USE OF MIXED BIOFUEL FOR PELLET PRODUCTION

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Abstract. One of the most important types of renewable energy in the Baltic region is biofuel (plant-derived fossil fuel) which has been valued because of the availability, stable prices and reliability of biomass – plant-derived material from which biofuel is made. In general, combustion of biofuels is more efficient and less harmful to the environment than traditional fuels, such as wood shavings or coal. Wood is one of the most popular types of biomass; and the Baltic countries have a big potential to exploit this source of biofuel since the region has an abundant resource of forests. This article discusses one of the newest types of biofuel – pellets. Pellets are small cylindrical shaped pieces made of wood, wood waste, sunflower husks, straw or similar. They are mostly homogeneous - made from one-material. As part of the research at the Aleksandras Stulginskis University, using combinations of biomass for fuel can be even more efficient than homogenous biofuel. Tests were made with sawdust and peat pellets, sawdust, sawdust and straw, peat, and wood dust pellets. Physical-mechanical and chemical properties of these pellets were tested, the results are intended to provide a background for the planning and production of new technology for new lines, composition of pellets and thus open a window to a new era of wider and much more efficient use of different materials for biofuel.

Keywords: biomass, biofuel, pellet, mixed biofuel pellet (MBP).

Introduction

Lithuania has very limited local fossil fuel resources. Most of fossil fuel, mainly oil and coal and to some extent natural gas, is imported from Russia, Kazakhstan, Ukraine and Poland. Over the last decade Lithuania started to actively support the use of renewable energy. In 1992 with the National Energy Efficiency Programme the Government of the Republic of Lithuania approved the priority directions for the energy sector development. The use of local and renewable energy resources are the two main goals set in the programme. Similarly, renewable energy resource development is one of the main short-term objectives of Lithuanian National Energy Strategy. These goals coincide with the European Union recommendation to include up to 12 % of local energy in the total country energy balance. Lithuania supports the Madrid Declaration of 1994, which, in order to reduce environmental pollution and its harmful effects on the environment, recommends the EU countries to increase the local and renewable energy sources to 15 % of the total balance [1-3].

Amongst all possible renewable energy sources, such as biogas or wind, Lithuania has a vast and still not completely exploited domestic energy resource of biomass, mostly from forest wastes. The amount of biomass per capita in Lithuania at the moment is the second highest in the European Union and it is estimated that in 2020 Lithuania will be the first in the EU according to the quantity of available biomass for biofuel production. The projected production of biofuels by 2020 in tons per capita are as follows: Lithuania – 0.25; Latvia – 0.23; Denmark – 0.22; France – 0.19; Estonia – 0.18; Hungary – 0.17; Czech Republic – 0.16; Spain – 0.14; Poland – 0.13; Sweden – 0.12; Ireland – 0.12; Greece – 0.09; Austria – 0.09; Germany – 0.08; Bulgaria – 0.08; Romania – 0.07; Italy – 0.06; Slovakia – 0.06; Slovenia – 0.05; United Kingdom – 0.05; Belgium – 0.04; Portugal – 0.04; Netherlands – 0.03; Finland – 0.2; Luxembourg – 0; the Cyprus – 0; Malta – 0 [4].

According to the Lithuanian National Forest Service data, the total forest land in Lithuania is over 2 million ha or 33.3 % of the country territory. In the period of 2003-2012 the land of forest and the percentage of forest resources per capita increased. The country forest coverage has increased from 31.3 % to 33.3 %, forest land increased from 128 thousand ha to 2173 thousand ha. During the same period the forest stands expanded by 104,000 ha to 2,055,000 ha, the forest area per capita increased from 0.59 to 0.68 ha, the total growing stock volume increased from 453.4 million m^3 to 501.3 million m^3, and the average growing stock volume – from 226 $m^3 \cdot ha^{-1}$ to 240 $m^3 \cdot ha^{-1}$. The growing stock volume per capita increased from 131 m^3 up to 157 m^3. [5]. These key forest resource indexes have been rising for several years and therefore having a positive impact on the overall socio - economic situation in the forest sector in Lithuania. Nevertheless, Lithuania has been planning to expand forest stand areas by planting short rotation stands. This intensive forestry can be developed in areas that are relatively limited, but very favourable for forest cultivation. This would be an efficient way of increasing the wood supplies in the country [6-8].

