ENVIRONMENTAL ASSESSMENT OF SAWDUST BLENDS WITH GLYCEROL BURNING

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Abstract. Biodiesel production is limited by the development of the relatively high cost of the product. To reduce the cost it is reasonable to maximize the use of rape methyl ester (RME) production by-products – cake and glycerol fraction. Rapeseed cake is widely used for animal feed, this cake economically is best to use as a vitamin and protein additive product for cattle, pigs and poultry. In production of 1000 kg of RME about 101 kg of green glycerol is obtained, in which there is 87-92 % of pure glycerol. At the low RME output the most economical way of glycerol use is to use it as an additive for fuel briquettes production. In the experimental basis of the Aleksandras Stulginskis University, Institute of Agricultural Engineering the investigations in the sawdust and green glycerol mixture combustion process and environmental assessment are carried out. The tests showed that the calorific value of glycerol was 22-23 $MJ \cdot kg^{-1}$, also it is suitable as a binder by pressing sawdust briquette production. There were investigated wood sawdust mixes with 30, 50 and 80 % glycerol. It was determined that after insertion of 80 % green glycerol in wood sawdust mixture of 8 % moisture content, the calorific value increased from 16.28 $MJ \cdot kg^{-1}$ to 23.7 $MJ \cdot kg^{-1}$. As well as experimentally the mixture combustion temperature dependence on the supplied air was determined. The investigations in wood chip and glycerol mixture combustion showed that the NO_x content in the smoke did not exceed the permissible limit of 650 $mg \cdot m^{-3}$, SO_2 content in the smoke was found only as the traces and the ash content increases slightly with increasing of the glycerol content in the mixture.

Key words: biodiesel, green glycerol, wood sawdust, mixtures, emissions.

Introduction

By-products received during the production process of bio-diesel (rape methyl ester – RME) – are cake and glycerol fraction – rational usage of which may significantly reduce the product prime-costs. Rape cake is widely used in pet food production. Economically, it is better to use rape cake for production of protein vitamin mineral additives for cattle, pigs and birds [1; 2]. Cattle diet lacks approx. 10-15 % of digestible proteins. Often, cattle lack energy due to poor quality of green and juicy pet food. These problems may be solved using rape cake and bits. It is also rather economical since imported protein raw materials – soya, sunflower seeds, cotton bits – are quite expensive. Apart from that, due to spread of mad cow disease, it is prohibited to use meat, meat-bone and blood flour. Thus, it is necessary to search for compensating the protein sources.

In rape cake received during mechanical pressure, the following amounts of materials remain: about 90-93 % of dry materials, 10-20 % of fat, 26-31 % of proteins, 8-12 % of fibre. 1 kg of rape cake contains 1.2-1.3 pet food unit and 210-270 g digestible proteins. Rape proteins contain many unchangeable amino-acids (lysine, methionine, cystine, tryptophan, etc.), and fat contains unchangeable fatty acids (olein, linol, linolen) which are necessary for growing pets and have positive effect on their health and productivity [3].

Depending on the raised requirements for the quality of by-products, in various production technologies of rape methyl ester various ways of glycerol fraction are used. When producing 1000 kg RME, 101 kg of green glycerol is received. This quantity contains 87-92 % of pure glycerol [4-8].

Pure glycerol received by application of various ways indicated in literature sources may be used in many areas: food, beverage, medicine, cosmetics, tobacco, and textile. However, it requires high energy input [9]. Such production is cost-effective if not less than 10 thousand tons per year of green glycerol are made; this quantity is obtained by producing more than 100 thousand tons per year RME.

It is comfortable and economical to mix non-fractioned glycerol phase (green glycerol), which is received during RME production, with liquid fuel, e.g., black oil and burn in boiler houses. However, glycerol and other phase components do not mix with oil products and divide into layers; so, their usage becomes rather problematic [10].

As it has been shown by literature analysis, glycerol usage for fuel mixing it with wood sawdust and producing briquettes or pellets is the most perspective. Therefore, there are not much data about thermal features and burning impact on environment.

It is necessary to note that glycerol phase may be used to this end. Methanol should be removed from glycerol phase because it may cause fire and explosion conditions in the briquette production line [11].

Aim of the research is to determine thermal features of wood sawdust with addition of green glycerol and its environmental impact during burning.

