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QUALITY OF DENSIFIED SOLID BIOFUELS PRODUCED FROM SOME ENERGY CROPS SPECIFIC TO THE CONDITIONS OF THE REPUBLIC OF MOLDOVA

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Abstract

This paper refers to the qualitative study of densified solid biofuels, obtained from the plant biomass of the Asteraceae family. Nestro cylindrical briquettes produced at a hydraulic press manufactured by Briklis company within the Laboratory of Solid Biofuels, SAUM, served as the object of the research. The plant biomass of Silphium perfoliatum cultivated under the conditions of the Republic of Moldova was used as raw material. The research results demonstrate the prospects of using the studied crops as raw material for the production of densified solid biofuels in the form of briquettes.

***Key words**: solid biofuels, Silphium perfoliatum, properties, briquettes, ENPlus 3.*

INTRODUCTION

New trends regarding renewable energy are required by increasing global energy demand and Moldova's enhanced interest in decreasing dependence on the sources of imported energy, the urgent need to mitigate climate change, inevitable depletion of fossil fuels and their negative effects on the environment.

The energy obtained from biomass is one of the most accessible directions for the promotion of renewable energy under the conditions of the Republic of Moldova (Arion et al., 2008). This is explained by the existence of an inherent variety of plant biomass that can be used as raw material for the production of densified solid biofuels. It should be mentioned that the lignocellulosic biomass from agricultural residues is the most comprehensively studied in our country.

The research conducted at ITA "Mecagro" (Habasescu et al., 2012; Habasescu, 2008) and the State Agrarian University of Moldova (Marian, 2016; Gudima, 2018; Pavlenco, 2018) contributed to the identification of energy potential and qualitative estimation of residual biomass from different crops. Meanwhile, researchers from the Laboratory of Solid Biofuels, SAUM showed that only 9% of the whole number of residues generated from agricultural activities can be used directly without being modified as raw material for the production of densified solid biofuels with the features that comply with European requirements and ENPlus 3 standards (Gudima, 2017; Pavlenco et al., 2018).

Thus, the search for raw material sources needed to produce densified solid biofuels with the characteristics that are in line with the requirements of ENPlus 3 standards is interesting for both producers of densified solid biofuels and researchers in the field.

A number of energy plants can serve as an important source of raw materials for the production of solid biofuels that comply with ENPlus 3 requirements. *Silphium perfoliatum,* a plant from the Asteraceae family, is of special interest.

The increased interest in this plant is explained by its high biomass productivity, resistance to both drought and frost and the possibility to cultivate it on marginal lands that are not efficient enough to grow other crops (Titei, 2014).

It should be noted that existing studies on the use of *Silphium perfoliatum* biomass as raw material for solid biofuels are quite modest, which limits its efficient use for the production of solid biofuels with the characteristics that meet international standards.

The paper presents research results on qualitative estimation of the biomass derived from growing *Silphium perfoliatum* and the finished product obtained from the biomass in the form of briquettes.

MATERIALS AND METHODS

The research was conducted at the Laboratory of Solid Biofuels (LSBF), SAUM. The samples were taken from the experimental plantations of the Botanical Garden (Institute) of the Academy of Sciences of Moldova. The samples were taken and prepared in accordance with the requirements of the following standards SM EN ISO 18135: 2017 and SM EN ISO 14780: 2017.

The taken biomass was crushed in the SV 7 hammer crusher, and its densification took place at the hydraulic press produced by Briklis company within the LBCS, SAUM (Figure 1).

Figure 1. The pictures taken while preparing and testing the samples of *Silphium perfoliatum:* a) Grinding of the raw material; b) Biomass densification process; c) Determination of the calorific value of the studied samples; d) Determination of moisture content; e) Determination of ash content; f) Chemical analysis of the sample at the Vario MACRO cube CHNS and Cl elemental analyzer

The quantity of heat produced by the combustion of *Silphium perfoliatum* samples was determined by measuring the calorific value at the constant volume by means of LAGET 10 calorimeter. Measurements and calculations were performed in accordance with the requirements of the standard SM EN ISO 18125: 2017.