From all available types of renewable energy in Lithuania and in the Baltic region, wood has the biggest lower heating value (LHV). To compare with other biomasses, birch has 18.30 MJ·kg^{-1}, willow – 17.6 MJ·kg^{-1}. Straw, on the other hand, has the lowest LHV - 16.5 MJ·kg^{-1}. The LHV of tall perennial grasses (reed canary grass, Arctic brome) and their mixtures with legume grasses is from 17.5 to 18.17 MJ·kg^{-1}. All of the natural resources with a calorific value similar to wood can be used for fuel [9].

In terms of the specially grown energy crops (wheat, rye, barley, oats, willow, poplar, the fast-growing aspen, and various perennial grasses), the highest energy value can be obtained from poplar (from155 to 167 GJ·ha^{-1}). Perennial grasses can produce from 154 to 158 GJ·ha^{-1}. Rye can produce from 137 to 140 GJ·ha^{-1}, but if only the straw of rye is evaluated, without the other parts, its energy value is only 90 GJ·ha^{-1} [10; 11].

What regards the chemical composition of wood fuels, any type of wood fuel consists of: up to 0.5 % of minerals (calcium, magnesium, phosphorus); combustible materials (carbon (50-52 %), hydrogen (6-6.5 %), sulphur (about 0.2 %), oxygen (40-44 %), nitrogen (about 0.2 %)); and water (the quantity varies from 20 % to 60 %) [12].

Wood pellets are the most popular type of the new wood fuel, because they are a clean, natural and completely environmentally friendly form of biofuel. Pellets are made from wood sawdust, sunflower husks, various straws, or wood chips, which are milled, dried and pressed into 6 mm diameter small cylindrical shaped pieces. During pellet combustion almost no volatile or harmful substances are released to the environment. The kilowatt-hour of the heat energy produced from wood pellets costs about 0.11 LTL. It is just a little more than the price of firewood. It is important to note that wood pellets are at least 2 times more calorific than firewood; therefore, using wood pellets for fuel is more useful, more efficient, and more cost-effective. It is estimated that the cost of wood pellet energy is 0.08 LTL·kWh^{-1}, while the heat energy of natural gas costs 0.14 LTL·kWh^{-1}, and the kilowatt-hour of electricity costs 0.35 LTL. These figures indicate that wood fuel pellets are not only greener, but also more financially efficient [7].

The main wood pellet parameters, regulated by different European country operating standards are as follows: **The size.** It has a direct impact on the transportation costs and the selection of fuel burning equipment. Equal-sized pellets enable better combustion control, i.e., the fuel burns more efficiently. In Austria, for example, the grain size parameters vary between Ø4-20, with the maximum length of 100 mm. The EU proposed standards contain two types of granules: Ø6 mm (± 0.5 mm), with the length of <5 × Ø, and Ø8 mm (± 0.5 mm), with the length of <4 x Ø. **Pellet bulk density.** If the fuel bulk density is relatively low, it results in higher transportation and storage costs. According to the Swedish standards, this parameter varies between 500 and 600 kg·m^{-3}. The Lithuanian Standards Board (LSB) does not provide any guidelines. **Pellet fraction % < 3 mm.** This parameter indicates what part of the pellets is disordered, or broken. LSB offers two categories: when the disordered particles do not exceed 1 % and 2 %. **Pellet density.** The density of the individual piece (pellet) should be between 1 and 1.4 g·cm^{-3}. **Humidity.** This parameter has a direct impact on the pellet heat value and combustion efficiency. According to the European Union standards, the moisture content in pellets must not exceed 10 %. Some other countries (e.g.: Great Britain, Norway) allow up to 12 % of humidity. **Calorific value.** It is recommended that the calorific value of wood pellets is 16.9 MJ·kg^{-1} or 4.7 kWh·kg^{-1}. **Individual chemical elements.** The content of some harmful chemical elements in pellets and briquettes is limited. Such elements include sulphur, nitrogen, chlorine, arsenic, Cadiz, chromium, copper, mercury, lead, zinc and extractable organic halogen compounds (EOX). **The percentage of broken pellets (briquettes) presented to the user.** The EU does not define any recommendations for this parameter. According to the German and Austrian standards, this parameter should not exceed 1 %. **Additives.** It is recommended that there should be up to 2 % of additives of the dry weight of the fuel. It is required that the additives cannot be chemically treated.