Materials and methods

Preparation of sawdust blend with addition of green glycerol. Sawdust of conifers with the moisture content 5-8 % was weighted with electronic scale DS 4 with ±10 g error. The sample weight is 1 kg. Before mixing, green glycerol was heated up to 40-45 ℃ and poured into sawdust. Samples with addition of 10, 30, 50 and 80 % of green glycerol were prepared. The test sawdust sample was without glycerol. Sawdust was mixed with glycerol manually and, later on, the sample in a closed vessel was placed into a thermostatic cabinet with the constant temperature 95±1 ℃. The sample was kept in this temperature for 3 hrs so that glycerol soaked into sawdust.

To determine *fuel caloricity,* combustion bomb was used; it was placed into calorimeter V-08 MA (B-08 MA) filled with water. The tests were performed in special premises in which constant temperature was kept ±1 ℃. The operating principle of the calorimeter is based on measuring cooling water temperature alteration by burning mass fuel sample. Digital recorder ABL 646.00.00 was used to measure temperature [12].

According to caloricity determined by calorimeter bomb, total fuel caloricity was calculated [13]:

$$Q_b^s = Q_b^a \frac{100}{100 - W_a},$$ (1)

where Q_b^s – total caloricity of dry fuel, kJ·kg^{-1};
    Q_b^s– sample caloricity determined in calorimeter bomb, kJ·kg^{-1};
    W_a– sample moisture content, %.

The burning tests were performed three times in a row while determining fuel arithmetic average caloricity and measuring average square deviation if reliability is 0.95.

For analysis of fuel burning, determination of the burning temperature and CO and NO$_x$ quantity in smoke experimental fuel burning equipment with a chimney type furnace was used [14].

Fuel mass is determined by weighing the samples with scale RP-50Š11 with ±0.01 kg error. Air quantity needed for burning is measured by rotameter. Air flow speed in burning stand is measured by rotameter with ±0.1 m·s^{-1} error, flow sensor FVA915-S120 and equipment ALMEMO-2290-8. Burning temperature in burning stand is measured by thermoelement NiCroSil-NiSil (N) and is registered by equipment ALMEMO-2290-8 with 1 ℃ precision. Test duration is set according to time measures of the mentioned equipment. Burning quality is set by burning analysator PCA-65 produced by BACHARACH measuring oxygen, carbon monoxide, nitrogen oxide quantity in smoke and smoke temperature. Measuring precision: oxygen – 0.3 %; CO – 10 ppm; NO – 5 ppm; smoke temperature – 1 ℃.

During the tests the fuel feeder operated with maximum productivity. For burning support from 10.4 m³·h^{-1} till 30.6 m³·h^{-1} air was blown into the furnace with equal intervals. Each regime operated for 300 s. Burning temperature is registered with periodicity of 10 s, smoke composition – with periodicity of 20-30 s. Burning temperature is calculated as the average measure of 18 measurements for every operating regime.

According to the test data, it was calculated:

1) hourly fuel consumption:

$$B = \frac{B_k}{\tau},$$ (2)

where B – fuel consumption, kg·h^{-1};
    B_k – mass of the fuel burned during the test, kg;
    τ – test time, h.

2) quantity of air supplied for burning:

$$2V_o = \frac{V_{ok}}{B},\qquad(3)$$

where V_o – comparative quantity of air supplied for burning, m³·kg⁻¹;
V_{ok} – debit of the air supplied to the furnace, m³·h⁻¹.

Results and discussion

Total caloricity of sawdust with mixture of green glycerol was determined during the tests in calorimeter bomb. Sawdust of coniferous wood (moisture of which was 8.0±1.5 %) was used for the burning tests. Based on the received experimental data, using equation (1), caloricity of dry and wet fuel mass was determined (Fig. 1).
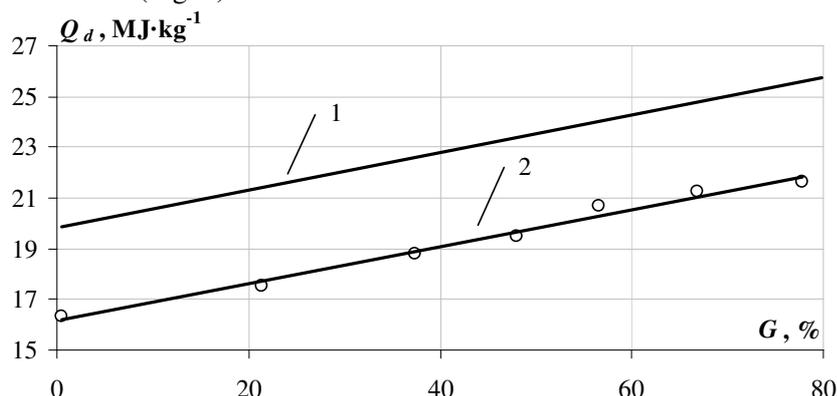

