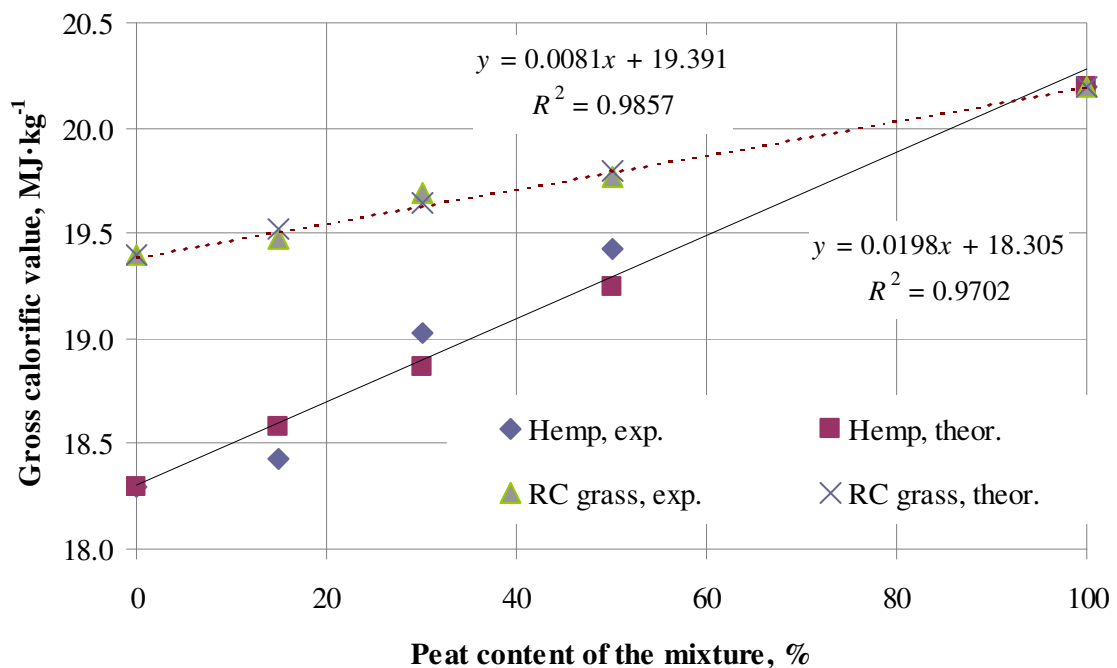Fig. 1. **Change of the net calorific value at constant pressure of reed depending on the biomass humidity**

Fig. 2. **Variation of higher calorific value of biomass mixture, depending on the quantity of components**

Higher calorific value change is directly proportional to the percentage of the two components. The resulting linear regression equation corresponds to the theoretically obtained equation (9). This may be checked transforming the equation (8) in the following way.

First of all, express:

$$x_1 = 100 - x_2 . \tag{9}$$

The value x_1 obtained in equation (9) by inserting in equation (8) and converting:

$$Q_{am} = \frac{Q_{a2} \cdot x_2 + Q_{a1} \cdot (100 - x_2)}{100} = (Q_{a2} - Q_{a1}) \cdot \frac{x_2}{100} + Q_{a1} . \tag{10}$$
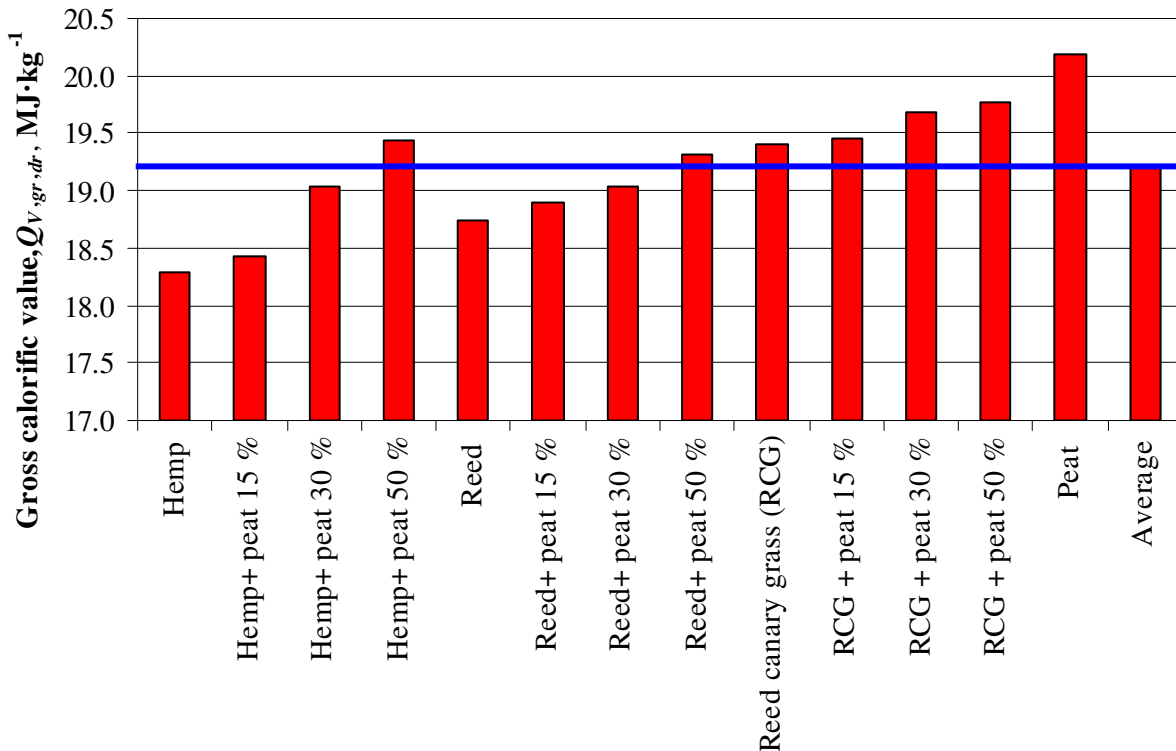

Fig. 3. **Calorific value of biomass mixtures compared
with the average calorific value**

Inserting the hemp and peat calorific values straight line equation coefficients are obtained:

$$Q_{am} = (Q_{a2} - Q_{a1}) \cdot \frac{x_2}{100} + Q_{a1} = (20.2 - 18.29) \cdot \frac{x_2}{100} + 18.29 = 0.019 \cdot x_2 + 18.29 . \tag{11}$$

The resulting linear equation coefficients sufficiently precisely coincide with the regression equation values (see. Fig.2). The error does not exceed 5 %; given that biomass is a non-homogeneous material, such a result is considered to be accurate. This is also confirmed by the values of the determination coefficient R^2 (see. Fig. 2.); $R^2 = 0.97$ (hemp) and $R^2 = 0.99$ (canary grass).

Analyzing all the investigated biomass mixture calorific values we see that the average gross calorific value is 19:21 MJ·kg^{-1} (Fig. 3).

By calculating different biomass calorific values deviations from the obtained mean value, we can conclude that it does not exceed ± 5 %. This means that the effect of the higher calorific values of biomass on the amount of actually obtained heat is not significant. The main condition for good heat transfer from biomass is minimization of the moisture content of the fuel.

Ash content and the melting point of biomass and their mixtures were analyzed in detail in previous studies [8].

Conclusions

1. Reeds are environmentally friendly biofuel sources with average calorific value 18.75 MJ·kg^{-1} that is slightly less than the calorific value of wood, but higher than the average calorific value of straw. Compared with straw, the reed gross calorific value is about 12% greater.

2. Net calorific value of fuel decreases in proportion to the moisture content and, if biomass humidity is around 40%, the calorific value is only half of the higher calorific value.
3. The highest gross calorific value 20.8 MJ·kg^{-1} (dry weight) was determined to peat, but the smallest 18.29 MJ·kg^{-1} was found of the hemp straw.
4. Total calorific value of the mixture was determined experimentally and by the linear regression equation, which describes the change of the mixture calorific value depending on the quantity of the additives in the mixture. The resulting theoretically obtained data points correspond to the experimentally obtained.

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