Many European countries widely use these biomasses and have positive consumer feedbacks. However, the production of pellet fuel is mostly limited to making pellets from homogeneous materials (one material only), such as wood, straw or other. The aim of our research at the Aleksandras

Stulginskis University is to extend the application range of materials for biofuel pellet manufacturing, combine two different materials to make mixed biofuel pellets (MBP) and to determine their chemical - mechanical properties.

The object of investigation

The pellets chosen for this research were: sawdust, sawdust + straw, sawdust + peat, peat, and wood dust (Fig. 1a; 1b; 1c; 1d; 1e)

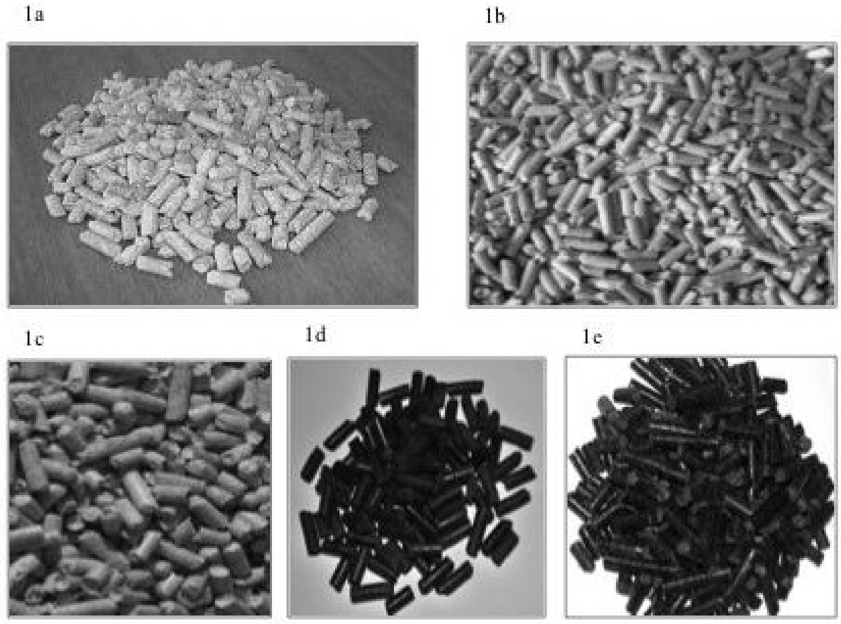

Fig. 1. **Sawdust + straw pellets (1a); homogeneous sawdust pellets (1b); homogeneous wood dust pellets (1c); sawdust + peat pellets (1d); homogeneous peat pellets (1e)**

There have been no binding materials used for the manufacturing of these pellets. MBPs were produced with the ratio of 50:50 % and then used in all of the tests performed during the research.

Methodology and results

To investigate the pellet moisture content the latest generation thermogravimetric analyser EXSTAR TG/DTA7300 was used. The humidity of five different types of biofuel pellets was tested.

It was known that a pellet normally breaks apart if its moisture content is higher than 12-14 %. In this respect, MBP's are better to use - they are more resistant to mechanical damage. The pellets from wood materials & peat that we studied remained in good quality even with greater than 12 % moisture content (Fig. 2).

