COMPARISON OF COMBUSTION EMISSION OF TOBACCO STALKS BIO-BRIQUETTES AND BEECH WOOD

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Due to instability in the global market, especially in crude oil and natural gas, alternative energy sources are needed more than ever. Also, climate change is on a critical level because of greenhouse gasses emitted from fossil fuel combustion. The Republic of Serbia seriously depends on imported energy sources, which makes the country vulnerable to these negative global trends. One of the possible solutions is the recognition and use of green energy sources, such as agricultural waste.

The present research used experimental methods to investigate the emission of combustion gasses of tobacco stalk briquettes. Results were compared to the emission recorded after the combustion of beech wood. Additional investigations of the usability of tobacco stalks were performed, especially considering the emission of flue gasses (CO, NO, O_2, and CO_2) and volatile organic compounds (total hydrocarbons). The results have demonstrated the satisfactory heating capacity of tobacco stalks bio-briquettes, accompanied by the flue gasses emission within limits provided by the European Union and national legal documents. Therefore, tobacco stalk bio-briquettes could be a valuable alternative green energy source.

Keywords: RES (renewable energy sources), agricultural waste, greenhouse gas emission, tobacco stalks bio briquettes

1. Introduction

Due to the political instability of regions with most natural gas and crude oil production, the supply of fossil fuels is highly uncertain. Also, there is increasing awareness of climate change caused by the emission of greenhouse gasses due to the excessive use of fossil fuels. Therefore, many countries in the world are trying to replace fossil fuels with alternative energy sources, including agricultural waste.

As a part of the negotiations for accession to the EU, the Republic of Serbia, through Chapter 27, has begun the process of establishing a waste management system and adapting it to the EU goals and *Acquis Communautaire*, and adopted the Waste Management Program of the Republic of Serbia for the period 2022-2031, according to The Law on the Planning System of the Republic of Serbia [1, 2].

The goals which were set by the Strategy have not been fully achieved, while, in the meantime, new EU goals have been postulated in the field of waste management within the "green transition",

which emphasized the necessity of changing the strategy in the field of waste management in the Republic of Serbia. Several legal documents, including The Law on Air Protection, The Law on Agricultural Land, and The Law on Energy were harmonized with laws of the EU [3, 4, 5], thereby completing the regulatory premises of agricultural waste utilization as an alternative energy source.

In the Republic of Serbia, agricultural waste is abundant (approximately 12.5 million tons per year) and still inadequately discarded or recycled. The origin of agricultural waste in Serbia varies in amount and type in different regions, but most of it can be used for energy production. An example of good practice is the production of biogas from animal waste as well as from the remains of wheat stalks. Having in mind that the Republic of Serbia depends to a great extent on energy import, the exploitation of agricultural waste becomes even more important.

The profitability of agricultural waste sources for energy production is satisfactory and their consumption should be encouraged [6]. The use of biomass in the form of briquettes and pellets can be reasonable in areas where there is a lack of other energy sources [7]. It should be noted that agriculture is at the same time producer and consumer of a great amount of energy [8]. If only 25% of the produced biomass was used as an energy source, it would be more than 3 million tons or 1.4 million tons of fuel oil. According to the estimations, this biomass could completely cover all energy needs in the agricultural sector [9].

One of the agricultural waste sources in the Republic of Serbia is tobacco stalks, the byproduct of the tobacco industry. Tobacco production in Serbia in 2021, according to the record of the Statistical Office of the Republic of Serbia, was 10097 tons collected from 5803 hectares. The byproducts of tobacco industry are tobacco stalks, while leaves are used for cigar and cigarettes production [10].

It is expected that tobacco stalks could be one of the possible sustainable energy sources. Up until this moment, the main problem of tobacco stalk usage is their content of nicotine and heavy metals [11] although nicotine quantity in tobacco leaves is approximately 2%, while in stalks it is less than 1%. Also, the reported decrease in nicotine content from tobacco stem to tobacco briquettes is 36-72% [12]. According to the Waste Catalogue of the Republic of Serbia, tobacco is rated as a non-toxic waste [13]. Research performed by other authors suggests that briquettes and pellets from the oriental tobacco stalks contain less than 500 ppm of nicotine, which means that usage of tobacco stalks briquettes and pellets is ecologically acceptable [14]. To decrease nicotine content even more, tobacco stalks can be mixed with other similar biomass samples.

Tobacco stalks primarily contain cellulose, lignin, and hemicellulose which makes them potentially the high value-added biomass with a high production of heat. It was reported that irrespective of the farming method, tobacco stalks present a source of biomass particularly suitable for energy purposes [15, 16]. The results of our previous investigation suggested that the heating value of tobacco stalks is satisfactory and also, there is a very low and acceptable nicotine content in tobacco stalks briquettes of 0.5%. Therefore, the current research primarily aimed to establish the emission of the most important flue gasses during the tobacco stalk bio-briquette combustion, in order to evaluate their potential as a green energy source.

