EVALUATION OF COMBUSTION PROPERTIES OF BIOMASS MIXTURES

Aivars Kakitis, Dainis Ancans, Imants Nulle
Latvia University of Agriculture in Jelgava
aivars.kakitis@llu.lv

Abstract. The main resources for solid biofuel in rural areas of Latvia are wood, residues of cereal crops, reed canary grass, peat, hemp and emergent vegetation in lakes as common reeds (*Phragmites australis* L.). Reeds are environmentally friendly biofuel source with average calorific value 18.75 $MJ \cdot kg^{-1}$ that is slightly less than the calorific value of wood, but higher than the average calorific value of straw. Growing of hemp can be a good alternative source for energy producing. Hemp is a phytosanitary plant that enables its introduction into each crop rotation, practically after any plant. In recent years, expanding Latvian reed canary grass production and in the near future it could be a major set of bioenergy resource. To ensure the environmental safety requirements, one of the most important rules are: any fuel, including reed, hemp and other cereal crop's briquettes and pellets must be with the greatest possible net calorific value. This also means that the moisture content of the product be kept to a minimum. The ash content and the melting and sintering temperature are essential for good furnace operation. Increasing of the chlorine and sulphur content leads to increase the risk of equipment corrosion. The study found that the chlorine content of the reed fuel is less than 0.1 % and sulphur content is exceeding 0.16 %. The use of reed briquettes for heat production is with less risk of boiler corrosion than the use of straw briquettes. Ash melting temperature of the hemp exceeds 1400 ºC but ash melting temperature of the hemp-peat mixture decreases to 1150 ºC. It was stated that increasing peat content in biomass mixtures increases gross calorific value and of briquettes durability.

Keywords: ash melting, calorific value, hemp, reed.

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. Traditionally, biomass has been much used in Finland and Sweden. The share of biomass as a fuel in Latvia is 29.2 %, which is the highest percentage in the enlarged EU [1].

The demand for different biomass materials for biofuel production has increased in recent years, causing shortage of the traditional raw materials sawdust and wood shavings. 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 area of Latvia are wood, residues of cereal crops, peat and emergent vegetation in lakes as common reeds (*Phragmites australis* L.). The Baltic Sea countries play an important role in the development and implementation of biofuel technologies.

Growing of the hemp, which is a good fibre, oil and biofuel resource can be a good alternative source for energy producing. Hemp is a phytosanitary plant that enables its introduction into each crop rotation, practically after any plant. The yield of industrial hemp produces 10-15 tons of dry biomass from a 1 hectare plantation. It is estimated that cultivation of 1 ha of hemp absorbs about 2.5 tons of CO_2, which contributes significantly to the lessening of the greenhouse effect [2]. Hemp with its rich leafage suppresses weeds, and leaves left on the soil after harvesting, improve the soil structure [3]. In 2009 in Latvia about 200 ha are planted with hemp. To successfully develop the industry, the need to sow hemp is at least 1000 ha [4]. The Latvia University of Agriculture provides growing experiments with two varieties: variety Bialobrezskie for fibre production and local hemp Purini for seed, which has been grown in Latvia for 200 years [5].

Ash content depends on the content of potassium and silica in the fuel. It also means that ash residue after burning is higher than that of wood biofuels. In approximate terms, the ash content is as follows:

- wood fuel 0.5-1 % ash;
- cereal grains and straw 3.5-6 % ash.

Ash is more than an issue of convenience for the user. The composition and quantity of combustion residue are the primary factors determining whether or not a feedstock can be burned effectively in a particular appliance.

Alkali metals, in combination with silica and sulphur, are primarily responsible for melting or sintering at relatively low temperatures. This undesirable process is facilitated by the presence of chlorine [6]. Slagging is caused when the ash residue of a fuel "melts" in a boiler during the combustion process. This can reduce the efficiency of operation and if not prevented will cause major operational problems.