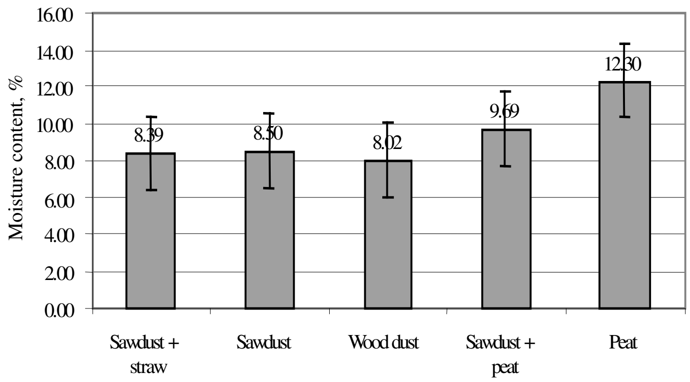

Fig. 2. **Average moisture content in investigated pellets, %**

When testing the pellet humidity, it was found that the peat pellets had the highest moisture content. If during pellet production 50 % of wood sawdust was mixed in, the humidity ratio could be reduced by almost 2.5 %. The humidity of the sawdust pellets and sawdust + straw pellets was similar: approximately 4 % lower than the peat pellets and approximately 1.5 % higher than the peat + sawdust pellets. The wood dust pellets were the driest of all materials used.

Next, the basic chemical composition of pellets was measured using a 2400 Series II CHNS / O elemental analyser. It was found that depending on the type of biomass, carbon (C) can take from 48.19 % to 53.56 % of biofuel dry weight (Fig. 3).

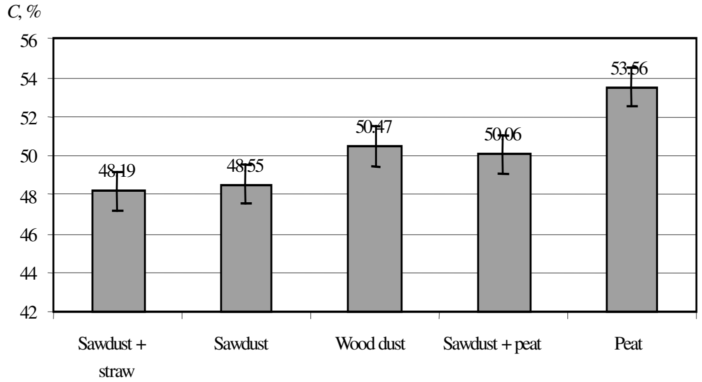

Fig. 3. **Content of carbon in investigated pellets, %**

Peat is geologically older fuel compared to wood and has higher carbon content. This was proved by our research: the carbon content in the peat pellets was the highest – 53.56 %. The least amount of carbon was found in the sawdust + straw pellets – 48.19 %. The difference between the highest and lowest however was not very big. To summarize, it is useful to mix in sawdust in peat pellets in order to make the carbon content decline by about 3.5 %.

Hydrogen (H) takes 5.62 % to 6.20 % of biofuel dry weight (Fig. 4).

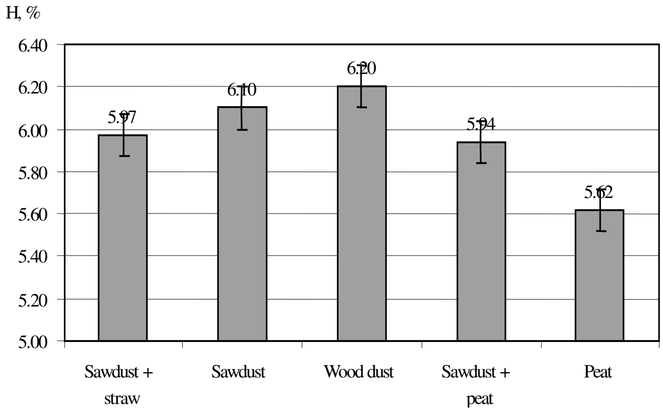

Fig. 4. **Content of hydrogen in investigated pellets, %**

The biggest amount of hydrogen was found in wood dust granules – 6.2 %, while the peat pellets had the least hydrogen – 5.62 %. The content of hydrogen in the investigated pellets varied very slightly, less than 1 %. The Austrian and Swedish standards for pellets do not indicate any requirements for the hydrogen content.