The lower calorific value was determined for the biomass with humidity 0% and 10% using the following relations:

$q_{p,net,d}=q_{v,gr,d}-212{,}2\cdot w(H)_d-0{,}8\cdot[w(O)_d+w(N)_d]$,.(1)

$q_{p,net,M}=q_{v,gr,d}-(1-0{,}01M)-24{,}43M$, (2)

where:

$q_{(p,net,d)}$ is net calorific value at constant pressure of the dry (moisture-free) fuel, J/g;

$q_{p,net,m}$ is net calorific value at constant pressure of the biofuel with moisture content M, J/g;

$q_{v,gr,d}$ is gross calorific value at constant volume of the biofuel of the dry (moisture-free) fuel (dry basis, in the dry matter), J/g;

$w(H)_d$; $w(O)_d$; $w(N)_{d.}$ are, respectively, the hydrogen, oxygen and nitrogen content, in percentage by mass, of the moisture-free biofuel, %;

M - moisture content, in percentage by mass.

The moisture content was determined on a dry basis and on a wet basis according to the SM EN ISO 18134 1-3: 2017 series of standards by heating them in the Memmert UNBU furnace.

The moisture content was calculated using the following calculation formulas:

$$U_d = \frac{m-m_0}{m_0}100\%, \quad (3)$$

$$M_{ar} = \frac{m-m_0}{m}100\%, \quad (4)$$

where:

U_d and M_{ar} are the moisture content of the dry basis and, respectively, of the wet basis;

m - the mass of the biomass sample in the wet state, g;

m_0 - the mass of the same biomass sample estimated after drying in the furnaces to a constant value, g.

The ash content was determined for the samples previously crushed in the SM 100 hammer crusher with sieve mesh sizes up to 1 mm according to the SM EN ISO 18122: 2017 standard.

The method involves heating the examined samples to a temperature of (250 ± 10)ºC at a rate of +5ºC/min for 50 minutes, maintaining this temperature for 60 minutes, with subsequent heating of the furnace to a temperature of (550 ± 10)ºC for 60 minutes, maintaining the temperature at this level for at least 120 minutes and cooling the samples to the room temperature.

The ash content was calculated by means of the formula 5:

$$A_d = \frac{(m_3-m_1)}{(m_2-m_1)}\cdot 100 \cdot \frac{100}{100-W}, \quad (5)$$

where:

m_1 is the mass of the empty crucible, g;

m_2 is the mass of the crucible plus the mass of the test sample, g;

m_3 is the mass of the crucible plus the mass of ash, g;

W - humidity of the analyzed sample, %.

The chemical analysis of the biomass was carried out at the elementary analyzer Vario MACRO cube CHNS & Cl at the Laboratory of Solid Biofuels of SAUM. The detection and quantitative analysis were done using a TCD (Thermal Conductivity Detector). The results were processed with the EAS software.

The particle density was determined by means of the stereometric method in accordance with the SM EN ISO 18847: 2017 standard.

The density of the chopped bulk biomass and briquettes was determined according to the MS EN ISO 17828: 2017 standard in the dry basis and the one with the humidity of 10%, using a standard cylindrical container of 50 l. The sample was poured slowly into the container, after that the excess material on the top was leveled with a wooden bar.

The ability of briquettes to withstand shock and wear resistance was estimated by determining the mechanical durability according to the requirements of the SM EN ISO 17831-2: 2017 standard. The tested samples in the amount of (2 ± 0.1) kg were subjected to controlled blows by their collision with each other and with the walls of a rotating chamber for 5 min with a frequency of (21 ± 0.1) min^{-1}. The tested samples were then passed through a 45 mm eye sieve in a circular motion about 5-10 times along the diameter of the sieve.

RESULTS AND DISCUSSIONS

Silphium perfoliatum is a representative of the *Silphimgen Steraceae* family. The name of the *Silphium* genus originates from the Greek “silphion” and means “the one that secretes resin”.

