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Relation of energy content variations of straw to the fraction size, humidity, composition and environmental impact

S. Kalinauskaitė[1,*], A. Sakalauskas[1], E. Šarauskis[1], A. Jasinskas[1] and M. Ahlhaus[2]

[1]Aleksandras Stulginskis University, Studentų g. 11, Akademija, Kauno r. LT-53361, Lithuania; [*]Correspondence: solveiga.kalinauskaite@gmail.com
[2]Fachhochschule Stralsund, Institut für Regenerative Energie Systeme (IRES), Zur Schwedenschanze 15, 18435 Stralsund, Germany

Abstract. Biomass is the major source of renewable energy, the use of which is very important in energy, environment and economical aspects. Biomass enables the replacement of fossil fuels, the importance of biomass usage is related to global warming questions. Biomass moisture content is one of the main factors affecting straw preparation for the usage cost.
In this research the main focus is on straw and different biomass composition and how it influences the solid biofuels preparation for usage, paying attention to straw fraction, humidity, composition and finally how it influences the energy and environmental aspects. Tested samples consist of different composition- raw straw, 100% yellow straw pellets, 100% grey straw pellets, 98% straw pellets with 2% additives, 50% straw and 50% hay pellets, 49% straw and 49% hay pellets with 2% additives, 100% hay pellets, 98% hay pellets with 2% additives and additionally two samples of straw briquettes with different chop size – (20 mm) and (30 mm and 10 mm). This research pays attention to the main material characteristics – moisture value, ash content, HHV (higher heating value), pyrolysis coke. Research results will help to find the best biomass pellet and briquette composition for solid biofuel usage. During the research it was found that the lowest moisture value was 98% hay pellets with 2% CaO additive – 5.79%. Highest amount of ash value was found in 50% straw and 50% hay composition pellets – 0.021 g. Highest amount of HHV were tested pellets which consisted of 98% hay with 2% CaO additives. Highest amount of pyrolysis coke in organic and dry matter were in 100% yellow straw tested samples.
Achieved results will help to estimate material fraction, humidity and composition on biomass preparation for conversion steps, following biomass usage energy and environment requirements. These research results will help to realise further tasks of agricultural biomass usage in practice.

Key words: biomass, straw, ash, energy, environment, fraction, humidity, composition.

INTRODUCTION

The role of biomass as a main source of food is primordial, but it is more and more regarded as a potential energy source, for the following reasons: a) thermodynamic high value of available energy; b) maintaining the natural circuit of CO_2; c) biosphere protection to pollution, virtually having a depolluting role (Matache & et al., 2007).

Generally, an alternative/classic solid fuel, including biomass is composed out of: organic mass, inanimate matter, water / humidity (Wt). Total humidity (W_t), is the sum of:

- impregnation humidity – W_i^i, free or superficial (surface) from large capillaries, which has normal vapour pressure and is dissipated relatively easy through simple outside storage;
- hygroscopic humidity – W_i^i i, represents the physically linked water to the internal pore structure, has smaller vapour pressure smaller than normal pressure and is lost only through drying process at temperatures of over 100 °C (up to 105 °C) (Vladut & et al., 2010).

The use of biomass for energy purposes means a series of advantages over fossil fuels: a) neutral balance of emitted carbon dioxide during combustion, since the CO_2 of the living biomass forms part of a flow of continuous circulation between atmosphere and vegetation; b) the combustion of residual biomass does not emit either sulphur or nitrogenous pollutants, or hardly any solid particles, thus being much more respectful to the environment; c) the exploitation of residual biomass means to change a residue into an energy resource; d) the use of energy crops for biomass production, replacing other surplus crops, means an important social and economic improvement of the rural sector; e) decrease of external dependence on fuel supply; f) technological innovation processes will lead to optimisation of the energy yield of biomass. (Mateos & et al., 2007). The quantity of straw biomass, which can be removed without significantly affecting the carbon cycle, varies from 20% to 50% of the quantity of the available crop residue (Smits & Kronbergs, 2012).

Because of its high moisture content, irregular shape and size, and low bulk density, biomass is very difficult to handle, transport, store, and use in its original form (García-Maraver & et al., 2010). Straw used for fuel purposes usually contains between 14 and 20% water, which vaporises during burning. Straw has a calorific value of between approximately 13.5 and 14.8 MJ kg^{-1} on a lower heating value basis. The calorific value of straw is about the same as well-seasoned wood, approximately half the value of coal or one third that of oil. Straw can be used to produce heat, power, or heat and power. Electrical efficiencies of around 30% can be expected from burning straw, while thermal efficiencies can be up to 70 or 80%. As a fuel, straw can be considered to be CO_2 neutral, as the carbon dioxide absorbed from the atmosphere during growth is approximately equal to that released during combustion (Smyth, 2007).