Nitrogen (N) takes 0.27 % to 0.99 % of biofuel dry weight (Fig. 5).

It was found that the sawdust pellets have the smallest amount of nitrogen – 0.26 %, and the wood dust pellets have only 0.01 % more. The highest content of nitrogen was found in the peat pellets – could be as high as 0.99 %. The difference is very big.

Our studied pellets did not always comply with the Austrian and Swedish granular fuel standards. According to the Austrian National Standards, the allowed nitrogen content can be ≤ 0.3 %. Our investigated sawdust + straw, sawdust + peat and peat pellets all had a higher content of nitrogen than the allowed limit. The nitrogen content in homogeneous peat pellets exceeded the legal Austrian limit more than three times. The sawdust + straw pellets exceeded the limit two times and sawdust + peat pellets exceeded the standard by almost one and a half time. In the Swedish standards, however, no percentage for the nitrogen content in pellets is provided.

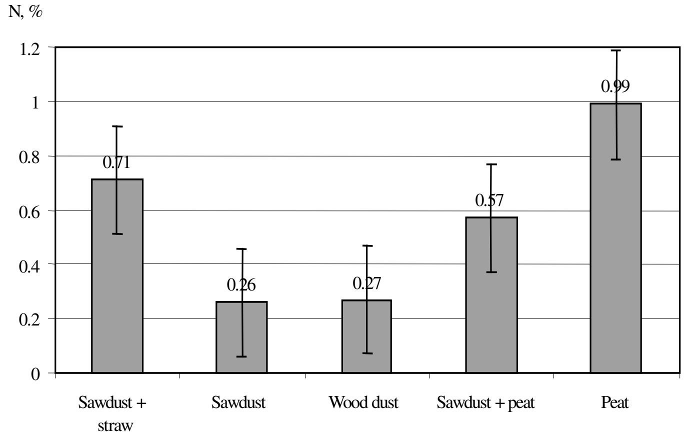

Fig. 5. **Content of nitrogen in investigation pellets, %**

The amount of sulphur (S) in the tested pellets ranged from 0 to 0.1 %. The sawdust + wood dust pellets had 0 % sulphur. The peat pellets showed the sulphur content of 0.1 %. Less sulphur was found in the sawdust + straw pellets – 0.06 %, and in sawdust + peat pellets – 0.05 %.

Next, one of the most important pellet physical properties – calorific value, was analysed using a bomb calorimeter. The calorimeter showed the higher heating value (HHV); the lower heating value (LHV) was obtained by the following formula [13]:

$$Q_{\check{z}}^{n} = Q_{a}^{n} - 2500 M_{\mathrm{H_2O}}, \tag{1}$$

where $Q_{\check{z}}^{n}$ – LHV;

Q_a^n – HHV;

2500 – condensation heat, $kJ \cdot kg^{-1}$;

$M_{\mathrm{H_2O}}$ – water vapour content from combustion of 1 kg fuel.

The pellet calorific value test results are shown in Figure 6.

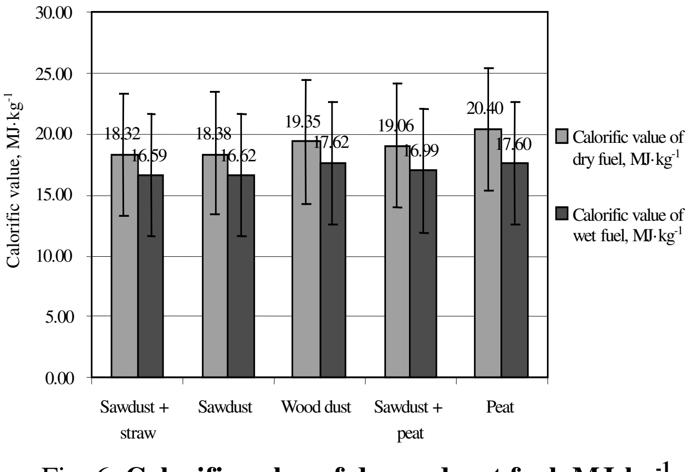

Fig. 6. **Calorific value of dry and wet fuel, MJ·kg^{-1}**

The above histogram (Fig. 6) shows the difference of the calorific values in wet (12-14 %) and dry (8-12 %) fuel. During wet fuel combustion, some energy is used for water evaporation, therefore less energy is produced.