Fig. 1. **Dependence of mixture of dry and wet sawdust and green glycerol caloricity Q_d on the quantity of glycerol G in it:** 1 – caloricity of dry mass (calculated); 2 – caloricity of 8 % moisture blend (experimental value)

As our research shows, caloricity of dry mass of clean sawdust (without glycerol) is 19.7±1.35 MJ·kg⁻¹, and caloricity of 8 % moisture blend is 16.28 MJ·kg⁻¹. Having added 80 % of green glycerol, caloricity of dry fuel increases up to 25.5±1.83 MJ·kg⁻¹, and that of moist blend is 23.7 MJ·kg⁻¹.

If burning fuel blends of various compositions, the highest temperature was achieved supplying to the furnace 3-5 m³·kg⁻¹ of air. When blowing more air, the burning temperature reduces.

Burning temperature increases when burning fuel mix with a higher amount of glycerol (Fig. 2).
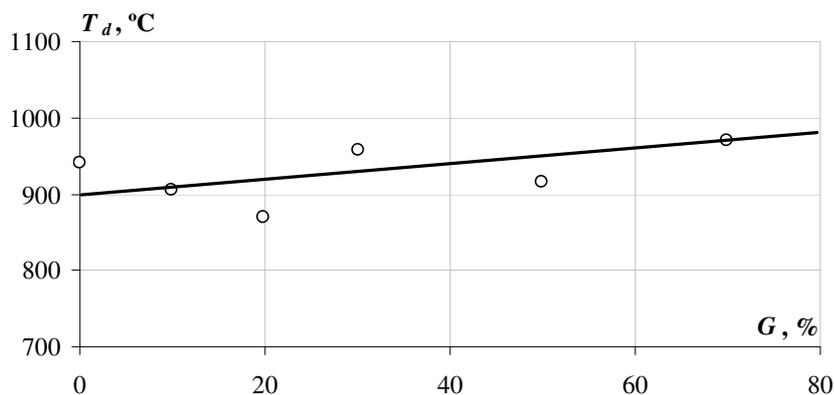

Fig. 2. **Dependence of burning temperature T_d on the quantity of green glycerol in fuel blend G – comparative quantity of the blown air V_o = 5 m³·kg⁻¹**

As it may be seen, a higher amount of green glycerol in a blend signifies higher burning temperature. This is explained by higher caloricity of glycerol.

Fuel burning temperature conditions the amount of nitrogen oxide NO_x in the smoke. Fig. 3 shows changes of nitrogen oxide quantity in smoke depending on the quantity of green glycerol in the blend.
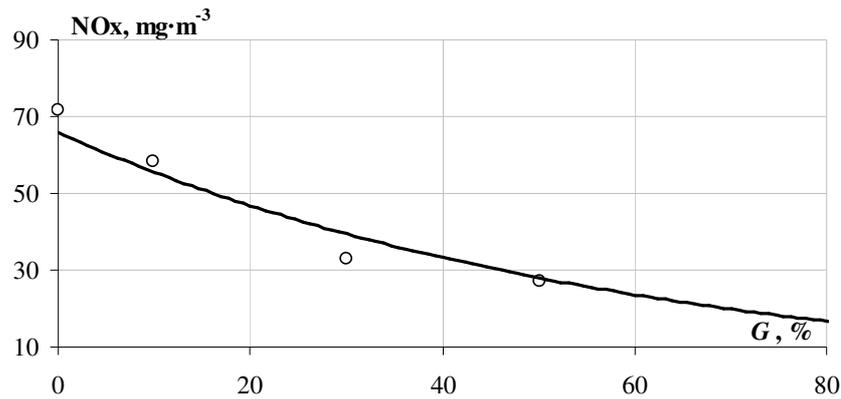
Fig. 3. **Quantity of nitrogen oxide NO_x in smoke depending on green glycerol in fuel blend G – comparative quantity of air $V_o = 5$ m^3·kg^{-1}**

This dependence may be approximated in correlation ratio 0.96 by exponential equation:

$$NO_x = 66.1 \exp(-0.017\,G). \tag{4}$$

While increasing the quantity of green glycerol in fuel blend, burning temperature increases, and the quantity of nitrogen oxides NO_x in smoke decreases. From the point of view of environmental protection, this phenomenon is positive since nitrogen oxides are classified as hazardous to human health compounds.