Biomass processing and use typically requires a degree of particle size reduction. Size reduction performance depends on the combined effect of failure stresses applied to material, material condition such as moisture, and on the equipment operating parameters such as classifying screen size, rotary speed (rpm), and mass throughput (Womac & et al., 2007). Fine sized straws (5–2 mm) improve the combustion behaviour. However, large sizes (10–5 mm) of biomass do not adversely affect the combustion performance. The moisture content of the raw material before entering the compression press must be 12–17% (Kargbo & et al., 2010). Biomass particle size impacts handling, storage, conversion, and dust control systems. Size-related parameters, namely, geometric mean diameter, Rosin–Rammler size parameter, median diameter, and effective size had strong correlation among themselves and good negative correlation with hammer mill speed (Bitra & et al., 2009). Particle size and shape are of great importance for densification. It is generally agreed that biomass material of 6–8 mm size with 10–20% powdery component (< 4 mesh) gives the best results. The percentage of moisture in the feed biomass to extruder machine is a very critical factor. In general, it has been found that when the feed moisture content is 8–10%, the briquettes will have 6–8% moisture. But when the moisture content is more than 10%, the briquettes are poor and weak and the briquetting operation is erratic. Therefore, it is necessary to maintain an optimum moisture content (Stelte & et al., 2012).

The optimum final moisture content of densified biomass is very important and greatly depend on process conditions like initial moisture content, temperature, and pressure. In general, the caloric value of pellets and briquettes depends on process conditions like temperature, particle size, and feed pre-treatment (Tumuluru & et al., 2011). The results showed that moisture content plays a predominant role in biomass densification process. Densities of biomass compacts decreased with increasing moisture content. Samples with 12% moisture content results in lower densities, while 15% moisture produced the lowest densities with more cracks observed on the surface. Combination of low moisture (9%) and high pressure resulted in higher durability (Tumuluru & et al., 2011). Briquettes with moisture content lower than 10% or higher than 18% are not suitable for subsequent combustion process. If material moisture content is very low or very high (it means out of the interval 10%–18%), the elements are not consistent and the briquette is falling to pieces. When the material moisture content is very high, the vaporisation of surplus water tears the briquette to pieces. Therefore material moisture content should be reduced before briquetting by the drying process. Lower moisture content improves briquette quality (Kers & et al., 2010). Different kinds of biomasses are being used to maximise the energy output during the combustion process. To maximise the energy output many different criteria must be utilised. These criteria for the pellets include but are not limited to moisture content, density, and energy content of the biomass. Moisture content of the biomass pellets must fall somewhere between 10–15%. Other criteria also affect the combustion process in turn affecting the energy output. The main criterion among many is ash content. Ash content refers to the amount of unburned material at the end of combustion. To create an optimal pellet this content must be as low as possible (Eggerstedt & et al., 2011). Fuel moisture is a limiting factor in biomass combustion due to its effect on heating value (Jenkins & et al., 1998). Biomass generally has a lower heating value than coal due to its higher moisture, oxygen and volatile matter content (Musialik-Piotrowska & et al., 2010).

Straw humidity suitable for fuel usage should not be more than 18–25%. Reduced chaff of straw is not only necessary but also beneficial. Reducing the straw chaff during harvest to 5–20 mm length has a greater influence on storage or bale production, for it reduces storage costs and increases conversion and straw combustion efficiency. However, 5–10 mm length straw chaff adversely affects the combustion process. Energetically, the production of briquettes and pellets is quite difficult because it requires a higher level of disintegration of input material while reducing its moisture content (Gürdil & et al., 2010).