The pellet calorific value test showed that all tested pellets have more or less similar calorific values. The most calorific were the peat (20.4 $MJ \cdot kg^{-1}$) and wood dust (19.36 $MJ \cdot kg^{-1}$) pellets. The sawdust + peat pellets showed similar results (19.07 $MJ \cdot kg^{-1}$). The sawdust + straw (18.32 $MJ \cdot kg^{-1}$) and homogeneous sawdust (18.38 $MJ \cdot kg^{-1}$) pellets had the lowest calorific value.

According to the Austrian first-class grain standard, the calorific value should be ≥ 18 $MJ \cdot kg^{-1}$. The sawdust + straw and sawdust pellets just barely matched the requirements. The remaining pellets (peat, wood dust, and sawdust + peat) all met the Austrian requirements. The Swedish Standard specified ratio is lower that that of Austria (≥ 16.9 $MJ \cdot kg^{-1}$).

Another important indicator that defines the pellet quality is their mechanical durability. A compressed pellet has to snap – hence, it has been pressed with high quality. The pellet mass must also be free of drop offs. Small chips falling out of pellets indicate that they were not properly sieved or insufficiently pressed. Such pellets lose their value.

During our study, the pellet mechanical durability was investigated and the findings are presented in the above diagram (Fig. 7).

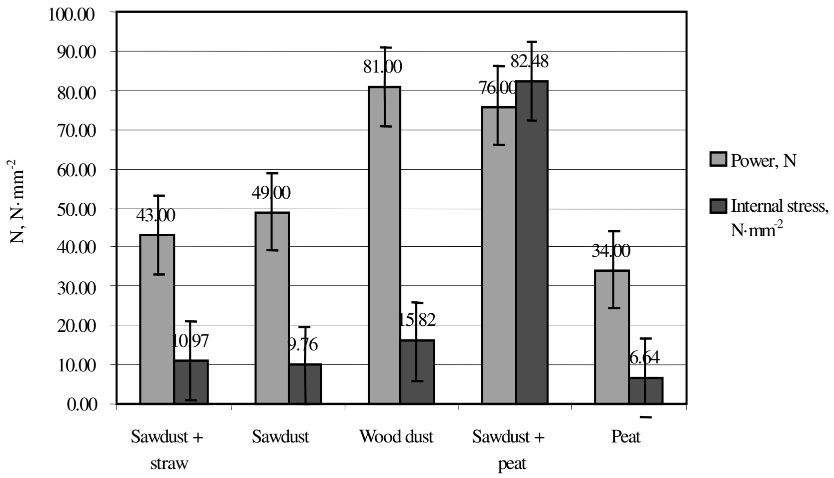

Fig. 7. **Average internal stress and load force**

It was found that wood dust could withstand the maximum force of all pellets – 81 N; the sawdust pellets were similar – 76 N. The peat pellets could withstand only 34 N. The peat pellet moisture content exceeds the permissible moisture levels; this affects their break down under the influence of a relatively low force (34 N).

An important finding of our study was that pellets produced without additional binding materials could withstand pressure from 6.6 $N \cdot mm^{-2}$ to 22.5 $N \cdot mm^{-2}$. We can safely assume that there is no need to use binding materials for our tested pellets except for the peat pellets which break down at a very low load – 6.6 $N \cdot mm^{-2}$.

Conclusion

The pellet biofuel is not only important because it is environmentally-friendly – our study has shown that it has great fuel properties. Our tested mixed biofuel pellets have had as good and sometimes even better properties than pellets made of homogeneous materials. MBPs have enough of calorific value; the content of the basic chemical elements in them does not exceed the norms; their mechanical strength is sufficient and, most importantly, they do not require any binding materials for production, therefore they can be produced industrially.

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