The plant was imported in Europe around the 18th century as a decorative plant. However, they expanded the range of *Silphium perfoliatum*’s use quite quickly and it has become a multifunctional plant due to the advantages that characterize it (Peni et al., 2020). It has low maintenance requirements and increased energy potential due to its high productivity; it can be used for up to 15 years (Gansberger, et al., 2015). The flowers of the plant, which appear in the first summer months and last until late autumn, make the plant an attractive and important source of food for pollinating insects (Frączek, et al., 2011).

The increasing number of scientists support the idea of using *Silphium perfoliatum* for energy purposes, because its energy potential is high, cultivation costs are reduced, production profitability is also high (RHS A-Z, 2008), calorific value is satisfying (Mariani et al., 2014; Fraczek et al., 2011; Titei, 2014). It is known as a raw material for biogas production from the energy point of view (Haaga et al., 2015; Wever et al., 2019).

The analysis of data from various sources has shown that the information on the use of *Silphium perfoliatum* biomass as raw material for the production of densified solid biofuels is modest enough, and it also has a contradictory character in some cases. For example, researchers from Lithuania (Jasinskas et al., 2014) showed that the calorific value of the *Silphium perfoliatum* ranges from 16.98 to 17.58 MJ/kg depending on the amount of nitrogen in the soil and the pH of the soil itself. Researchers of Lithuanian Research Center for Agriculture and Forestry along with their colleagues from the Institute of Agricultural Engineering and Safety, do not recommend the use of the *Silphium perfoliatum* biomass for the production of densified solid biofuels based on the analysis of quality parameters of densified solid biofuels in the form of pellets (Siaudinis et al., 2015) (Table 1).

At the same time, researchers from the University of Agriculture in Krakow say that *Silphium perfoliatum* briquettes are of very good quality. The statements are based on the study of the biomass and the finished product in the form of briquettes. Thus, according to the data presented by the authors, the calorific value of the biomass is equal to 17.3 MJ/kg (it is not specified which calorific value - the upper or the lower one) and the ash content equals to 3.4%, mechanical durability of briquettes is equal to 93.1% and particle density of briquettes is 920 kg/m^3 (Fraczek et al., 2011).

Table 1. Data for the qualitative analysis of densified solid biofuels from *Silphium perfoliatum*

Parameters	**[Siaudinis, G et al., 2015]**	**Values obtained in SBFL, SAUM**	**Requirements according to ENPlus 3 standards (SM EN 17225: 2017)**					
			ENplusA1	**ENplusA2**	**En-B**	**ENplusA1**	**ENplusA2**	**En-B**
	Briquettes	Briquettes	Pellets			Briquettes		
W_r, %	11.6 ± 0.09	9.97 ± 0.37	≤ 10			≤ 12	≤ 15	
A_d, %	9.96 ± 0.38	6.5 ± 1.11	≤ 0.7	≤ 1.2	≤ 2	≤ 0.7	≤ 1.5	≤ 3
A_r, %		6.69 ± 0.79						
$q_{v, gr, d}$, J/g		18.673 ± 0.85						
$q_{p, net, d}$, J/g		17.405 ± 0.94						
$q_{p, net, m=10\%}$, MJ/kg		15.42 ± 0.085	≥ 16.5			≥ 15.5	15.3	14.9
C, %	45.44 ± 1.16	45.58 ± 0.47						
N, %	0.68 ± 0.32	0.22 ± 0.13	≤ 0.3	≤ 0.5	≤ 1	≤ 0.3	≤ 0.5	≤ 1
H, %	5.28 ± 0.46	5.8 ± 0.11						
S, %	0.07 ± 0.28	0.17 ± 0.05	≤ 0.04	≤ 0.05		≤ 0.04		≤ 0.05