2. Materials and methods

The greenhouse gas emission was tested by combustion of Burley tobacco stalks bio-briquettes and beech wood. Tobacco stalks bio-briquettes were made from the material obtained from Šabac

tobacco fields in the Mačva region, Serbia. Tobacco leaves and stalks are obtained after mowing and drying, according to the standard procedure. After that, leaves were removed from stalks and used in the tobacco industry for cigars and cigarettes, while the tobacco stalks, considered agricultural waste in this process, were ground and homogenized in the mill [17]. Briquettes were made in the briquette machine Junior, produced by P.O.R. Micucci system srl, Technologie del recupero [18]. Technical characteristics of the briquette machine were as follows: briquette diameter was 50 mm; briquette output was 50 kg/hour. The machine was operated by a pressure of 8-10 MPa. Briquettes were 5-8 cm long and made from raw material without any binding additives. Only tobacco stalks bio-briquettes of the same size were used for combustion. Briquette humidity was in the range of 9-10%. The length of beech wood logs was 20 cm.

2.1. Physical and chemical characteristics

Determination of the heating value and chemical composition for tobacco stalks bio-briquettes and beech wood were presented in earlier stages of this study [19, 20].

2.2. Laboratory analysis

The combustion process was performed in the Joint Stock Company for Quality Testing - Kvalitet a.d. Niš testing division laboratory. The laboratory is accredited by the Accreditation Body of Serbia according to standard SRPS ISO/IEC 17025/2017. Among others, the laboratory is certified for testing of characteristics of a solid fuel heating device. The laboratory is carrying out performance testing, the heat output of the device, and the coefficient of device usefulness. Also, emission testing is certified according to actual valid standards. The composition of flue gasses was performed according to following standards: SRPS EN 16510-1:2023, SRPS EN 16510-2-1:2023 A.4 [21, 22] (Fig.1).

A flue gasses analyzer with 3 measuring cells for CO (carbon monoxide), NO_x (nitrogen oxides), and O_2 (oxygen) was produced by Siemens – Type Ultramat 23. Temperature measuring equipment was Ahlborn with k-type thermocouples.

Measuring of parameters was performed in intervals of ten seconds. All data was collected by the SCADA (supervisory control and data acquisition) application and automatically written and stored in a Microsoft Excel file.

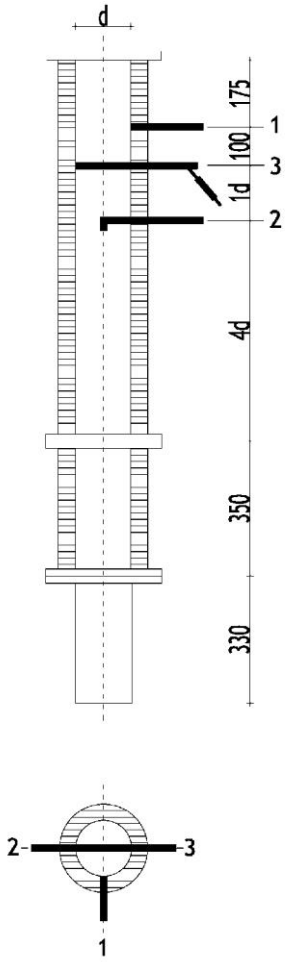

Figure 1. Example details and dimensions of measurement section for vertical flue gas outlet
Flue gas outlet diameter ø - (d=150mm), 1-Flue draught measurement, 2-PM measurement, 3- Suction pyrometer

3. Results and discussion

Testing of the fuel samples was performed in three series. The first one was with tobacco stalks and bio-briquettes.

The mass of the combusted fuel was 640 g. The combustion process duration was 22.83 minutes. The draft regulator of the heating device was set to 4 mm/%. The fire door and charging door were closed. The flue gas temperature was 188 °C. To improve the combustion process parameters, a second test was performed with the same fuel.

In the second round, 1080 g of tobacco stalks bio-briquettes were burned. The duration of the test period was 21.85 minutes. The draft regulator of the heating device was set to 12 mm/%. The fire door and charging door were closed. The detected flue gas temperature was 284 °C.

The third series of tests was performed with beech wood. 1740 g of beech wood logs were incinerated. The duration of the test period was 40.50 minutes. The draft regulator of the heating device was set to 4 mm/%. The fire door and charging door were closed. The flue gas temperature was at 327 °C.

Combustion process characteristics are presented in Tab. 1.

Table 1. Combustion process characteristics

Fuel sample	**Burley tobacco stalks bio-briquettes**	**Burley tobacco stalks bio-briquettes**	**Beech wood logs**
Serial number of test	1	2	3
Mass of the fuel test	640 [g]	1080 [g]	1740 [g]
The flue gas temperature	188 [°C]	284 [°C]	327 [°C]
The combustion process duration	22.83 [min]	21.85 [min]	40.50 [min]
The draft regulator	4 [mm/%]	12 [mm/%]	4 [mm/%]

Oxygen, carbon monoxide, carbon dioxide, and nitrogen oxide values were tracked during the combustion of fuel samples. The results of the concentration of oxygen in flue gasses are shown in Tab. 2.