To avoid slag formation, fuel must be burnt in a two-stage process:

- biomass should be pyrolised on the grate at low temperature (less than 700 ºC);
- biogas produced from the pyrolysis must be burned in a separate combustion zone (secondary combustion can take place at much higher temperatures).

The separation of combustion zones is achieved by having a large combustion chamber and this allows differential temperature control which prevents slagging. Temperature control is maintained by regulating the flow of air to the primary and secondary combustion zones.

Materials and methods

Experimentally were tested burning properties of reed, reed canary grass and hemp stalks. Main burning properties were stated also of mixtures from mentioned biomass with peat in different proportions. Gross and net calorific values were determined according to standard EN 14918. Measurement uncertainty was ±3 %.

The gross calorific value was measured according to ISO 1928 using the oxygen bomb calorimeter Parr 1341. Lower calorific value was calculated by formula (1) according to [7]:

$$Q_z = Q_a - 2454(W + 9H), \tag{1}$$

where Q_z – lower calorific value, kJ·kg^{-1};
Q_a – gross calorific value, kJ·kg^{-1};
2454 – heat for water evaporation at 20 ºC, kJ·kg^{-1};
W – humidity, %;
H – content of hydrogen, %.

The ash content is characterized by non-flammable fuel minerals. Increased ash content in general lowers the fuel quality. 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-melting and sintering temperature is an important quality of boiler operation. Low ash melting temperature leads to ash sintering and trouble boilers ash disposal system operation. Ash melting temperature to be carried out using a number of recommendations for 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.

Typical ash cone, visible changes in the Figure 1:

- *1* – ash cone in the original form before the start of the heating;
- *DT* – initial point of deformation: the sharp peak is rounding;
- *ST* – softening temperature, the ash cone deforms to such extent that the height of the structure reduces to the size of its diameter ($H = B$);
- *HT* – the point of formation of hemisphere or, the cone collapses and becomes dome-shaped ($H = 0.5B$);
- *FT* – flow temperature, the liquid ash dissipates along the surface.

Experimentally was stated ash melting temperature of the hemp, reed and reed canary grass and mixtures of mentioned biomasses with peatat the company "Virsma" LTD according to ISO 540.

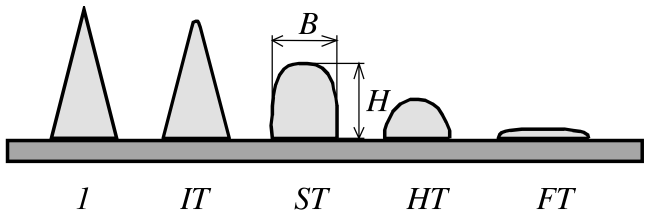


Fig. 1. **Changes in the shape of a standard ash cone by burning**

Results and discussion

Experimentally were tested biomass mixtures of reed, red canary grass and hemp with peat. In previous experiments, it was found that 50 % is the maximum amount of peat in the biomass mixtures. As can be seen from the Table 1, with increasing peat content in the mixture, gross calorific value increases. This can be explained by the fact that the peat calorific value is greater than the reed calorific value.

Table 1

Parameters of the biomass mixtures

Material	**Moisture, %**	**Gross calorific value, MJ·kg^{-1}**	**Net calorific value, 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	15.68	19.40	15.12	5.13
Reed canary grass+ peat 15 %	16.13	18.80	15.16	4.33
Reed canary grass+ peat 30 %	15.00	19.56	15.39	4.15
Reed canary grass+ peat 50 %	14.85	19.77	15.60	3.63

Peat calorific value is 20.8 MJ·kg^{-1} [2]. The net calorific value significantly affects the moisture content and was calculated according formula (1). Compared with straw, reed gross calorific value is about 12 % higher.

Reed ash content in the average is 2.73 %, but the reed-peat mixture of ash content ranges from 2.5 % to 3.2 % (Table 1). A clear correlation with ash content of peat in this case is not identified because the reed and peat samples dispersion properties are essential. Ash content of the reed-peat briquettes greatly exceeds the amount of wood fuel ash, but is significantly lower than the straw fuel ash content. From this point of reed and reed-peat briquettes for heating are preferable to the use of straw briquettes.