Wheat straw is mainly made up of cellulose, hemicelluloses and lignin. Due to the high content of chlorine (0.1–0.6%) and potassium (0.7–0.8%), combustion of wheat straw leads to a greater risk of sintering and corrosion compared to wood fuels (Olsson, 2006). Most biomass materials have significant inorganic matter contents, which dominate nature of biomass ash components and other inorganic constituents (Sultana & Kumar, 2012). The effect of adding chemical binders on briquetting was studied using switch grass grind mixed with 2% (wt.) lime powder, 5% (wt.) lime powder, 2% (wt.) lime paste, 2% lime powder plus sprinkled water. For switch grass grind with a nominal moisture content of 10% (w.b.), and inclusion of either 2% (wt.) lime powder or 2% (wt.) sodium bentonite powder did not significantly increase switch grass briquette durability compared to that of the control ($p > 0.05$). Addition of 5% (wt.) lime significantly increased the durability of the briquettes from 67.3% to 76.2% ($p < 0.05$). Adding lime to the feedstock may be beneficial because lime could control the sulfur dioxide produced during combustion or gasification of the biomass briquettes (Kaliyan & Morey, 2009). Biomass combustion appliance manufacturers often recommend the addition of lime (CaO) to reduce clinker formation and slagging. Limestone creates a chemical compound such as $CaSO_4$ which has a higher melting temperature, thus these species stay in the bottom ash. The authors felt this additive would be most valuable in larger combustion systems where the increased ash content of the fuel would have minimal negative impacts on combustion efficiency. The limestone also has the added benefit of reducing HCl formation (Kallio, 2011). High moisture content decreases the heating value of fuel, which in turn reduces the conversion efficiency as a large amount of energy would be used for the initial drying step during the conversion processes. The particle size distribution affects the flowability, heating, diffusion and rate of reaction (Zhang, 2012).

The higher moisture content was observed to delay the start and end of volatiles combustion slightly but overall burning times exhibited greater scatter (apparently due to an intrinsically greater variation in particle-to-particle behaviour) and could not be concluded to have changed significantly. The dry mass (size) of the particle was therefore found to be much more important in determining overall burning times than likely variations in moisture content for this type of biomass (Flower & Gibbins, 2009). Moisture contents of 10–20% are the precondition for storability of the grass and as well advantageous with respect to the heating value. Biofuel characteristics of herbaceous biomass require various specific adaptations of the different combustion technologies, as for sulphur oxide emission reduction: sulphur fixation in the ash, addition of limestone or dolomite, efficient technology for dust precipitation (Prochnow & et al., 2009).

Literature overview shows that there is still a need for a more detailed solid biofuel analysis to estimate material fraction, humidity and composition on biomass preparation for conversion steps, following biomass usage energy and environment requirements, and best possible usage in the practice.

MATERIALS AND METHODS

Research was done at Fachhochschule Stralsund laboratory. Tested samples consisted of different compositions– raw straw, 100% yellow straw pellets, 100% grey straw pellets, 98% straw pellets with 2% CaO additives, 50% straw and 50% hay pellets, 49% straw and 49% hay pellets with 2% CaO additives, 100% hay pellets, 98% hay pellets with 2% CaO additives and additionally two samples of straw briquettes with different chop size – (20 mm) and (30 mm and 10 mm). Straw and hay were harvested in the north and west parts of Lithuania.

Moisture content was determined in laboratory under oven– drying method. All samples were weighed with digital balance (KERN 470). Samples were placed in the dish and weighed. Prepared samples were left in the oven (WS 51) at 100 °C temperature till constant weight. The dish with dried samples was left in the desiccator at the room temperature and later weighed. Moisture continent was calculated:

$$MC = \frac{WW - DW}{WW} \cdot 100$$

where MC – the moisture content (%); WW – the wet weight of the sample and dish (g); DW – the dry weight of the sample and dish (g).

Model C 4000 Adiabatic Calorimeter was used to determine the tested samples calorific value. Material was grinded with el. mill Fritsch (max power 1,800 W), used 0.5 mm diameter sieve. 0.7 g of each tested sample was weighed in 0.1 g accuracy. 5–10 ml distillated water was filled into the container. The inhibit wire and the tied up cotton thread has been fastened. Prepared bomb was filled oxygen. The primary temperature transducer, placed inside the unit, recorded the change in the system temperature due to the combustion of the fuel in the bomb. Calorific value is defined as the amount of energy released by a mass unit of combustible mass.

Using Thermogravimetric analysis (TGA 51) received tested samples mass lost curves permitted to determinate samples humidity content, volatile components and the ash content in the firm arrears coke.

Tested samples moisture value, ash continent, HHV (higher heating value), pyrolysis coke data represented in this article will help to find the best pellet and briquette composition for solid biofuel usage.

RESULTS AND DISCUSSION

Moisture is one of the major factors which influence biomass as renewable energy conversation, usage, combustion energy and environmental subjects.