The research results show that when burning clean sawdust, the quantity of NO_x in smoke was 72 mg·m^{-3}, and in fuel blend with addition of 80 % green glycerol, the amount of this hazardous gas reduced to 19 mg·m^{-3}. The quantity of NO_x is minimal and does not increase the permitted limit – 650 mg·m^{-3}. The research results of determination sulphur dioxide SO_2 in smoke show that only traces of SO_2 were found in smoke and the ash content increases slightly with increasing of the glycerol content in the mixture.

The change in the ash quantity after burning fuel blend depending on green glycerol is shown in Fig. 4. This dependence may be approximated in correlation ratio 0.95 by exponential equation:
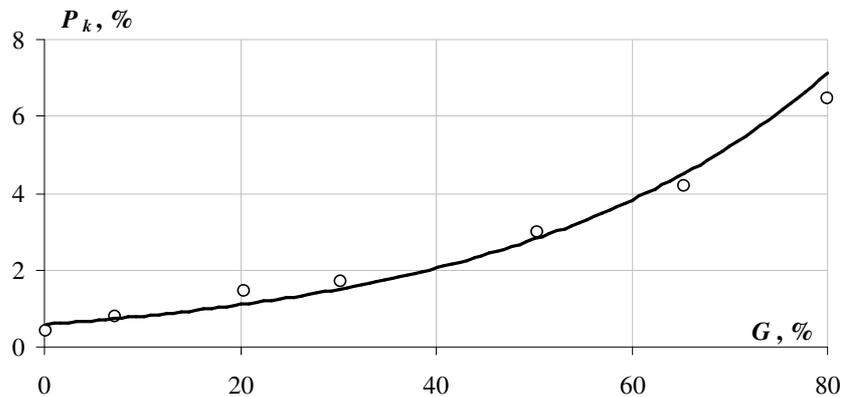
$$P_k = 0.59 \exp 0.03\,G. \tag{5}$$

Fig. 4. **Dependence of ash quantity P_k in fuel blend on quantity of green glycerol G**

As it can be seen from the graph of Fig. 4, the higher the quantity of green glycerol in fuel blend, the higher the quantity of ash in fuel. This may be explained analysing the element composition of the used green glycerol. It is composed of 2.2 % potassium and 0.11 % sodium; these materials are incombustible and remain in ashes.

The research results of the experiments show that a higher amount of green glycerol improves caloricity of blends and reduces emissions of NO_x. However, in the future investigations it is necessary to prove its highest permissible quantity in a blend that affects the pressing (briquetting) process and physical-mechanical features of the produced briquettes.

Conclusions

1. Based on literature analysis, it may be stated that usage of glycerol (as a by-product of RME production) for fuel has good perspectives. It may be mixed with sawdust, and the blend may be pelleted or granulated.
2. It was determined that after introduction of 80 % of green glycerol into sawdust of 8 % moisture, caloricity of the blend increased from 16.28 MJ·kg^{-1} to 23.7 MJ·kg^{-1}.
3. As it has been determined experimentally, burning temperature of sawdust and green glycerol changes depending on the blend composition and the supplied air quantity. The highest burning temperature 980 °C is reached if the blend contains 80 % glycerol and the supplied air makes 5 m^3·kg^{-1}.
4. The higher quantity of glycerol affects higher burning temperature and lower quantity of NO$_x$ in smoke. When burning clean sawdust, the quantity of NO$_x$ in smoke was 72 mg·m^{-3}, and in fuel blend with addition of 80 % green glycerol, the amount of this hazardous gas reduced to 19 mg·m^{-3}. The quantity of nitrogen oxides was minimal and did not exceeded the permissible limit – 650 mg·m^{-3}. Only traces of sulphur dioxide SO$_2$ were found in smoke and the ash content increases slightly with increasing of the glycerol content in the mixture.
5. It was determined experimentally that a higher amount of green glycerol improves caloricity of blends and reduces emissions of NO$_x$, but it is necessary to prove its highest permissible quantity in a blend that affects the briquetting process and physical-mechanical features of briquettes.

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