Hemp briquettes ash content is greater than the reed ash content and increased addition of peat (Table 1). Gross calorific value is slightly lower calorific value of the reed.

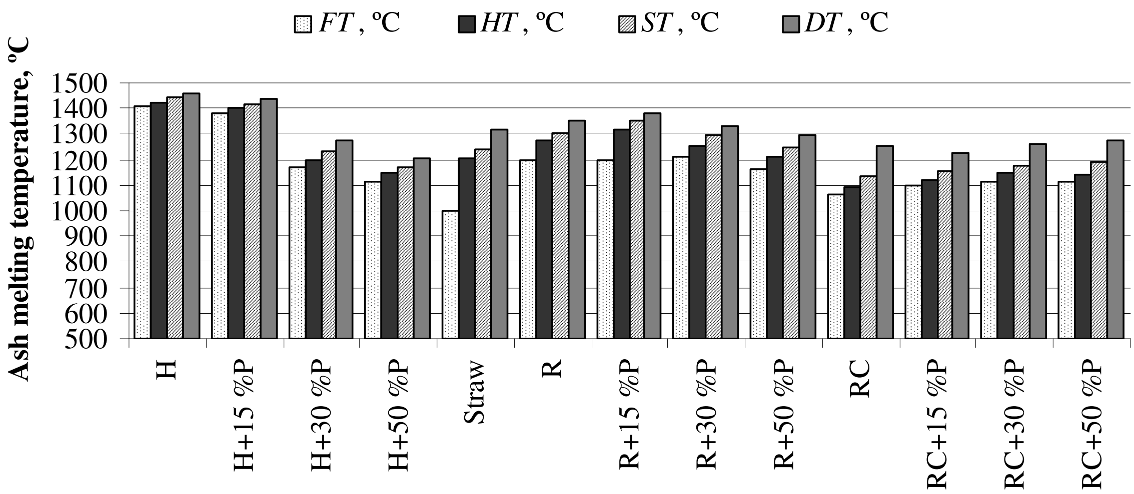
Reed ash cone deformation temperature is 1200 ºC. The same deformation starting temperature of the reed-peat mixture with 15 % peat content was stated (Fig. 1). It is approximately the same as the starting ash deformation temperature of wood chips. Increasing peat content of mixture till 30 %, ash cone deformation temperature increases and reaches 1220 ºC, this practically coincides with the wood ash melting point temperature. Increasing peat content to 50 %, ash cone deformation temperature decreases to 1170 ºC. Flow point temperature of the ashes in all cases is above 1300 ºC, which is more than wood ash flow temperature. We can conclude that the ash melting temperature of reed or reed-peat mixture is sufficient to ensure the normal operation of the burner.

Hemp ash cone deformation temperature exceeds 1400 ºC. Increasing peat content of mixture 30 %, ash cone deformation temperature decreases to the 1150 ºC (Fig. 1). The ash melting temperature of hemp or hemp-peat mixture is sufficient to ensure the normal operation of the burner.

Reed canary grass ash melting point *DT* is 1062 ºC and slightly increased with increasing amount of peat in the mixture.

Increased production of chlorine and sulphur content in flue gases creates corrosion of the chimney and other metal structures.

From the results obtained we can conclude that the chlorine content of the reed and reed-peat mixtures does not exceed 0.12 % (Fig. 2). Sulphur content of reeds is 0.11 %, which is similar to other studies, the authors obtained values [6]. Increasing the share of peat in the mixture, the sulphur content increases, and reaches 0.16 %, at the peat content is 50 %. The sulfur content of the hemp is 0.13 %; it is the same than the reed canary grass. Chlorine content of the hemp is 0.16 %, which is less to the chlorine content of the reed canary grass. Increasing the share of peat in the hemp-peat mixture, the sulfur content decreases, and reaches 0.11 %, at the peat content is 50 %. At the same time chlorine content of hemp and peat mixture increases and reaches 0.27 %, the proportion of peat is 50 %. It is not recommended because of increased chlorine compared with a sulfur content significantly increases the risk of corrosion of boilers. It should be noted that biomass is inhomogeneous materials and the dispersion parameter is significant. This means that further experiments to clarify chlorine and sulphur hemp peat mixture. Certainly it can be argued that the use of pure hemp for fuel production is recommended.