Highest moisture level was determinate at the raw straw sample, the average was even 14.59% (Fig. 1). During the pellets or briquettes production, straw moisture level usually goes down in comparison to raw straw moisture. Received results have showed that high moisture level was in straw briquettes samples too. Major differences have been found in pellets which composition consist of yellow and grey straw, received data average varies from 7.16% to even 9.69%. Rather small moisture continent was found in straw pellets samples with 2% CaO additive –7.31%. Lowest moisture value of all tested examples was identified at 98% hay pellets with 2% CaO additive – 5.79%. High moisture value was found in straw and hay composition pellets, incl. 2% CaO additive – respectively10.40% and 9.48%.

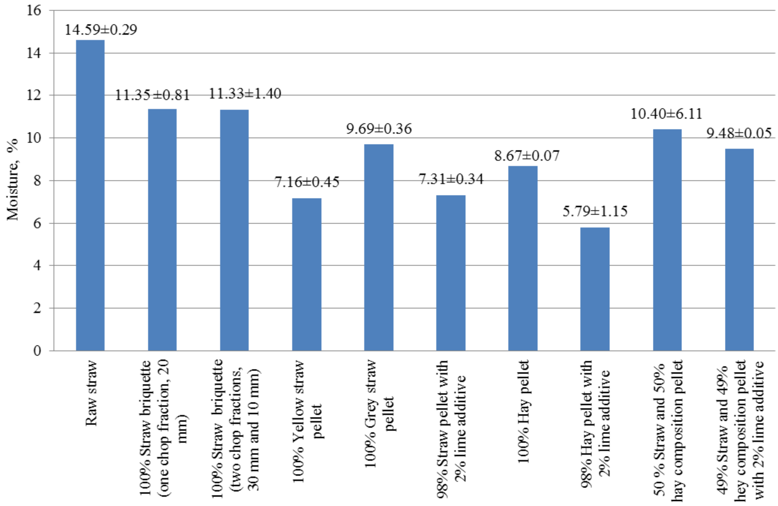

Figure 1. Moisture content in tested samples.

Ash content of tested samples is represented in (Fig. 2). Biomass usage for renewable energy purpose's limiting factor is usually a big amount of ash. High ash content of straw can lead to problems in the combustion unit. In a thermo-chemical conversion process, the chemical composition of ash can present significant operational problems. According to received results the highest amount of ash value was found in the samples of pellets which composition was 50% of straw and 50% of hay – even 0.021 g. High ash value was found and in 100% grey straw samples – 0.019 g and pellets which consist of 98% straw and 2% CaO additives – 0.016 g. Lowest amount of ash was determined in straw briquettes sample – 0.006 g. Respectively 100% hay pellets and 49% straw and 49% hay pellets with 2% CaO – 0.01 g and 0.012 g. Yellow straw pellets ash value – 0.14 g.

The HHV is the total energy content released when the fuel is burnt in air, including the latent heat contained in the water vapour and therefore represents the maximum amount of energy potentially recoverable from a given biomass source.

Higher ash percentage is one of the reasons, which influences the heating values. Low ash content is also crucial to the combustion process.

Higher heating value (HHV) refer to ash content (Fig. 3). Higher ash percentage is one of the reasons, which influences the heating values. Low ash content is also crucial to the combustion process. Lowest amount of ash was determinate in 100% straw briquettes samples. HHV highest amount was found in tested 98% hay pellets with 2% CaO additives samples, biggest difference between ash and HHV value data showed 100% briquette samples.

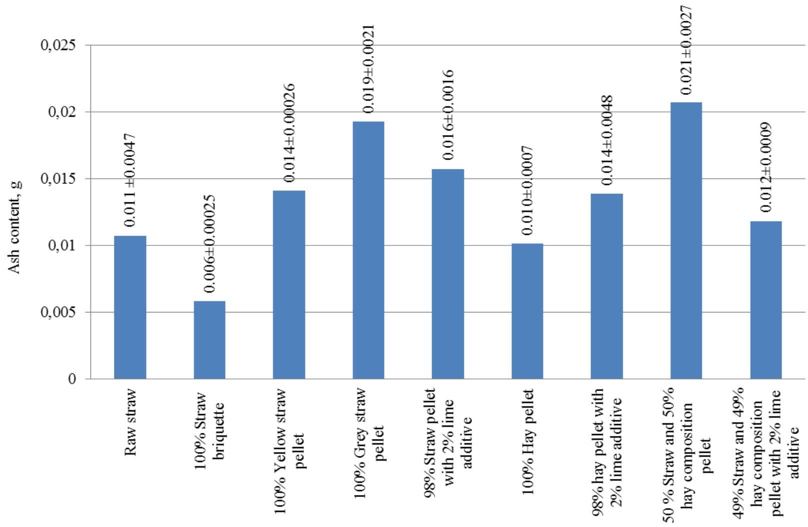

Figure 2. Ash content in tested samples.