Table 2. Concentration of Oxygen in flue gasses

Fuel sample	**Burley tobacco stalks bio-briquettes**	**Burley tobacco stalks bio-briquettes**	**Beech wood logs**
Serial number of test	1	2	3
Measuring	19.24 [%]	17.76 [%]	14.2 [%]
O_2 standard	13 [%]	13 [%]	13 [%]

Higher concentration of oxygen in flue gasses could be explanation for the lower high heating value of tobacco stalks bio-briquettes in comparison with beech wood logs.

In the Tab. 3, the results of carbon monoxide emission tracked during the combustion process are given.

Table 3. Concentration of Carbon monoxide in dry flue gasses

Fuel sample	**Burley tobacco stalks bio-briquettes**	**Burley tobacco stalks bio-briquettes**	**Beech wood logs**
Serial number of test	1	2	3
	3992.5 [$mgN^{-1}m^{-3}$]	2632.5 [$mgN^{-1}m^{-3}$]	2692.5 [$mgN^{-1}m^{-3}$]
	3194 [ppm]	2106 [ppm]	2154 [ppm]
	0.3194 [%]	0.2106 [%]	0.2154 [%]
*	1.4518 [%]	0.5200 [%]	0.2549 [%]
**	18148 [$mgN^{-1}m^{-3}$]	6500 [$mgN^{-1}m^{-3}$]	3186 [$mgN^{-1}m^{-3}$]
***	12605 [$mgMJ^{-1}$]	4515 [$mgMJ^{-1}$]	2213 [$mgMJ^{-1}$]

*CO avg convert to Content 13% / based O_2 measured; **CO avg convert to Content 13% / based O_2 measured; ***CO - concentration acc fuel input.

The results of our study clearly indicate that both fuels tested meet the requirements of the national Directive on emission limit values for air pollutants since the CO content is lower than 4000 mg/Nm^3.

The results of NO_x emission concentration in flue gasses during the combustion process are shown in Tab. 4.

Table 4. Concentration of NO_x in flue gasses

Fuel sample	**Burley tobacco stalks bio-briquettes**	**Burley tobacco stalks bio-briquettes**	**Beech wood logs**
Serial number of test	1	2	3
	137.7 [$mgN^{-1}m^{-3}$]	169.9 [$mgN^{-1}m^{-3}$]	66.8 [$mgN^{-1}m^{-3}$]
	67.2 [ppm]	82.9 [ppm]	32.6 [ppm]
*	626 [$mgN^{-1}m^{-3}$]	420 [$mgN^{-1}m^{-3}$]	79 [$mgN^{-1}m^{-3}$]
**	435 [$mgMJ^{-1}$]	291 [$mgMJ^{-1}$]	55 [$mgMJ^{-1}$]

* Mean NO_x at O_2 standard 13%; **NO_x - concentration acc fuel input

The concentration of nitric oxides in flue gasses of tobacco stalk briquettes is significantly higher compared to the combustion results of the beech wood. This could be explained by the utilization of nitric fertilizers in the process of tobacco growing [23]. A possible solution for this problem could be mixing the tobacco stalks with other plant waste in the process of bio-briquette production [24].

Tab 5. presents values of the percentage of presence of CO_2 in dry flue gasses.

Table 5. Concentration of CO_2 in dry flue gasses (measuring)

Fuel sample	**Burley tobacco stalks bio-briquettes**	**Burley tobacco stalks bio-briquettes**	**Beech wood logs**
Serial number of test	1	2	3
	1.57 [%]	3.10 [%]	6.35 [%]

The percentage of CO_2 content in dry flue gasses was much lower in tobacco stalk briquettes than those of beech wood which makes them very desirable in the context of greenhouse gasses reduction.

In all test series, the total hydrocarbon in propane equivalents (THC) was detected in the flue gasses after the combustion of tobacco stalk bio briquettes and beech wood. The results are shown in Tab. 6.

Table 6. Concentration of total hydrocarbon in propane equivalents

Fuel sample	**Burley tobacco stalks bio-briquettes**	**Burley tobacco stalks bio-briquettes**	**Beech wood logs**
Serial number of test	1	2	3
*	623 [mgm^{-3}]	385 [mgm^{-3}]	108 [mgm^{-3}]
**	380 [ppm]	235 [ppm]	66 [ppm]

* Total hydrocarbon content in propane equivalents, mean value; ** total hydrocarbon content in propane equivalents, mean value

The measurements have demonstrated the increased presence of THC in tobacco stalk briquette combustion exhaust gas in comparison with beech wood logs combustion emission, which makes them less environmentally friendly than the classic energy source.

4. Conclusion

Substitution of fossil fuels with green energy sources is necessary and urgent because climate change already causes terrible disasters all around the world. Tobacco stalks are widely accessible agricultural waste that can be used as a source of green energy which was proved by the results of this study. Tobacco stalk briquettes can be inexpensively produced. Although tobacco stalks contain small concentrations of nicotine, they are considered non-toxic. Results of tests of gasses that are toxic as the products of the combustion process are promising and in range of Directives and standards regarding requests for lowering greenhouse gas emission. HHV of these briquettes is satisfactory although, in combination with some other agricultural waste materials, the performance can be enhanced.

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