Explanation of Legends

Sample	Material mixture	Sample	Material mixture
H	Hemp	R+30 %P	Reed+ peat 30 %
H+15 %P	Hemp+ peat 15 %	R+50 %P	Reed+ peat 50 %
H+30 %P	Hemp+ peat 30 %	RC	Reed canary grass
H+50 %P	Hemp+ peat 50 %	RC+15 %P	Reed canary grass+peat 15 %
Straw	Straw	RC+30 %P	Reed canary grass+peat 30 %
R	Reed	RC+50 %P	Reed canary grass+peat 50 %
R+15 %P	Reed+ peat 15 %		

Fig. 1. **Ash melting temperature of the solid biofuel**

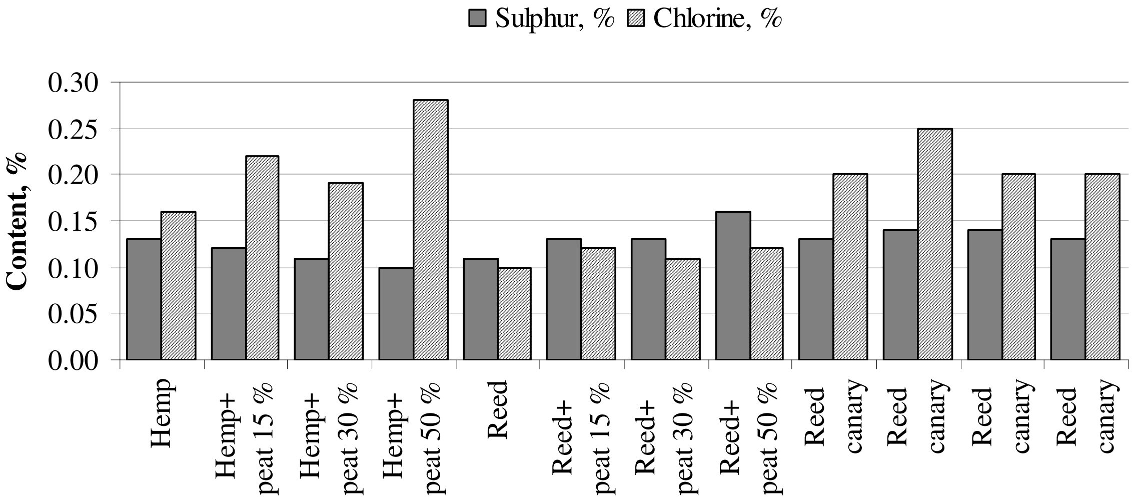


Fig. 2. **Sulphur and chlorine content of fuel reed and reed peat mixture**

Conclusion

1. Reeds are environmentally friendly biofuel source with average calorific value is 18.75 $MJ \cdot kg^{-1}$ that is slightly less than the calorific value of wood, but higher than the average calorific value of straw.
2. The ash content of reed briquettes is 2.7 %. This is at least two times more than for wood fuel, but much less than for cereal straw fuel.
3. Ash-melting temperature of reed fuel is close to the wood ash melting point and significantly higher than the straw ash melting temperature.
4. Chlorine content of the reed fuel is less than 0.11 % and sulfur content is exceeding 0.16 %. The use of reed briquettes for heat production is with less risk of boiler corrosion than the use of straw briquettes.
5. Ash melting temperature of the hemp exceeds 1400 ºC but ash melting temperature of the hemp-peat mixture decreases to 1150 ºC.
6. Ash melting temperature of reed canary grass is 1062 ºC (point DT) and slightly increases by adding peat in the mixture.

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