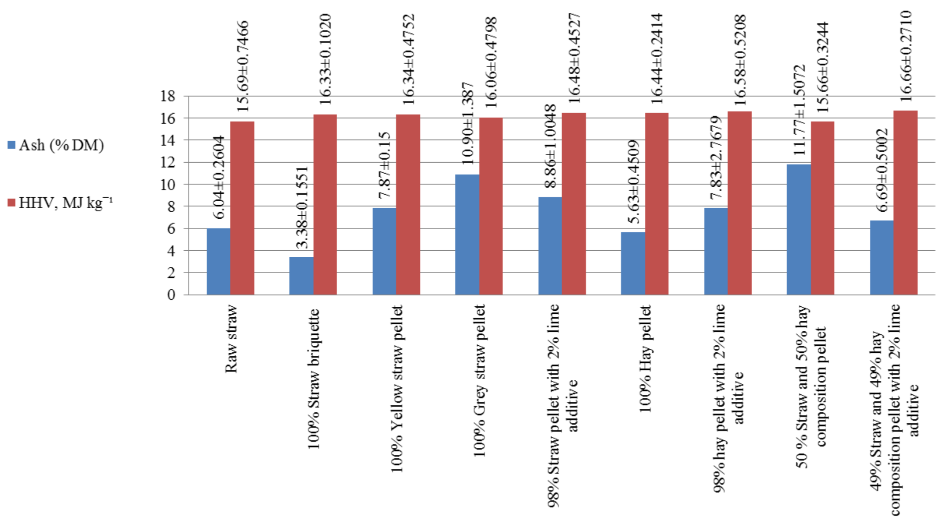

Figure 3. Ash amount and HHV in tested samples.

(Fig. 4) represents tested samples HHV values variation to HHV water free figures. Lowest amount of HHV refer to HHV water free was received at tested raw straw examples, also low amount found in straw pellets which composition consist of 50% straw and 50 hay%. Highest amount of HHV refer to HHV water free was found in tested 100% straw briquettes samples, also 50% straw and 50% hay pellets and 49% straw, 49% of hay with 2% CaO additives composition pellets, have showed strong reliance too.

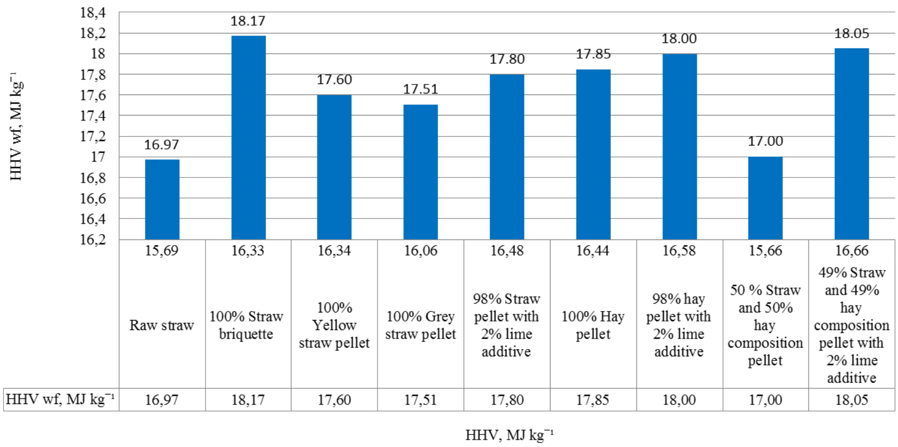

Figure 4. HHV values variation to HHV water free in tested samples.

Under data (Fig. 5) it is possible to estimate HHV without water and ash values under HHV values changes. Lowest amount of HHV refer to HHV water and ash free was found in tested raw straw samples, 100% straw briquettes and 100% hay pellets examples. Highest value was determined in 100% grey straw pellets and pellets which composition was 98% straw with 2% CaO and 98% hay and 2% of CaO with additives.