Parameters	**[Siaudinis, G et al., 2015]**	**Values obtained in SBFL, SAUM**	**Requirements according to ENPlus 3 standards (SM EN 17225: 2017)**					
			ENplusA1	**ENplusA2**	**En-B**	**ENplusA1**	**ENplusA2**	**En-B**
	Briquettes	Briquettes	Pellets			Briquettes		
O,%	38.57	45.18						
DU, %		94.78±0.38	≥ 98.0	≥ 97.5				
F (< 3.15 mm)			(≤ 1.0)[1)]; (≤ 0.5)[2)]					
BD, kg/m^3			600 ≤ BD ≤ 750					
DE, g/cm^3		0.83±0.02				≥1	≥0.9	≥0.9

[1)]*at the factory gate or when loaded on trucks to be delivered to end users (a part of the delivered cargo and the completely delivered cargo);* [2)]*at the factory gate, when filling bags with pellets or when sealing big bags.*

Note: W_r - moisture content as received; A_d - ash content (w-% dry basis); A_r - ash content (w-% as received); BD - dulk density; DU - mechanical durability; $q_{v,gr,d}$ - gross calorific value at constant volume of the biofuel of the dry basis; $q_{(p,net,d)}$ - net calorific value at constant pressure of the dry (moisture-free) fuel; $q_{p,net,m}$ - net calorific value at constant pressure of the biofuel with moisture content m; *C, N, H, S, O* are, respectively, the Carbon, Nitrogen, Hydrogen, Sulphur and Oxygen content, in percentage by mass, of the moisture-free biofuel; *DU* - mechanical durability; *BD* - bulk density; *DE* - particle density.

Similar conclusions are made by the researchers from the National Botanical Garden (Institute), Chisinau. Therefore, Titei states that the biomass of *Silphium perfoliatum* can be used to produce pellets and briquettes, showing that the biomass collected in winter has a calorific value of approximately 18.3 MJ/kg and the ash content equal to 2.5% (Titei, 2014).
According to Titei et al., a more recent research on the *Siphium perfoliatum* biomass, collected in March, showed that its ash content is 3.0%, its net calorific value is 16.7 MJ/kg, bulk density of pellets is 656 kg/m^3, specific density of briquettes is 949 kg/m^3 and that of pellets equals to 1038 kg/m^3.
The following table presents the results of the *Silphium perfoliatum* briquettes analysis obtained by us at LSBF. The values provided by researchers from Lithuania and regulations imposed by ENplus 3 standards for pellets and briquettes are given for comparison.
Comparing the results obtained by us in this study with the values recommended by the ENPlus 3 standards, we can state that the briquettes produced from *Silphium perfoliatum* comply with strict ENPlus 3 standards only in case of the calorific value at the lower limit (15.42 ± 0.085 MJ/kg) and the content of nitrogen (0.22 ± 0.13)%. The other parameters exceed the limits stipulated in the standard, particularly, the high ash content (6.5 ± 1.11)%. It should be noted that the research carried out by the colleagues from Lithuania shows an even higher ash percentage (9.96 ± 0.38) %.
Furthermore, *Silphium perfoliatum* can be used as raw material for energy purposes to produce biogas or as a filler for biomass mixtures to produce densified solid biofuels in the form of briquettes. This biomass cannot be used as a raw material for the production of pellets.

CONCLUSIONS

The demand for raw materials to produce densified solid biofuels with qualitative characteristics according to the requirements of the ENPlus 3 international standards is constantly increasing.
Studies published in specialized literature along with our data show that *Silphium perfoliatum* is both of increased interest for the chemical and the pharmaceutical industries to protect the ecosystem and feed pollinating insects and a promising source in terms of quantity to be used as a raw material for energy purposes.
The testing results of densified solid biofuels in the form of briquettes demonstrate that the biomass obtained from the cultivation of *Silphium perfoliatum* in the raw state does not ensure a finished product that would meet all the quality requirements densified solid

biofuels have and it is not recommended to be used in the raw state for the production of briquettes and pellets for non-industrial uses. Although, it can be used as a filler to form mixtures with other types of biomass, which will later be used for the production of briquettes.

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