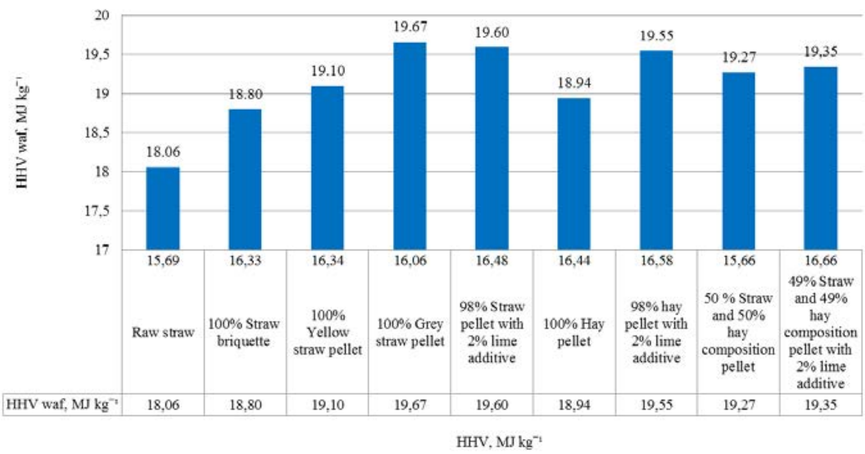

Figure 5. HHV values variation to HHV water and ash free figures in tested samples.

Coke is a friendly material where there is no ash, for this reason from the environmental point of view it is important to investigate biomass pyrolysis coke amount in biomass. (Fig. 6) represented figures of determinate organic and dray matter pyrolysis coke amounts. Highest amount of pyrolysis coke in organic and dry matter was found in 100% yellow straw pellets. Biggest difference between organic and dry matter pyrolysis coke was determined in 50% straw and 50% hay pellets samples. Lowest differences showed 100% straw briquettes samples.

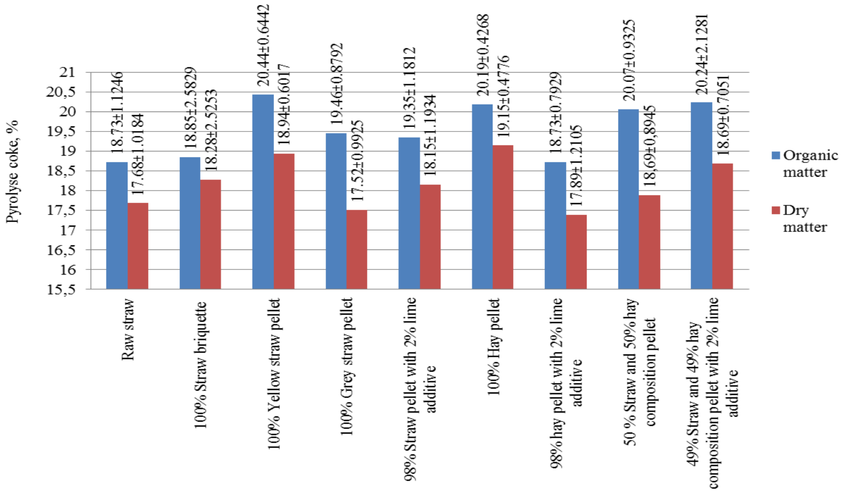

Figure 6. Organic and dry matter pyrolysis coke variation of tested samples.

CONCLUSIONS

1. Major moisture differences were determined in pellets produced from 100% yellow and grey straw, received data average varies from 7.16% to even 9.69%. Lowest moisture value of all tested samples was identified in 98% hay pellets with 2% CaO additive – only 5.79%.

2. Highest amount of ash value was found in pellets whose composition was 50% straw and 50% hay – 0.021 g. Lowest amount of ash was determined in straw briquettes sample – 0.006 g.

3. Lowest ash amount was found in 100% straw briquettes samples. Highest amount of HHV was found in tested pellets which consist of 98% hay with 2% CaO additives samples.

4. Lowest amount of HHV refer to HHV water free was found in tested raw straw, 100% straw briquettes and 100% hay pellets examples. Highest amount was found in 100% grey straw pellets samples.

5. Highest amount of pyrolysis coke in organic and dry matter has been found in 100% yellow straw tested samples.

6. Among tested straw pellets material, which composition consist of yellow, grey straw and 98% straw with 2% CaO additive, best solid biofuel parameters were definite in yellow straw samples.

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